Universidad de La Laguna

Escuela superior de ingeniería y tecnología

Grado en Ingeniería Electrónica Industrial y Automática

Trabajo de Fin de Grado

DISEÑO DE VEHÍCULO PERSONAL SUBMARINO

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Septiembre 2020

Agradecimientos

Quisiera agradecer a todos esos profesores que al pasar por nuestras vidas académicas nos dan aliento para seguir adelante, motivos para ser, valores para tener presentes. Agradecer a esos profesores que transmiten que la ingeniería no son solo números y resultados correctos, sino que enseñan que la ingeniería es filosofía, arte, historia, pasión, sacrificio y enriquecimiento. Quisiera agradecer especialmente a Francis, ya que, gracias a ti, en el lejano primero de bachillerato, me hiciste ver más allá, a ver la belleza en el conocimiento.

A mis padres y hermana y a mis amigos por recoger tantas veces, lo poco que quedaba de mi al salir de la biblioteca.

Agradecer de nuevo a mis padres y hermana por apoyarme siempre incondicionalmente en mi camino, por hacerme sentir orgulloso de lo que soy y lo que he conseguido.

Especialmente quiero agradecer a “Los Tiburones del Desierto”, por que, gracias a vosotros, es que esto ha sido posible. Mis méritos son los vuestros y los vuestros los celebrare como míos. La ingeniería nos juntó, espero que nuestra amistad nos mantenga unidos.

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Resumen

Una de las características de la ingeniería es la multidisciplinariedad, ya que, aunque existen diferentes ramas dentro de esta, todas parten de la misma base. Una de las aptitudes más relevantes para un ingeniero es la capacidad para moverse entre estas ramas. Este proyecto busca reflejar esta característica, englobando conocimientos tanto de Electrónica como de Mecánica, tratando de denotar el aprendizaje obtenido durante su desarrollo. Se toma como referencia un dispositivo existente para la asistencia en el buceo, el cual denominamos en este trabajo como VPS (Vehículo Personal Submarino). Partiendo de esta inspiración, diseñamos un dispositivo que busca proporcionar las mismas prestaciones y añadir otras nuevas respecto al dispositivo de referencia. Para garantizar la funcionalidad del diseño, se realizaron los estudios, simulaciones, mediante el software SolidWorks y LTspice, y prototipado pertinentes, haciendo uso de una placa Arduino. Nuestro dispositivo tiene 61 cm y 28 cm de longitud y diámetro respectivamente, funciona con un motor de corriente continua, energía proveniente de un *pack* de baterías de 20 células. El objetivo de este proyecto no es obtener un producto acabado y listo para su producción, es sentar las bases para realizar un diseño posterior más profundo.

Abstract

One of the characteristics of engineering is multidisciplinarity, even though there are different branches within it, they all start from the same base. One of the most relevant skills for an engineer is the ability to jump among these branches. This project seeks to reflect this characteristic, encompassing knowledge of both Electronics and Mechanics, trying to highlight the learning obtained during its development. An existing device for assistance in diving is taken as a reference, which we call in this work as VPS (Underwater Personal Vehicle). Based on this inspiration, we designed a device that seeks to provide the same features and add new ones compared to the reference device. To ensure the functionality of the design, relevant studies, simulations, using SolidWorks and LTspice software, and prototypes, using an Arduino board, were carried out. Our device is 61 cm and 28 cm in maximum length and diameter respectively, it works with a direct current motor, energy coming from a 20-cell battery pack. The objective of this project is not to obtain a finished product ready for production, but it is to set the foundations for a deeper subsequent design.

Capítulo 1. Introducción

1.1. Antecedentes

El buceo tiene su origen miles de años atrás, siendo, en sus inicios, una práctica usada por el ser humano para conseguir comida que estaba fuera de su alcance. Los buceadores entrenaban desde la infancia la capacidad pulmonar y la resistencia para permanecer bajo el agua. Llegados a un punto, los límites físicos se hicieron notorios y fue entonces cuando comenzó a desarrollarse el equipamiento de buceo. Los primeros artilugios consistían en solventar problemas básicos, como resistir mejor las bajas temperaturas, facilitar entradas y salidas del agua, con lastres y flotadores o ver mejor bajo el agua.

Figura 1: Buceadora *Ama* (del japonés *mujer buceadora*) de la costa japonesa [8]

Con el paso de los años, se añadieron nuevas motivaciones para bucear, bien por razones militares, bien por la búsqueda de riquezas o por deporte, lo que dio como resultado la reinvención del equipamiento, buscando ir más profundo y aguantar mayor tiempo bajo la superficie.

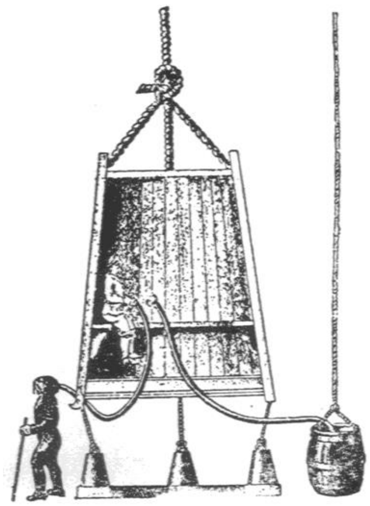

Figura 2: Campana de buceo del siglo XVIII [9]

Figura 3: Buceadora *Haenyeo* (del koreano *mujer del mar*) [12]

A medida que avanzó el tiempo, poco a poco se fue abriendo paso la vertiente del buceo recreativo, la cual buscaba acercar a las personas el buceo como entretenimiento, sin necesidad de que aquel que lo practicara debiera tener una forma física y un entrenamiento riguroso. Teniendo esto en cuenta, se adaptan equipamientos militares para su uso civil, como puede ser el traje de buceo y se inventan otros nuevos, como el dispositivo objeto de este Trabajo de Final de Grado (TFG).

Figura 4: Torpedo de buceo marca SEABOB [10]

Figura 5: Máscara de buceo modelo EASYBREATH marca TRIBORD [11]

El Vehículo Personal Submarino (VPS) suele partir de dos morfologías, una morfología tipo torpedo o submarino y otro tipo elipsoide, siendo esta última en la que se ha basado nuestro proyecto. Las diferencias entre morfologías se detallarán en el apartado 3.3 del capítulo 3.

Figura 6: VPS tipo torpedo

Figura 7: VPS tipo elipsoide marca SEADOO [13]

1.2. Objetivo del proyecto

El objetivo de este proyecto es el diseño desde cero y mejora de un torpedo para submarinismo o VPS basado en morfologías ya existentes. En cuanto al diseño se refiere, entrarían apartados tales como electrónica de potencia e instrumentación que el dispositivo requiere, así como estudios de flotabilidad, presurización, aerodinámica y propulsión. La propuesta de mejora entra dentro del apartado de la electrónica y consiste en la implementación de sensores que cuantifiquen el medio circundante, así como datos propios del dispositivo que pueden ser de relevancia para el usuario; estos datos son procesados por una placa de Arduino como microprocesador y mostrados por display LCD (*Liquid Crystal Display*) o notificados mediante una señal LED (*Light Emitting Diode*).

1.3. Estructura de la memoria

Luego de esta breve introducción, la memoria se estructura de la siguiente manera. En capítulo 2 se explica el software utilizado para desarrollar las diferentes partes de este proyecto, además en él se denota el proceso de aprendizaje en el programa SolidWorks®. En el capítulo 3 se habla acerca de los problemas para tener en cuenta a la hora de realizar el diseño de nuestro dispositivo, el estudio de la morfología y por último se describe la realización en SolidWorks de las diferentes piezas que conforman el dispositivo. Luego de esto, en el capítulo 4 analizamos, en función del modelaje realizado, la flotabilidad del dispositivo basándonos en el principio de Arquímedes. Más tarde valiéndonos de herramientas de análisis que nos proporciona el programa SolidWorks, estudiamos la resistencia y desempeño de las piezas críticas y del conjunto ensamblado. El capítulo 5 está dedicado a la descripción y análisis de los elementos electrónicos a implementar en el VPS, en concreto, los sistemas de medida, la comunicación y control de estos, el motor y su control de velocidad y la salida por pantalla de las lecturas de los sensores. En el capítulo 6 se habla del diseño del sistema de alimentación, el cual está dividido en tres partes: baterías, BMS (*Batterry Management System*) y cargador escogido para las baterías. El capítulo 7 está destinado al presupuesto estimado de realización de este proyecto. Por último, en cuanto al contenido técnico de esta memoria está el capítulo 8, en el cual se analizarán los resultados de la simulación electrónica del circuito de acondicionamiento del sensor de temperatura, además de analizar un prototipo de montaje del sistema de sensores y su salida por pantalla. En el capítulo 9 se verán reflejadas las conclusiones de este proyecto y se hablará de las propuestas de continuación de este. Por último y para concluir la memoria tendremos el capítulo 10, el cual contiene la bibliografía utilizada para el desarrollo del proyecto y el apartado de anexos, donde se incluirán las *datasheets* de los sensores, hojas de cálculo y vistas de las piezas que conforman el dispositivo.

Capítulo 2. Software utilizado

2.1. SolidWorks

Este proyecto consta de dos partes bien diferenciadas, una parte hidrodinámica y otra electrónica. Para respaldar los análisis hidrodinámicos y para elaborar la carcasa externa del VPS y los demás elementos que conforman el dispositivo, nos hemos servido para el diseño y análisis estructural, del programa SolidWorks.

SolidWorks es un programa de diseño, desarrollo y análisis el cual no se limita al ámbito de la Mecánica, ya que este tiene la capacidad para desenvolverse en el terreno de la electrónica, poniendo a disposición del usuario recursos para el diseño de circuitos impresos, además de prestar herramientas para el diseño eléctrico. Para estos tres vértices, el programa facilita los servicios de validación para la producción, mantenimiento y reparación de lo diseñado, también herramientas y métodos para la generación de la documentación de cada una de sus funciones, las cuales mantienen interconexión y son gestionables mediante su sistema PDM (*Product Data Management*), a través del cual llevar el control de los diseños, documentos, listas de materiales y procesos a fin de maximizar la eficiencia de la Ingeniería y la productividad.

Mediante este programa realizaremos el diseño de las piezas que conforman nuestro dispositivo y llevaremos a cabo simulaciones a fin de respaldar su correcto desempeño en el entorno de trabajo. Así pues, someteremos las piezas críticas a ensayos de carga y en caso de ser necesario, a ensayos aerodinámicos.

2.2. Arduino

Por otro lado, en cuanto a la electrónica se refiere y a pesar de las insondables limitaciones para su desarrollo en este proyecto, se ha buscado fundamentar lo máximo posible la instalación, programación y consonancia de los elementos electrónicos. Para poder llevar a cabo lo anteriormente mencionado, haremos uso de las herramientas que pone a nuestra disposición la comunidad de creadores del proyecto Arduino.

La compañía Arduino tiene como principal actividad el desarrollo de software y hardware libre. Cuenta con una gran comunidad internacional enfocada en el diseño y manufactura de placas para el desarrollo de hardware para la creación de dispositivos digitales. Además, esta comunidad se dedica al desarrollo de código para facilitar al usuario la utilización de este hardware, las llamadas librerías. Estas librerías nos han permitido realizar pruebas de funcionamiento con sensores, tanto individualmente, como en conjunto, entre las que cabe destacar:

- Librerías relacionadas con el módulo BMP180:
  - **SFE_BMP180.h**: Nos permite tener comunicación mediante el bus I^2C (*Inter-Integrated Circuit*) con este módulo de medida de temperatura y presión, y tener acceso a funciones relacionadas con la obtención de sus lecturas de manera directa.

- Librerías relacionadas con el módulo de pantalla LCD 20x4:
  - **Wire.h**:Establece la conexión con la pantalla LCD mediante bus I^2C.
  - **LCD.h**: Acceso a las funciones de la pantalla LCD.
  - **LiquidCrystal_I2C.h**: Envío y recepción de mensajes de la pantalla LCD mediante bus I^2C.

- Librería relacionada con el módulo DHT22:
  - **DHT.h**: Nos permite tener comunicación mediante el bus I^2C con este módulo para la medida de temperatura y humedad, y tener acceso a funciones relacionadas con la obtención de sus lecturas de manera directa.

2.3. LTspice

Por último y para la verificación del diseño del puente de Wheatstone, del cual hablaremos en el apartado 3 del capítulo 5, se han realizado el montaje y la simulación de este en el programa LTspice, el cual es un software de simulación de circuitos electrónicos analógicos basado en SPICE (*Simulation Program with Integrated Circuit Emphasis*). Este programa es desarrollado actualmente por la empresa de manufacturación de semiconductores Analog Devices, aunque originalmente estuvo al cargo de su desarrollo Linear Technology.

2.4. Aprendizaje en SolidWorks

El modelado 3D no es objeto de estudio en la carrera de Ingeniería Electrónica Industrial y Automática. Por ello, gran parte del trabajo desempeñado en este TFG consistió en aprender a utilizar un programa tan versátil y potente como es el SolidWorks. En una primera instancia y con el conocimiento en AutoCAD como referencia, uno pudiera llegar a pensar que para el diseño temprano, no debería diferir demasiado de un programa de diseño 2D. Sin embargo, la dinámica es totalmente distinta. Si bien en el trazado en AutoCAD no es necesario que lo diseñado mantenga relaciones de restricción entre figuras o líneas, en SolidWorks partimos de un diseño ambiguo al cual le iremos dando relaciones de restricción, como dimensión, paralelismo, coincidencia, entre muchas otras más. Las relaciones han de mantener coherencia entre sí, una contradicción ocasionará una geometría imposible y la figura no será realizable, además de que existen relaciones que tienen preferencia frente a otras, bien sea por ser más estrictas o por ser asignadas antes. Estos conceptos se aplican tanto en dos como en tres dimensiones, una vez extruida la figura respecto de un plano, se tendrán en cuenta las mismas reglas de diseño. Comprender y saber aplicar lo mencionado con anterioridad guarda una complejidad y dificultad que se acentúa cuando se parte de una base nula en el diseño tridimensional. Por otra parte, el programa tiene una serie de herramientas destinadas a la validación estructural, como análisis de cargas o la simulación de fluidos, y hacer uso adecuado de estas herramientas también formó parte de la instrucción. La fuente principal de información para llevar a cabo este aprendizaje procede del canal “CAD CAM para todos” [1] de la plataforma YouTube.

Cabe destacar que antes de embarcarnos en el aprendizaje en SolidWorks se probó una alternativa de software libre, un programa llamado FreeCAD, el cual se descartó ya que no contaba con herramientas para el análisis estructural.

Capítulo 3. Diseño general

3.1. Problemas del medio

Existen claros problemas inherentes al medio circundante, por el mero hecho de que nuestro dispositivo desarrolla su actividad bajo el agua y es por esto que hemos de tener en cuenta factores como la protección IP (*Ingress Protection*) de los sensores externos, puesto que estarán en contacto directo con el agua; la medición atmosférica dentro de la carcasa, con la finalidad de tener controlados parámetros determinantes para el correcto funcionamiento del VPS, como la humedad relativa, ya que si excede ciertos valores podría provocar derivas y cortocircuitos en la electrónica; la presurización de este y la temperatura interna, siendo la presión interna un parámetro enfocado principalmente a favorecer la estabilidad estructural y de manera secundaria y junto con la temperatura son variables destinadas a ser controladas para asegurar un entorno adecuado para el correcto funcionamiento de las electrónica. Por otra parte, es necesario tener en cuenta que las aberturas entre el interior de la carcasa y el exterior han de estar adecuadamente selladas e impermeabilizadas, como pueden ser en los emplazamientos de los sensores externos, en la conexión para presurización y en la conexión de carga de las baterías.

No es objeto de este TFG el diseño e implementación de sistemas y medios para la impermeabilización del dispositivo, en cuanto a la unión de las diferentes piezas que puedan conformar la carcasa externa se refiere.

3.2. Elección de materiales

Es necesario aclarar que debe existir un equilibrio entre la resistencia, el peso y el precio del material escogido, puesto que la elección de un material donde primara la resistencia tal vez sería en detrimento del peso y precio. Atendiendo a lo anterior, se propone como solución el PVC (de las siglas en inglés de cloruro de polivinilo, *PolyVinyl Chloride*), ya que este material cuenta con una excelente resistencia a la corrosión y abrasión, buena resistencia mecánica y frente al impacto, además de una baja densidad y resistencia al agua, todo lo cual, sumado a la rentabilidad del material, lo hacen más que adecuado para cumplir con las expectativas de nuestro proyecto.

3.3. Morfología de estructura tipo

Como se menciona en el capítulo 2, existen dos tipos de morfologías para el desarrollo de dispositivos VPS. La morfología tipo torpedo o submarino prima la potencia y eficiencia aerodinámica en detrimento de la ergonomía, mientras que en la morfología tipo elipsoide es habitual que se priorice la compacidad y la ergonomía, a costa de la pérdida de potencia. Para el desarrollo del diseño nos hemos decantado por la morfología de VPS tipo elipsoide, la cual a nivel de modelaje es más compleja, pero mantiene concordancia con la premisa de que nuestro dispositivo no será de gran potencia.

3.4. Diseño en SolidWorks

3.4.1. Carcasa externa

El diseño general consistirá en un elipsoide compuesto de dos elipses que conforman la mayor parte de la estructura y, para favorecer la aerodinámica, en la zona donde irá emplazada la hélice se cierra la estructura con una esfera. Toda la estructura es hueca con un espesor de 3 mm, una longitud máxima de 54,75 cm y un diámetro máximo de 15 cm; más adelante en el capítulo 4 apartado 4.3 hablaremos de los resultados de la simulación que pone a prueba la resistencia a presión de la estructura y se decidirá si se aumenta este espesor. La parte delantera del dispositivo, la cual corta el agua a su paso, es la denotada por el centro de coordenadas a la izquierda de la figura 8 y, por ende, la parte trasera es el lado contrario, siendo esta última donde se emplace el motor junto con la hélice.

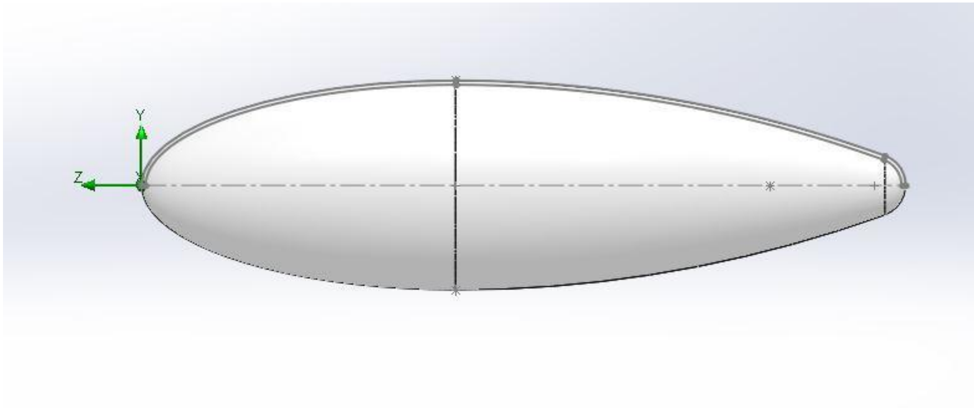

Figura 8: Carcasa externa vista lateral

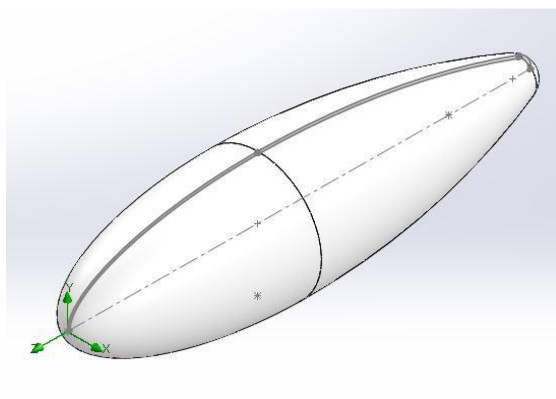

Figura 9: Carcasa externa vista axonométrica

Para aportar mayor resistencia a la presión del agua se diseñó una estructura interna inspirada en la estructura interna de un dirigible. Esta consiste en siete bandas que recorren la carcasa por su cara interna, que salen de la punta de la parte delantera y se detienen poco antes de llegar a la parte trasera (ver figura 10), para dejar mayor holgura al motor, el cableado que este pueda necesitar y un hipotético soporte para el mismo. Al hacerlo de esta manera no perjudica la resistencia a la presión del conjunto, ya que como veremos más adelante, esta área de la estructura es la que menos se ve afectada por la carga del agua. A su vez, como se observa en la figura 10, se añadió una bandeja para que reposara la hipotética electrónica que acarrearía este dispositivo. Como observaremos en los análisis de resultados de las simulaciones posteriores, esta bandeja le aporta a la carcasa resistencia a la presión.

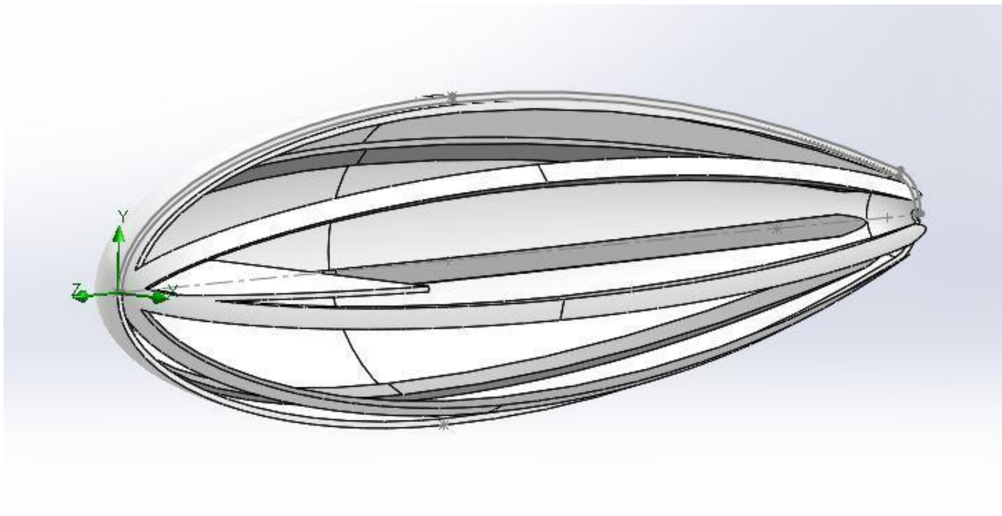

Figura 10: Visual de estructura interna en corte al medio

3.4.2. Hélice

El diseño de la hélice consiste en dar solución al sistema que transformará el par proporcionado por el motor para la propulsión del dispositivo. Los apartados técnicos que atañen a esta, como el dimensionamiento y ángulo de inclinación y curvatura para maximizar la dirección y la fuerza de propulsión que es capaz de generar en función del máximo par motor, son factores claves para tener en cuenta para su diseño. Sin embargo y de manera deliberada para la realización de este TFG, nos hemos limitado a un diseño básico, ciñéndonos a la premisa que encabeza este párrafo. Se han realizado simulaciones para observar la respuesta de la pieza ante el flujo y la presión del agua, emulando su funcionamiento nominal, las cuales analizaremos más adelante.

La hélice consiste en tres aspas que parten de un cilindro como cuerpo de esta. Los bordes de las aspas cuentan con una operación de redondeo, buscando que estos filos corten el agua con suavidad. El cilindro tiene una perforación con forma de media circunferencia destinado a albergar el eje proveniente del motor, que está diseñada para la justa medida del eje que se verá más adelante, en este mismo capítulo, en el diseño del motor. El material en el cual está diseñada es fibra de carbono, a fin de asegurar su resistencia ante el impacto constante de agua. Su diseño está inspirado en una hélice común de barco.

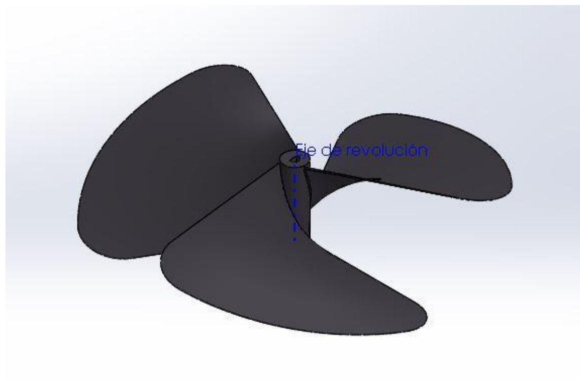

Figura 11: Hélice vista frontal

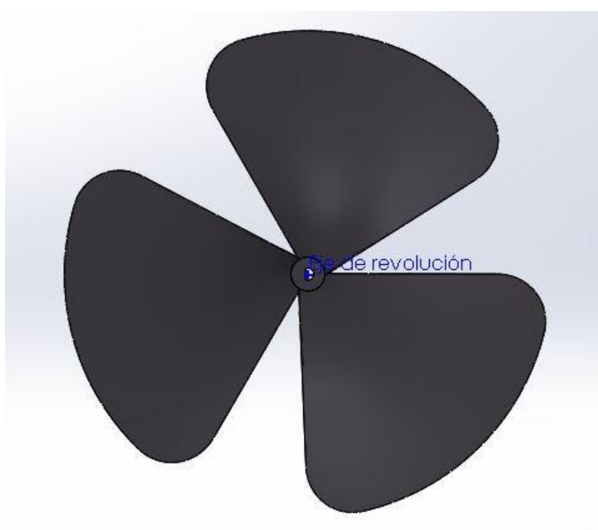

Figura 12: Hélice vista axonométrica

3.4.3. Motor

Siguiendo los planos proporcionados por la página web de BlueRobotics, la cual es la empresa distribuidora del motor escogido, se recreó el diseño en 3D del mismo, con el objetivo de contrastar si el diseño de la carcasa externa se adecua con las dimensiones del motor y para tenerlo en cuenta para los posteriores cálculos de ensamblaje y simulaciones.

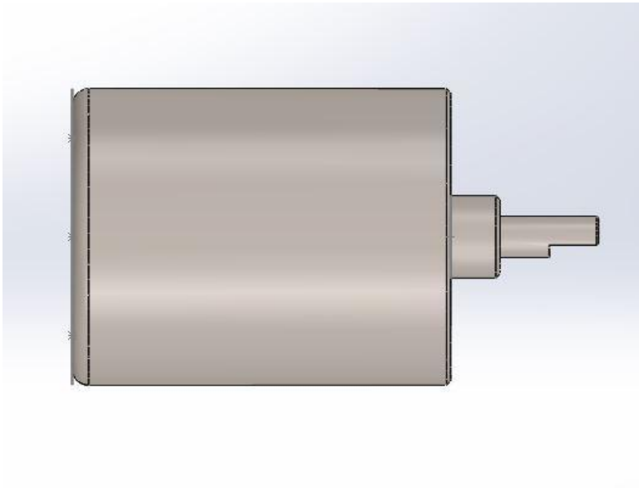

Figura 13: Motor M200 Brushless Underwater vista lateral

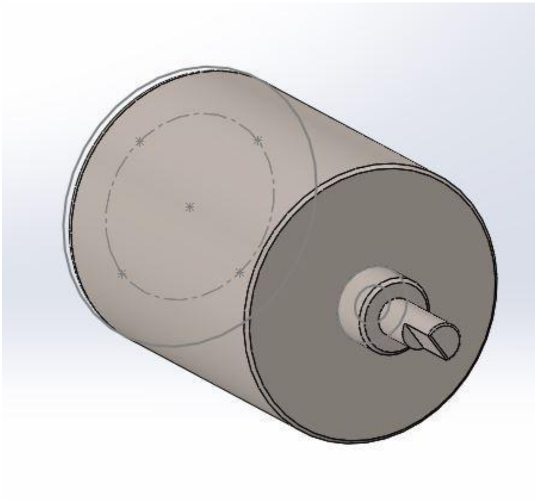

Figura 14: Motor M200 Brushless Underwater vista axonométrica

3.4.4. Pieza que recubre la hélice

Por otra parte, debido a la complejidad de diseño, se ha obviado el agarradero para el usuario y se ha tomado parte del diseño del usuario *Hans de Ridder* [2], del repositorio Grabcad de libre distribución para la comunidad de ingenieros y diseñadores enfocados a la impresión 3D.

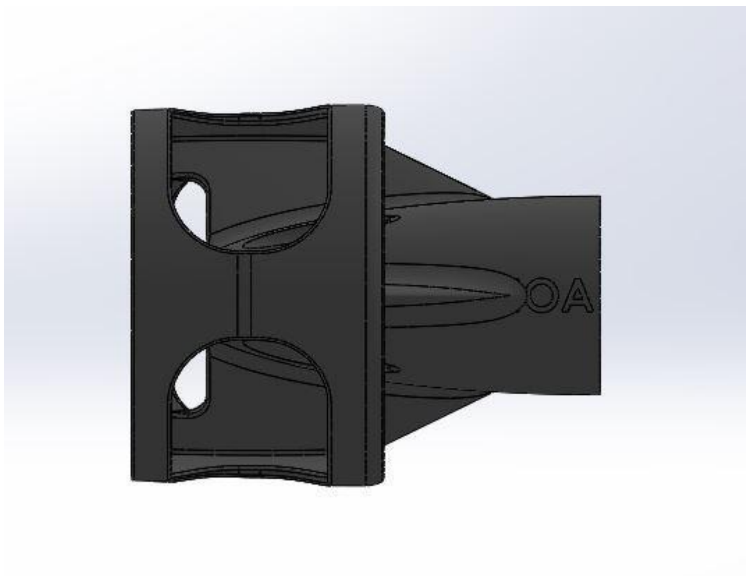

Figura 15: Pieza que recubre la hélice vista lateral

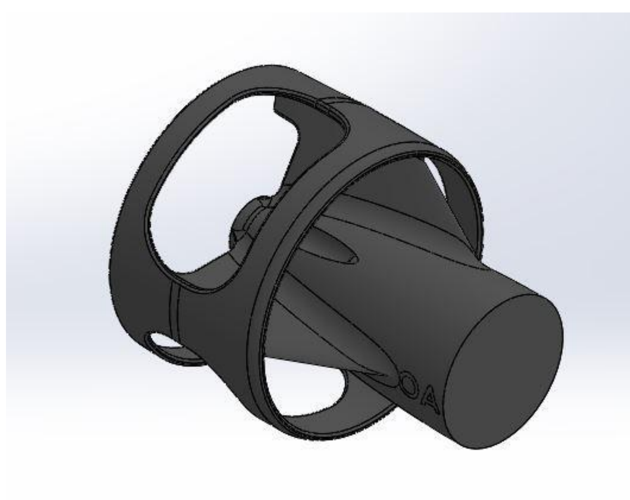

Figura 16: Pieza que recubre la hélice vista axonométrica

Para que esta pieza concuerde con el diseño de nuestra carcasa, fue modificado su tamaño en función de un factor de escala y se modificó el material con el que estaba diseñado, además, como se puede apreciar en la figura 16, la pieza es maciza. Para evitar grandes variaciones en el cálculo de masas y por ende en el centro de gravedad, se vació esta pieza a fin de ensamblarla.

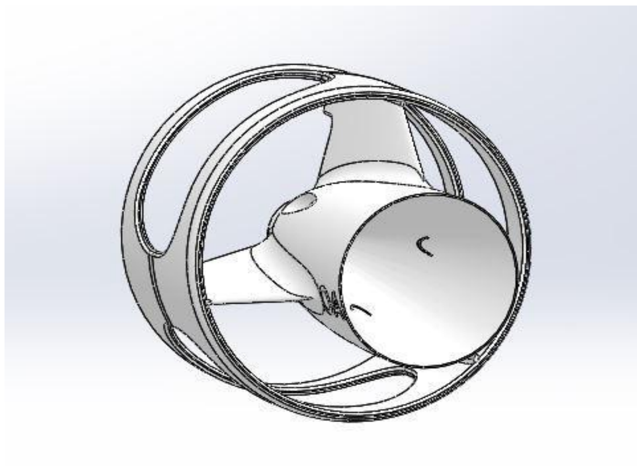

Figura 17: Pieza que recubre la hélice de PVC vaciado

3.4.5. Ensamblaje

Por último, analizaremos todas las piezas ensambladas. En la figura 18 se observa el conjunto al completo que conforma nuestro dispositivo, sobre este ensamblaje se realizó el análisis aerodinámico, del cual se hablará en el capítulo 4 apartado 4.3.2.

En las figuras 19 y 20 podemos observar las dimensiones globales de nuestro dispositivo, el cual tiene una longitud máxima de 61,074 cm y un radio máximo de 28,728 cm.

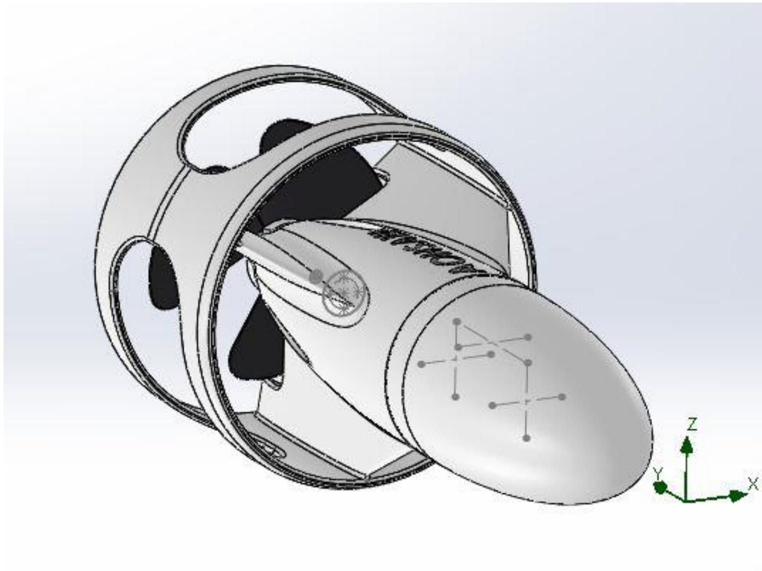

Figura 18: Ensamblaje VPS vista axonométrica

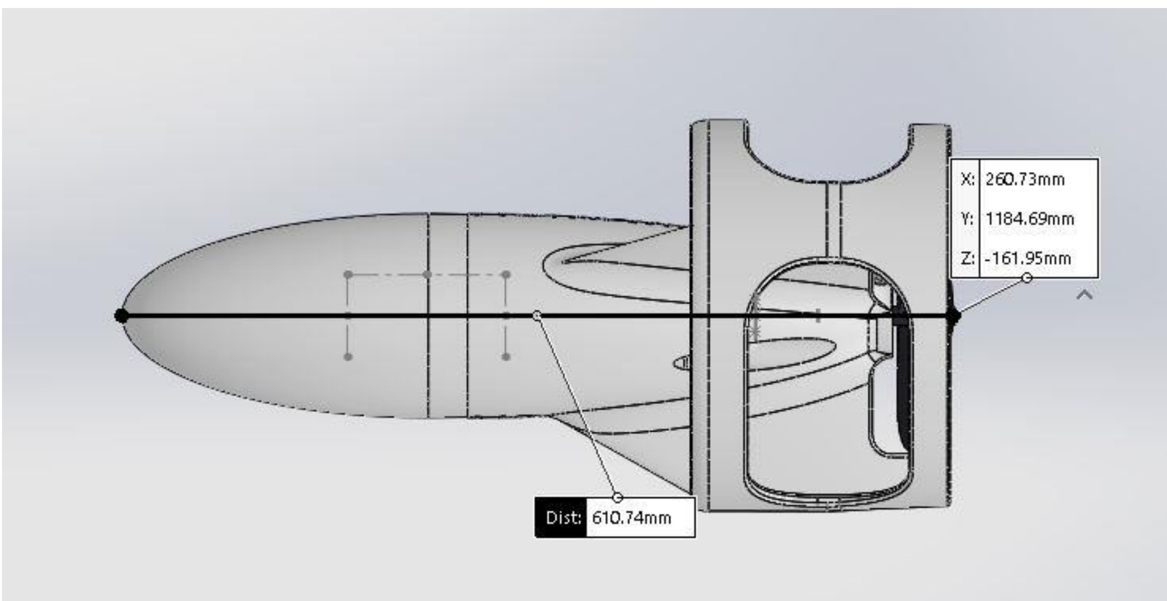

Figura 19: Ensamblaje vista lateral

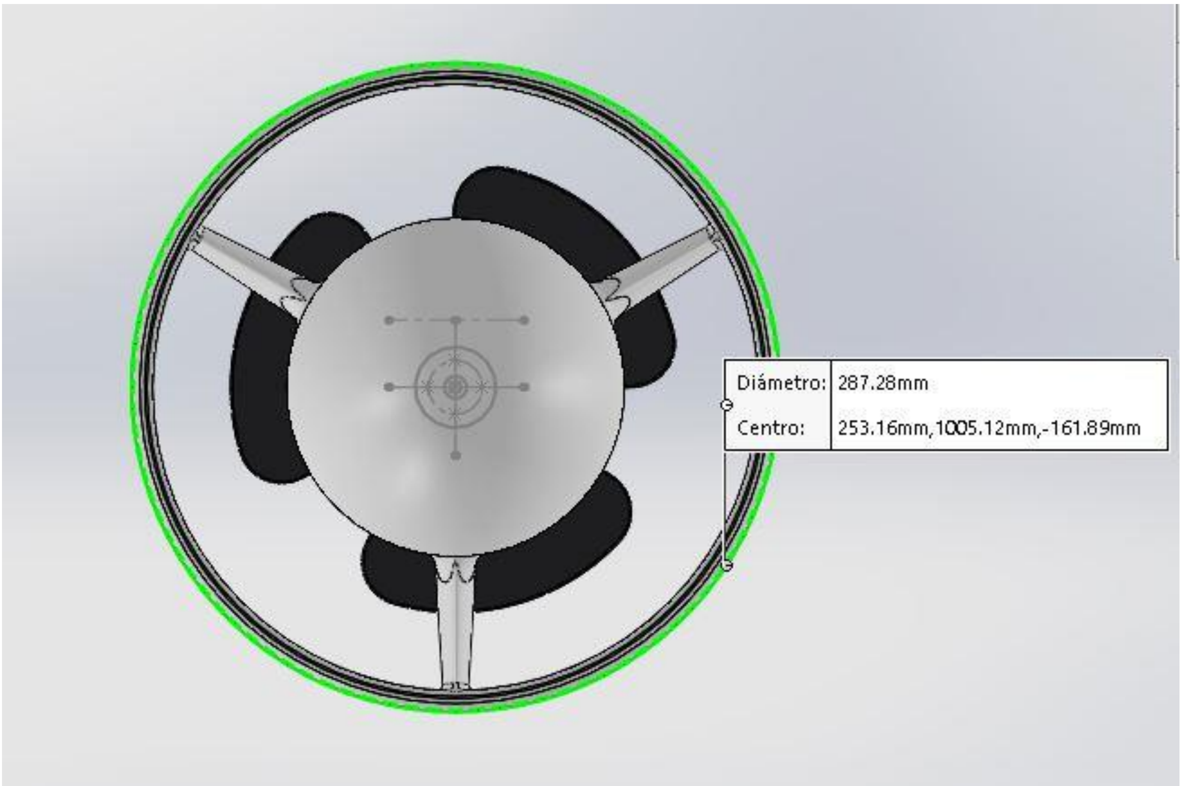

Figura 20: Ensamblaje vista frontal

Capítulo 4. Estudio y modelización hidrodinámica

4.1. Estudio de flotabilidad

La flotabilidad es el balance de fuerzas ejercidas sobre un cuerpo. Por lo general se tienen en cuenta el peso del cuerpo y la presión ejercida por el fluido que esté en contacto con el mismo. Este factor es importante a la hora de diseñar el VPS, para el cual buscamos una flotabilidad próxima a cero, es decir, que el objeto se mantenga estático mientras se encuentre en reposo sumergido en el agua. Para proporcionarle esta cualidad al dispositivo llevaremos a cabo un estudio de flotabilidad, en el cual determinaremos cuál es la masa necesaria para que el balance entre las fuerzas del peso y empuje del fluido sea cero.

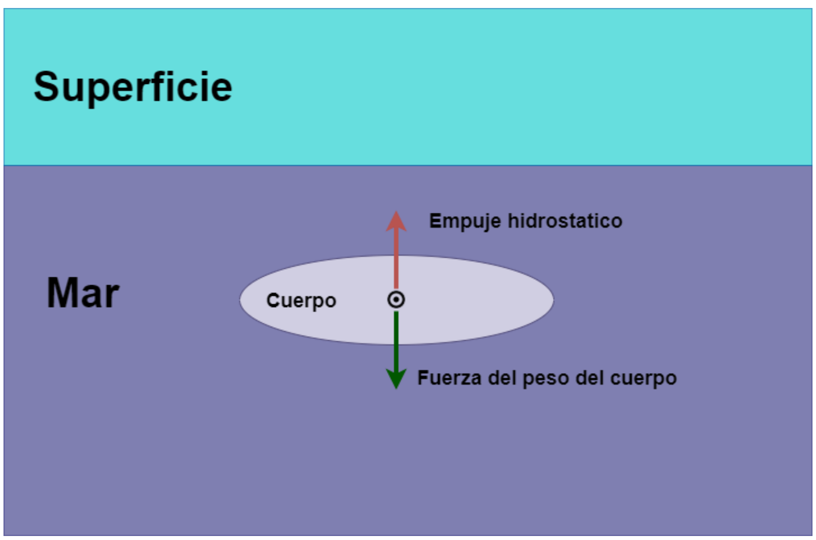

Figura 21: Diagrama conceptual de fuerzas de empuje y peso

El análisis de flotabilidad está basado en el principio de Arquímedes, el cual postula lo siguiente:

“Un cuerpo total o parcialmente sumergido en un fluido en reposo experimenta un empuje vertical hacia arriba igual al peso del fluido desalojado”.

La anterior premisa queda reflejada matemáticamente por la siguiente expresión:

$$E = \rho \cdot g \cdot V$$

Donde **E** es el empuje resultante de la presión del fluido, **ρ** es la densidad del fluido, en nuestro caso el agua de mar, cuya densidad supondremos constante al ser nuestro rango de profundidad de operación muy reducido como para tener un cambio significativo en esta, **g** es la aceleración de la gravedad y **V** es el volumen del líquido desplazado por el cuerpo sumergido. Por tanto, este volumen coincide con el volumen total de nuestra estructura, el cual obtenemos del programa SolidWorks.

Es necesario aclarar que el punto de aplicación de la fuerza del peso de la estructura es distinto del punto de aplicación de la fuerza de empuje ejercido por la presión del agua. Estos son el centro de masas y el metacentro o centro de flotación respectivamente. Es importante determinar la disposición de estos puntos, puesto que son de suma importancia para asegurar la estabilidad del dispositivo, ya que de manera natural la estructura en el agua buscará una posición en la que el metacentro quede por encima del centro de masas, siendo esta la posición más estable. Con motivo de simplificar los cálculos para el estudio de flotabilidad, supondremos que el metacentro y el centro de masas son coincidentes.

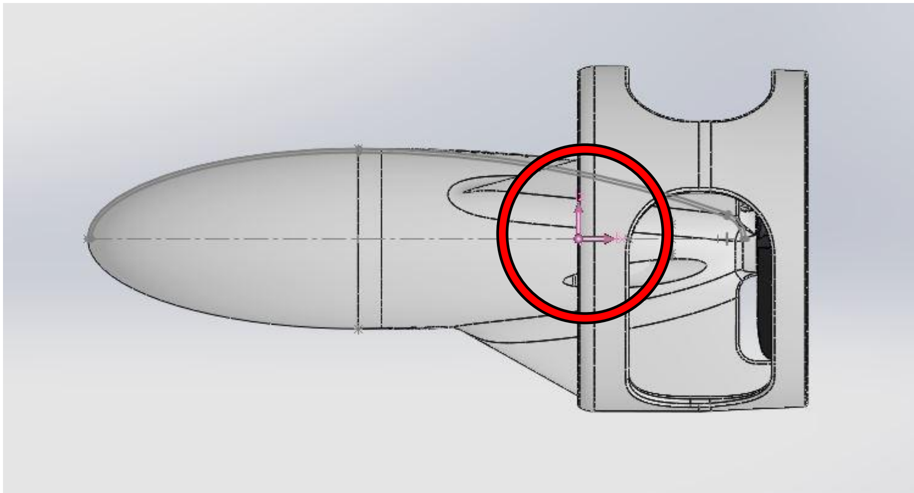

Figura 22: Sistema de ejes que referencian el centro de masas

Para poder analizar adecuadamente el volumen que encierra la figura, se modelizó el volumen interno que encierra la carcasa, a fin de obtener directamente el valor desde el programa SolidWorks haciendo uso de la herramienta de "propiedades físicas", del apartado de herramientas de "Calcular". Esta herramienta nos proporciona magnitudes físicas referentes al sólido modelizado, entre ellas el volumen que comprende la figura. Se realizó este modelaje, porque la herramienta solo proporciona el volumen del sólido y a nosotros nos interesa tanto al volumen del sólido, como el volumen de aire que encierra. Atendiendo a lo mencionado anteriormente concluimos que el dispositivo debe tener una masa aproximada de **9,7 kg** para tener una flotabilidad aproximadamente nula.

El VPS tiene, sin carga, 5 kg de masa. Para la carga se han tomado en cuenta los componentes electrónicos de mayor peso, como las baterías o sensores externos y esta consiste en 1,6 kg. Así, para obtener el peso requerido se le añadirá una plomada de unos 3 kg. Estos cálculos se verán mejor reflejados en el apartado de "Cálculo de flotabilidad y masas" de los Anexos.

Diseñaremos una carga para el dispositivo que comprenda tanto la carga de la electrónica del VPS como la plomada necesaria. Este diseño es llevado a cabo para tener la mayor rigurosidad posible a la hora de realizar las simulaciones posteriores, en este caso, para tener la influencia del peso real que cargaría el dispositivo.

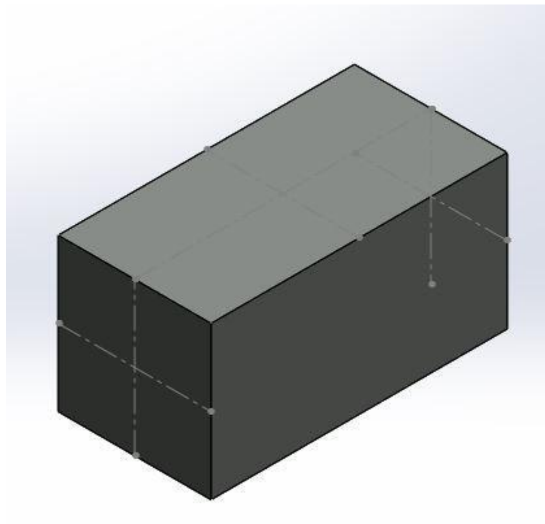

Figura 23: Cubo de plomo que representa la carga del VPS

Para la colocación de esta pieza en el ensamblaje final se ha tenido en cuenta que deben coincidir los ejes transversales de la plomada con el de la estructura de la carcasa, el cual es coincidente con el eje de revolución del motor. Estos tres ejes han de estar alineados para no desplazar el centro de masas respecto de los ejes restantes y así, cuando la estructura sea impulsada, no acabe girando sobre sí misma.

4.2. Resistencia a presión de la estructura

En una primera instancia, comprobaremos que los elementos que conforman nuestra estructura serán capaces de soportar, sin una deformación significativa, la presión de diez metros de profundidad en el agua, presión equivalente a una atmósfera. El elemento crítico al cual se le realizó el estudio es la carcasa externa, ya que esta contendrá toda la electrónica y el motor de nuestro dispositivo.

Para realizar esta simulación usaremos el módulo de simulación del SolidWorks, llevaremos a cabo un análisis estático, en el cual se ha de suponer que el sólido a analizar cuenta con un punto de apoyo y se denota este en la figura para poder realizar la simulación. Nuestro VPS no contará con un punto de apoyo definido a la hora de realizar su desempeño bajo el agua, más que la propia agua. No obstante, no es compatible la definición de un apoyo que envuelva toda la superficie de la figura como haría el agua y una carga distribuida aplicada por la misma superficie, por tanto, para llevar a cabo la simulación. Supondremos que la esfera que define la parte trasera de la carcasa se encontrará sujeta y no expuesta a ninguna fuerza. Esta suposición se sustenta en la idea intuitiva de que esta será la zona que menos se verá afectada por la presión a diferencia de la parte central de la estructura, la cual apunta a ser la más afectada. Luego de definir los apoyos y la distribución de fuerzas, se define una malla de estudio, que divide la superficie de la pieza en diferenciales para su análisis o, en otras palabras, discretiza la pieza. Una mayor resolución de la malla implica que la pieza total será dividida más veces, generando así más diferenciales que analizar.

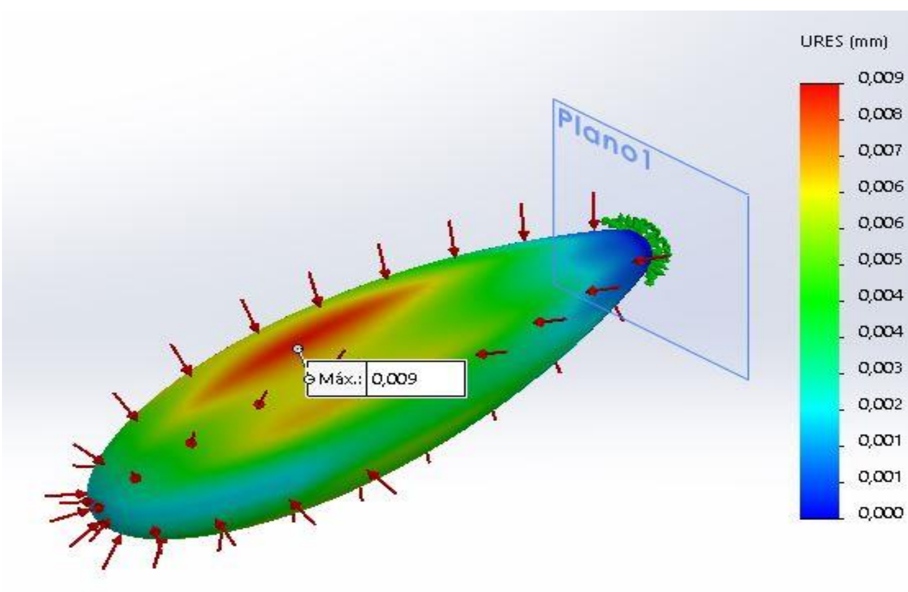

Figura 24: Resultado de simulación de presión, deformaciones de la carcasa externa

Como podemos observar en la figura 24, de la simulación obtenemos un gradiente que representa las deformaciones que experimenta la carcasa, donde las tonalidades más rojas o cálidas representan las mayores deformaciones. Queda denotado en la figura 24 que la deformación máxima experimentada corresponde a los 0,009 milímetros, por ello podemos considerar que soporta adecuadamente la presión del agua. Por otra parte, analizando el gradiente cromático, confirmamos que la suposición de distribución de presión es acertada. A pesar de que con tres milímetros la estructura soporta adecuadamente la presión en las simulaciones, por motivos de seguridad y en vistas de un diseño posterior, se aumentará el espesor de la estructura hasta los cinco milímetros.

Por otra parte, a fin de favorecer la resistencia a la presión y asegurarnos de que la carcasa se mantiene en todo momento estanca, se llevará a cabo antes de cada inmersión un control de la presión interna de la carcasa, ajustando esta a la presión de una atmósfera a través de una válvula anti-retorno de entrada de gases.

4.3. Análisis aerodinámico

4.3.1. Hélice

Como se menciona en el apartado 4 del capítulo 3, se llevó a cabo un análisis aerodinámico de la hélice, con motivo de estudiar su comportamiento en un supuesto entorno de trabajo. La pieza fue sometida a una presión de una atmósfera y fue afectada por un flujo de agua a una velocidad constante de 1 m/s. Para la configuración de esta simulación es necesario declarar un plano en el cual se representarán el gradiente cromático, las isolíneas y las representaciones vectoriales. También es necesario definir sobre qué superficie se analizará la distribución de presiones y por último la dirección y velocidad del fluido de estudio. Por otra parte, análogamente con la simulación de presión de la carcasa, es necesario la definición y configuración de una malla de estudio. En este caso, definiremos dos, una primera con una resolución estándar, la cual será la que está en contacto con la superficie de la pieza y una segunda con mayor resolución que estará entre el fluido y la primera malla. La definición de estas mallas nos proporcionará una mejor visualización de las isolíneas, gradiente y representación vectorial en las zonas más cercanas a la superficie de la pieza.

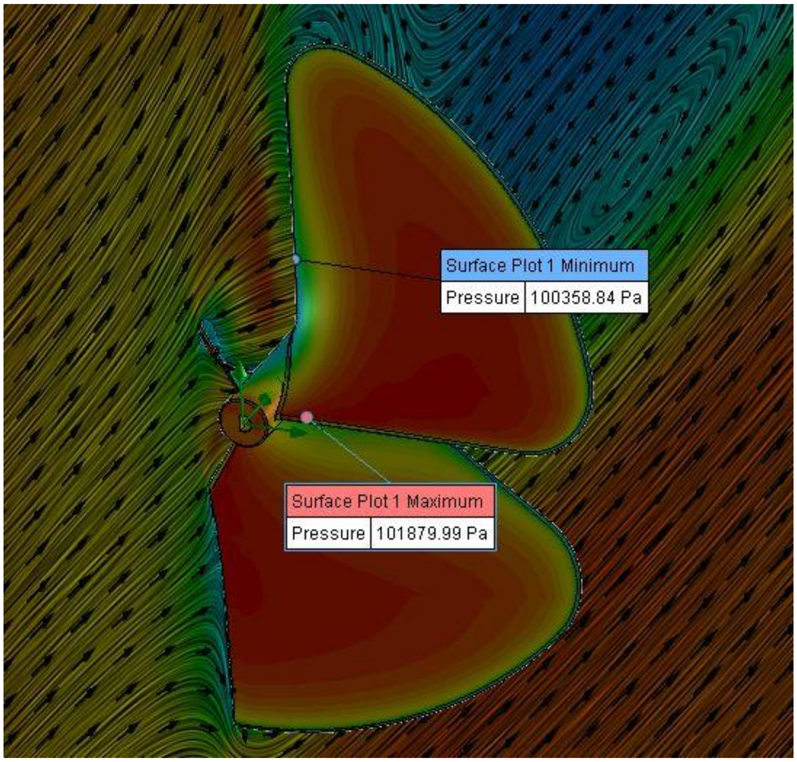

Figura 25: Distribución de presión en la superficie de la hélice

En la figura 25 se aprecia un gradiente cromático en la superficie de la hélice, que nos indica la distribución de la presión sobre dicha superficie, siendo los colores más cálidos los relativos a mayor presión y los colores más fríos a menor. Analizando este gradiente, se observa una tendencia de la presión a concentrarse en la zona central y al comienzo de las aspas y se va distribuyendo hacia los bordes a medida que disminuye su valor. Esta distribución de la presión es ocasionada por la incidencia del agua y podemos interpretar de ella que favorecerá el movimiento de la hélice impulsada por el motor.

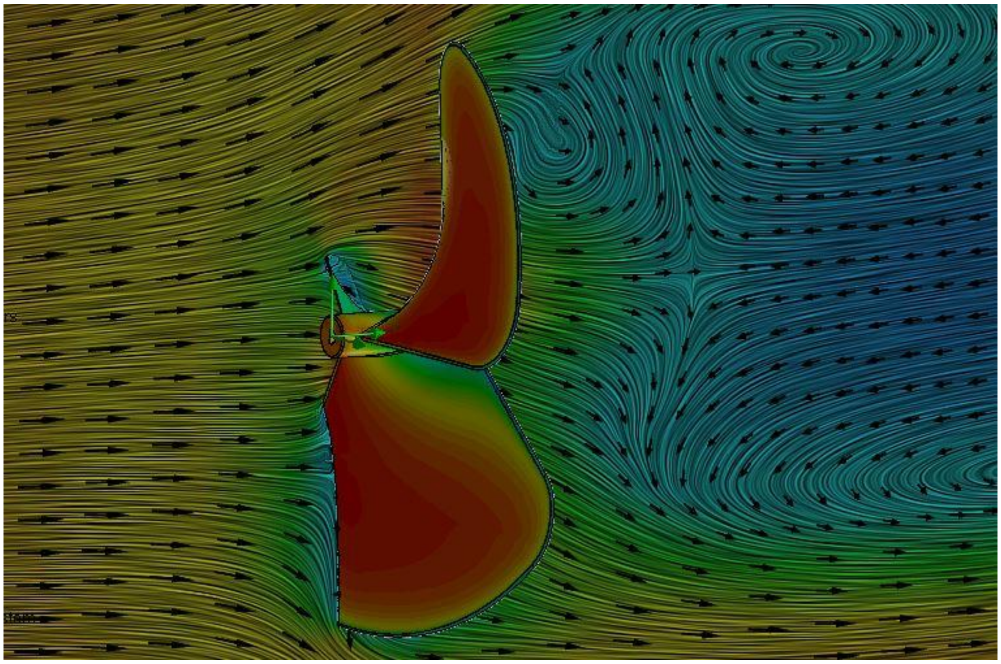

Figura 26: Flujo de agua a través de la Hélice

En la figura 26 tenemos una visión más clara de la dirección y sentido del flujo del agua, el cual es obstaculizado abruptamente por la pieza, lo cual podría significar que es necesaria una modificación del ángulo de inclinación de las aspas.

4.3.2. Ensamblaje

Es menester comprobar que nuestro diseño, una vez ensambladas todas las piezas, se comporta eficazmente a la hora de desplazarse a través del agua. Así pues, someteremos al conjunto a una simulación en la cual estará sometido a una presión de una atmósfera y experimentará un desplazamiento en el agua a una velocidad constante de 1 m/s. La definición de esta simulación es análoga a la realizada para la hélice en el apartado 4.3.1.

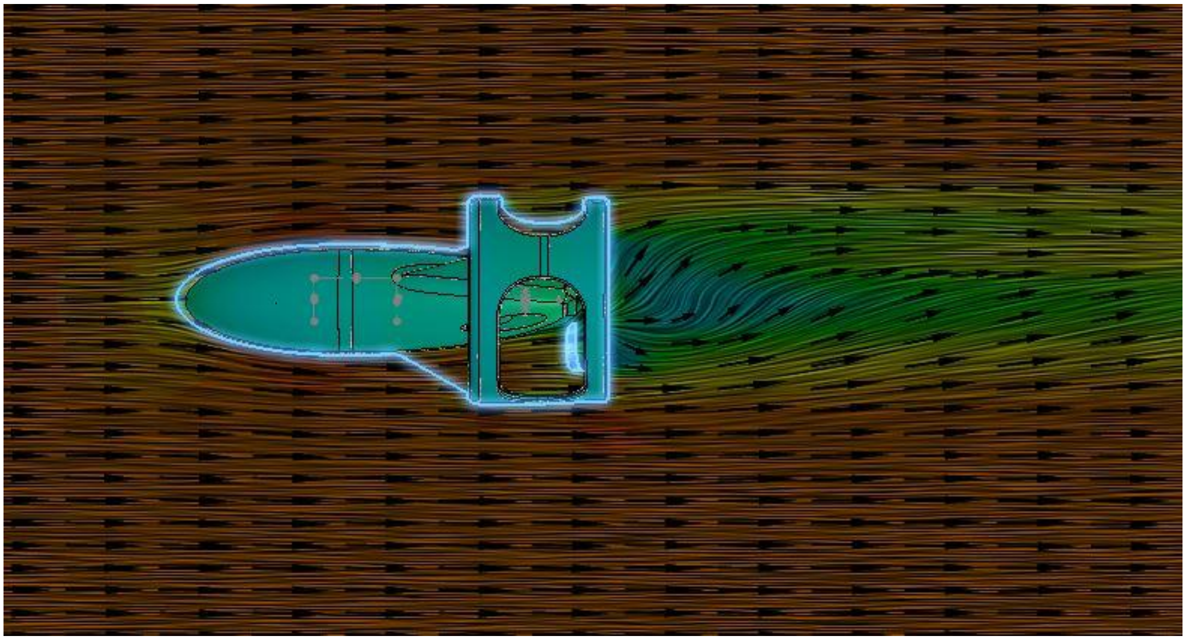

Figura 27: Resultado de simulación aerodinámica del conjunto ensamblado

En la figura 27 podemos apreciar de nuevo un gradiente cromático, donde los colores más cálidos representan los valores cercanos a 1 m/s, mientras que los fríos representan una disminución de la velocidad, incluyéndose además las isolíneas que están acompañadas por una leyenda vectorial que indican la dirección y sentido del flujo del agua.

En conclusión, en la simulación se observa una disminución leve de la velocidad del agua en la parte delantera de la estructura, la pieza que recubre la hélice no parece representar un impedimento significativo para el paso del agua y por último se advierte una gran disminución de la velocidad del agua en la zona donde está emplazada la hélice, lo cual es beneficioso puesto que significa que esta zona de baja velocidad será impulsada por el sistema motriz y que la hélice tendrá una buena entrada de agua.

Capítulo 5. Electrónica y sistema motriz

5.1. Microcontrolador Arduino

Con el propósito de implementar la propuesta de mejora de nuestro diseño, haremos uso de una placa de Arduino, basada en el microcontrolador ATMEL, que posee una interfaz de entrada a la cual conectar los periféricos y una de salida en la cual volcar información procesada por el microcontrolador sirviéndose o no de los periféricos de entrada. La reprogramación del microprocesador se lleva a cabo en el entorno de desarrollo integrado Arduino IDE, desde el cual se escribe el código, se compila y posteriormente se carga en la placa. Como solución para el control de los sensores se propone usar una placa Arduino UNO.

Figura 28: Placa Arduino UNO para la gestión de los sensores [14]

Para el control de la regulación de voltaje de entrada del motor, de la cual hablaremos posteriormente en este mismo capítulo, se propone el uso de una placa Arduino NANO, la cual estaría destinada únicamente a la tarea mencionada. Esto lo hacemos para evitar que, si una placa falla, todo el sistema falle y además facilitando así la capacidad del dispositivo para que sus piezas sean repuestas. El modelo NANO, a diferencia del modelo UNO, es de menor potencia y mucho más compacto, pudiendo ser instalado directamente en una *protoboard.*

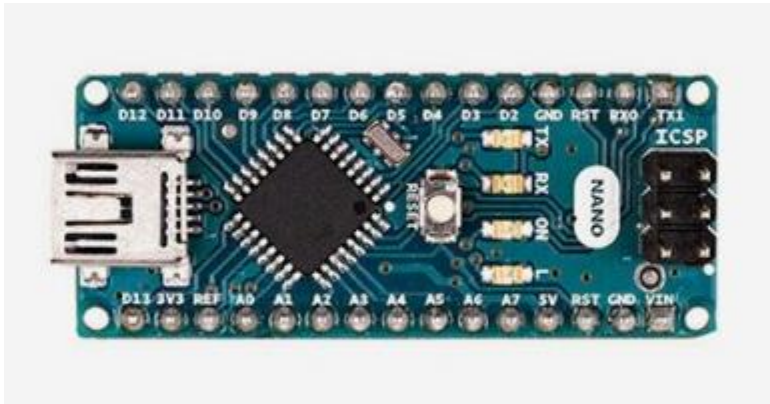

Figura 29: Placa Arduino NANO para la generación de la señal para el motor [15]

5.2. Bus de comunicación I²C

Una de las herramientas, de la cual se facilita su uso gracias a las librerías adquiridas de la comunidad de programadores del proyecto Arduino, es el bus de comunicación I^2C, que utilizaremos indirectamente para mantener conexión con distintos dispositivos. Este bus integra lo mejor de los protocolos SPI (*Serial Peripheral Interface*) y UART (*Universal Asynchronous Receiver-Transmitter*). Mediante este protocolo I^2C podemos configurar uno o varios maestros para controlar uno o varios esclavos, haciendo uso de dos vías de comunicación análogamente con el protocolo UART. Estas son:

- SDA (*Serial Data*): Vía de comunicación serial entre maestros y esclavos por la cual se transmite la información bit a bit coordinadamente.

- SCL (*Serial Clock*): Vía de comunicación que transmite la señal de reloj gracias a la cual los maestros y esclavos trabajan de manera síncrona.

Dentro de las características de este protocolo está la velocidad de transmisión de la información y la cantidad de dispositivos que pueden conectarse, siendo capaz de transmitir entre 100 kbps y 5 Mbps y permitir la instalación de una cantidad ilimitada de maestros y 1008 esclavos en total.

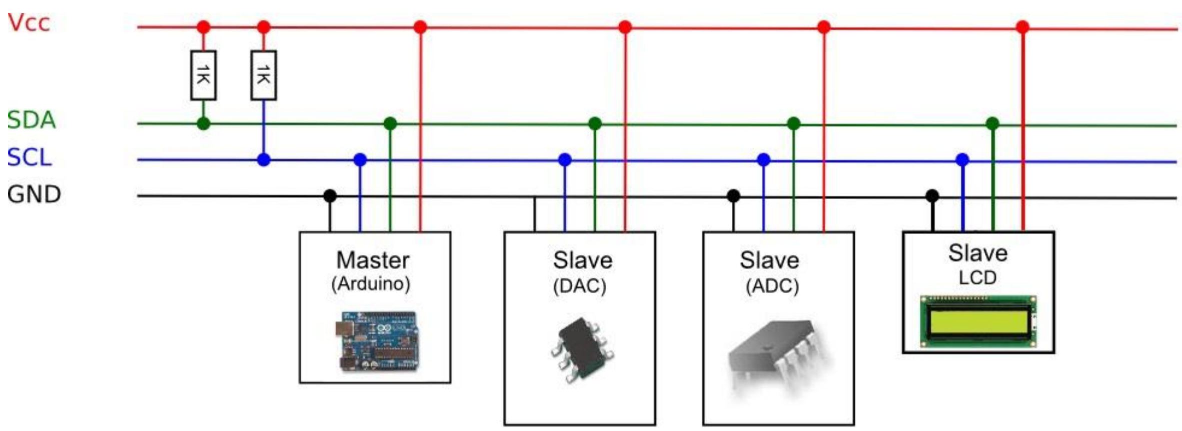

Figura 30: Diagrama de la capa física del bus de comunicación I^2C [18]

En la figura 30 se denotan dos resistencias de 1kΩ que van conectadas a las líneas de SDA y SCL. Estas resistencias, denominadas resistencias de *pull-up*, nos evitarán que en estado de reposo midamos un valor erróneo, suprimiendo la influencia de factores externos sobre las mediciones, como puede ser el ruido eléctrico.

5.3. Sensor de humedad

La humedad relativa es un factor determinante cuando no se cuenta con un sistema electrónico aislado, tanto un porcentaje alto, que podría ocasionar derivas o cortocircuitos, como uno bajo, que podría perjudicar la soldadura de los componentes. Por tanto, es conveniente monitorear e informar al usuario cuando el interior de la carcasa se encuentre fuera de un rango de [40-80]% de humedad relativa en el aire.

Para llevar a cabo lo mencionado en el párrafo anterior, haremos uso del sensor DHT22, el cual es un sensor diseñado para la medición de temperatura y humedad relativa. Este sensor funciona con el bus de comunicación I^2C, lo cual facilita mucho su conexión y programación.

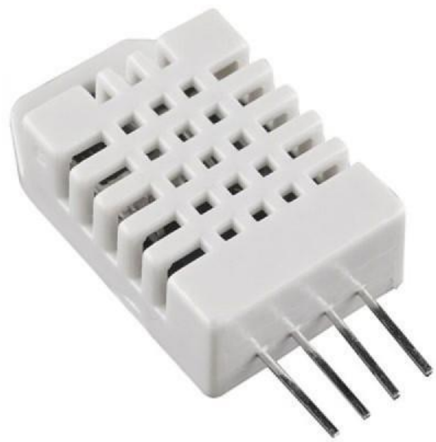

Figura 31: Sensor de humedad y temperatura DHT22 [16]

5.4. Sensores de temperatura

La medición de la temperatura es un factor clave para el desarrollo de nuestro proyecto. Su medición en el interior de la carcasa nos permite asegurar que la electrónica está funcionando correctamente y a pesar de que las baterías tendrán instalado un BMS (*Battery Management System*), si este fallara, podría producirse un sobrecalentamiento de las baterías, lo cual es sumamente peligroso y sería necesario avisar al usuario si llegara a suceder. Es por todo lo anteriormente mencionado que se realizará la medición de temperatura interna. Por otra parte, la cuantificación de la temperatura externa no tiene una finalidad de estricta seguridad, sino que se hará para aportar al usuario buceador información del medio que le rodea y, en caso de sobrepasar la temperatura límite, informar mediante una salida LED. Para realizar estas dos mediciones se hará uso de dos sensores de temperatura RTD (*Resistance Temperature Detector*) tipo PT100, acompañados por sus circuitos de acondicionamiento. El sensor dedicado a la temperatura interna no contará con ninguna protección especial, más que el propio encapsulado. Sin embargo, el sensor dedicado a la temperatura externa estará en contacto directo con el agua, por lo que contará con una protección normalizada **IP67.**

Figura 32: Sensor RTD PT100 cedido por el Departamento de Ingeniería Industrial de la ULL

5.5. Circuito de acondicionamiento para PT100

El sensor PT100 es un transductor, es decir, es capaz de convertir una manifestación de energía de entrada en otra distinta de salida. Este se caracteriza por variar la resistencia entre sus terminales en función de la temperatura, lo que hace de manera lineal. Sin embargo, es necesario hacer uso de un circuito de acondicionamiento para facilitar la lectura de esta variación de temperatura. Para transformar esa variación de resistencia en un valor de voltaje fácil de registrar y transmitir haremos uso de un puente de *Wheatstone*, del cual obtendremos una tensión diferencial. El circuito del puente de *Wheatstone* está formado por dos divisores de tensión de dos resistencias cada uno, uno de los cuales incluirá a la PT100.

Las resistencias que componen el puente, para que este equilibrado, siguen la siguiente relación [3]:

$$\frac{R_3}{R_4} = \frac{R_1}{R_0} = k$$

Donde cada denominador conforma un divisor de tensión y $\mathbf{R_0}$ corresponde con la resistencia que proporciona el sensor PT100 a 0 ºC. Fijamos el valor de $\mathbf{R_3}$ en 10 kΩ, por tanto, el valor de $\mathbf{R_1}$ será el mismo y el valor de $\mathbf{R_0}$ a 0ºC es de 100 Ω y por ello $\mathbf{R_4}$ coincidirá con este valor.

Por otra parte, hemos de tener en cuenta que las variaciones de temperatura generarán pequeñas variaciones de resistencia y por tanto pequeñas variaciones en la tensión diferencial. A raíz de esto, es indispensable la amplificación de esta señal diferencial mediante un amplificador de instrumentación, optando en nuestro caso concreto por el circuito integrado INA 126 [4]. A este amplificador se le puede modificar la ganancia variando el valor de la resistencia $\mathbf{R_g}$ según la siguiente ecuación:

$$G = 5 + \frac{8k\Omega}{R_g}$$

$$G = \frac{V_{out}}{(V_2 - V_1)}$$

$$R_{PT} = R_0 \cdot (1 + \alpha \cdot \Delta T)$$

Queremos obtener para el valor de 100 ºC, el cual es el valor máximo medible por la PT100, una salida de 5 V del amplificador de instrumentación a partir del valor de salida de los divisores de tensión, por tanto, determinamos el valor de salida de los divisores de tensión del puente de *Wheatstone*, que obtendremos de la simulación. Una vez teniendo los valores de voltaje de entrada y salida, obtenemos el valor de la ganancia necesaria y despejamos el valor de la resistencia $\mathbf{R_g}$, el cual es de 307,74 Ω, valor que usaremos para las simulaciones, sin embargo, para un diseño posterior deberá usarse un valor comercial de 310 Ω.

5.6. Sensores de presión

Análogamente con el registro de temperatura, se realizarán mediciones internas y externas de la presión y por consiguiente llevarán las mismas protecciones. Nos interesa la lectura de la presión interna puesto que, al estar el dispositivo presurizado, la variación de esta podría significar una fisura en la carcasa. Por otro lado, la lectura de la presión externa, al igual que la temperatura, servirá para aportar información relevante al usuario y, en caso tal de salirse del rango entre el valor de presurización y la presión límite, notificar al usuario mediante salida LED. Para realizar estas mediciones haremos uso de un módulo de Arduino BMP180, para la lectura de la presión interna, compatible con la comunicación I^2C y para medición de la presión externa un sensor IPSU-M12 con protección IP67.

5.7. Sensor de voltaje

El sensor de voltaje INA 219 es un circuito integrado de fácil instalación y utilización compatible con la comunicación I^2C, el cual es capaz de registrar en corriente continua, tensión, intensidad y potencia. Para nuestro proyecto nos interesa la medición del voltaje de salida de las baterías, con el objetivo de controlar posibles sobretensiones.

5.8. Estimación de la altitud

Como se ha mencionado, nuestro dispositivo está pensado para operar a una profundidad máxima de 10 metros bajo el agua. Exceder demasiado esta profundidad podría suponer el colapso de la estructura, por lo que se realizará el control de este parámetro mediante su estimación en función de la entrada del sensor de presión externa, haciendo uso de la siguiente ecuación fundamental de la estática de fluidos sobre la presión hidrostática:

$$\boldsymbol{\Delta P = \rho \cdot g \cdot \Delta h}$$

Donde $\Delta \mathbf{P}$ es la presión, $\boldsymbol{\rho}$ es la densidad del agua de mar, **g** es la aceleración de la gravedad y $\Delta \mathbf{h}$ sería la diferencia de altitud resultante entre la posición del objeto y la superficie del mar.

5.9. Motor

A pesar de que se modeliza y se implementa en la simulación un modelo de motor (modelo M200) el cual mantenía consonancia con la hélice diseñada, en el transcurso del desarrollo de este proyecto este motor fue descatalogado y se retiró la información referente al mismo. Por ello, proponemos el motor T200 [5] de BlueRobotics para la propulsión del VPS, siendo este motor análogo al M200 en cuanto a su desempeño. El T200 se comercializa con un sistema de propulsión instalado de fábrica y los estudios de su desempeño, proporcionados por la empresa, giran en torno al funcionamiento en conjunto de motor y sistema propulsor. Tomamos los datos proporcionados por la empresa para los dimensionamientos que conlleven cálculos, como pueden ser el cálculo de baterías, estudio de flotabilidad o análisis de cargas. Cabe destacar que este motor mantiene una relación de potencia superior al escogido inicialmente el cual operaba entre los 7 y 26 voltios y podía tener una corriente máxima de 30 amperios. No obstante, no podía superar los 600 vatios sin dañarse, frente al actual que opera entre 7 y 20 voltios y una corriente máxima de 32 amperios y es capaz de operar con la potencia máxima entregable de 645 vatios.

Electrical	
Operating Voltage	7-20 volts
Full Throttle Current @ Nominal (16 V)	24 Amps
Full Throttle Current @ Maximum (20 V)	32 Amps
Full Throttle Power @ Nominal (16 V)	390 Watts
Full Throttle Power @ Maximum (20 V)	645 Watts

Figura 33: Tabla de desempeño eléctrico del motor T200 [19]

En la figura 33 se observa que el voltaje nominal es de 16 voltios, lo que se debe a que la mejor relación entre empuje y eficiencia se encuentra cuando el motor opera entre 12 y 16 voltios, así se denota en la página oficial [5].

Por otra parte, de la figura 34 determinamos el empuje y aceleración máxima que podemos obtener del motor junto con el sistema de propulsión de fábrica. La aceleración y empuje máximas son de 6,7 y 5,05 kg·f respectivamente, obteniendo este desempeño al aplicar 20 voltios. Como nuestro dispositivo está pensado para tener una flotabilidad aproximadamente nula, podemos considerar que esta aceleración y empuje será la que experimentara el VPS horizontalmente.

Performance

Full Throttle FWD/REV Thrust @ Nominal (16 V)	5.25 / 4.1 kg f	11.6 / 9.0 lb f
Full Throttle FWD/REV Thrust @ Maximum (20 V)	6.7 / 5.05 kg f	14.8 / 11.1 lb f
Minimum Thrust	0.02 kg f*	0.05 lb f*

Figura 34: Tabla de aceleración y empuje en función del voltaje del T200 [5]

5.10. Señal de entrada del motor

El motor funciona a un voltaje máximo de 20 V para que no sufra daños permanentes. Como propuesta de solución para la variación de velocidad del motor, se plantea la implementación de un Arduino NANO dedicado exclusivamente a proporcionar una señal PWM con una frecuencia supeditada a la “marcha” que se le quiera dar al VPS, siendo esta modificada por el usuario mediante pulsadores. Este sistema consistiría en tres pulsadores los cuales serían entradas digitales del Arduino. A razón de cada pulsador, el microcontrolador daría una señal PWM cuyo voltaje y frecuencia serían usados para polarizar un transistor de tal manera que funcionara entre las regiones de corte y saturación, permitiendo el paso de los 20 V con una frecuencia tal, que de un voltaje eficaz que corresponda a 10, 15 y 20 voltios eficaces para la primera, segunda y tercera marcha respectivamente. A pesar de ser capaz de operar entre los 7 y 20 voltios, todas las gráficas, proporcionadas por la empresa distribuidora, que describen su funcionamiento (las cuales podrán analizarse en el apartado "Tablas de desempeño del motor T200" de los anexos) analizan su operación entre 10 y 20 voltios, lo cual suscita a pensar que no tiene buen desempeño a este voltaje mínimo de operación.

5.11. Pantalla LCD

Para que el usuario monitorice los valores de las lecturas en tiempo real de los sensores, se ha escogido mostrarlas por una pantalla LCD. Concretamente consiste en una pantalla LCD de 20x4 segmentos con un módulo acoplado para la comunicación mediante bus I^2C y la regulación del brillo de esta.

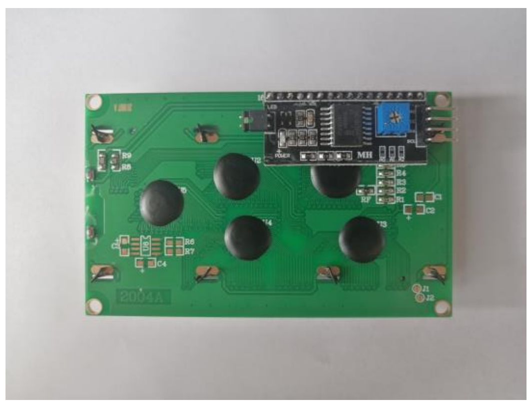

Figura 35: Pantalla LCD 20x4 con módulo de comunicación I^2C vista trasera

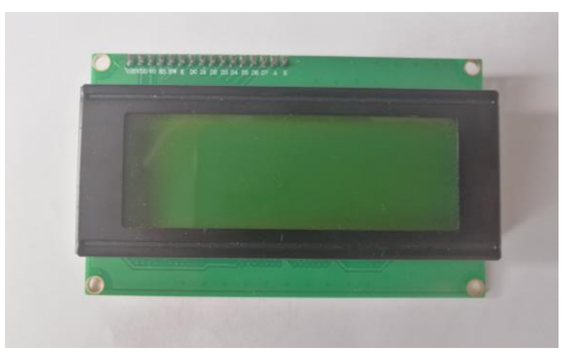

Figura 36: Pantalla LCD 20x4 con módulo de comunicación I^2C vista frontal

Capítulo 6. Alimentación

6.1. Baterías

Para alimentar todos los sistemas del VPS, haremos uso de un sistema de baterías dimensionado para suplir la demanda del dispositivo durante media hora. En nuestro dimensionamiento hemos de tener claro cuál será el consumo de los sistemas a alimentar. Por ello inicialmente realizamos un análisis de consumo, donde tendremos en cuenta los elementos de mayor consumo de voltaje para determinar cuántas células en serie hemos de colocar, como el motor, sensores externos y las placas de Arduino, mientras que para determinar cuántas células van en paralelo, realizamos el sumatorio de los consumos de corriente y lo multiplicamos por el tiempo de autonomía que requerimos. De ahí obtenemos la capacidad máxima que ha de tener nuestro *pack* de baterías y en función de la capacidad de nuestras células se determinan cuántas son necesarias en paralelo.

La célula escogida para suplir nuestras necesidades es la batería modelo 18650 de ion de litio Klarus Panasonic de 3,7 V y 3,4 Ah, de las cuales necesitaremos 20 unidades. Los cálculos se verán mejor reflejados en el apartado "Dimensionamiento de baterías" de los anexos.

6.2. BMS

A la hora de controlar el buen funcionamiento de las baterías, es conveniente la instalación de un BMS (*Battery Management System*), el cual es un dispositivo que se encarga de regular la entrada y salida de corriente, de equilibrar la tensión entre las células del *pack* y monitorear su temperatura. Para nuestro dispositivo se ha escogido un modelo compatible en la página web de BmsBattery [6], el cual tiene asociada una aplicación móvil con conexión *BlueTooth*, desde la cual ver el estado de las baterías.

6.3. Cargador

Para cargar nuestro *pack* de baterías [7], se ha escogido un cargador personalizable en la página web de BmsBattery, para el cual es posible especificar el voltaje de carga necesario, la configuración del *pack* de baterías y el tipo de conector entre cargador y baterías. Es necesario comentar que, dadas las circunstancias de trabajo de nuestro dispositivo, la conexión de entrada del cargador, mientras no esté fuera del agua o cargando el dispositivo, ha de permanecer sellada, se propone como sello de impermeabilización una tapa roscada con junta de goma, para que mientras esta esté roscada impida el paso del agua, polvo o cualquier cuerpo extraño.

Capítulo 7. Resultados

En este capítulo comentaremos los resultados obtenidos en la simulación del circuito de acondicionamiento del sensor PT100 y del prototipo de montaje de los sensores de presión, humedad y temperatura.

7.1. Fuente bipolar

Para suplir la necesidad de un voltaje bipolar de ±10 V se diseñó un circuito que parte de un divisor de tensión y un amplificador operacional en configuración de seguidor de tensión, al que se añaden un conjunto de dos diodos y dos transistores, uno PNP y otro NPN. La fuente de 20 V representa la salida de voltaje de las baterías la cual llega directamente al divisor de tensión. Gracias al divisor obtenemos una fuente bipolar de ±10 V, el cual usaremos para alimentar la electrónica posterior, y una tensión de cero voltios, voltaje que proporciona una tierra virtual mediante un amplificador operacional en configuración de seguidor de tensión. Los diodos que se observan en el montaje sirven para polarizar los transistores, los cuales son usados para absorber corriente que circulará por el regulador lineal de tensión y el amplificador de instrumentación en el montaje posterior.

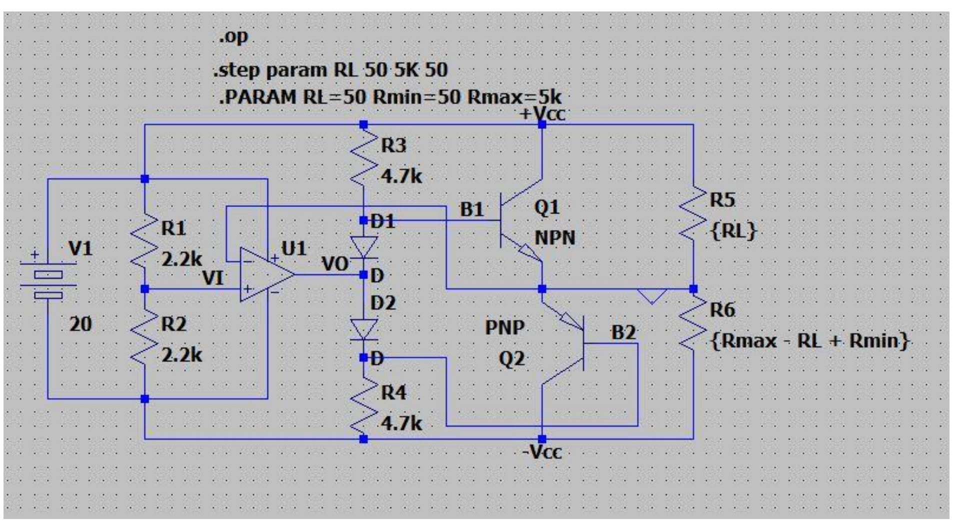

Figura 37: Circuito de la fuente bipolar

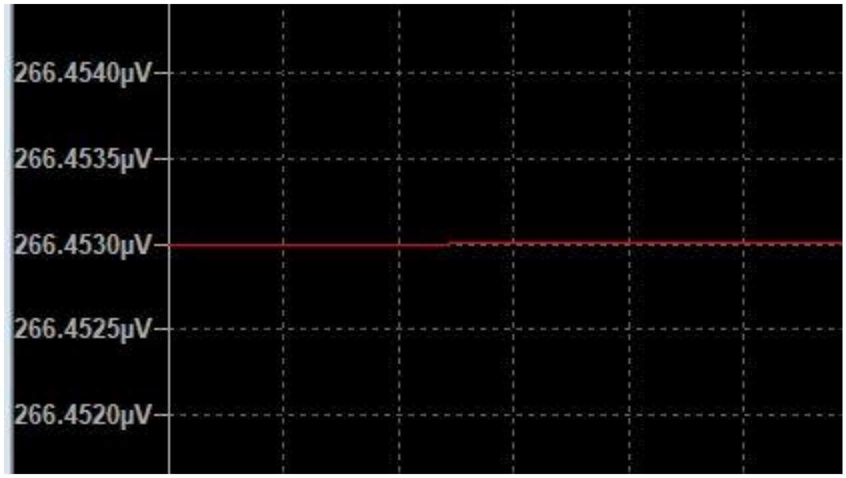

Figura 38: Voltaje de salida del divisor de tensión

En la figura 39 podemos observar el resultado de simular una variación de las cargas R5 y R6 en la salida de la fuente bipolar, comenzando R5 en un valor de 50 Ω incrementándose a razón de 50 Ω hasta llegar a los 5 kΩ, mientras que R6 hace lo contrario, parte de 5 kΩ y disminuye hasta llegar a los 50 Ω. Mientras que R5 tiene una resistencia baja, el transistor Q2 absorbe la corriente y a la inversa con la resistencia R6 y el transistor Q1.

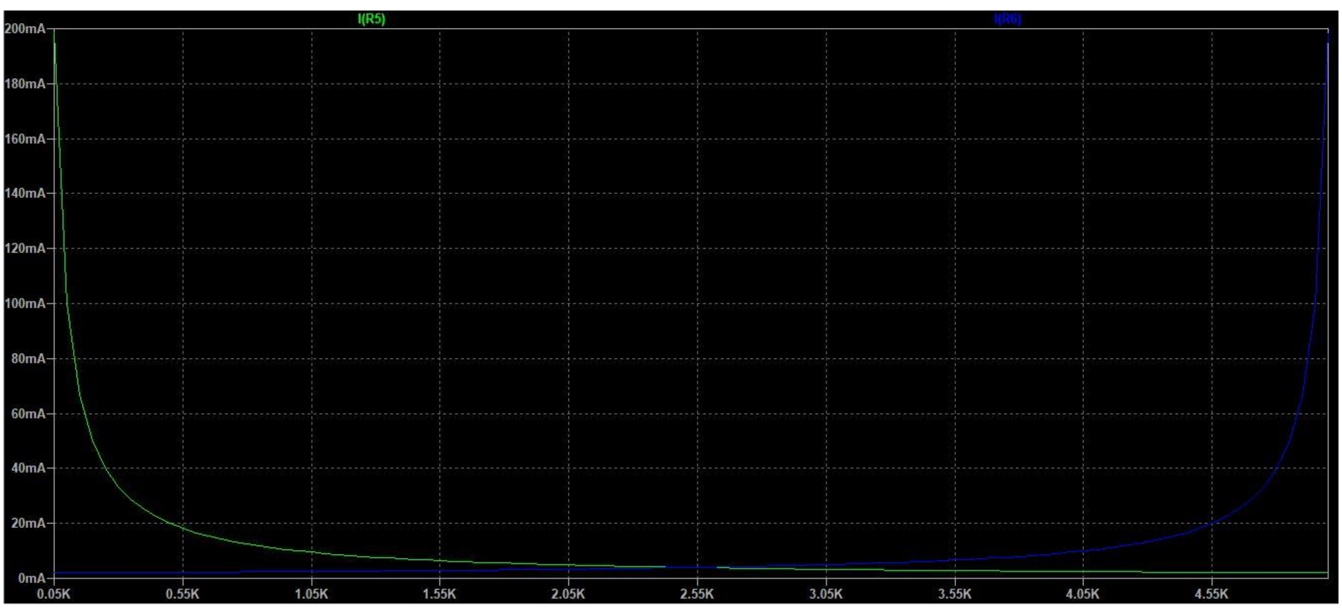

Figura 39: Simulación de la variación de la intensidad en la salida de la fuente bipolar para una variación de la carga RL

7.2. Circuito de acondicionamiento del sensor PT100

Podemos observar en la figura 40, comenzando por la izquierda, una fuente de alimentación de corriente continua de 20 V, que representa la salida directa de las baterías, la cual llega directamente al circuito para generar una tensión bipolar, la cual se comenta en el apartado 8.1.

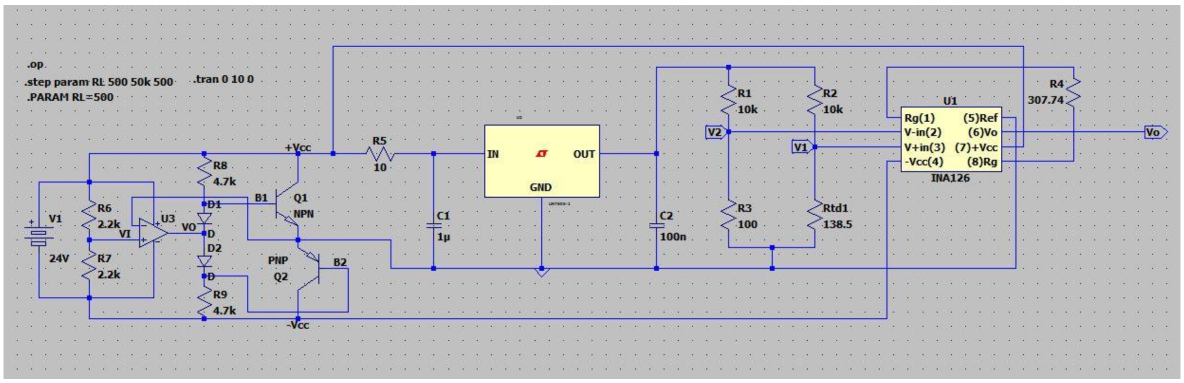

Figura 40: Simulación del circuito de acondicionamiento de el sensor PT100

Luego del divisor de tensión tenemos un regulador lineal de tensión LM7805, véase figura 41, al cual le entran los 10 V provenientes del divisor de tensión y obtenemos a la salida 5 V, los cuales nos servirán para alimentar el puente de *Wheatstone*.

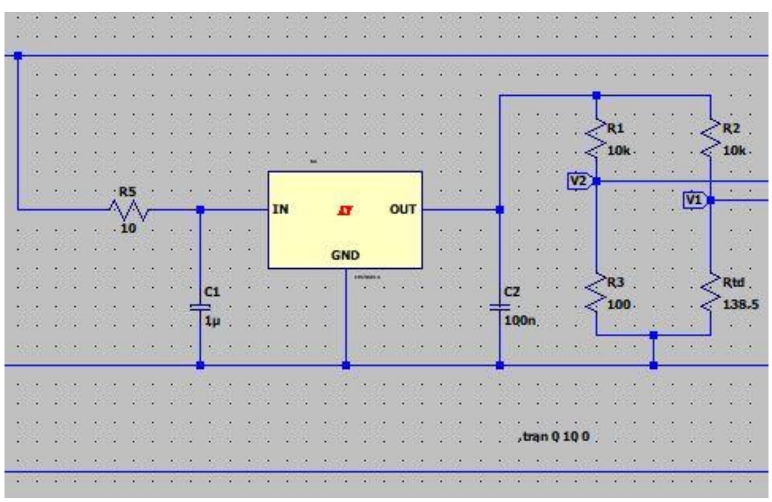

Figura 41: Sección del regulador lineal de tensión y el puente de *Wheatstone*

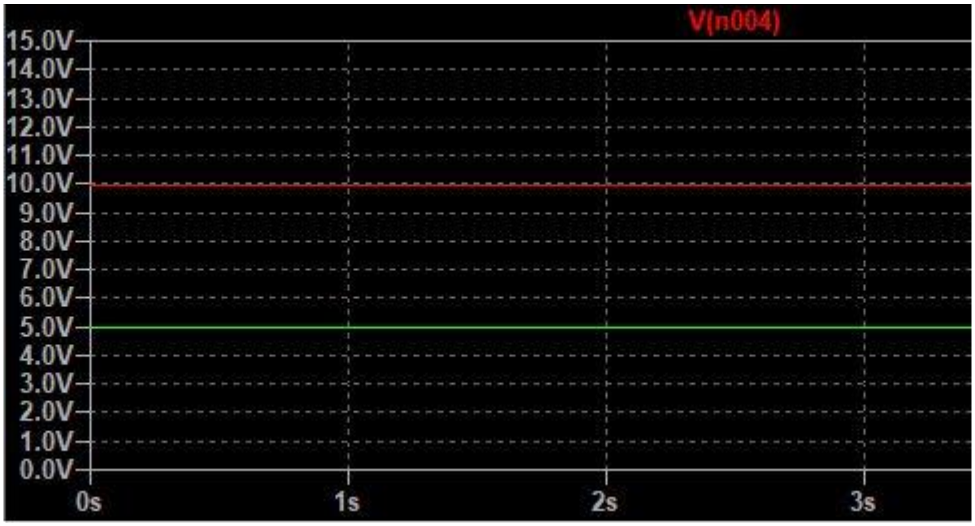

Figura 42: Entrada y salida del regulador lineal de tensión

Por último, tenemos el puente de *Wheatstone*, donde la salida del divisor compuesto por la PT100 va a la entrada no inversora del amplificador de instrumentación y la otra salida va a la entrada inversora. La diferencia de potencial entre estas entradas es amplificada por el INA 126.

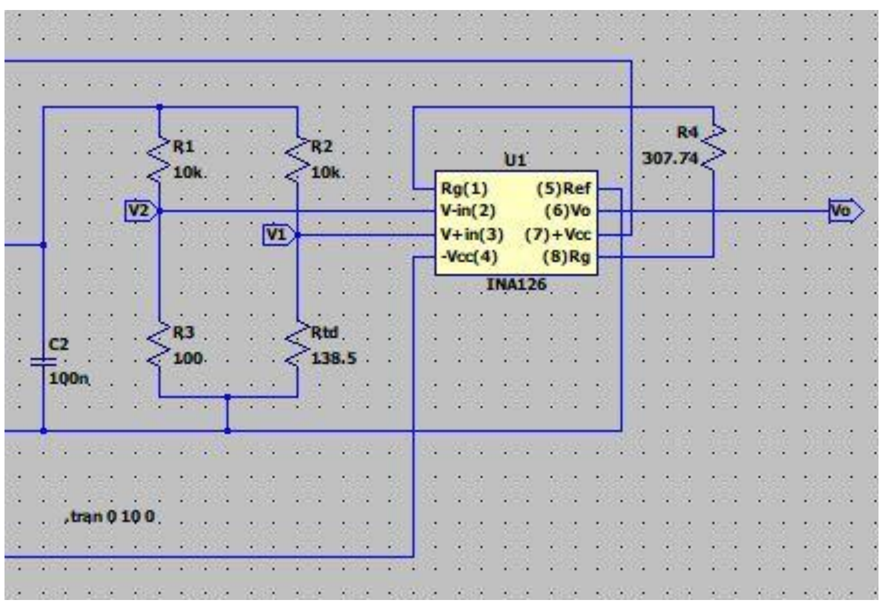

Figura 43: Sección del puente de *Wheatstone* y amplificador diferencial operacional de instrumentación

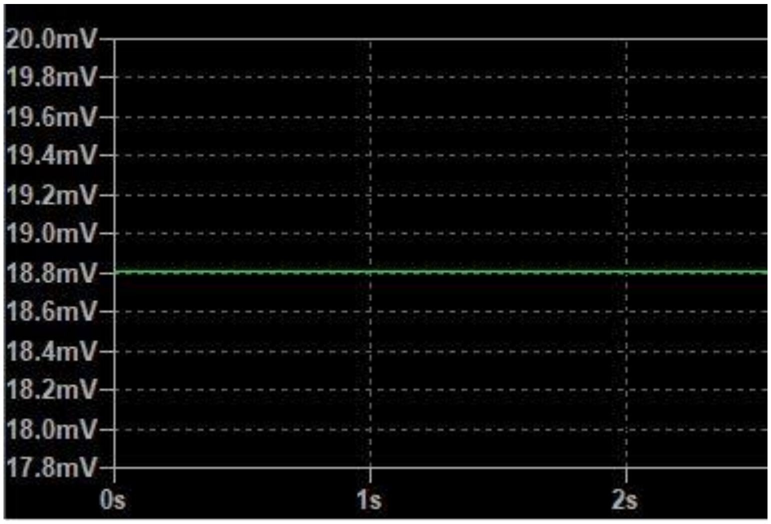

Figura 44: Diferencia de potencial entre las entradas del amplificador de instrumentación

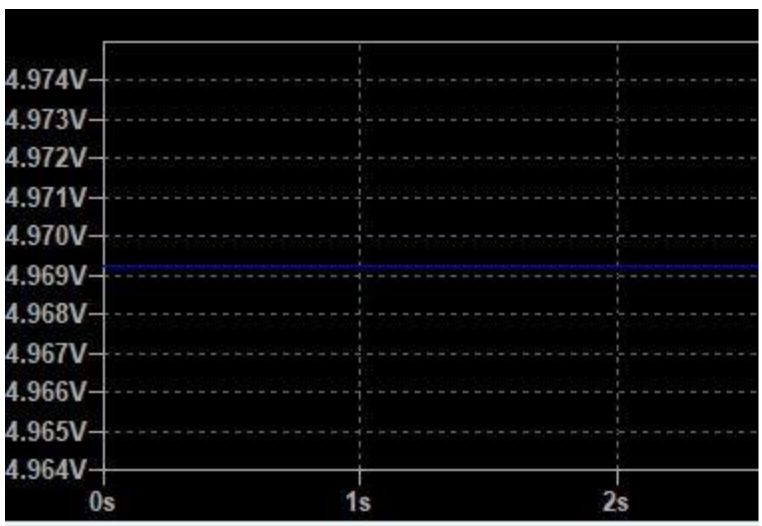

Figura 45: Voltaje de salida del amplificador de instrumentación

Como se observa en la figura 45, obtenemos la salida de voltaje en torno a los 5 V, teniendo un valor de resistencia de la PT100 de 138,5 Ω para una temperatura de 100 ºC, tal y como se comentó en el capítulo 5 apartado 5. En función de los resultados de simulación, podemos concluir en una primera instancia que el diseño y dimensionamiento del circuito de acondicionamiento es correcto.

7.3. Prototipo de instalación de sensores

Para comprobar que los sensores escogidos para la medida de parámetros internos funcionan como se espera, hemos realizado un prototipo de instalación de estos, para estudiar la programación requerida y analizar su comportamiento, tanto en conjunto como en solitario. Primero se comenzó con un sensor y se programó, en función de las librerías correspondientes, la recepción y lectura del parámetro que este cuantificará y posteriormente se fueron añadiendo uno a uno. En este primer prototipo los sensores implementados fueron: el sensor de presión BMP18, el sensor de humedad y temperatura DHT22; el sensor PT100 no se incluye en este diseño pues no se pudo acceder al laboratorio debido a las restricciones sanitarias. Una vez clara la recepción de información por parte de los sensores, instalamos y configuramos la pantalla LCD para mostrar la salida de los sensores, tal y como se haría en un diseño posterior, distribuyendo la información en la pantalla para una fácil lectura por el usuario. Por otra parte, realizamos una instalación y programación sencilla a fin de aportar una idea de cómo se haría el control de parámetros críticos, como la humedad. Esta última instalación, consiste en programar la salida de la placa Arduino para que, a ciertos rangos de valores de entrada, encienda LEDs correspondientes.

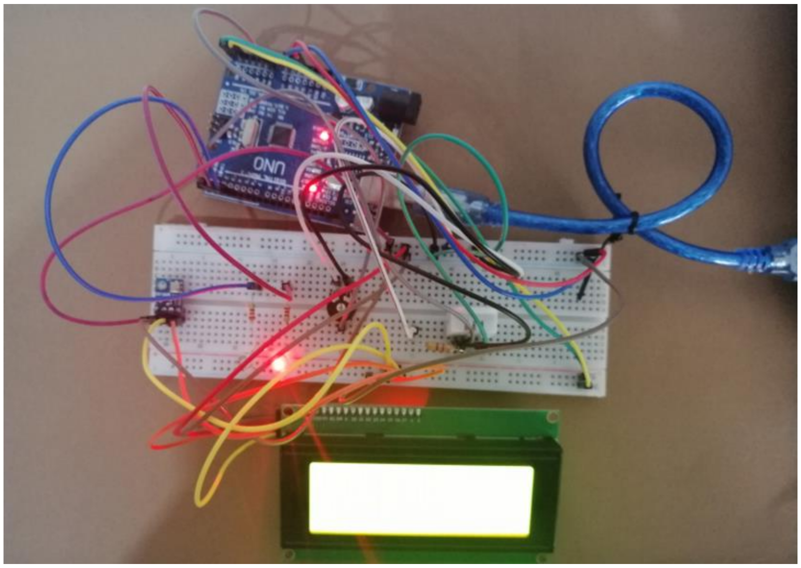

Figura 46: Instalación del prototipo de lectura y muestra por pantalla de los sensores

Figura 47: Pantalla LCD 20x4 con las lecturas de los sensores distribuidas

Capítulo 8. Presupuesto

El presupuesto de este proyecto asciende a 11740,70 €. En las tablas 1, 2 y 3 se descomponen los gastos materiales, de mano de obra y totales respectivamente. En ellas se indican los artículos o conceptos implicados, la unidad, precio unitario o precio por hora, si procede, y el coste total.

Articulo	Unidades	Precio[€]/unidad	Coste [€]
Batería 18650 ion de litio Klarus Panasonic	20,00	8,69	173,80
Amplificador operacional INA126	1,00	3,09	3,09
Regulador lineal de tensión LM7805	1,00	0,99	0,99
Sensor de temperatura y humedad relativa DHT22	1,00	9,95	9,95
Pantalla LCD 20x4 con módulo de comunicación I2C	1,00	19,50	19,50
Sensor de temperatura RTD PT100	2,00	5,99	11,98
Sensor de presión externa IP67 RS PRO Pressure Sensor	1,00	122,56	122,56
Sensor de presión interna módulo de arduino BMP180	1,00	3,99	3,99
Sensor de voltaje INA219	1,00	9,54	9,54
Placa de Arduino UNO	1,00	20,00	20,00
Placa de Arduino NANO	1,00	16,00	16,00
BMS modelo SMART BMS 7S~10S 20A WITH BLUE TOOTH APP	1,00	27,01	27,01
Cargador modelo 84W Lithium Battery Charger with Plastic Shell	1,00	30,39	30,39
Motor T200	1,00	174,63	174,63
	[g]	Precio [€/g]	
PVC	5000,00*	0,06	280,00
Fibra de carbono	39,26**	0,07	2,87
		Costes materiales	906,30

Tabla 1: Desglose de gastos materiales

* El volumen total de PVC necesario, es tomado del programa SolidWorks.

** El volumen total de fibra de carbono necesaria, es tomada del programa SolidWorks.

Concepto	horas	precio[€/h]	Coste [€]
Diseño y simulación mecánica	200,00	20,00	4000,00
Diseño y simulación electrónica	50,00	20,00	1000,00
Redacción del documento	50,00	20,00	1000,00
		Costes de mano de obra	6000,00

Tabla 2: Desglose de coste de la mano de obra

Concepto	Coste [€]
Costes materiales	906,30
Mano de obra	6000,00
Sub total	6906,30
IGIG (7%)	4834,41
Total	11740,70

Tabla 3: Costes totales

Capítulo 9. Conclusiones

El objetivo último de este trabajo era realizar un diseño general de un vehículo personal submarino, tratando de sentar las bases de un diseño posterior. En este proyecto nos hemos centrado en tratar todos los apartados referentes al funcionamiento teórico del dispositivo, proporcionando soluciones a las necesidades que este requería, de tal manera que se cumplen los siguientes objetivos:

1. Diseño de una estructura aerodinámica y resistente a la presión de operación. Ambos estudios contrastados mediante simulación.

2. Estudio de flotabilidad del dispositivo y modificación de la carga para que tenga la flotabilidad deseada.

3. Control del interior del dispositivo y a su vez del medio circundante a este.

4. Propuesta de solución para el sistema que propulsará el dispositivo, además de la regulación de velocidad de este.

5. Estudio de consumo eléctrico, dimensionamiento de baterías y control y alimentación de estas.

El balance entre las partes electrónicas y mecánicas de este proyecto se inclina a la mecánica, ya que, gran parte del trabajo invertido en él consistió en aprender a usar el software de diseño y análisis estructural SolidWorks para alcanzar los objetivos estructurales, lo cual supuso todo un reto. Una vez enfocado el diseño y análisis de la estructura, pudimos avanzar en los objetivos electrónicos, que resultaron ser más sencillos por estar relacionados con la titulación cursada.

Capítulo 10. Bibliografía

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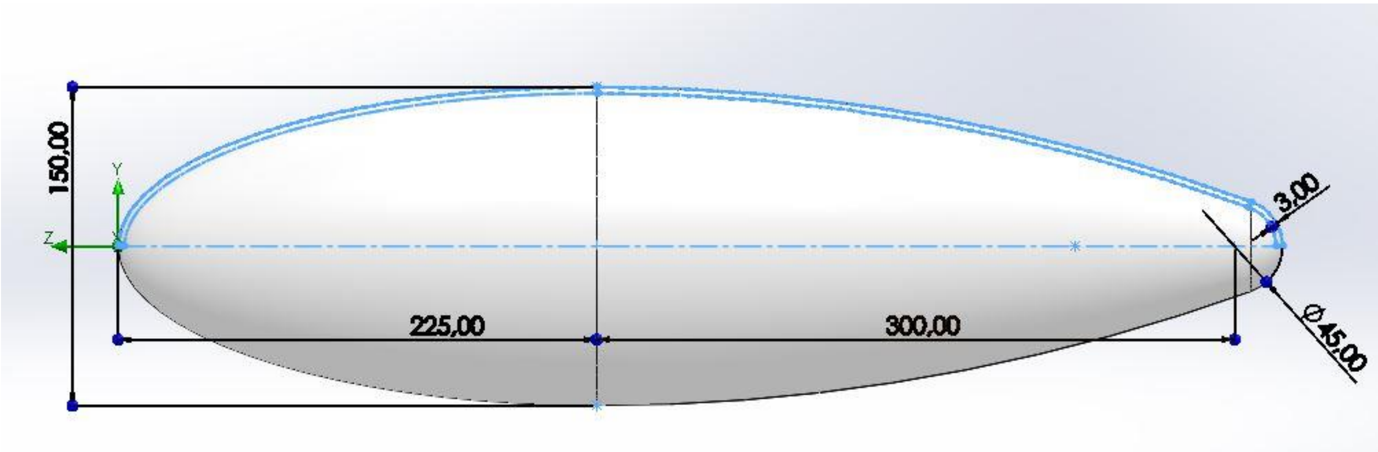
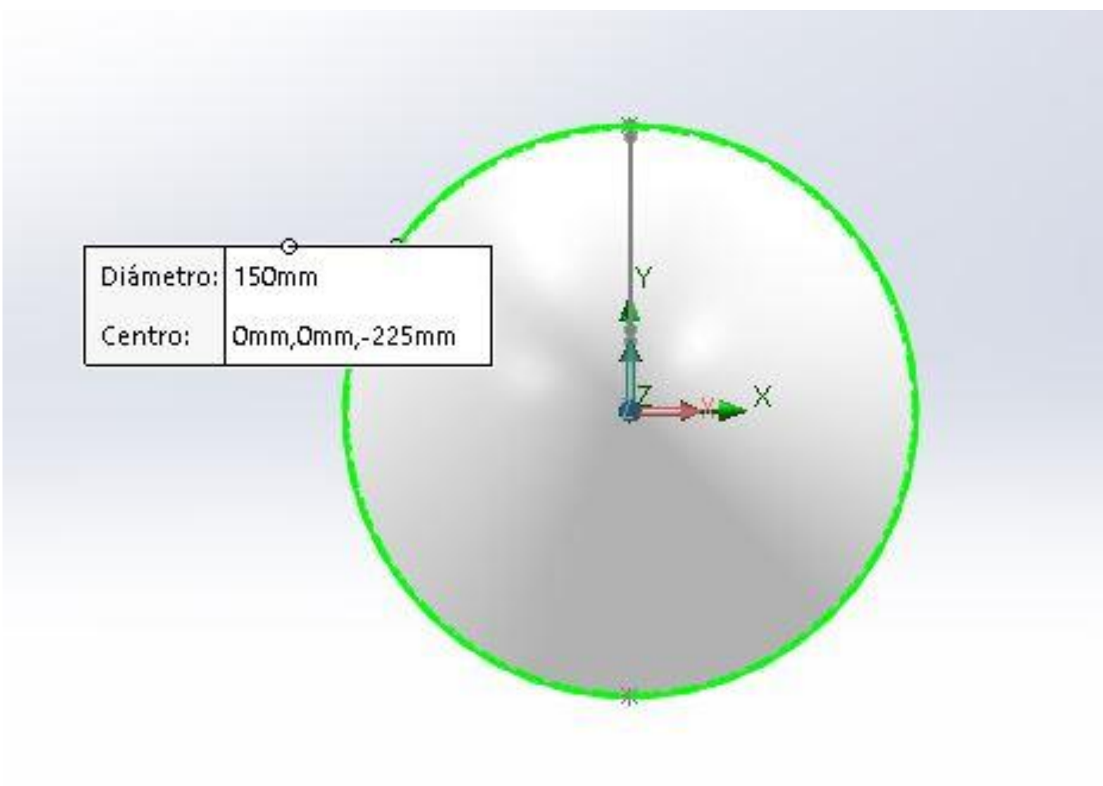
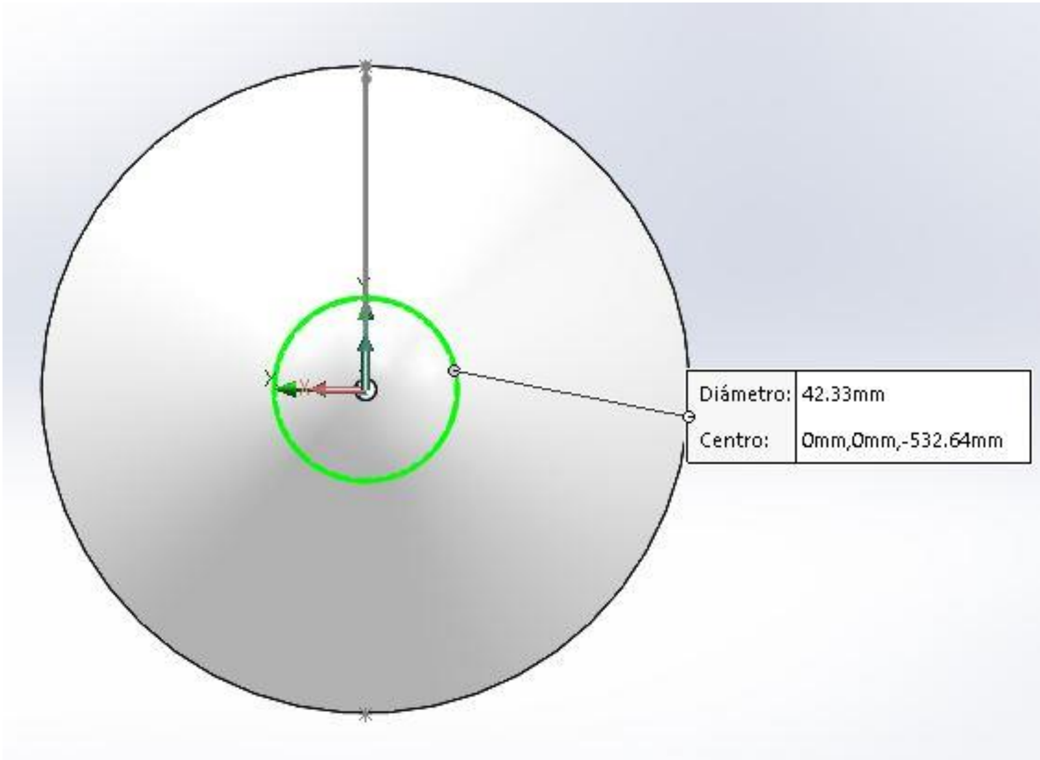
Anexo A. Vistas de la estructura mecánica

Carcasa



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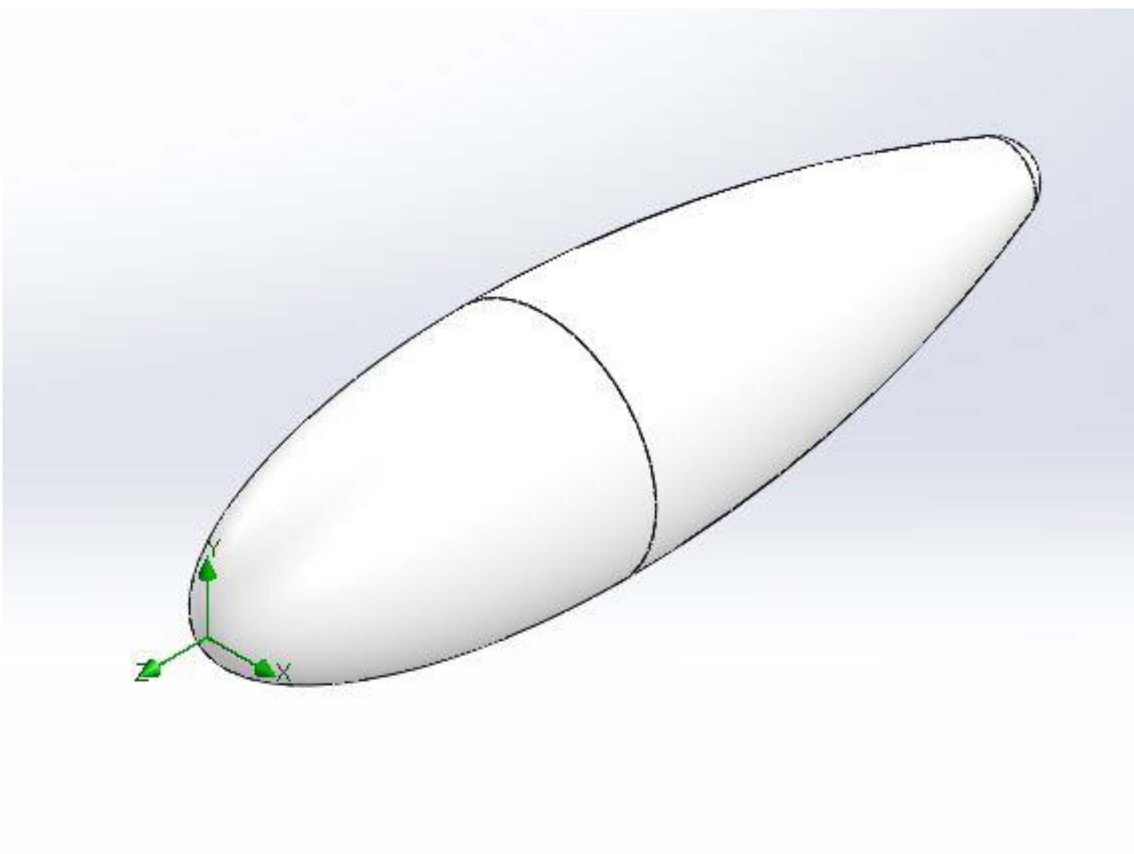
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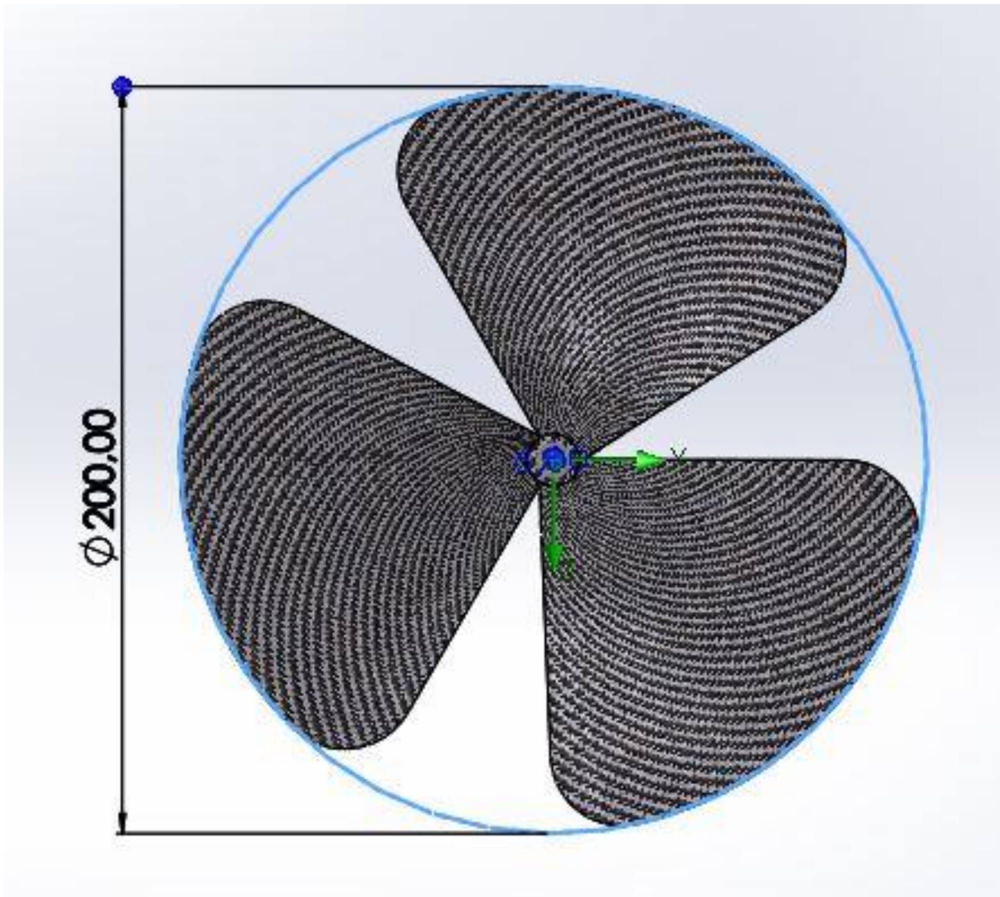

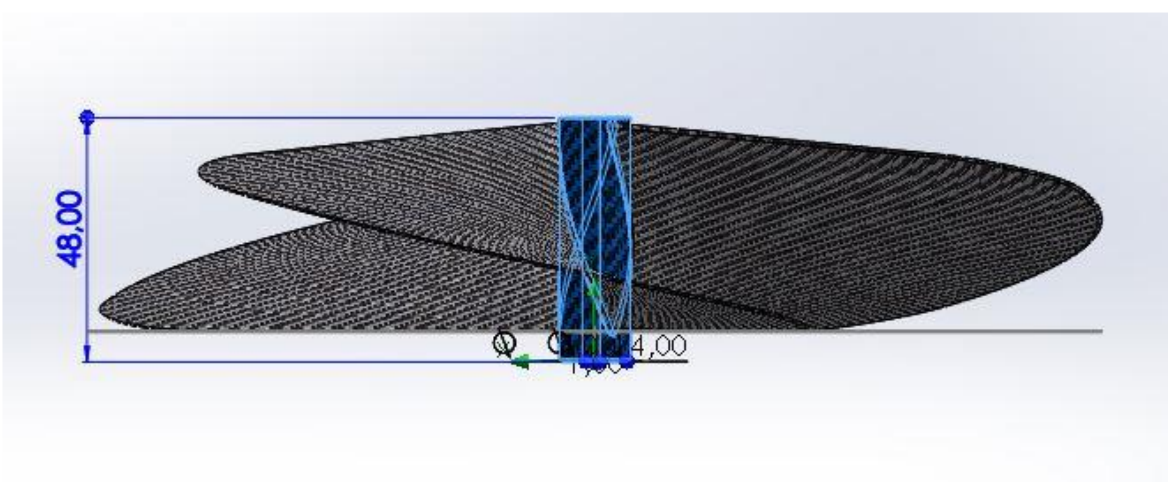

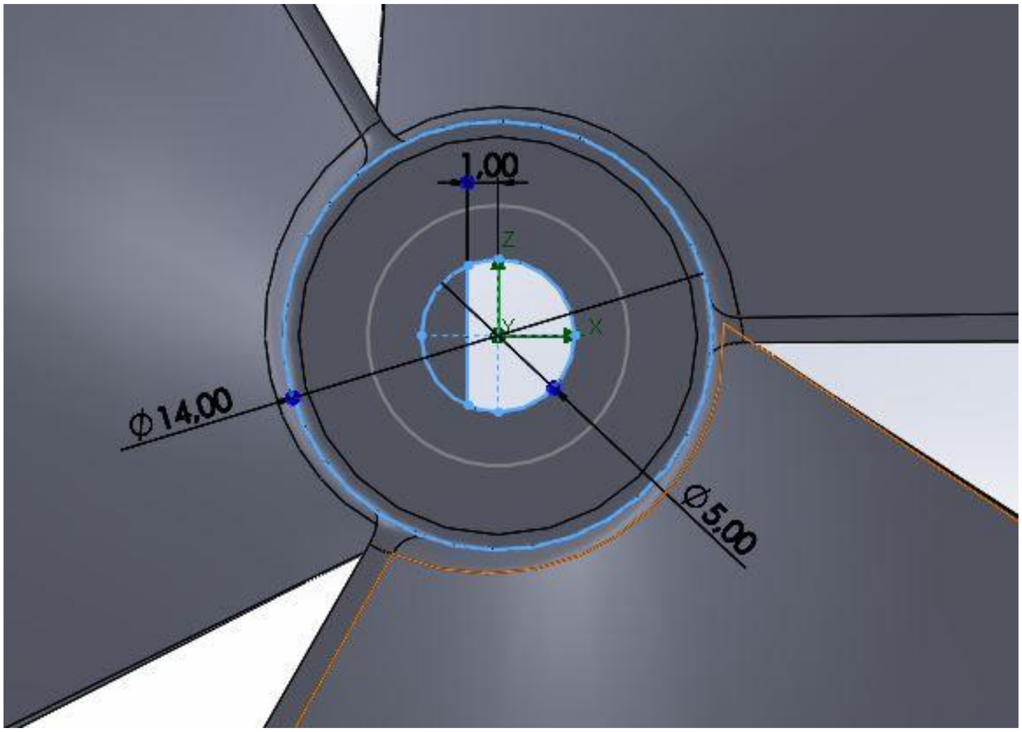
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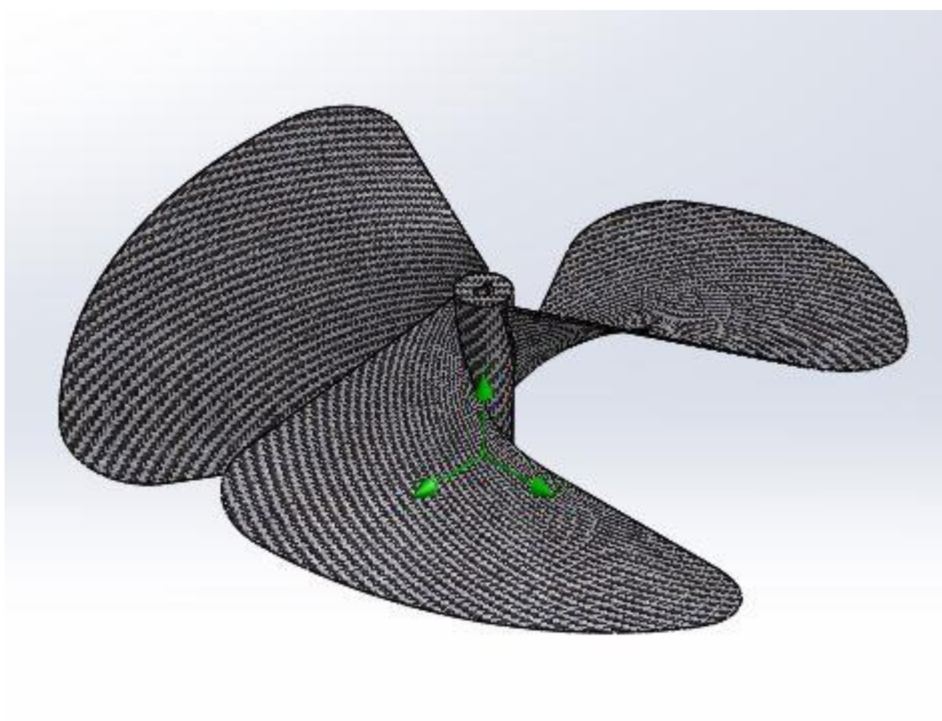
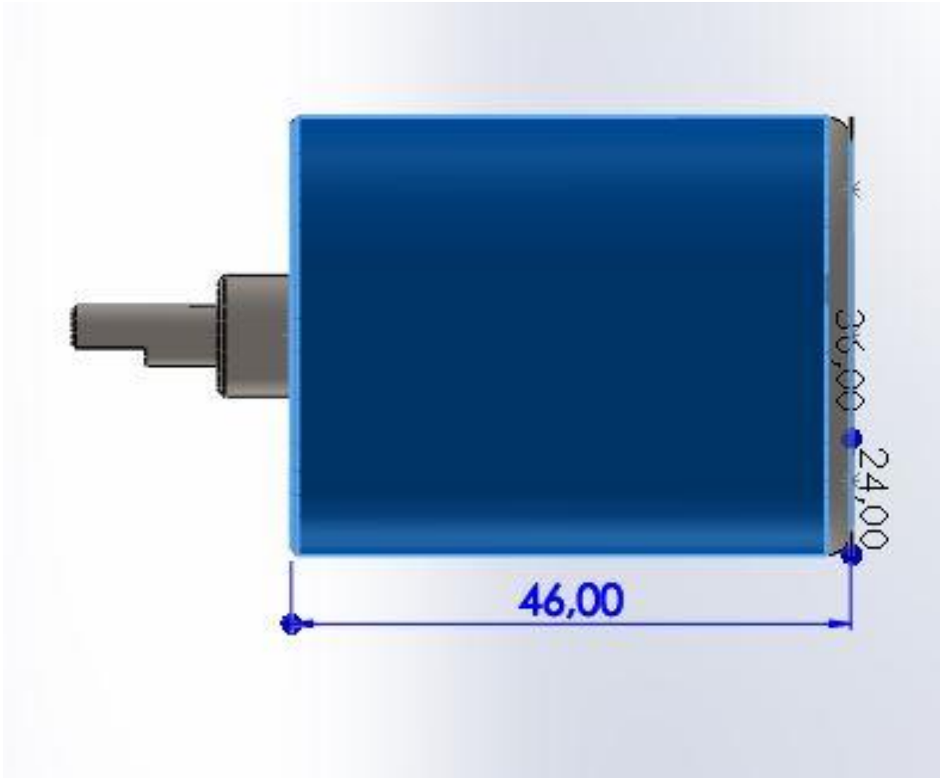
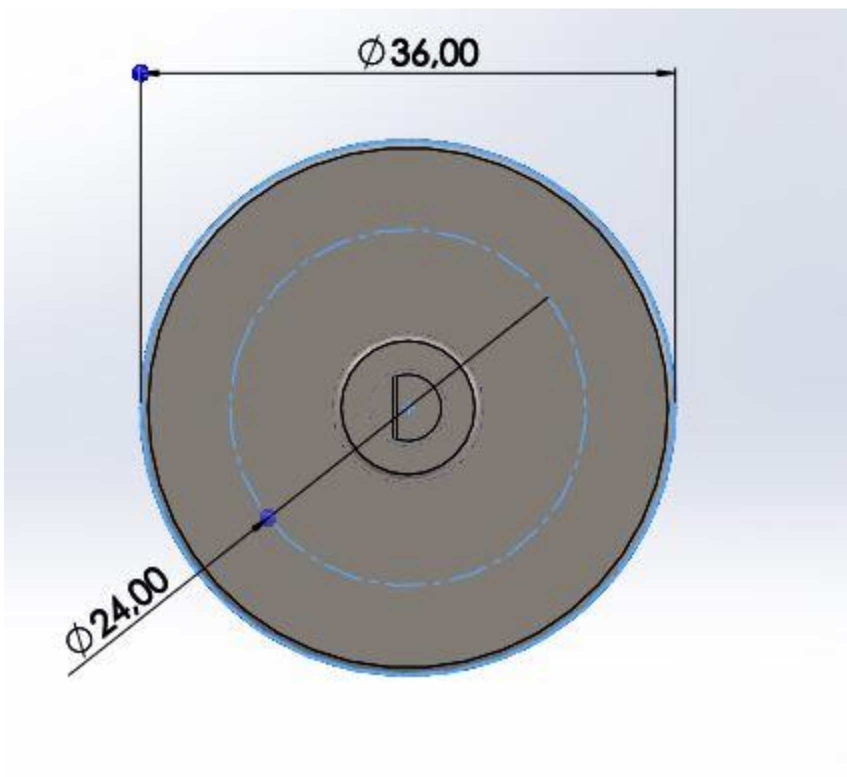
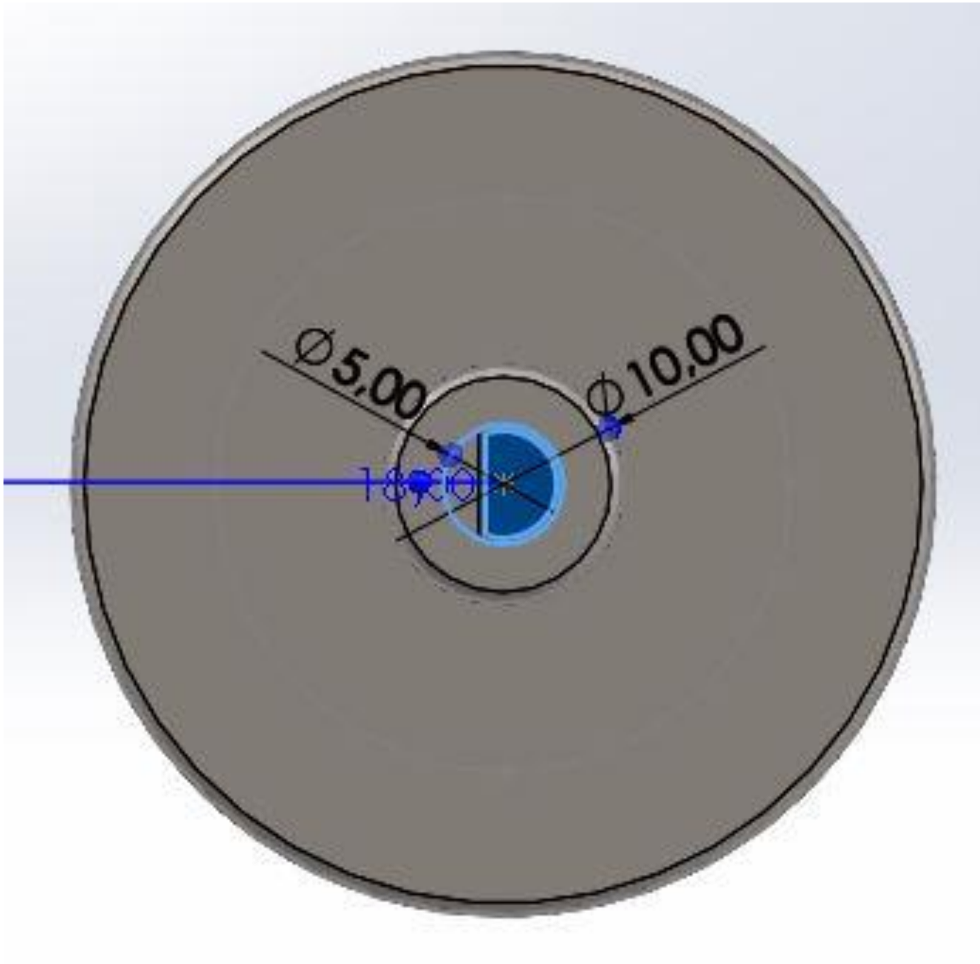


Motor







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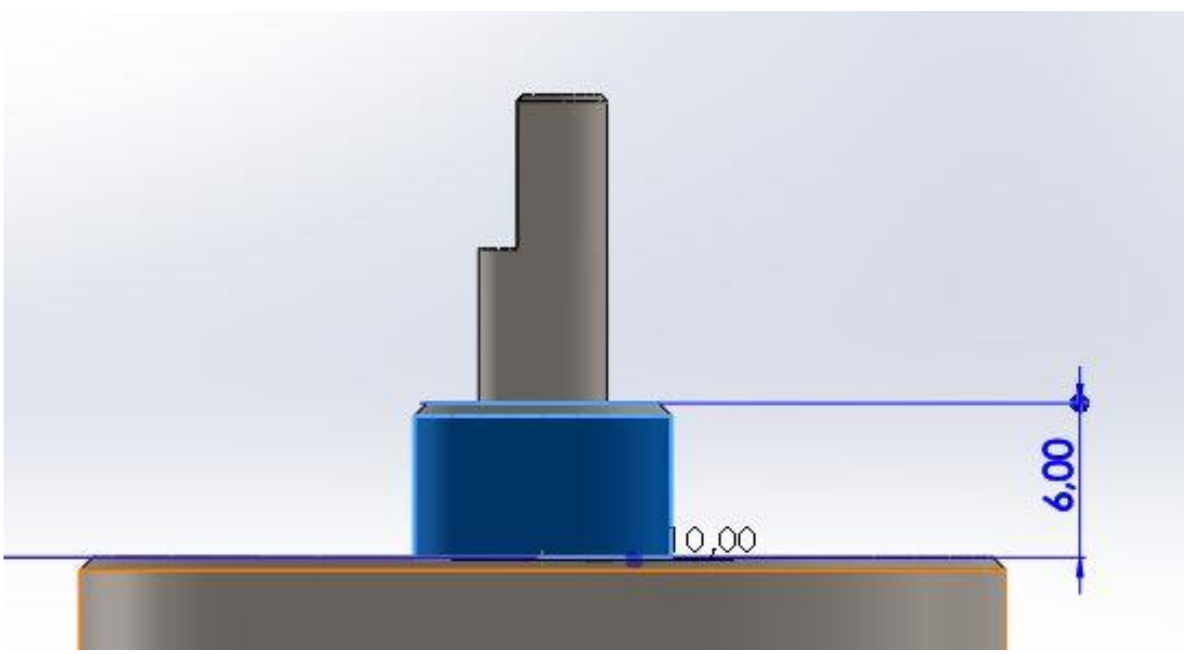

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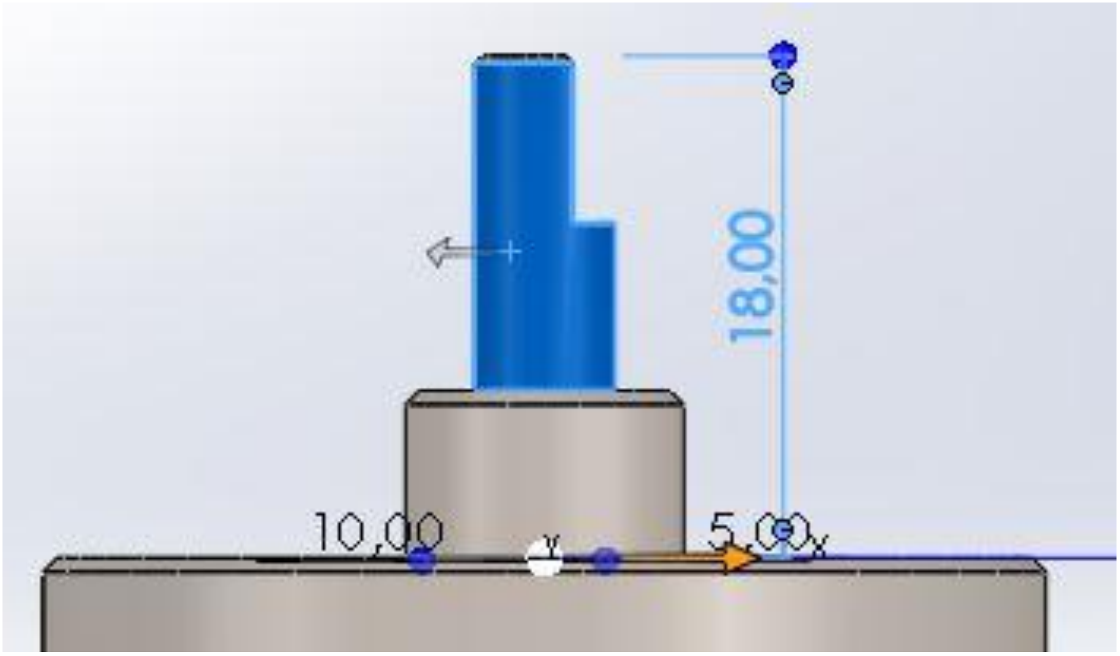
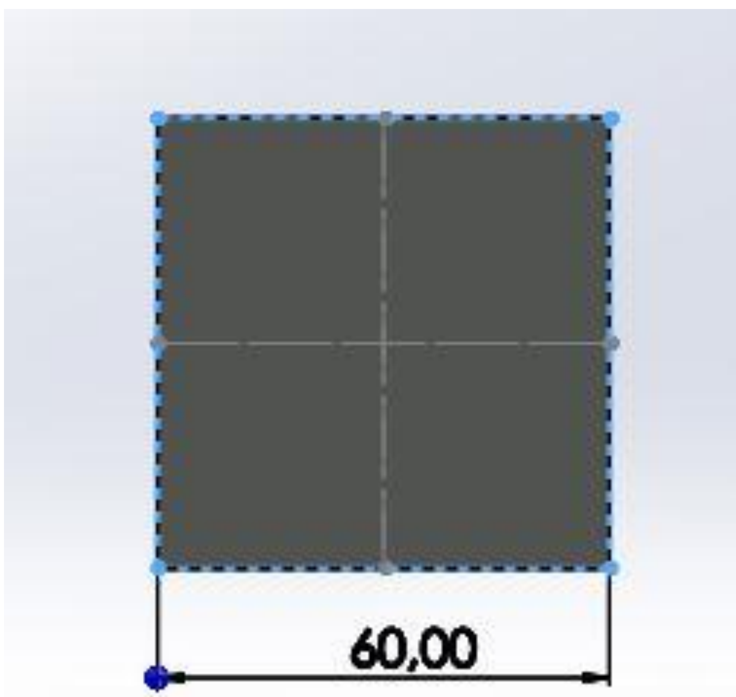
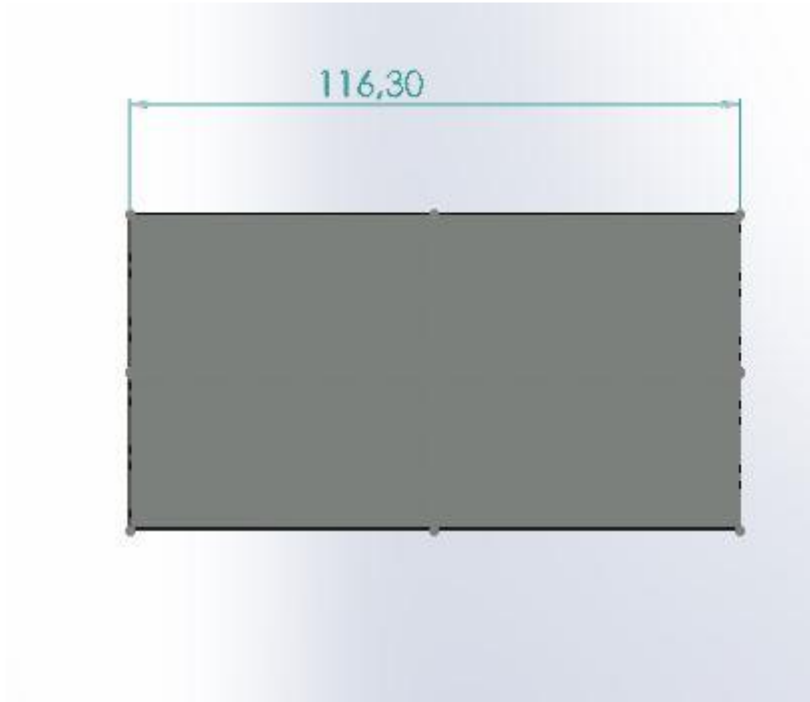
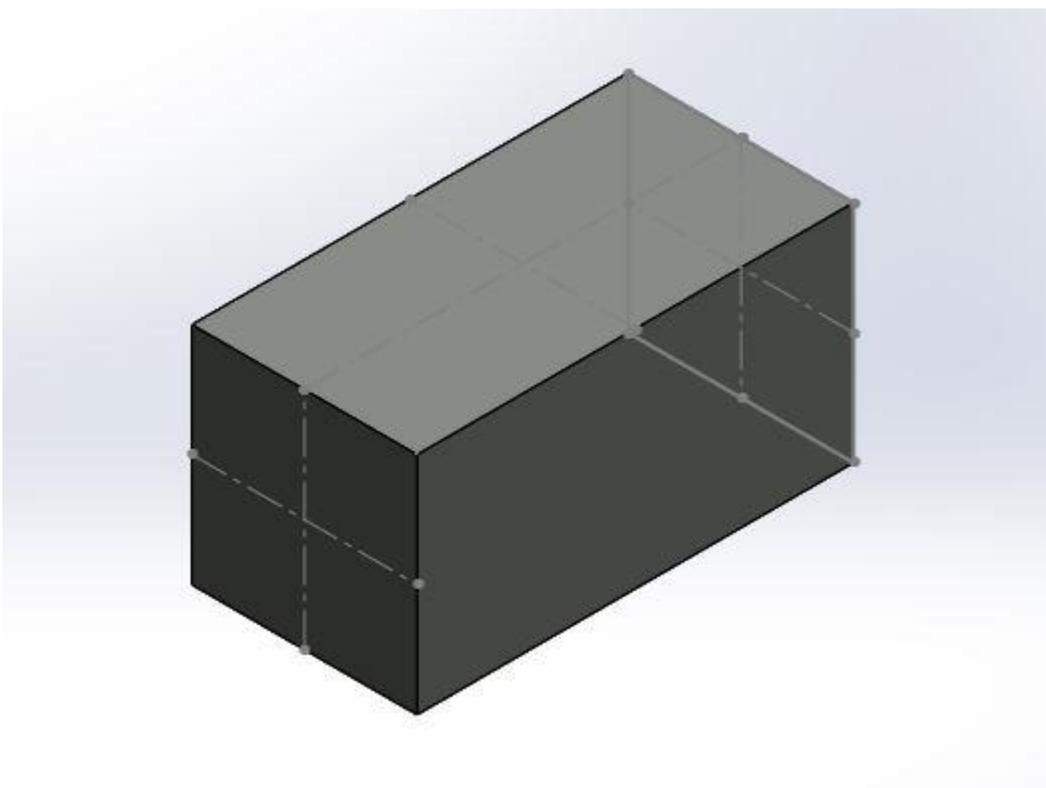


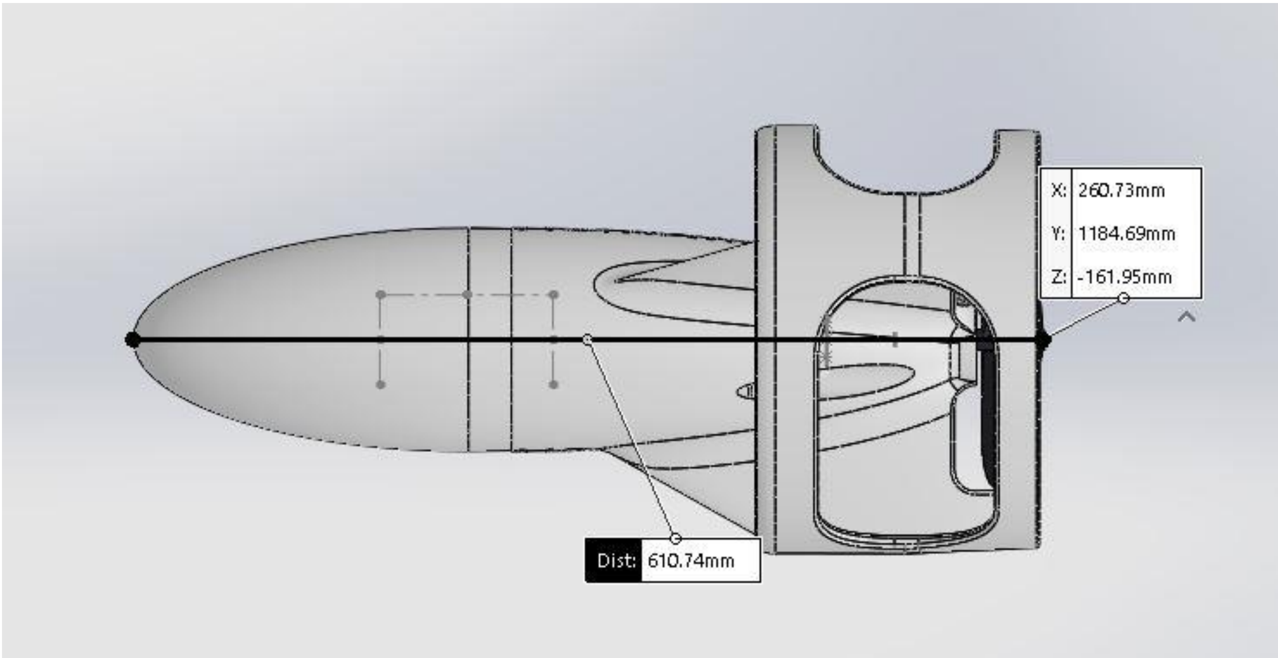
Carga

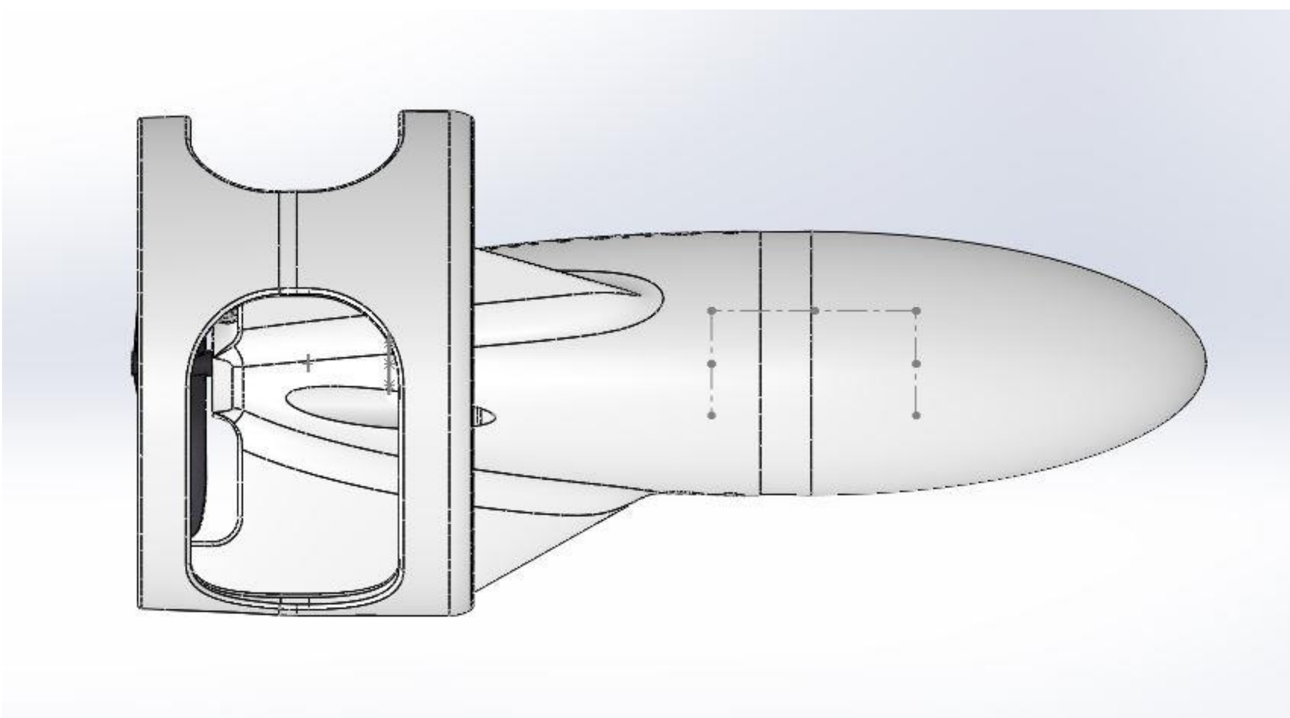


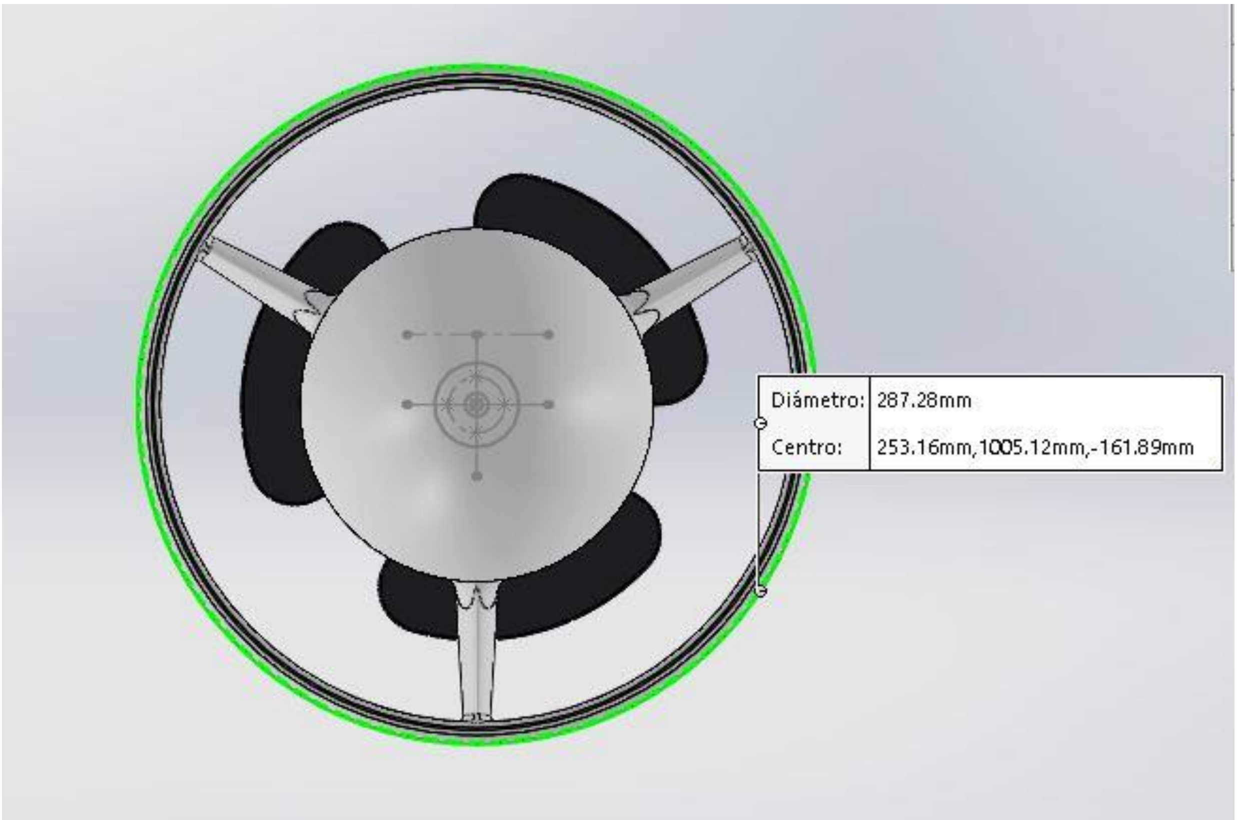

116,30

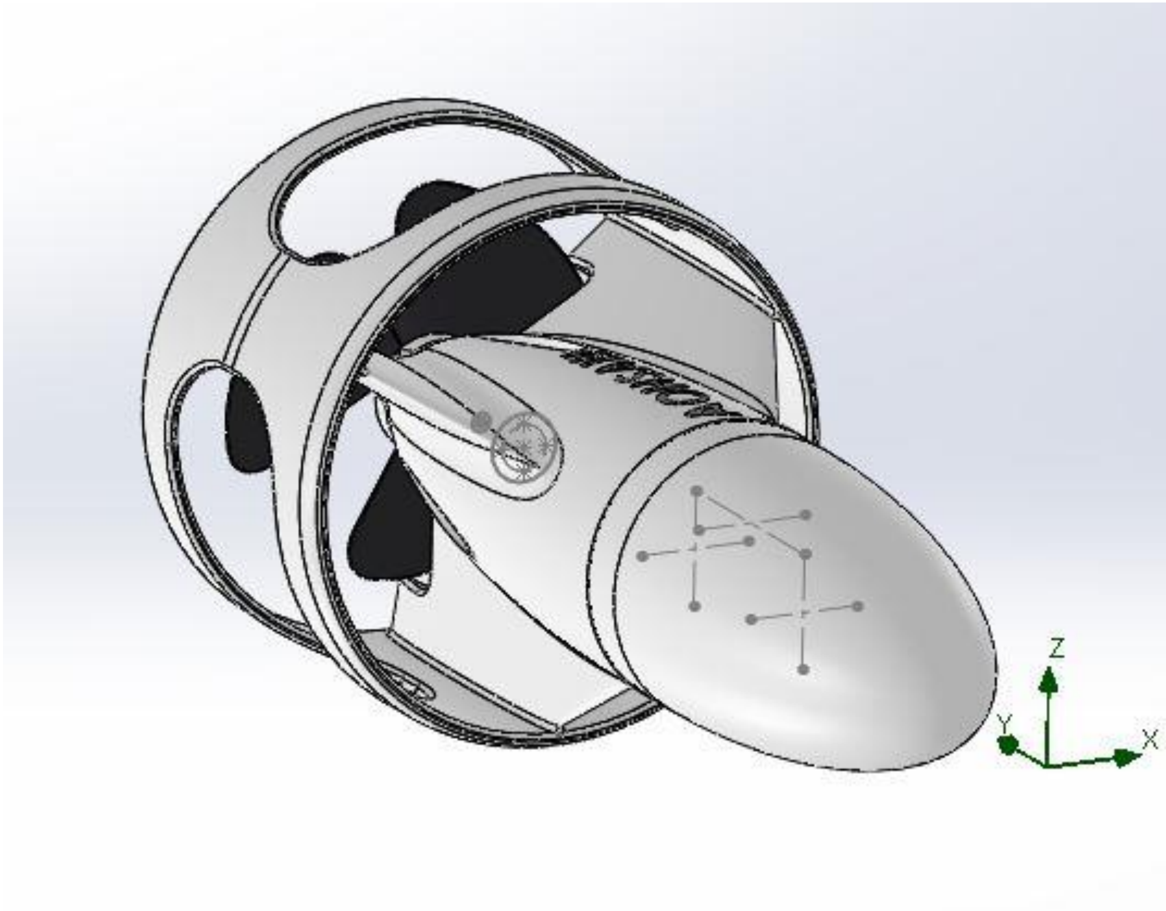


Ensamblaje






Diámetro: 287.28mm
Centro: 253.16mm,1005.12mm,-161.89mm


Z
Y
X

Anexo B. Cálculos detallados del diseño

Cálculo de flotabilidad y masas

Masa de la carga			
Objeto	Unidad	Peso [g]	Peso por unidad [g]
Batería Klarus Panasonic 18650 3400[mAh] 3,7[V]	20,00	50	1.000,00
Arduino	1	45,4	45,40
Sensor de presión externa IP67	1	100	100,00
Pantalla LCD 20X4	1	78	78,00
		Masa total	1.223,40

Peso necesario para flotabilidad nula, dependiente del volumen	
Densidad del agua **[kg/m³]**	1025
Volumen interno **[m³]**	0,005493654
Volumen externo **[m³]**	0,003953403
Volumen total VPS **[m³]**	0,009447057
Masa necesaria mvps **[kg]**	9,683233487
Masa del VPS sin carga [kg]	5,07782
Masa que ha de tener la plomada [kg]	3,38
Masa que representa toda la carga del VPS	4,61

Dimensionamiento de la plomada	
Densidad del plomo ρ [kg/m³]	11000
Volumen de la plomada [mm³]	418.673,95
Ancho=Alto [mm]	60
Largo [mm]	116,2983204

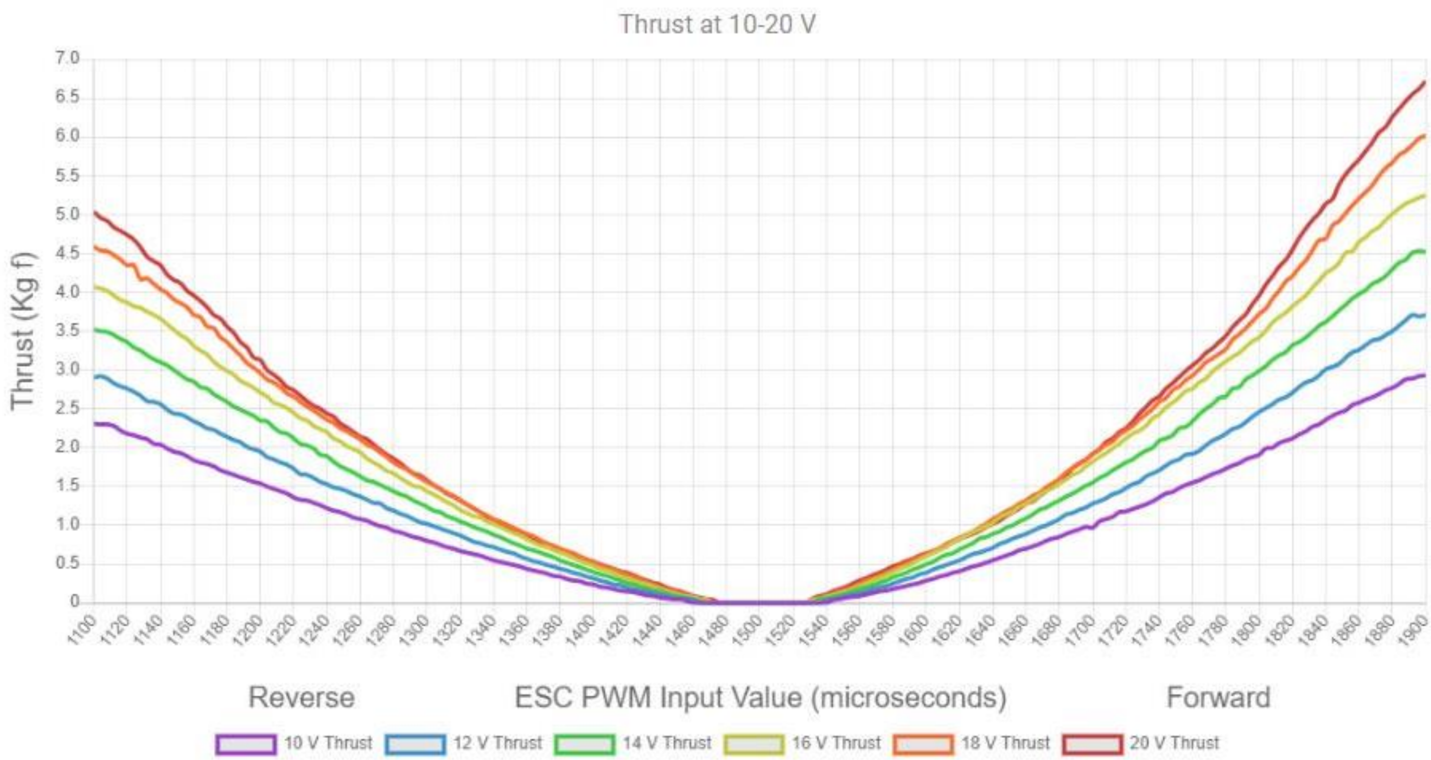
Dimensionamiento de baterías

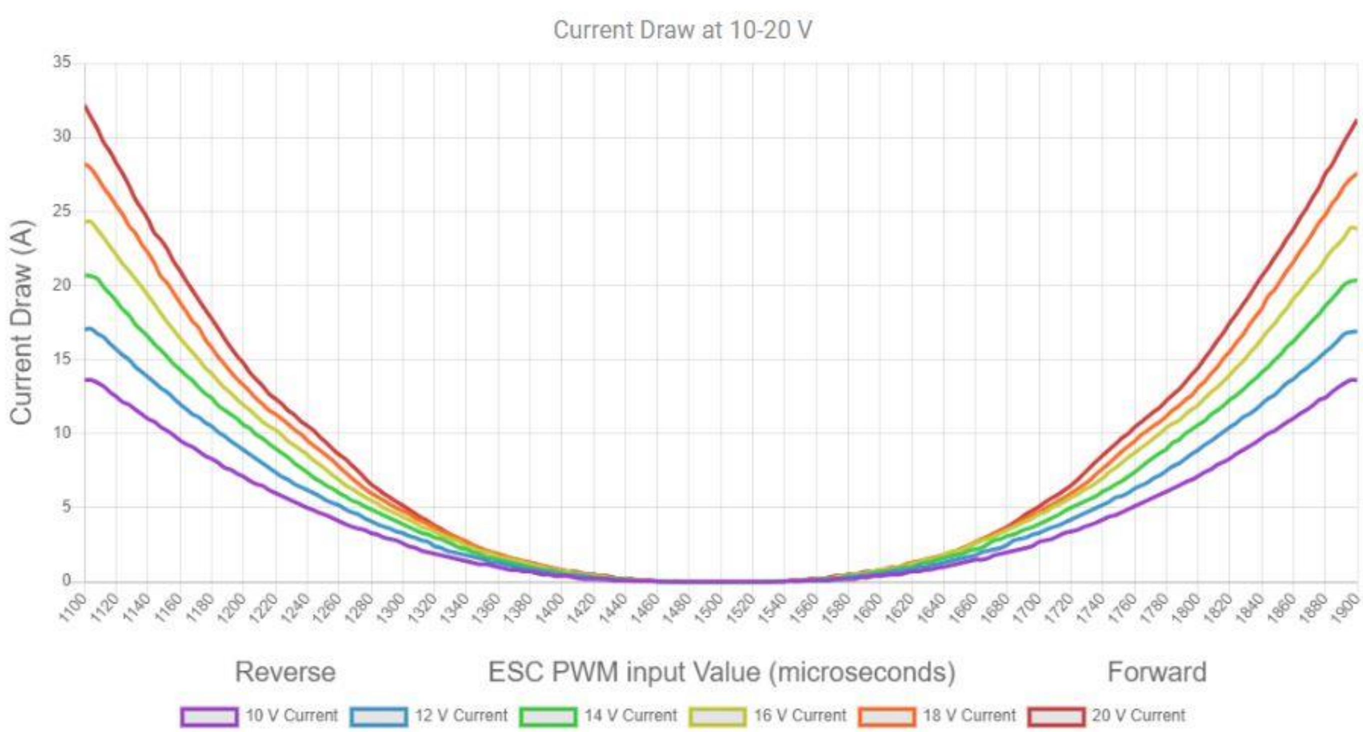
Dispositivo	Voltaje[V]	Intensidad[A]
Motor	20	24
Sensor Presión externa	9	2,00E-02
Arduino NANO	12	4,60E-02
Arduino UNO	12	4,60E-02
	20	24,112

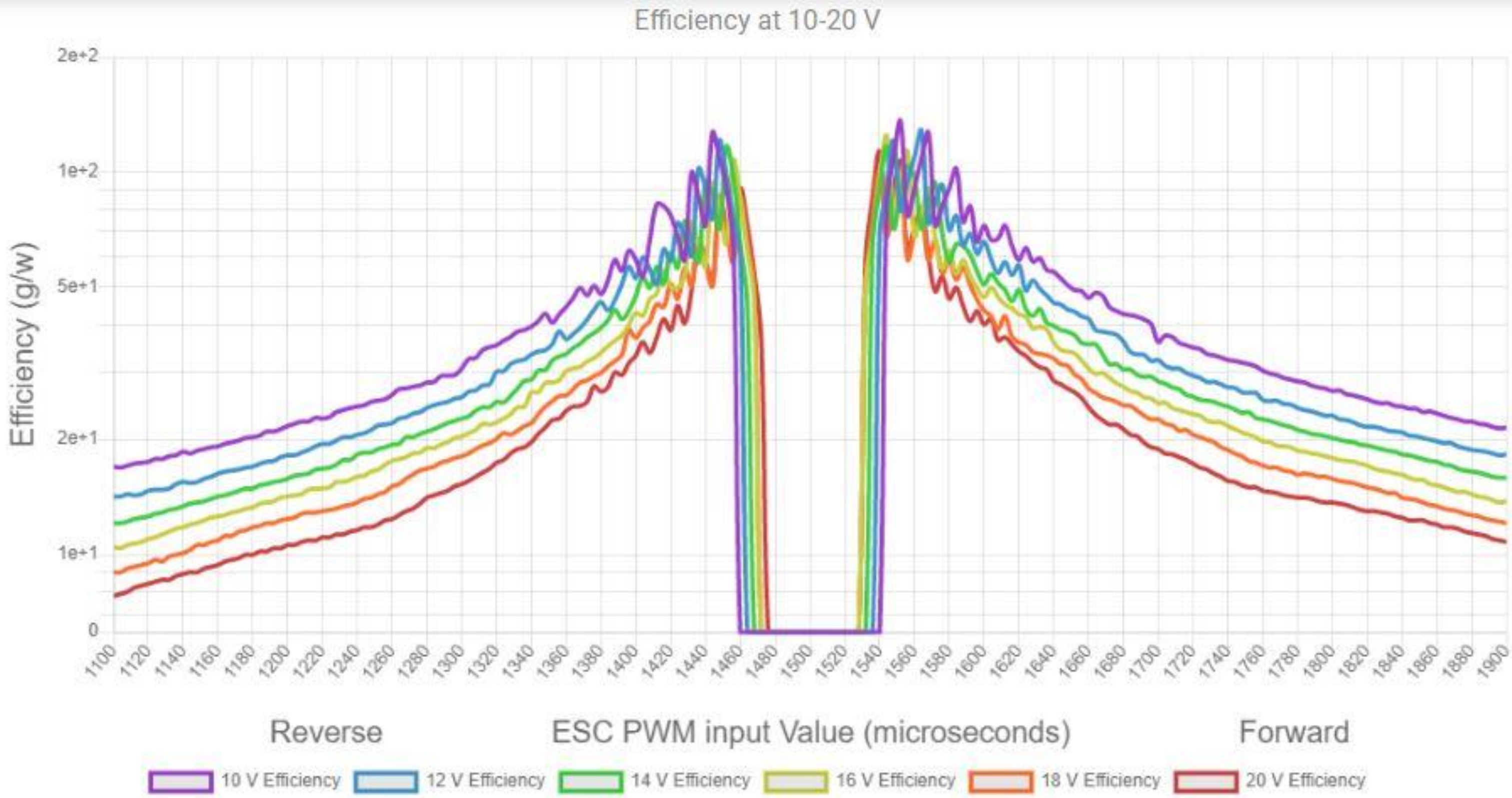
Funcionamiento de 30 [min]	
Capacidad requerida [Ah]	12,056

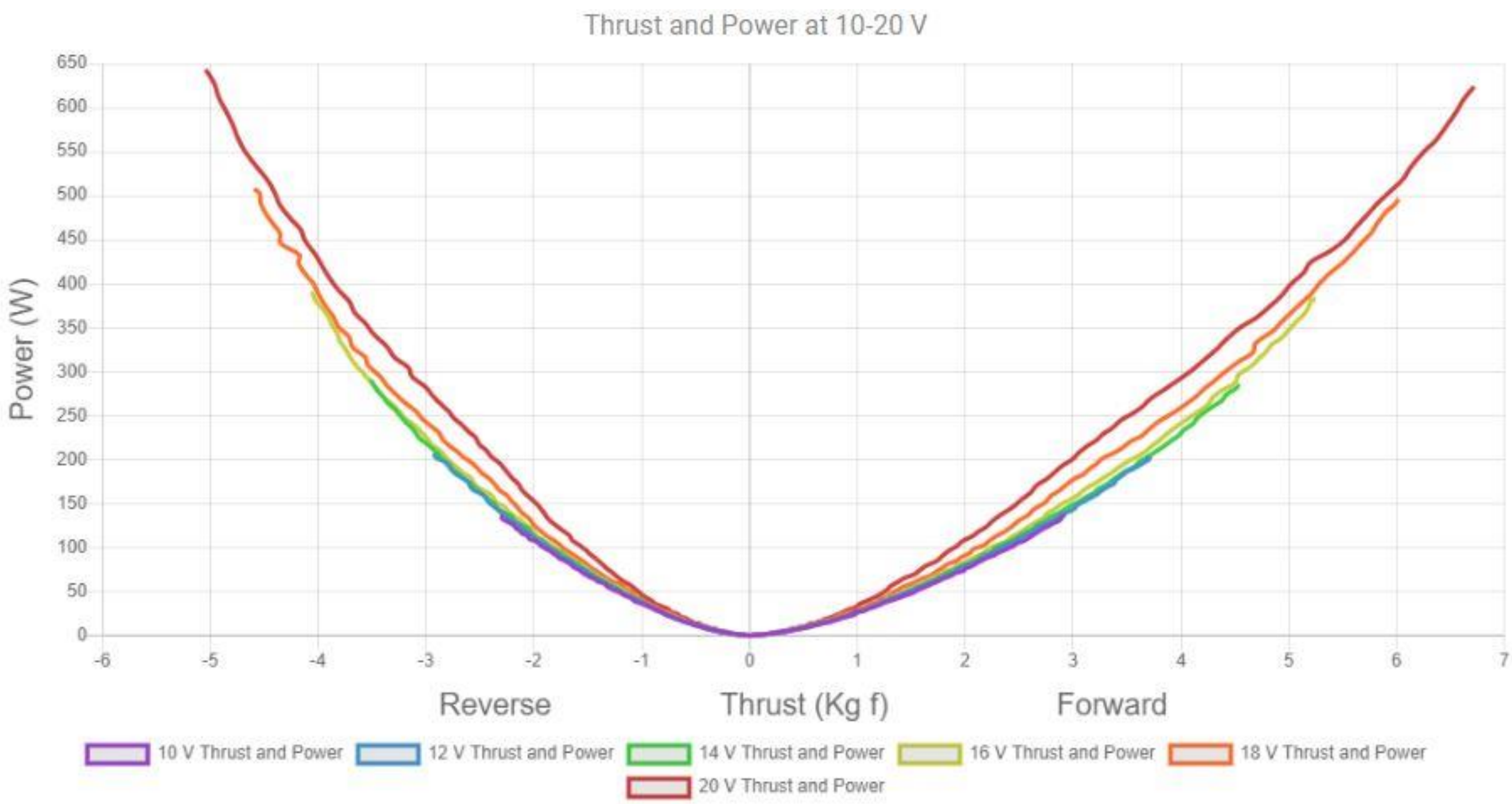
Baterías	Voltaje[V]	Capacidad[Ah]	Serie	Paralelo	Autonomia [min]	Unidades
Klarus panasonic (1)	3,7	3,40	5	4,00	33,84	20,00
Klarus panasonic (2)	3,6	3,60	5	4,00	35,83	20,00

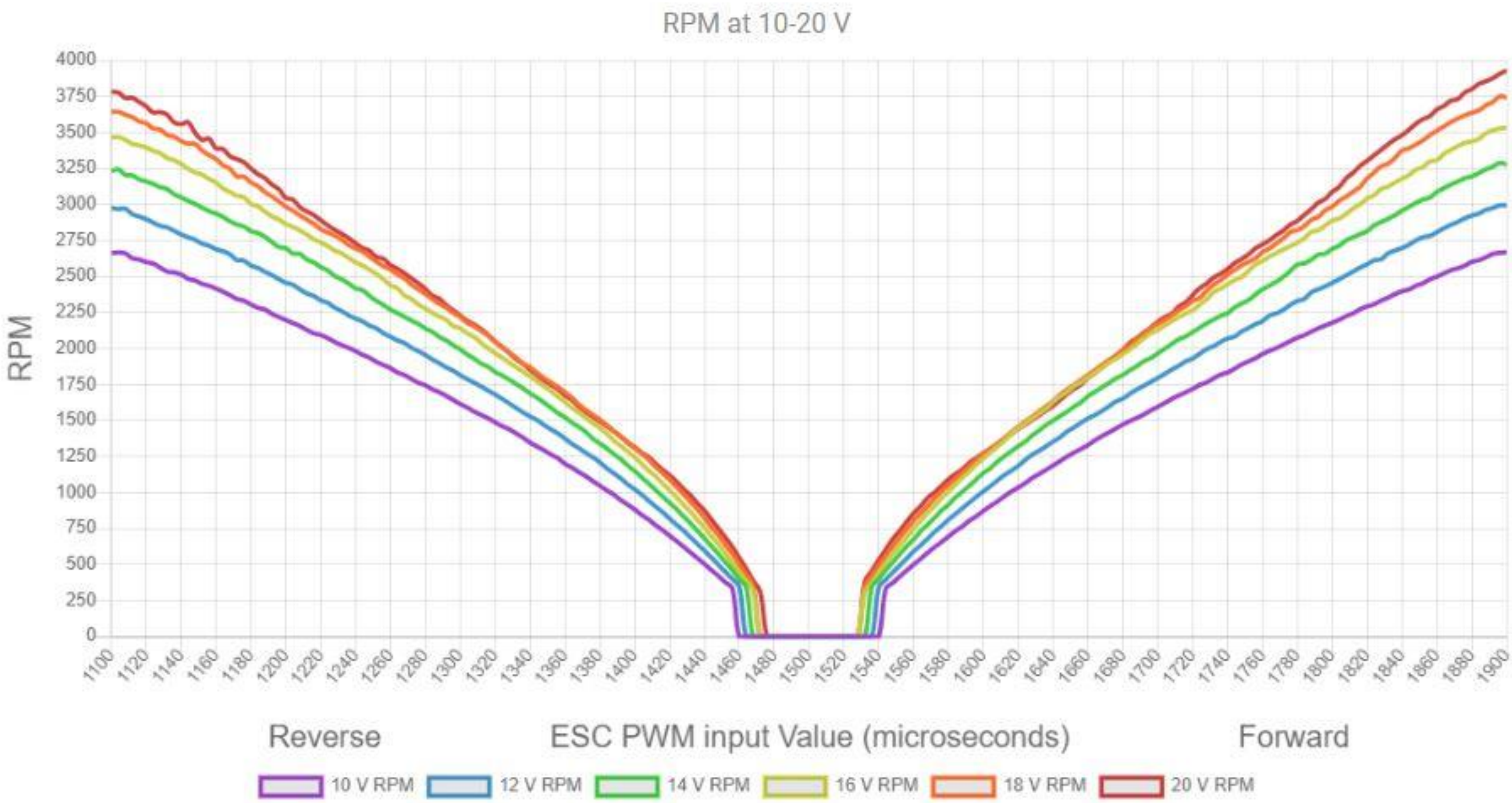
Anexo C. Tablas de desempeño del motor T200





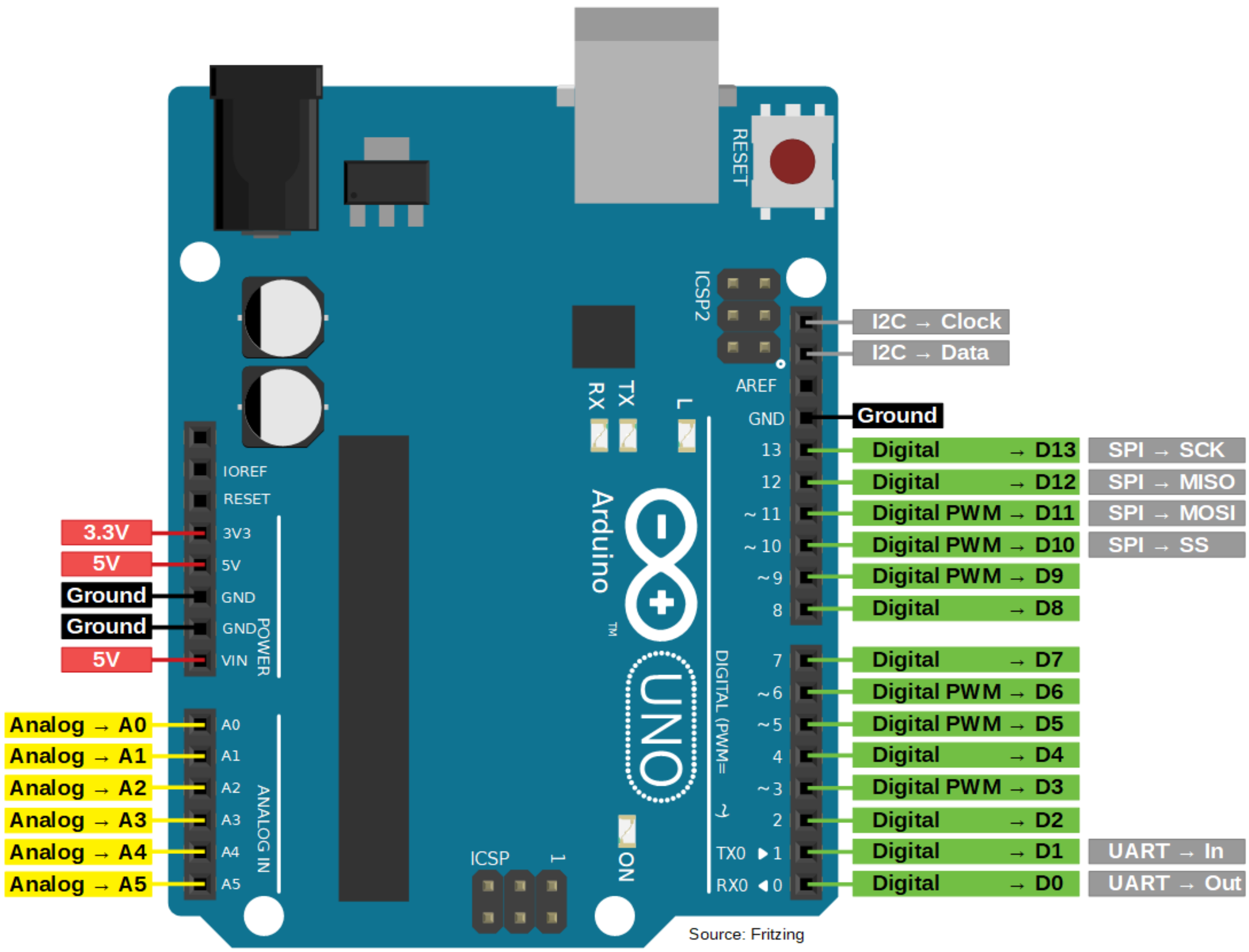

Efficiency at 10-20 V
Efficiency (g/w)
2e+2
1e+2
5e+1
2e+1
1e+1
0
1100 1120 1140 1160 1180 1200 1220 1240 1260 1280 1300 1320 1340 1360 1380 1400 1420 1440 1460 1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680 1700 1720 1740 1760 1780 1800 1820 1840 1860 1880 1900
Reverse
ESC PWM input Value (microseconds)
Forward
10 V Efficiency
12 V Efficiency
14 V Efficiency
16 V Efficiency
18 V Efficiency
20 V Efficiency


Thrust and Power at 10-20 V
Power (W)
650 600 550 500 450 400 350 300 250 200 150 100 50 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Reverse
Thrust (Kg f)
Forward
10 V Thrust and Power
12 V Thrust and Power
14 V Thrust and Power
16 V Thrust and Power
18 V Thrust and Power
20 V Thrust and Power

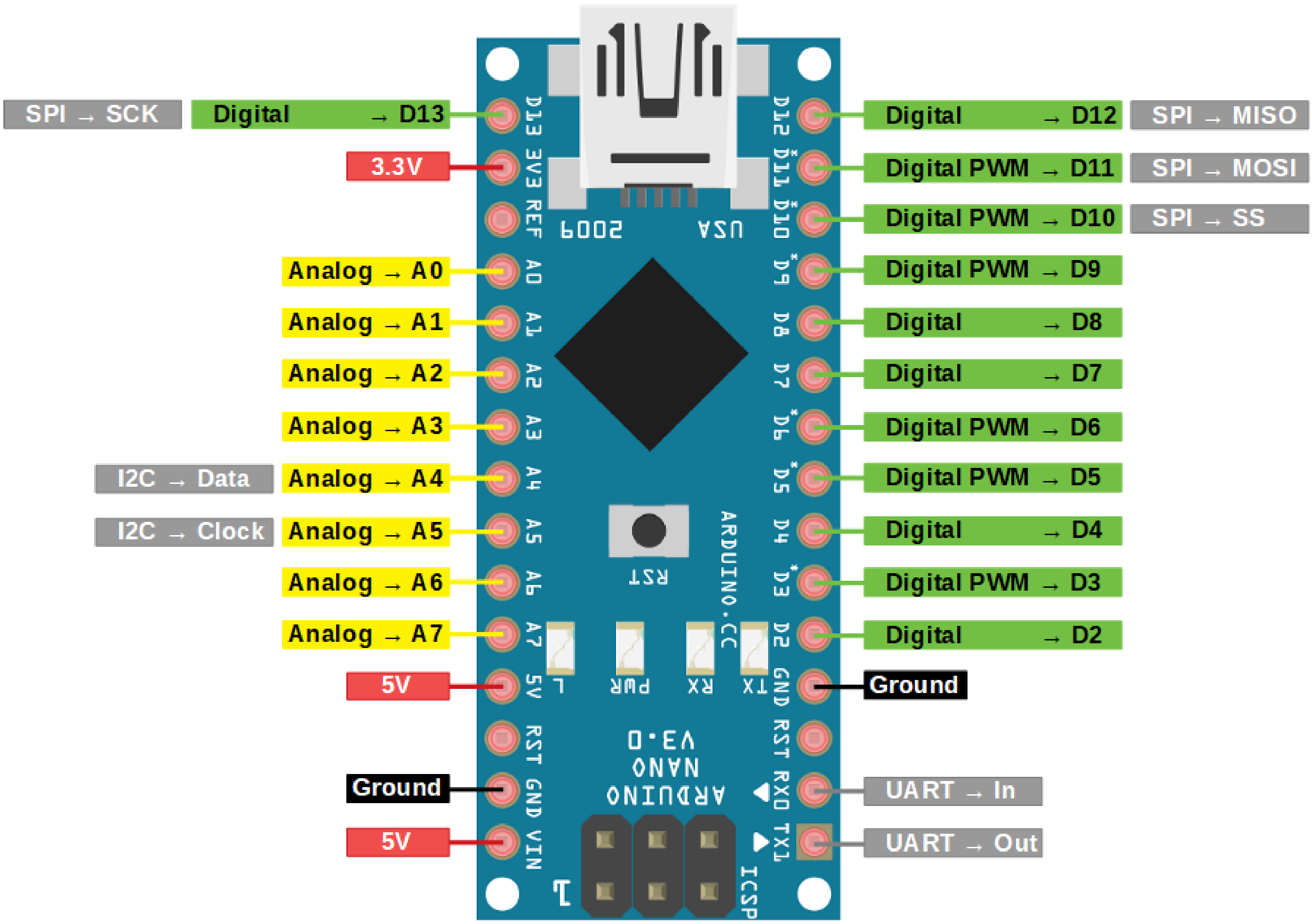

RPM at 10-20 V
RPM
4000
3750
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1100 1120 1140 1160 1180 1200 1220 1240 1260 1280 1300 1320 1340 1360 1380 1400 1420 1440 1460 1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680 1700 1720 1740 1760 1780 1800 1820 1840 1860 1880 1900
Reverse
ESC PWM input Value (microseconds)
Forward
10 V RPM
12 V RPM
14 V RPM
16 V RPM
18 V RPM
20 V RPM

Anexo D. Esquemas de las placas Arduino

Esquema de la placa Arduino UNO



Esquema de la placa Arduino NANO



Source: Fritzing

Anexo F. Códigos de Arduino

Código para la lectura de sensores

```
/*--------INICIALIZACION PARA EL SENSOR DE TEMPERATURA Y HUMEDAD (DHT22)----------*/
#include <Adafruit_Sensor.h>
#include <DHT.h>

//Constantes
int DHTPIN = 2   ;  // declaramos el pin digital que vamos a usar

DHT dht(DHTPIN, DHT22); /*Creamos un objeto tipo DHT y le pasamos el Pin y el tipo de sensor*/

//Variables
int chk;
float H;  //variale que almacena el valor de humedad

/*--------DECLARACIÓN DE LA SUPUESTA ENTRADA DE VOLTAJE----------*/
const int Sensor_Volt = A0;    // seleccionar la entrada para la supuesta entrada de voltaje



/*--------DECLARACIÓN DE LOS LED'S DE SALIDA----------*/
const int LED_Hum = 4;
const int LED_Volt = 3;



void setup() {
  Serial.begin(9600);
  dht.begin();/*Inicialización del sensor DHT22*/

  if (bmp180.begin())
    Serial.println("BMP180 iniciado");
  else
  {
    Serial.println("Error al iniciar el BMP180");
    while(1);
```

```
 }



 lcd.setBacklightPin(3,POSITIVE);  // puerto P3 de PCF8574 como positivo
 lcd.setBacklight(HIGH);   // habilita iluminacion posterior de LCD
 lcd.begin(20, 4);     // 20 columnas por 4 lineas para LCD 1602A
 lcd.clear();      // limpia pantalla


}

void loop() {

 char status;
 double T,P,A;

 status = bmp180.startTemperature(); //Inicio de lectura de temperatura
 if (status != 0)
 {
  /*Obtenemos el valor de latemperatura mediante el sensor BMP180, ya que este tiene mayor presición*/
  delay(status); //Pausa para que finalice la lectura
  status = bmp180.getTemperature(T); //Obtener la temperatura
  if (status != 0)
  {
   status = bmp180.startPressure(3); //Inicio lectura de presión
   if (status != 0)
   {
    delay(status); //Pausa para que finalice la lectura
    status = bmp180.getPressure(P,T); //Obtener la presión
    if (status != 0)
    {

     A= bmp180.altitude(P,PresionNivelMar); //Calcular altura

    }
   }
```

```
    }
  }


/*Salida de Temperatura por LCD*/
  lcd.setCursor(0,0);
  lcd.print("Temp: ");
  lcd.print(T, 1);
  lcd.print(" [C]");

/*Salida de Profundidad por LCD*/
  lcd.setCursor(0,1);
  lcd.print("Alt: ");
  lcd.print(A, 1);
  lcd.print(" [m]");

/*Salida de Presión por LCD*/
  lcd.setCursor(0,2);
  lcd.print("P: ");
  lcd.print(P, 1);
  lcd.print(" [mbar]");

  //Leemos y almacenamos los valores de humedad
  H = dht.readHumidity();

/*Salida de Humedad por LCD*/
  lcd.setCursor(0,3);
  lcd.print("Hum: ");
  lcd.print(H, 1);
  lcd.print(" [%]");

  if(H < 40 || H > 80){

    digitalWrite(LED_Hum , HIGH);

  }
```

```
  else{

    digitalWrite(LED_Hum , LOW);

  }


  float Valor_Volt = analogRead(Sensor_Volt);   // realizar la lectura

  if(Valor_Volt < 200 || Valor_Volt > 400){

    digitalWrite(LED_Volt , HIGH);

  }
  else{

    digitalWrite(LED_Volt , LOW);

  }

  delay(1000);
}
```

Código para la regulación de la señal del motor

```
int in_Marcha_1 = 2;
int in_Marcha_2 = 4;
int in_Marcha_3 = 7;

int out_Marcha = 3;
bool marcha_1 = LOW;
bool marcha_2 = LOW;
bool marcha_3 = LOW;

void setup() {
  pinMode (in_Marcha_1, INPUT);
```

```
  pinMode (in_Marcha_2, INPUT);
  pinMode (in_Marcha_3, INPUT);

  pinMode (out_Marcha, OUTPUT);
}

void loop() {

//exclusión de marchas mediante flanco de subida

  if(in_Marcha_1 || marcha_1){
    marcha_1 = HIGH;
    marcha_2 = LOW;
    marcha_3 = LOW;
    analogWrite(out_Marcha, 85);
  }

  if(in_Marcha_2 || marcha_2){
    marcha_1 = LOW;
    marcha_2 = HIGH;
    marcha_3 = LOW;
    analogWrite(out_Marcha, 170);
  }



  if(in_Marcha_3 || marcha_3){
    marcha_1 = LOW;
    marcha_2 = LOW;
    marcha_3 = HIGH;
    analogWrite(out_Marcha, 255);
  }

}
```

Anexo G. Hojas de características de dispositivos electrónicos

INAx126 MicroPower Instrumentation Amplifier Single and Dual Versions

1 Features

- Low Quiescent Current: 175 μA/channel
- Wide Supply Range: ±1.35 V to ±18 V
- Low Offset Voltage: 250-μV Maximum
- Low Offset Drift: 3-μV/°C Maximum
- Low Noise: 35 nV/√Hz
- Low Input Bias Current: 25-nA Maximum
- 8-Pin PDIP, SOIC, VSSOP Surface-Mount Dual: 16-Pin PDIP, SOIC, SSOP

2 Applications

- Industrial Sensor Amplifiers: Bridges, RTDs, Thermocouples
- Physiological Amplifiers: ECGs, EEGs, EMGs
- Multi-Channel Data Acquisition
- Portable, Battery-Operated Systems

3 Description

The INA126 and INA2126 are precision instrumentation amplifiers for accurate, low noise differential-signal acquisition. Their two-op-amp design provides excellent performance with low quiescent current (175 μA/channel). Combined with a wide operating voltage range of ±1.35 V to ±18 V, makes the INAx126 ideal for portable instrumentation and data acquisition systems.

Gain can be set from 5 V/V to 10000 V/V with a single external resistor. Laser-trimmed input circuitry provides low offset voltage (250-μV maximum), low offset voltage drift (3-μV/°C maximum), and excellent common-mode rejection.

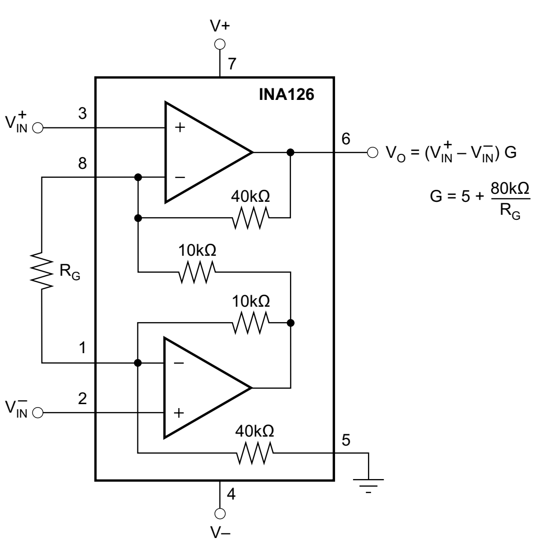
Single version package options include 8-pin plastic PDIP, SOIC-8, and fine-pitch VSSOP-8 surface-mount. Dual version is available in 16-pin plastic PDIP, SOIC-8, and the space-saving, fine-pitch SSOP-16 surface-mount. All are specified for the –40°C to +85°C industrial temperature range.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA126	PDIP (8)	6.35 mm × 9.81 mm
	SOIC (8)	3.91 mm × 4.90 mm
	VSSOP (8)	3.00 mm × 3.00 mm
INA2126	PDIP (16)	6.35 mm × 19.30 mm
	SOIC (16)	3.91 mm × 9.90 mm
	SSOP (16)	3.90 mm × 4.90 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic: INA126



Simplified Schematic: INA2126

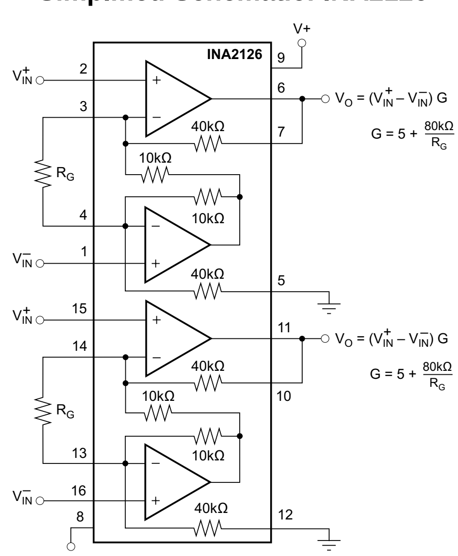


Table of Contents

4 Revision History

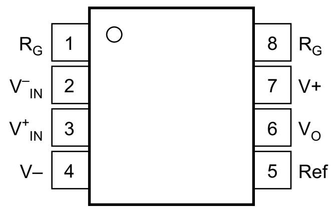
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (August 2005) to Revision B **Page**

- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1

5 Pin Configuration and Functions

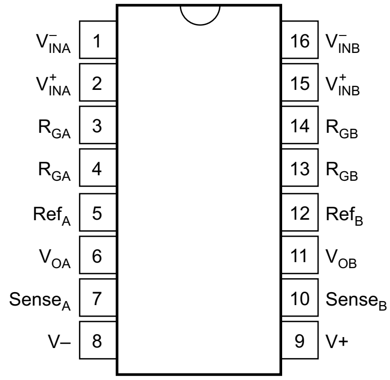
P, D, and DGK Packages
8-Pin PDIP, SOIC, VSSOP
Top View



Pin Functions: 8-Pin

PIN		I/O	DESCRIPTION
NO.	NAME		
1, 8	R_G	—	Gain setting pin. For gains greater than 5 place a gain resistor between pin 1 and pin 8.
2	$V-_{IN}$	I	Negative input
3	$V+_{IN}$	I	Positive input
4	V–	—	Negative supply
5	Ref	I	Reference input. This pin must be driven by a low impedance or connected to ground.
6	V_O	O	Output
7	V+	—	Positive supply

**N, D, and DBQ Packages
16-Pin PDIP, SOIC, SSOP
Top View**



Pin Functions: 16-Pin

PIN		I/O	DESCRIPTION
NO.	NAME		
1	$V-_{INA}$	I	Negative input for amplifier A
2	$V+_{INA}$	I	Positive input for amplifier A
3, 4	R_{GA}	—	Gain setting pin for amplifier A. For gains greater than 5 place a gain resistor between pin 3 and pin 4.
5	Ref_A	I	Reference input for amplifier A. This pin must be driven by a low impedance or connected to ground.
6	V_{OA}	O	Output of amplifier A
7	$Sense_A$	I	Feedback for amplifier A. Connect to VOA, amplifier A output.
8	V–	—	Negative supply
9	V+	—	Positive supply
10	$Sense_B$	I	Feedback for amplifier B. Connect to VOB, amplifier B output.
11	V_{OB}	O	Output of amplifier B
12	Ref_B	I	Reference input for amplifier B. This pin must be driven by a low impedance or connected to ground.
13, 14	R_{GB}	—	Gain setting pin for amplifier B. For gains greater than 5 place a gain resistor between pin 13 and pin 14.
15	$V+_{INB}$	I	Positive input for amplifier B
16	$V-_{INB}$	I	Negative input for amplifier B

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)

	MIN	MAX	UNIT
Power supply voltage, V+ to V–		36	V
Input signal voltage (2)	(V–) – 0.7	(V+) + 0.7	
Input signal current (2)		10	mA
Output short circuit	Continuous		
Operating temperature	–55	125	°C
Lead temperature (soldering, 10 s)		300	°C
Storage temperature, T_{stg}	–55	125	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input signal voltage is limited by internal diodes connected to power supplies. See text.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±500	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V+	V power supply	±135	±15	±18	V
V_O	Input common mode voltage for V_O = 0		±11.25		V
T_A	Operating temperature	–55		125	°C

6.4 Thermal Information: INA126

THERMAL METRIC (1)		INA126			UNIT
		PDIP	SOIC	MSOP	
		8 PINS	8 PINS	8 PINS	
$R_{θJA}$	Junction-to-ambient thermal resistance	52.2	116.4	167.8	°C/W
$R_{θJC(top)}$	Junction-to-case (top) thermal resistance	41.6	62.4	60.9	°C/W
$R_{θJB}$	Junction-to-board thermal resistance	29.4	57.7	88.9	°C/W
$ψ_{JT}$	Junction-to-top characterization parameter	18.9	10	7.3	°C/W
$ψ_{JB}$	Junction-to-board characterization parameter	29.2	57.1	87.3	°C/W
$R_{θJC(bot)}$	Junction-to-case (bottom) thermal resistance	–	–	–	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.5 Thermal Information: INA2126

THERMAL METRIC(1)		INA2126 PDIP 16 PINS	INA2126 SOIC 16 PINS	INA2126 MSOP 16 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	39.3	76.2	115.8	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	26.2	37.8	67	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	20.1	33.5	58.3	°C/W
ψ_{JT}	Junction-to-top characterization parameter	10.7	7.5	19.9	°C/W
ψ_{JB}	Junction-to-board characterization parameter	19.9	33.3	57.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	–	–	–	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.6 Electrical Characteristics

at T_A = 25°C, V_S = ±15 V, R_L = 25 kΩ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
INPUT							
RTI	Offset voltage	NA126P, U, E; INA2126P, U, E			±100	±250	µV
		INA126PA, UA, EA; INA2126PA, UA, EA			±150	±500	
	Offset voltage versus temperature	NA126P, U, E; INA2126P, U, E			±0.5	±3	µV/°C
		INA126PA, UA, EA; INA2126PA, UA, EA			±0.5	±5	
	Offset voltage versus power supply (PSRR)	V_S = ±1.35 V to ±18	VNA126P, U, E INA2126P, U, E		5	15	µV/V
			VINA126PA, UA, EA INA2126PA, UA, EA		5	50	
	Input impedance	INA126P, U, E; INA2126P, U, E			10^9 || 4		Ω || pF
	Safe input voltage	R_S = 0		(V–) – 0.5		(V+) + 0.5	V
		R_S = 1 kΩ		(V–) – 10		(V+) + 10	
	Common-mode voltage range	V_O = 0 V		±11.25	±11.5		V
	Channel separation (dual)	G = 5, dc			130		dB
	Common-mode rejection	R_S = 0, V_{CM} = ±11.25 V	INA126P, U, E INA2126P, U, E	83	94		dB
			INA126PA, UA, EA INA2126PA, UA, EA	74	90		
		NA2126U (dual SO-16)		80	94		
INPUT BIAS CURRENT							
	Input bias current	INA126P, U, E; INA2126P, U, E			–10	–25	nA
		INA126PA, UA, EA; INA2126PA, UA, EA				–50	
	Input bias current vs temperature				±30		pA/°C
	Offset current	INA126P, U, E; INA2126P, U, E			±0.5	±2	nA
		INA126PA, UA, EA; INA2126PA, UA, EA			±0.5	±5	
	Offset current vs temperature				±10		pA/°C
GAIN							
	Gain				G = 5 to 10k		V/V
	Gain equation				G = 5 + 80 kΩ/R_G		V/V
	Gain error	V_O = ±14 V, G = 5	INA126P, U, E INA2126P, U, E		±0.02%	±0.1%	
			INA126PA, UA, EA INA2126PA, UA, EA		±0.02%	±0.18%	
	Gain error vs temperature	G = 5			±2	±10	ppm/°C
	Gain error	V_O = ±12 V, G = 100	INA126P, U, E INA2126P, U, E		±0.2%	±0.5%	
			INA126PA, UA, EA INA2126PA, UA, EA		±0.2%	±1%	
	Gain error vs temperature	G = 100			±25	±100	ppm/°C

Electrical Characteristics (continued)

at T_A = 25°C, V_S = ±15 V, R_L = 25 kΩ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Nonlinearity	G = 100, V_O = ±14 V		±0.002%	±0.012%	
NOISE					
Voltage noise	f = 1 kHz		35		nV/√Hz
	f = 100 Hz		35		nV/√Hz
	f = 10 Hz		45		nV/√Hz
	f_B = 0.1 Hz to 10 Hz		0.7		μV_{PP}
Current noise	f = 1 kHz		60		fA/√Hz
	f_B = 0.1 Hz to 10 Hz		2		pA_{PP}
OUTPUT					
Positive voltage	R_L = 25 kΩ	(V+) – 0.9	(V+) – 0.75		V
Negative voltage	R_L = 25 kΩ	(V–) + 0.95	(V–) + 0.8		V
Short-circuit current	Short circuit to ground		+10 / –5		mA
Capacitive load drive			1000		pF
FREQUENCY RESPONSE					
Bandwidth, –3dB	G = 5		200		kHz
	G = 100		9		kHz
	G = 500		1.8		kHz
Slew rate	V_O = ±10 V, G = 5		0.4		V/µs
Settling time, 0.01%	10-V step, G = 5		30		µs
	10-V step, G = 100		160		µs
	10-V step, G = 500		1500		µs
Overload recovery	50% input overload		4		µs
POWER SUPPLY					
Voltage range		±1.35	±15	±18	V
Current (per channel)	I_O = 0		±175	±200	µA
Specification temperature range		–40		85	°C
Operation temperature range		–55		125	°C

6.7 Typical Characteristics

at T_A = 25°C, V_S = ±15 V (unless otherwise noted)

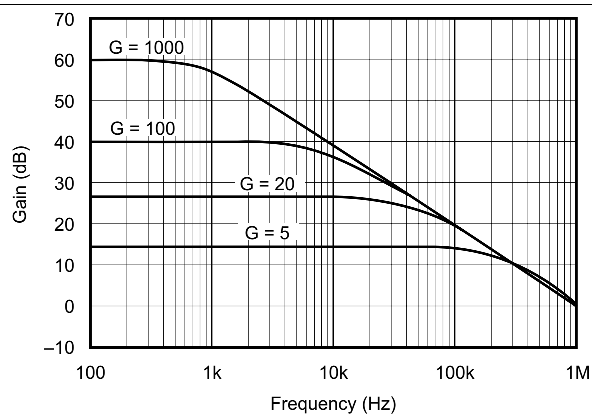


Figure 1. Gain vs Frequency

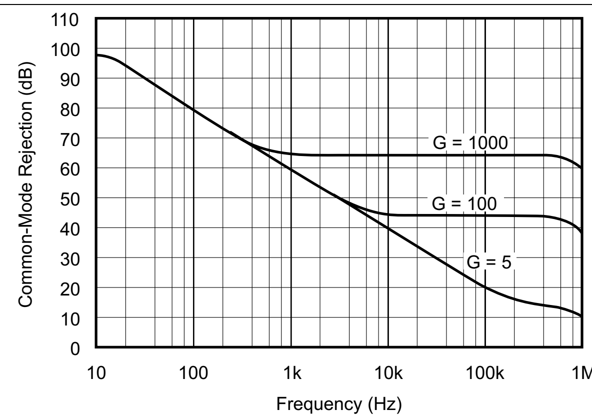


Figure 2. Common-Mode Rejection vs Frequency

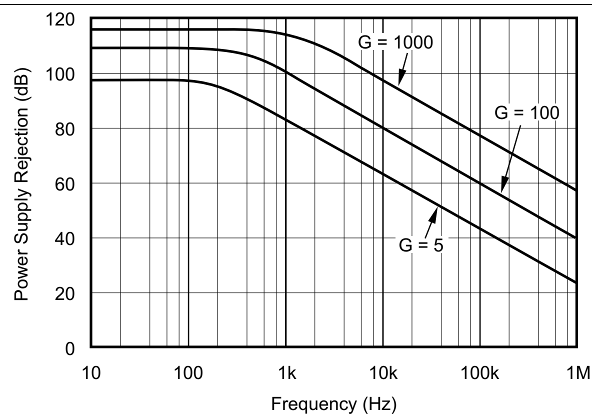


Figure 3. Positive Power Supply Rejection vs Frequency

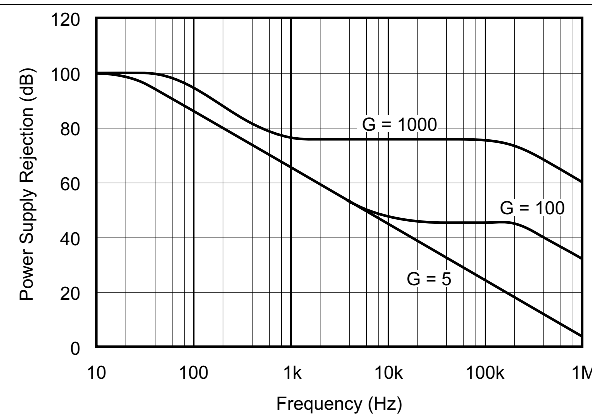


Figure 4. Negative Power Supply Rejection vs Frequency

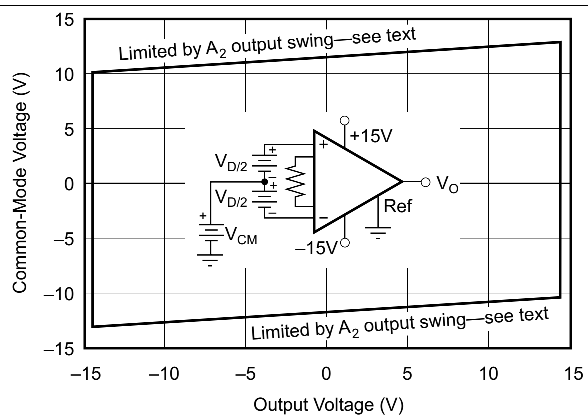


Figure 5. Input Common-Mode Range vs Output Voltage, V_S = ±15 V

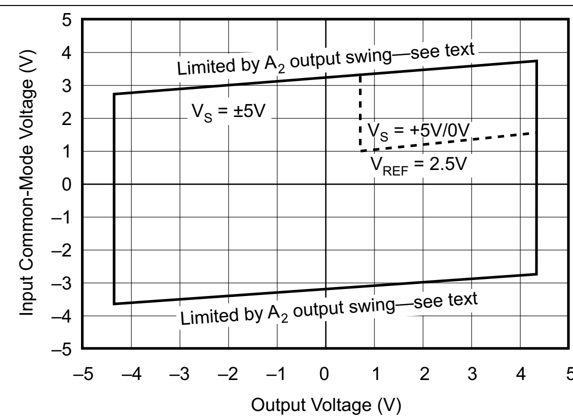


Figure 6. Input Common-Mode Voltage Range vs Output Voltage, V_S = ±5 V

Typical Characteristics (continued)

at T_A = 25°C, V_S = ±15 V (unless otherwise noted)

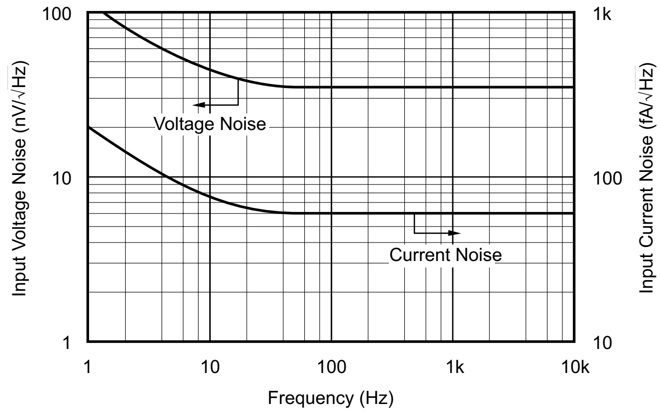


Figure 7. Input-Referred Noise vs Frequency

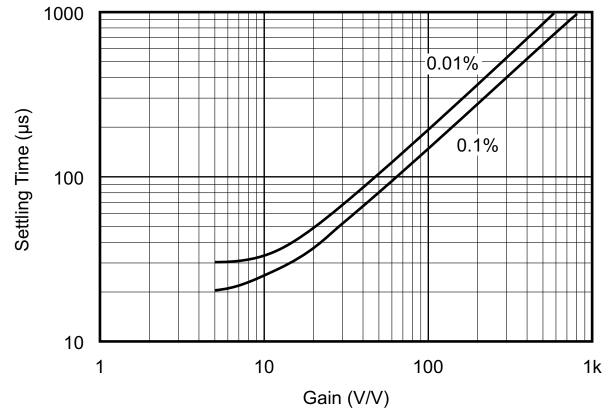


Figure 8. Settling Time vs Gain

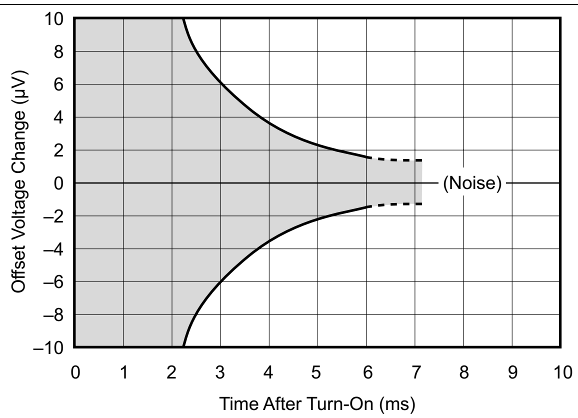


Figure 9. Input-Referred Offset Voltage Warm-Up

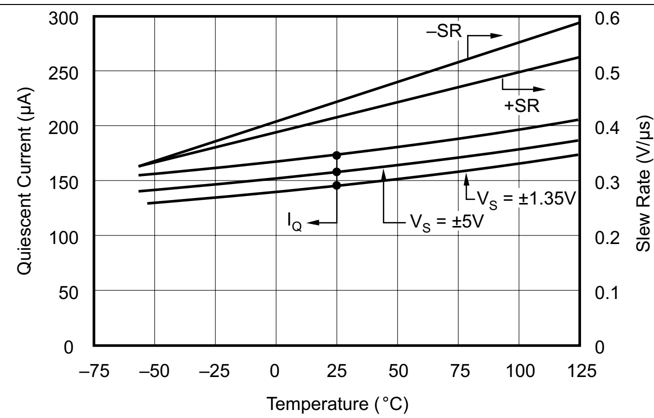


Figure 10. Quiescent Current and Slew Rate vs Temperature

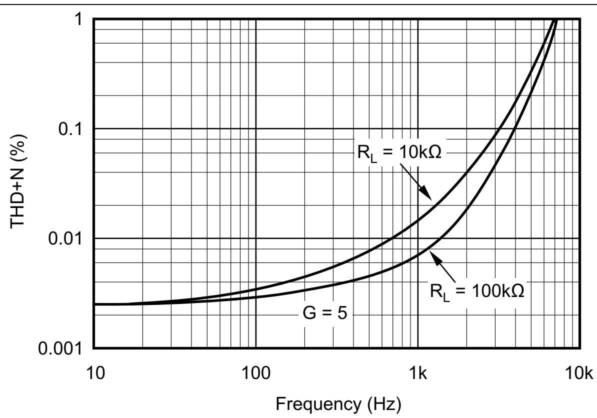


Figure 11. Total Harmonic Distortion + Noise vs Frequency

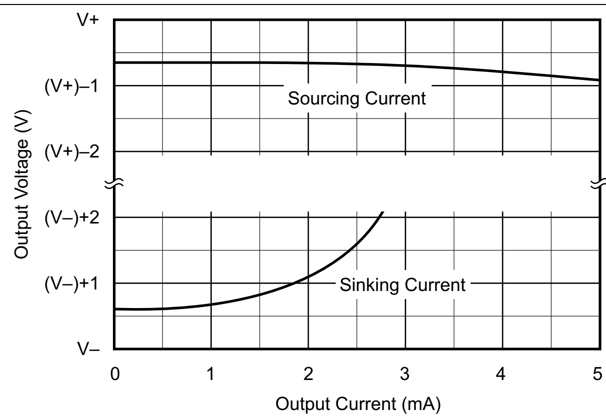


Figure 12. Output Voltage Swing vs Output Current

Typical Characteristics (continued)

at T_A = 25°C, V_S = ±15 V (unless otherwise noted)

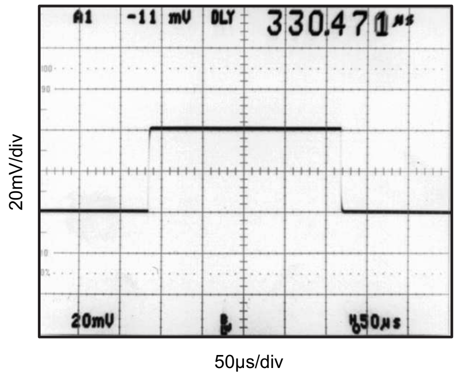


Figure 13. Small-Signal Response, G = 5

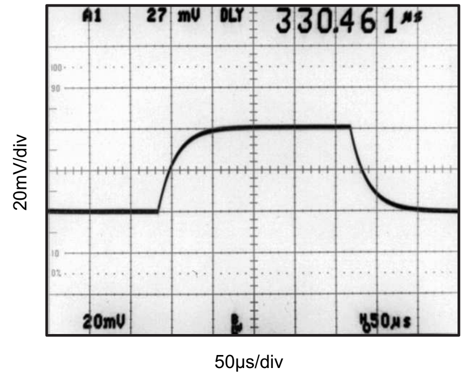


Figure 14. Small-Signal Response, G = 100

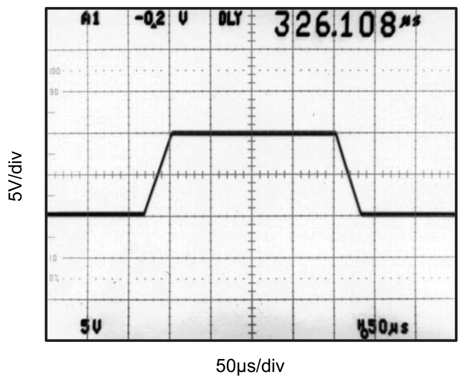


Figure 15. Large-Signal Response, G = 5

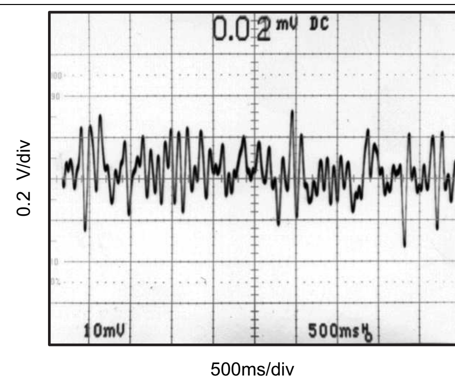


Figure 16. Voltage Noise, 0.1 Hz to 10 Hz

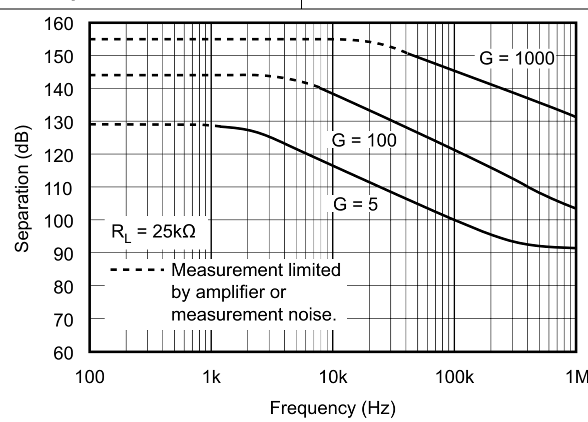


Figure 17. Channel Separation vs Frequency, RTI (Dual Version)

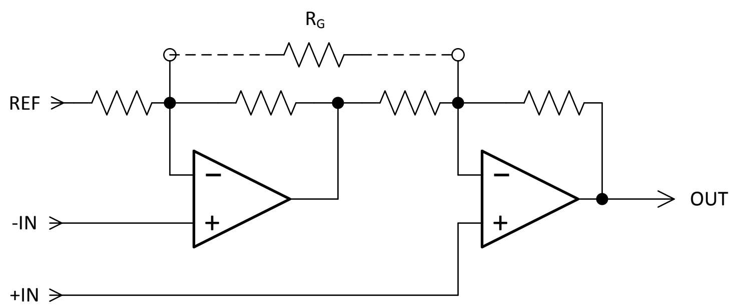
7 Detailed Description

7.1 Overview

The INAx126 use only two, rather than three, operational amplifiers providing savings in power consumption. In addition the input resistance is high and balanced, thus permitting the signal source to have an unbalanced output impedance.

A minimum circuit gain of 5 permits an adequate DC common mode input range, as well as sufficient bandwidth for most applications.

7.2 Functional Block Diagram



7.3 Feature Description

The INAx126 are low power, general-purpose instrumentation amplifiers offering excellent accuracy. The versatile two-operational-amplifier design and small size make the amplifiers ideal for a wide range of applications. The two op amp topology reduces power consumption. A single external resistor sets any gain from 5 to 10,000. These devices operate with power supplies as low as ±1.35 V, and quiescent current of 200 μA maximum.

7.4 Device Functional Modes

7.4.1 Single-Supply Operation

The INAx126 can be used on single power supplies of 2.7 V to 36 V. Use the output REF pin to level shift the internal output voltage into a linear operating condition. Ideally, connecting the REF pin to a potential that is midsupply avoids saturating the output of the amplifiers. See *Application Information* for information on how to adequately drive the reference pin.

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The INAx126 measures small differential voltage with high common-mode voltage developed between the noninverting and inverting input. The high input impedance make the INAx126 suitable for a wide range of applications. The INAx126 can adjust the functionality of the output signals by setting the reference pin, giving additional flexibility that is practical for multiple configurations.

8.2 Typical Application

Figure 18 shows the basic connections required for operation of the INA126. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

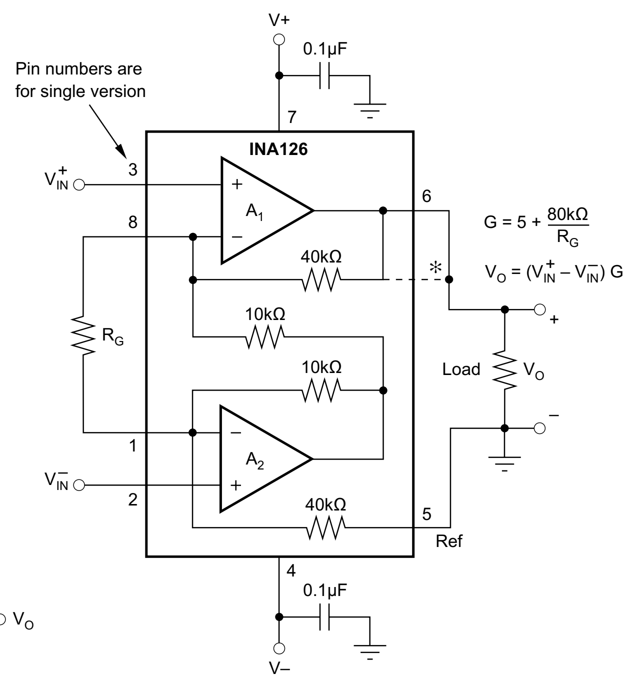
The output is referred to the output reference (Ref) terminal, which is normally grounded. This connection must be low-impedance to ensure good common-mode rejection. A resistance of 8 Ω in series with the Ref pin causes a typical device to degrade to approximately 80-dB CMR.

Figure 18 depicts a desired differential signal from a sensor at 1kHz and 5mV p-p superimposed on top of a 1-V p-p 60-Hz common mode signal (the 1-kHz signal can not be resolved in this scope trace). The FFT trace in Figure 22 shows the two signals. Figure 23 shows the clearly recovered differential signal at the output of the INA126 operating at a gain of 250. The FFT of figure 4 shows the 60-Hz common-mode is no longer visible.

The dual version (INA2126) has feedback-sense connections, $Sense_A$ and $Sense_B$. These must be connected to their respective output terminals for proper operation. The sense connection can sense the output voltage directly at the load for best accuracy.

DESIRED GAIN (V/V)	R_G (Ω)	NEAREST 1% R_G VALUE
5	NC	NC
10	16k	15.8k
20	5333	5360
50	1779	1780
100	842	845
200	410	412
500	162	162
1000	80.4	80.6
2000	40.1	40.2
5000	16.0	15.8
10000	8.0	7.87

NC: No Connection.



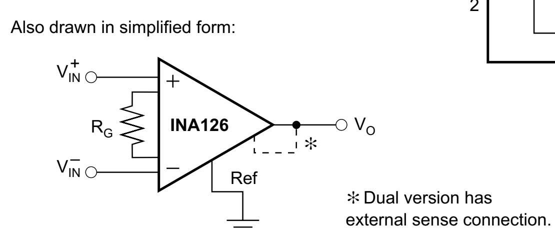


Figure 18. Basic Connections

Typical Application (continued)

8.2.1 Design Requirements

For the traces shown in Figure 19 and Figure 20:

- Common-mode rejection of at least 80dB
- Gain of 250

8.2.2 Detailed Design Procedure

8.2.2.1 Setting the Gain

Gain is set by connecting an external resistor, R_G:

$$g = 5 + 80\ k\Omega / R_G \qquad (1)$$

Commonly used gains and R_G resistor values are shown in Figure 18.

The 80-kΩ term in Equation 1 comes from the internal metal film resistors, which are laser-trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. The R_G contribution to gain accuracy and drift can be directly inferred from Equation 1. Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance, which contributes additional gain error in gains of approximately 100 or greater.

8.2.2.2 Offset Trimming

The INAx126 are laser-trimmed for low offset voltage and offset voltage drift. Most applications require no external offset adjustment. Figure 19 shows an optional circuit for trimming the output offset voltage. The voltage applied to the Ref terminal is added to the output signal. An operational amplifier buffer provides low impedance at the Ref terminal to preserve good common-mode rejection.

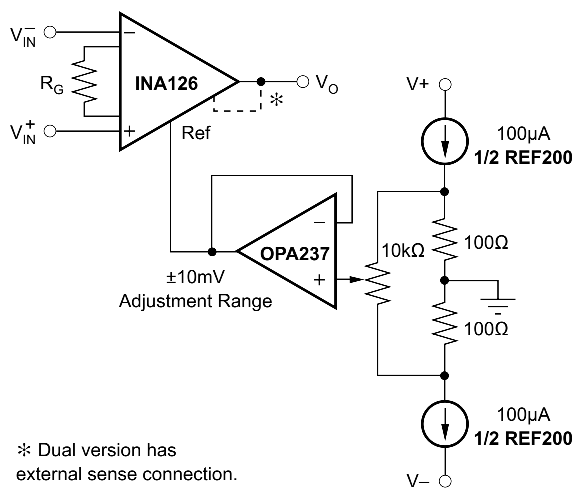


Figure 19. Optional Trimming of Output Offset Voltage

Typical Application (continued)

8.2.2.3 Input Bias Current Return

The input impedance of the INAx126 is extremely high, approximately 109 Ω. However, a path must be provided for the input bias current of both inputs. This input bias current is typically –10 nA (current flows out of the input terminals). High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 20 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range, and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 20). With higher source impedance, using two equal resistors provides a balanced input with the advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

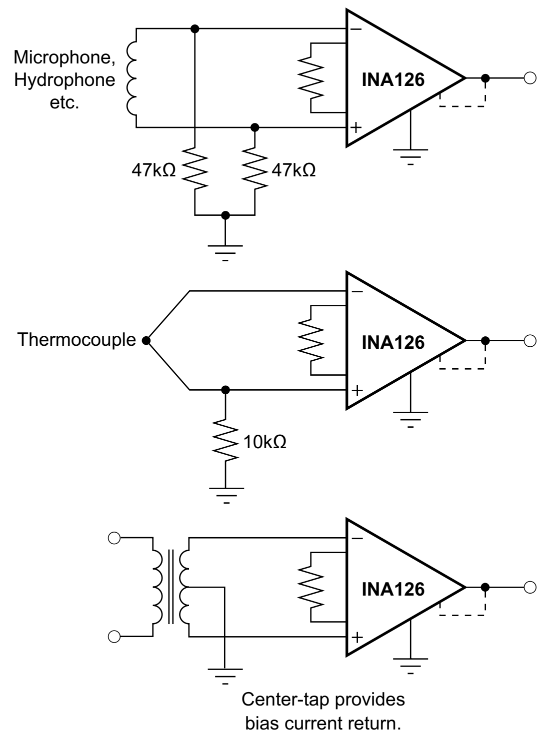


Figure 20. Providing an Input Common-Mode Current Path

8.2.2.4 Input Common-Mode Range

The input common-mode range of the INAx126 is shown in *Typical Characteristics*. The common-mode range is limited on the negative side by the output voltage swing of A_2, an internal circuit node that cannot be measured on an external pin. The output voltage of A_2 can be expressed as shown in Equation 2:

$$V_{O2} = 1.25\ V^{-}_{IN} - (V^{+}_{IN} - V^{-}_{IN})\ (10\ k\Omega/R_G)$$

where

- Voltages referred to Ref terminal, pin 5 (2)

The internal op amp A_2 is identical to A_1, and its output swing is limited to typically 0.7 V from the supply rails. When the input common-mode range is exceeded (A_2 output is saturated), A_1 can still be in linear operation and respond to changes in the non-inverting input voltage. The output voltage, however, will be invalid.

Typical Application (continued)

8.2.2.5 Input Protection

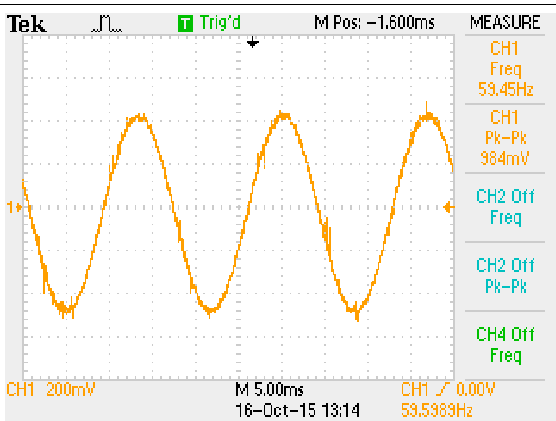
The inputs are protected with internal diodes connected to the power supply rails. These diodes clamp the applied signal to prevent it from exceeding the power supplies by more than approximately 0.7 V. If the signal-source voltage can exceed the power supplies, the source current should be limited to less than 10 mA. This can generally be done with a series resistor. Some signal sources are inherently current-limited, and do not require limiting resistors.

8.2.2.6 Channel Crosstalk—Dual Version

The two channels of the INA2126 are completely independent, including all bias circuitry. At DC and low frequency, there is virtually no signal coupling between channels. Crosstalk increases with frequency and is dependent on circuit gain, source impedance, and signal characteristics.

As source impedance increases, careful circuit layout can help achieve lowest channel crosstalk. Most crosstalk is produced by capacitive coupling of signals from one channel to the input section of the other channel. To minimize coupling, separate the input traces as far as practical from any signals associated with the opposite channel. A grounded guard trace surrounding the inputs helps reduce stray coupling between channels. Carefully balance the stray capacitance of each input to ground, and run the differential inputs of each channel parallel to each other, or directly adjacent on top and bottom side of a circuit board. Stray coupling then tends to produce a common-mode signal that is rejected by the IA input.

8.2.3 Application Curves



Differential signal is too small to be seen

Figure 21. Common-mode Signal at INA126 Input

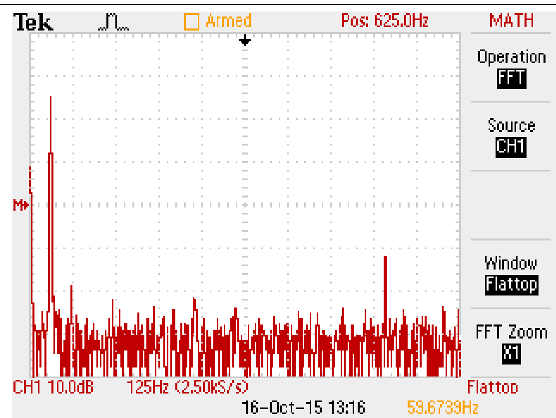


Figure 22. FFT of Signal in Figure 21 Shows Both the 60-Hz Common-mode Along With 5-kHz Differential Signal

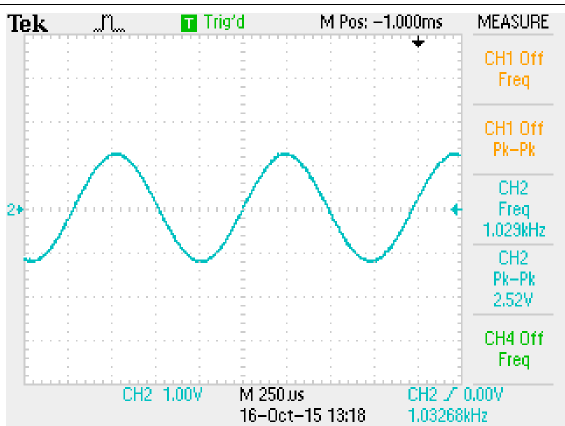


Figure 23. Recovered Differential Signal at the Output of the INA126 With a Gain of 250

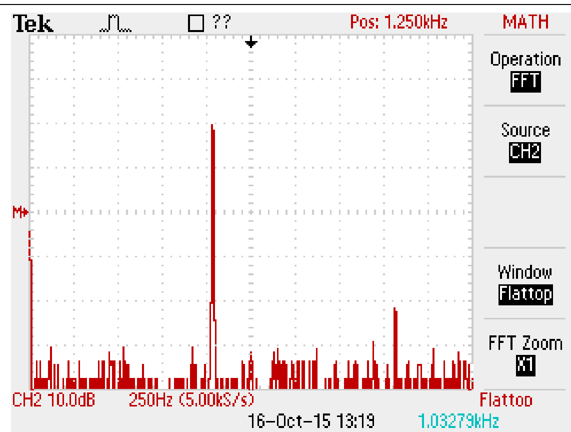


Figure 24. FFT of the INA126 Output Shows that the 60-Hz Common-mode Signal is Rejected

9 Power Supply Recommendations

9.1 Low Voltage Operation

The INAx126 can be operated on power supplies as low as ±1.35 V. Performance remains excellent with power supplies ranging from ±1.35 V to ±18 V. Most parameters vary only slightly throughout this supply voltage range (see *Typical Characteristics*). Operation at low supply voltage requires careful attention to ensure that the common-mode voltage remains within its linear range (see Figure 5 and Figure 6).

The INAx126 can be operated from a single power supply with careful attention to input common-mode range, output voltage swing of both op amps, and the voltage applied to the Ref terminal. Figure 25 shows a bridge amplifier circuit operated from a single +5-V power supply. The bridge provides an input common-mode voltage near 2.5 V, with a relatively small differential voltage.

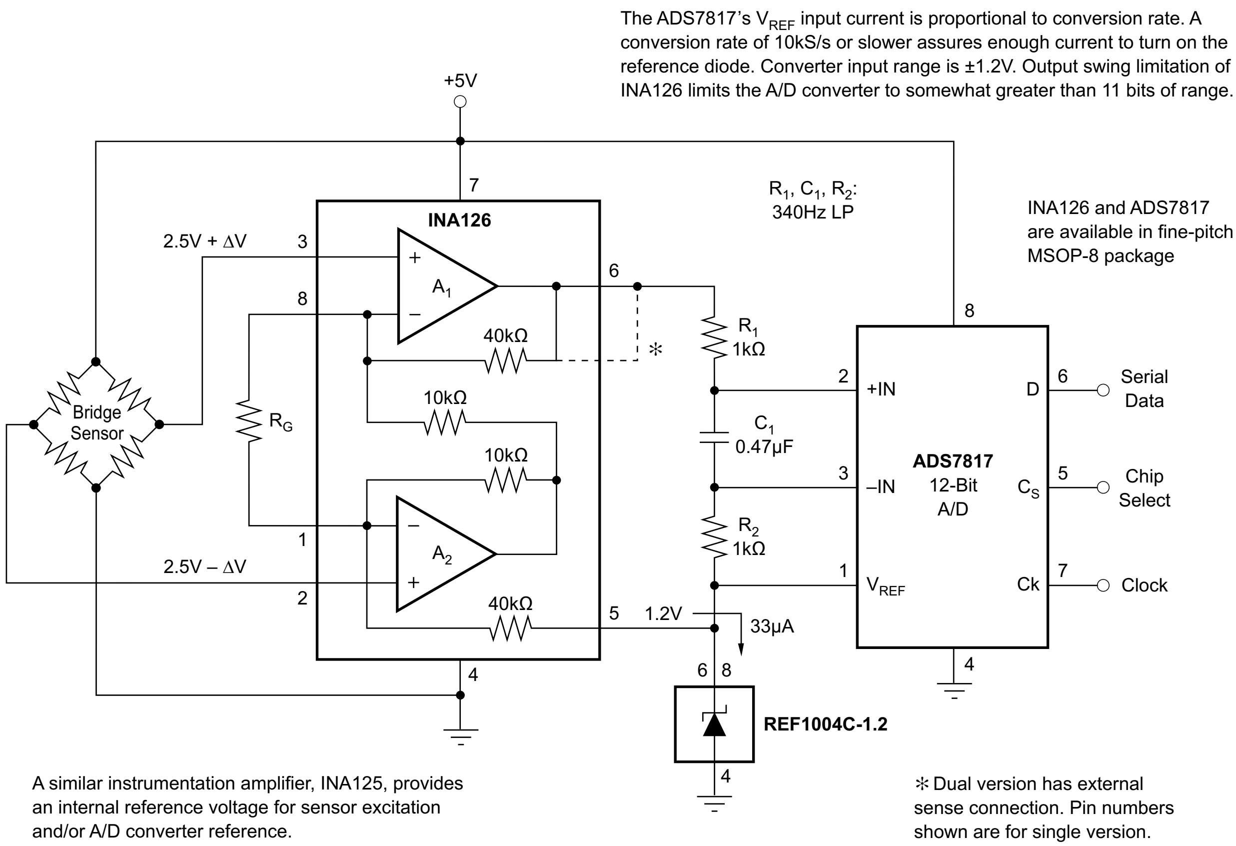


Figure 25. Bridge Signal Acquisition, Single 5-V Supply

10 Layout

10.1 Layout Guidelines

Attention to good layout practices is always recommended. For best operational performance of the device, use good printed circuit board (PCB) layout practices, including:

- Take care to ensure that both input paths are well-matched for source impedance and capacitance to avoid converting common-mode signals into differential signals. In addition, parasitic capacitance at the gain-setting pins can also affect CMRR over frequency. For example, in applications that implement gain switching using switches or PhotoMOS® relays to change the value of RG, select the component so that the switch capacitance is as small as possible.
  – Connect low-ESR, 0.1-μF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
- Separate grounding for analog and digital portions of the circuitry is one of the simplest and most effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds, paying attention to the flow of the ground current. For more detailed information, see SLOA089, Circuit Board Layout Techniques.
- In order to reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better than in parallel with the noisy trace.
- Place the external components as close to the device as possible. As illustrated in Figure 26, keeping RG close to the pins minimizes parasitic capacitance.
- Keep the traces as short as possible

10.2 Layout Example

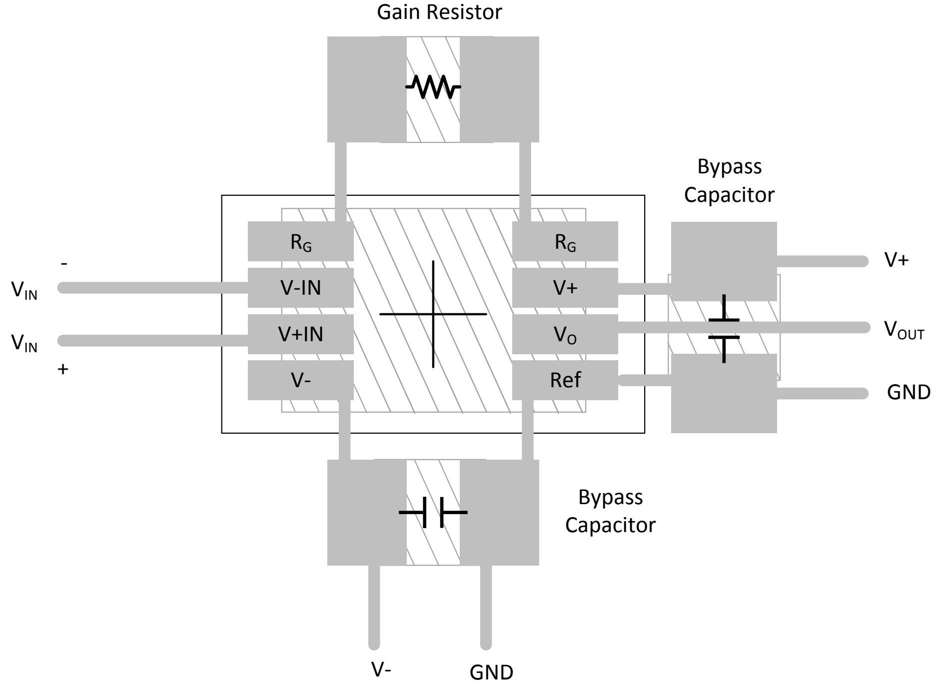


Figure 26. Layout for All Single INA126 Versions

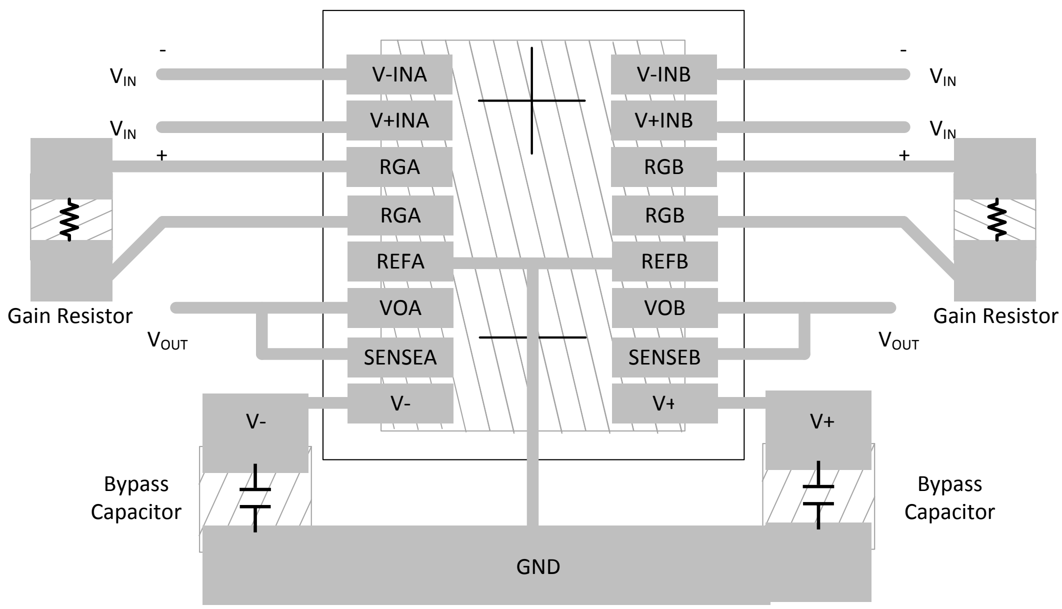


Figure 27. INA2126 Layout

11 Device and Documentation Support

11.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 1. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
INA126	Click here	Click here	Click here	Click here	Click here
INA2126	Click here	Click here	Click here	Click here	Click here

11.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.3 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.4 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA126E/250	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	NIPDAU | NIPDAUAG	Level-2-260C-1 YEAR	-55 to 125	A26	Samples
INA126E/250G4	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-55 to 125	A26	Samples
INA126E/2K5	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	NIPDAU | NIPDAUAG	Level-2-260C-1 YEAR		A26	Samples
INA126E/2K5G4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR		A26	Samples
INA126EA/250	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	NIPDAU | NIPDAUAG	Level-2-260C-1 YEAR		A26	Samples
INA126EA/2K5	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	NIPDAU | NIPDAUAG	Level-2-260C-1 YEAR		A26	Samples
INA126EA/2K5G4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR		A26	Samples
INA126P	ACTIVE	PDIP	P	8	50	Green (RoHS & no Sb/Br)	NIPDAU	N / A for Pkg Type		INA126P	Samples
INA126PA	ACTIVE	PDIP	P	8	50	Green (RoHS & no Sb/Br)	NIPDAU	N / A for Pkg Type		INA126P A	Samples
INA126U	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U	Samples
INA126U/2K5	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U	Samples
INA126U/2K5G4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U	Samples
INA126UA	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U A	Samples
INA126UA/2K5	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U A	Samples
INA126UAG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA 126U A	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA2126E/250	ACTIVE	SSOP	DBQ	16	250	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126E/250G4	ACTIVE	SSOP	DBQ	16	250	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126E/2K5	ACTIVE	SSOP	DBQ	16	2500	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126EA/250	ACTIVE	SSOP	DBQ	16	250	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126EA/250G4	ACTIVE	SSOP	DBQ	16	250	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126EA/2K5	ACTIVE	SSOP	DBQ	16	2500	Green (RoHS & no Sb/Br)	Call TI	Level-3-260C-168 HR		INA 2126E A	Samples
INA2126U	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA2126U	Samples
INA2126UA	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	INA2126U A	Samples
INA2126UA/2K5	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR	-40 to 85	INA2126U A	Samples
INA2126UE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	NIPDAU	Level-3-260C-168 HR		INA2126U	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

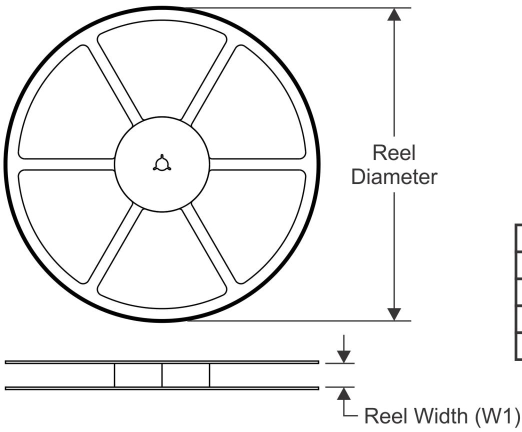
(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

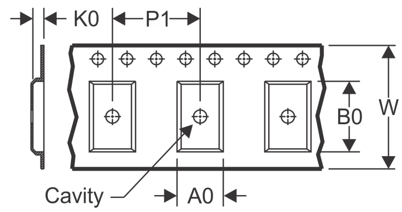
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

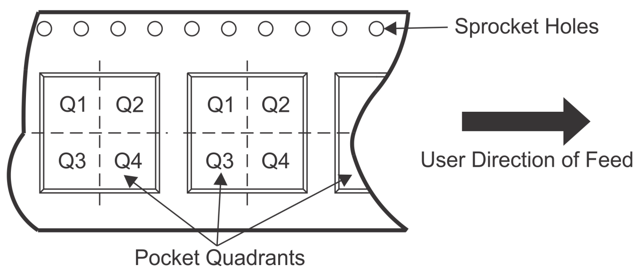


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

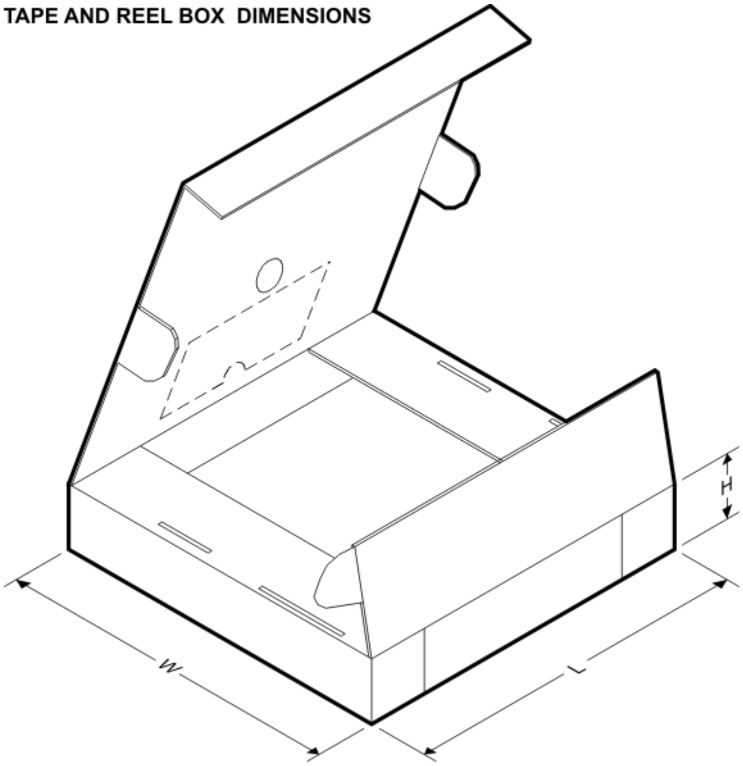
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA126E/250	VSSOP	DGK	8	250	180.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
INA126E/2K5	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
INA126EA/250	VSSOP	DGK	8	250	180.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
INA126EA/2K5	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
INA126U/2K5	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA126UA/2K5	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA2126E/250	SSOP	DBQ	16	250	180.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA2126E/2K5	SSOP	DBQ	16	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA2126EA/250	SSOP	DBQ	16	250	180.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA2126EA/2K5	SSOP	DBQ	16	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
INA2126UA/2K5	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1

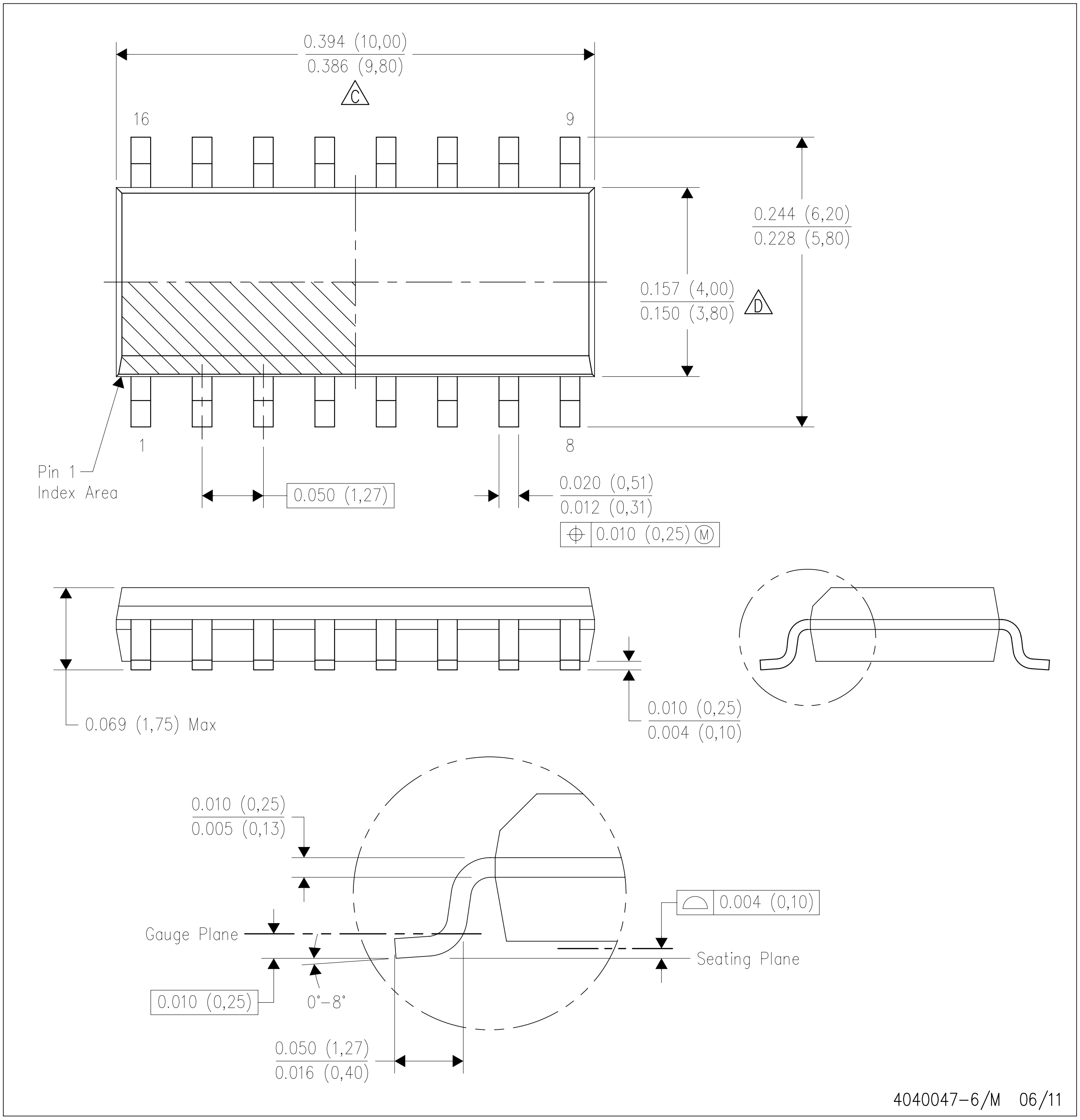
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

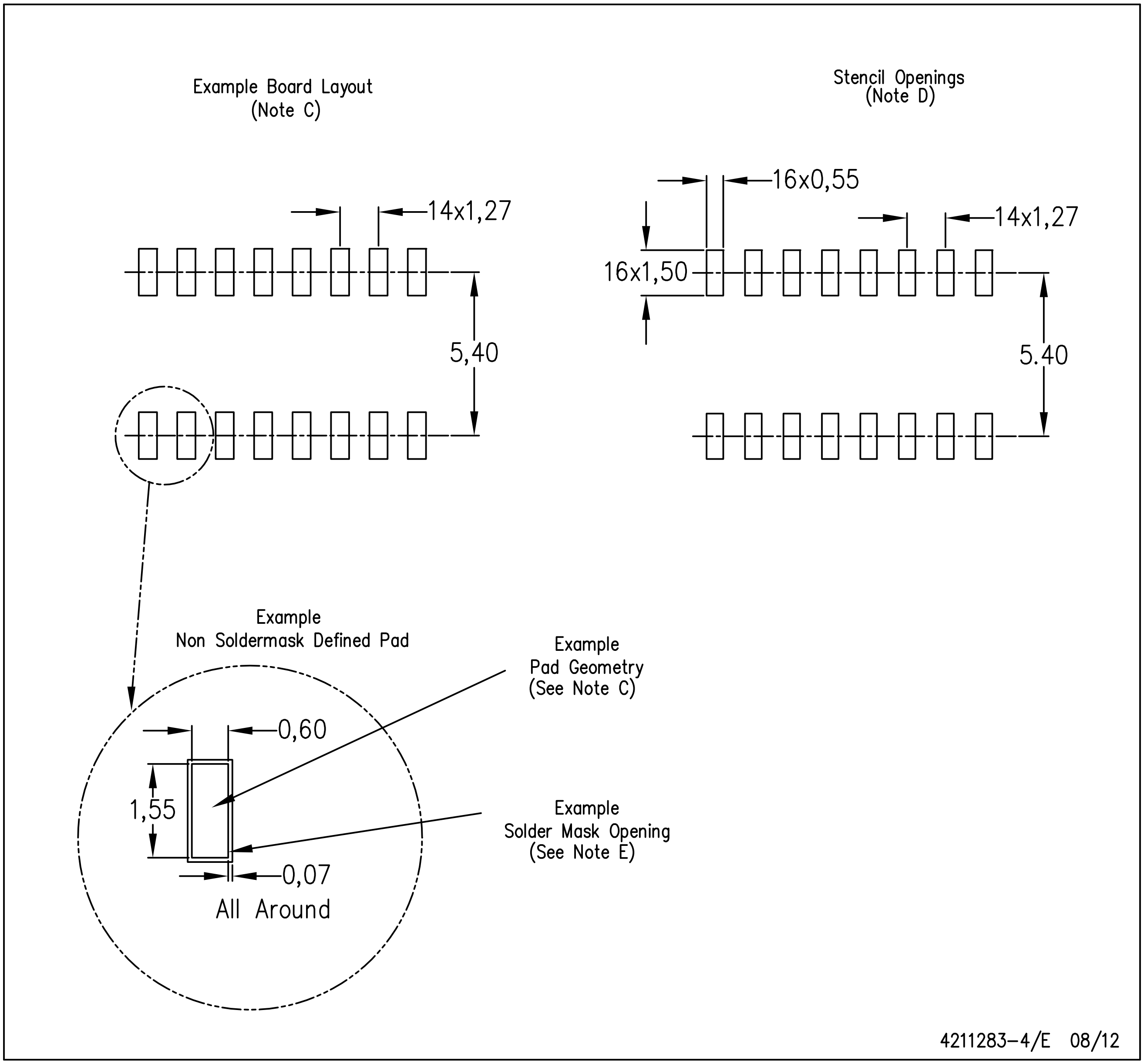
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA126E/250	VSSOP	DGK	8	250	210.0	185.0	35.0
INA126E/2K5	VSSOP	DGK	8	2500	367.0	367.0	35.0
INA126EA/250	VSSOP	DGK	8	250	210.0	185.0	35.0
INA126EA/2K5	VSSOP	DGK	8	2500	367.0	367.0	35.0
INA126U/2K5	SOIC	D	8	2500	367.0	367.0	35.0
INA126UA/2K5	SOIC	D	8	2500	367.0	367.0	35.0
INA2126E/250	SSOP	DBQ	16	250	210.0	185.0	35.0
INA2126E/2K5	SSOP	DBQ	16	2500	367.0	367.0	35.0
INA2126EA/250	SSOP	DBQ	16	250	210.0	185.0	35.0
INA2126EA/2K5	SSOP	DBQ	16	2500	367.0	367.0	35.0
INA2126UA/2K5	SOIC	D	16	2500	367.0	367.0	38.0

D (R–PDSO–G16) PLASTIC SMALL OUTLINE

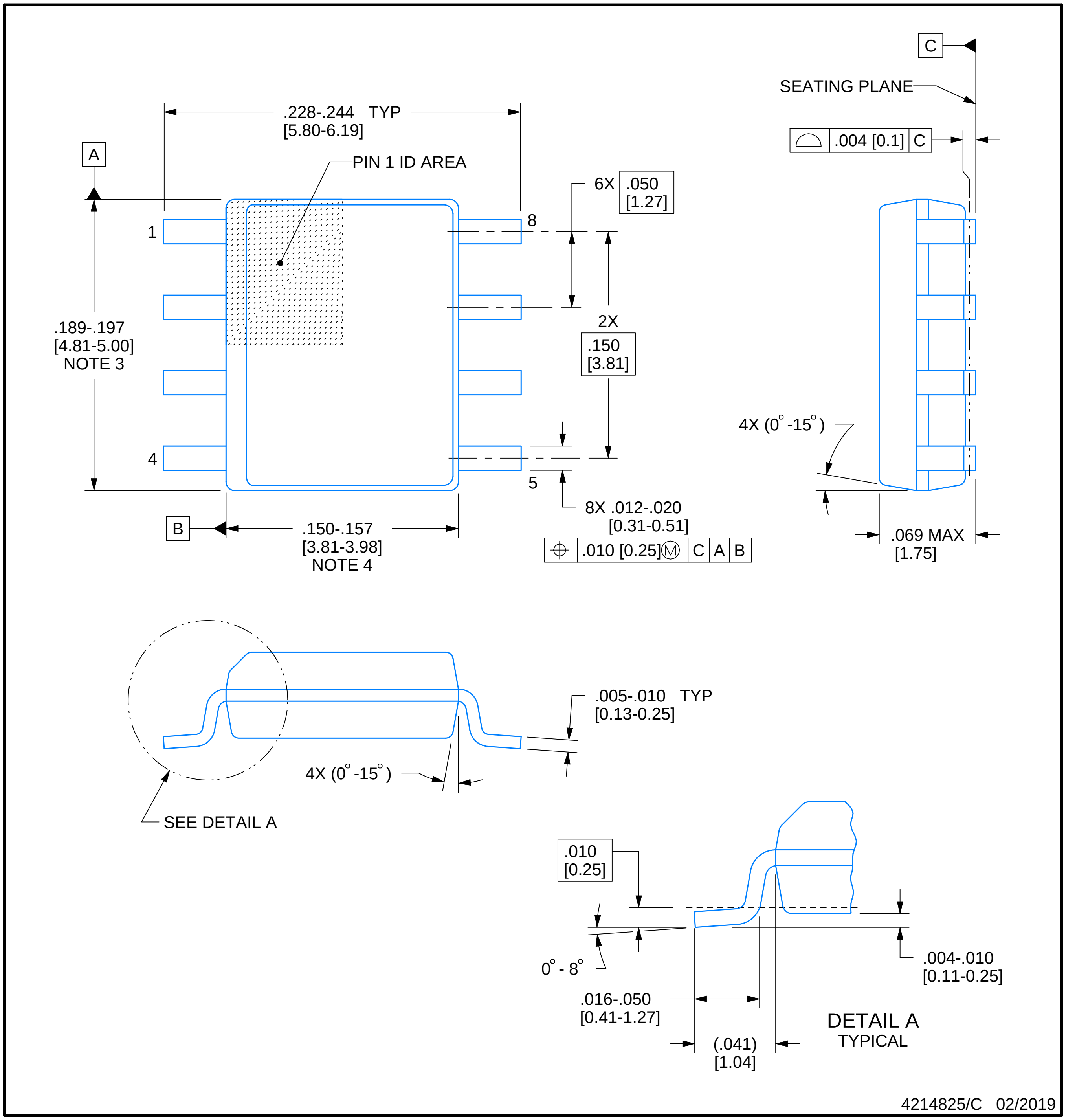


NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
- E. Reference JEDEC MS-012 variation AC.

D (R-PDSO-G16) PLASTIC SMALL OUTLINE

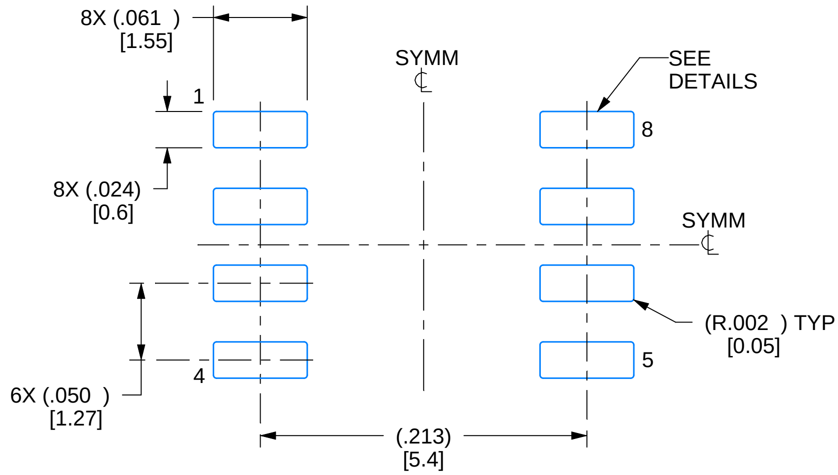


NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

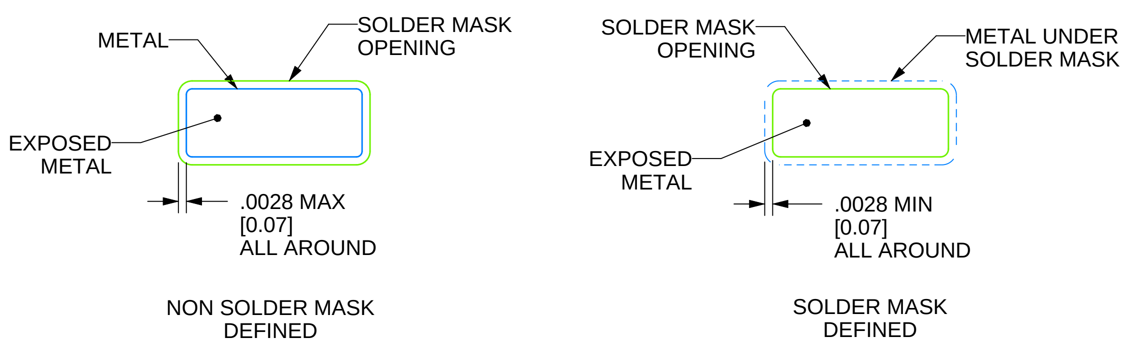


NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X

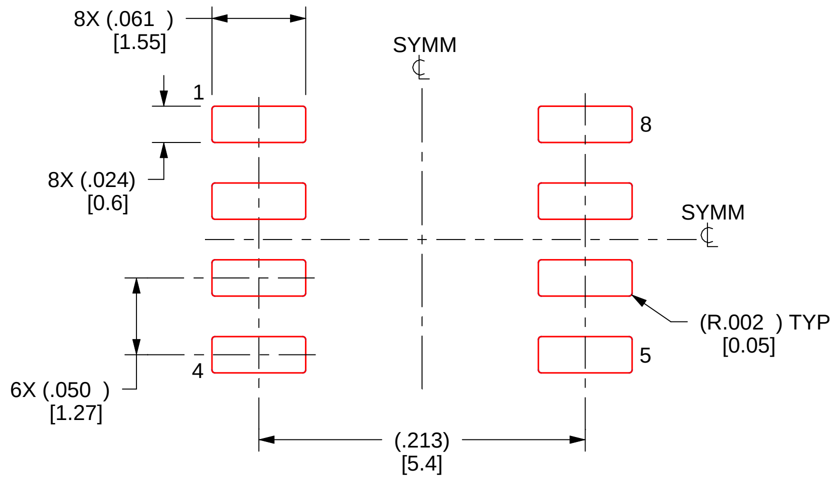


SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

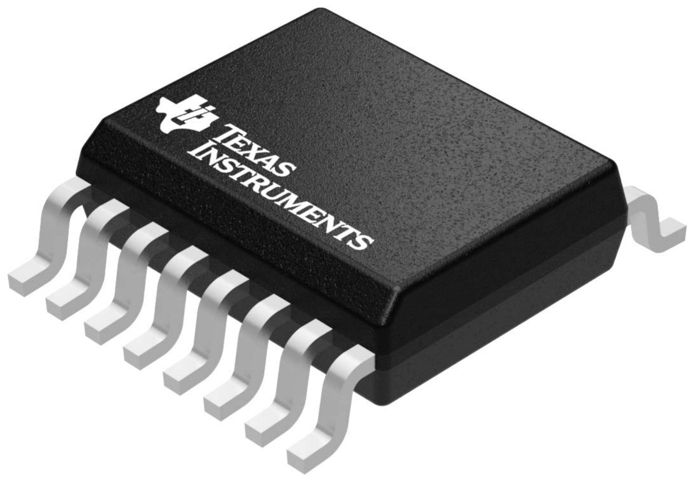


SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

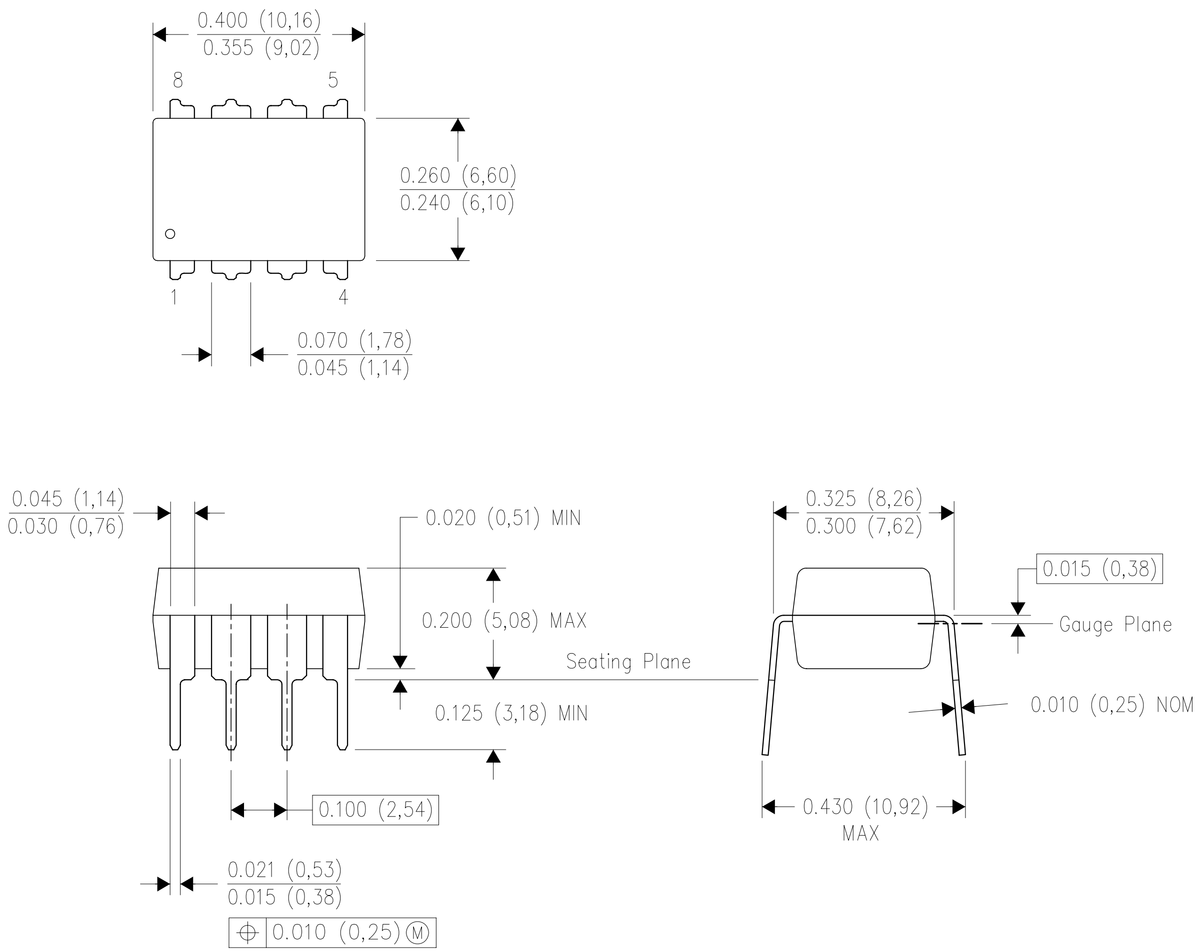
NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

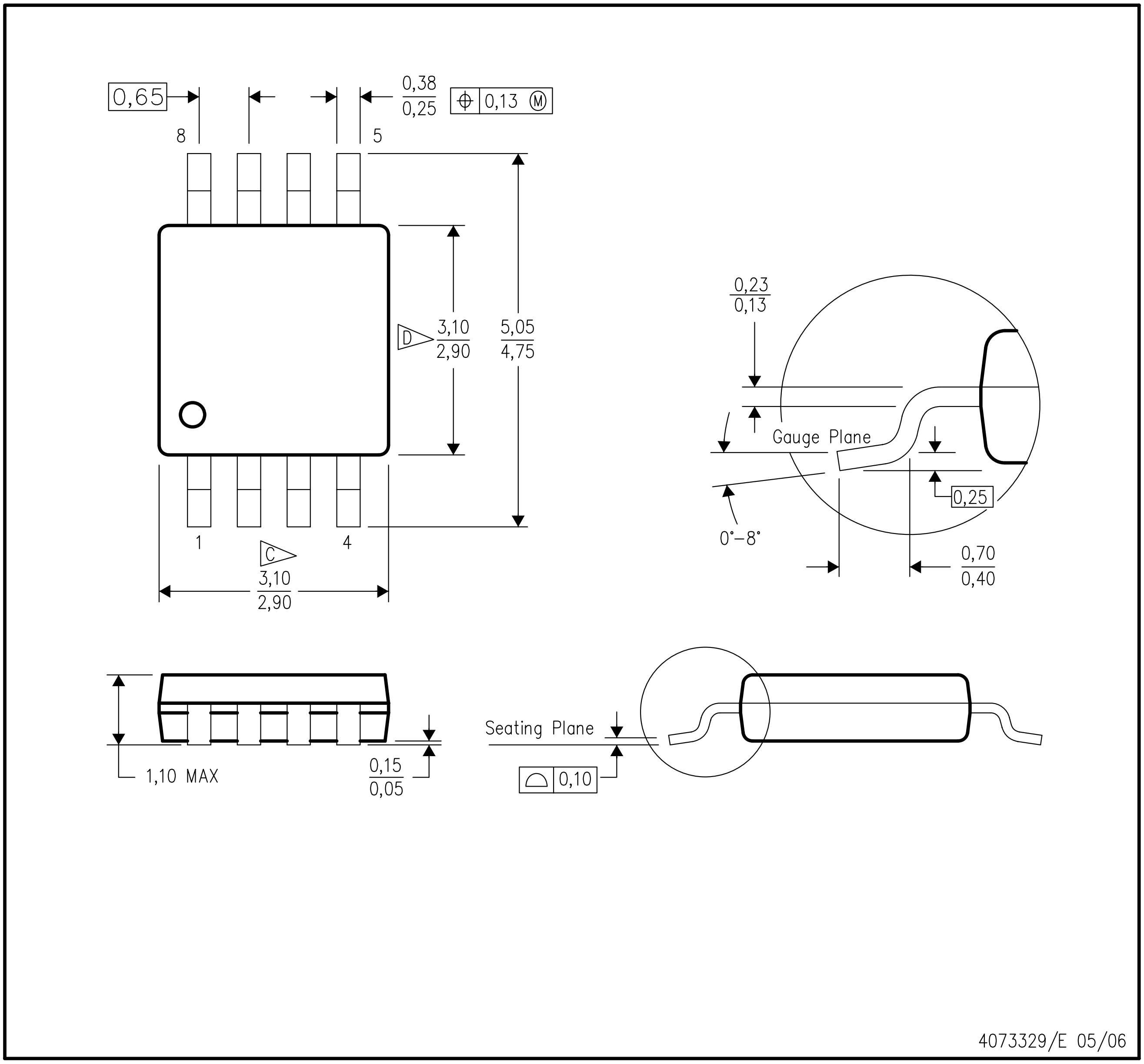
P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE



4040082/E 04/2010

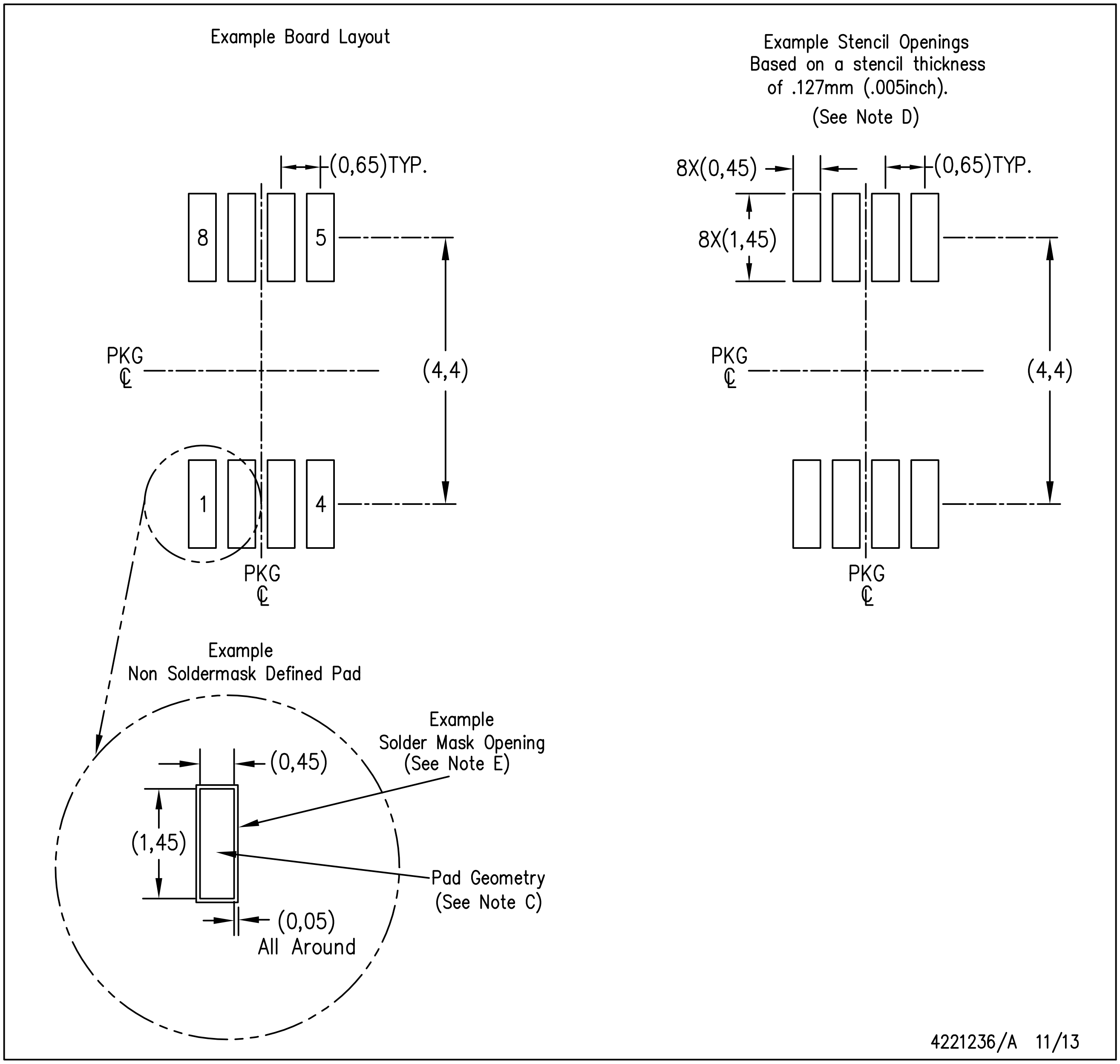
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

DGK (S-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO-187 variation AA, except interlead flash.

DGK (S-PDSO-G8) PLASTIC SMALL OUTLINE PACKAGE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

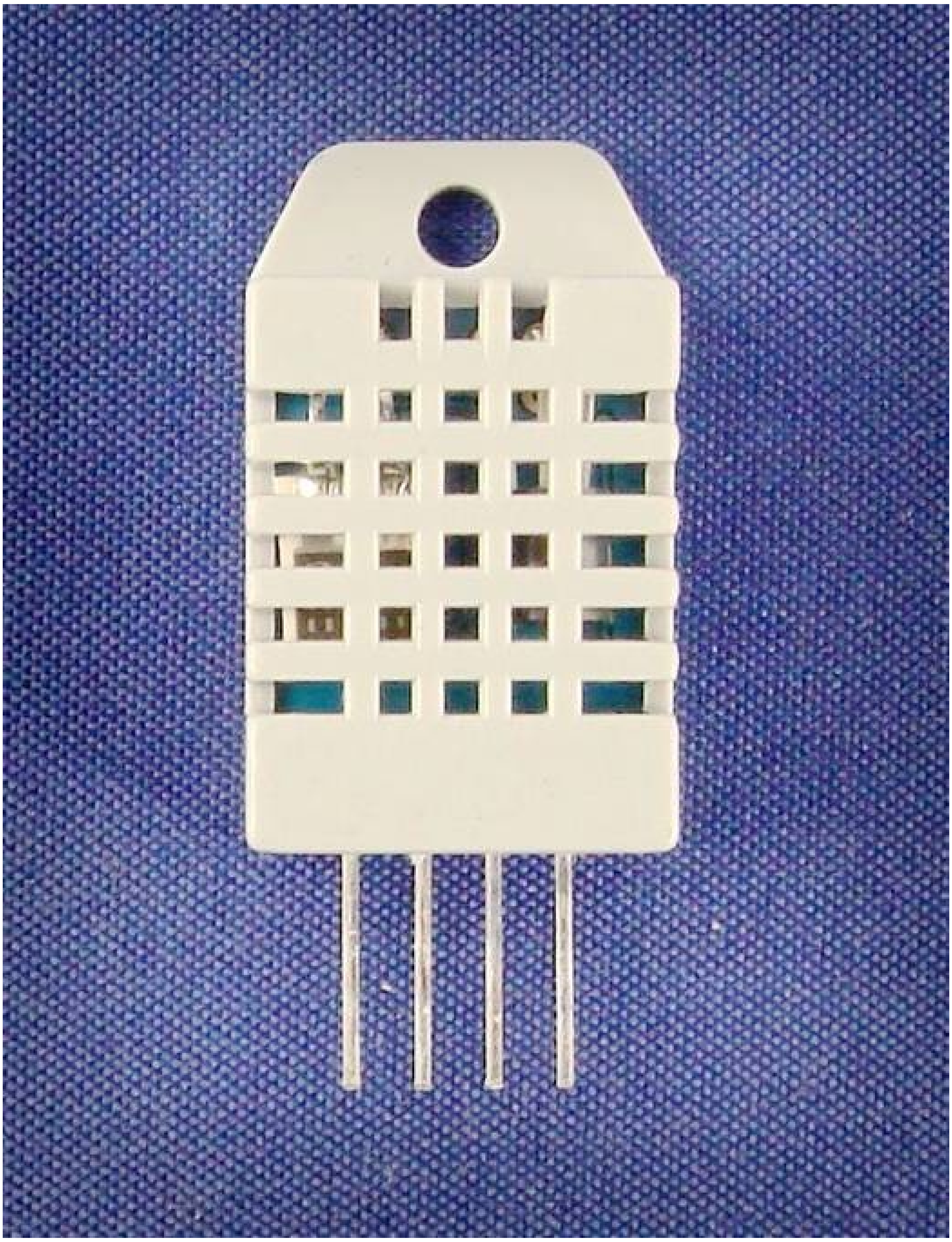
IMPORTANT NOTICE AND DISCLAIMER

Aosong Electronics Co.,Ltd

Your specialist in innovating humidity & temperature sensors

Digital-output relative humidity & temperature sensor/module

DHT22 (DHT22 also named as AM2302)



Capacitive-type humidity and temperature module/sensor

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Aosong Electronics Co.,Ltd

Your specialist in innovating humidity & temperature sensors

1. Feature & Application:

* Full range temperature compensated * Relative humidity and temperature measurement
* Calibrated digital signal *Outstanding long-term stability *Extra components not needed
* Long transmission distance * Low power consumption *4 pins packaged and fully interchangeable

2. Description:

DHT22 output calibrated digital signal. It utilizes exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability.Its sensing elements is connected with 8-bit single-chip computer.

Every sensor of this model is temperature compensated and calibrated in accurate calibration chamber and the calibration-coefficient is saved in type of programme in OTP memory, when the sensor is detecting, it will cite coefficient from memory.

Small size & low consumption & long transmission distance(20m) enable DHT22 to be suited in all kinds of harsh application occasions.

Single-row packaged with four pins, making the connection very convenient.

3. Technical Specification:

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

4. Dimensions: (unit----mm)

1) Small size dimensions: (unit----mm)

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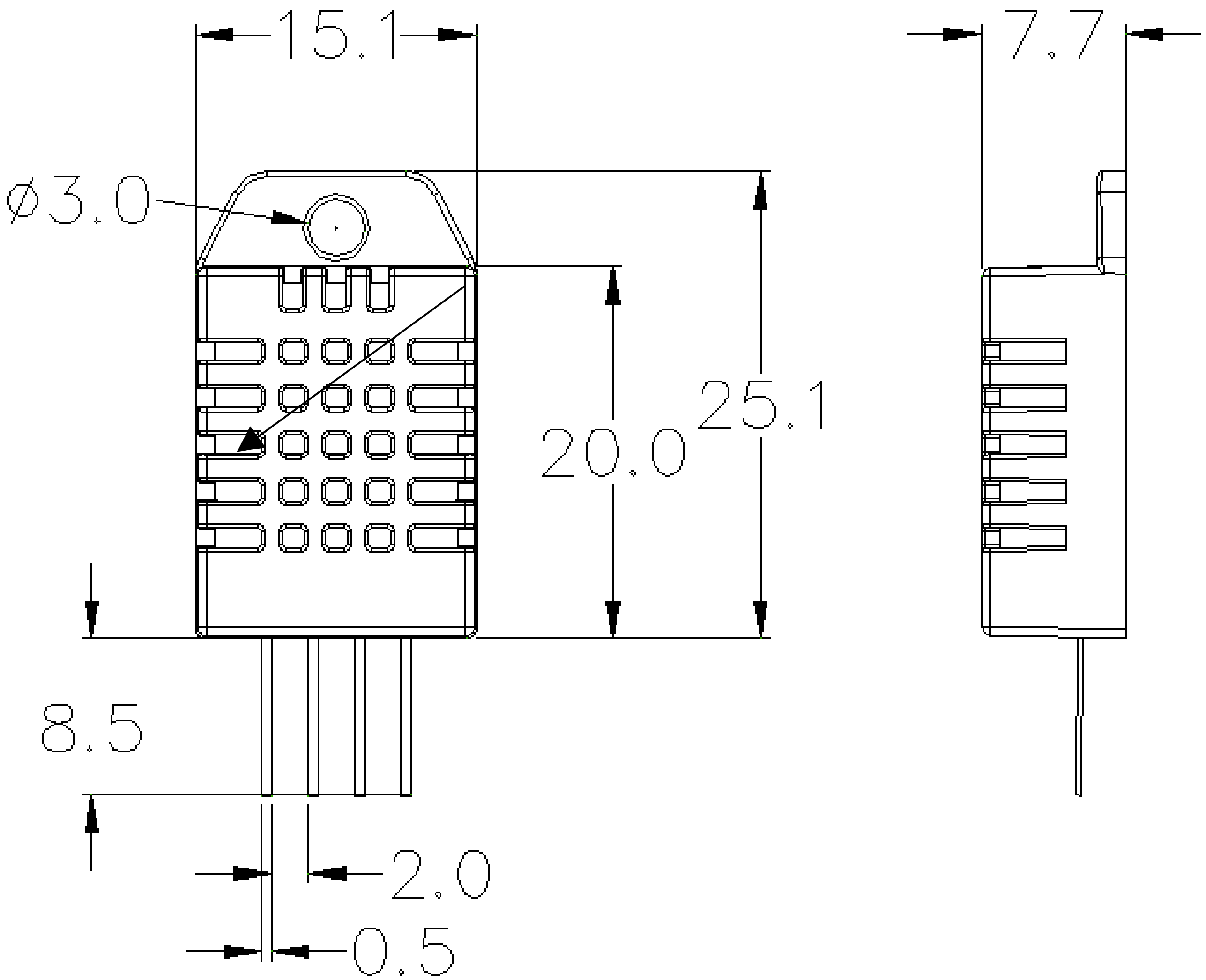

Pin sequence number: 1 2 3 4 (from left to right direction).

Pin	Function
1	VDD----power supply
2	DATA--signal
3	NULL
4	GND

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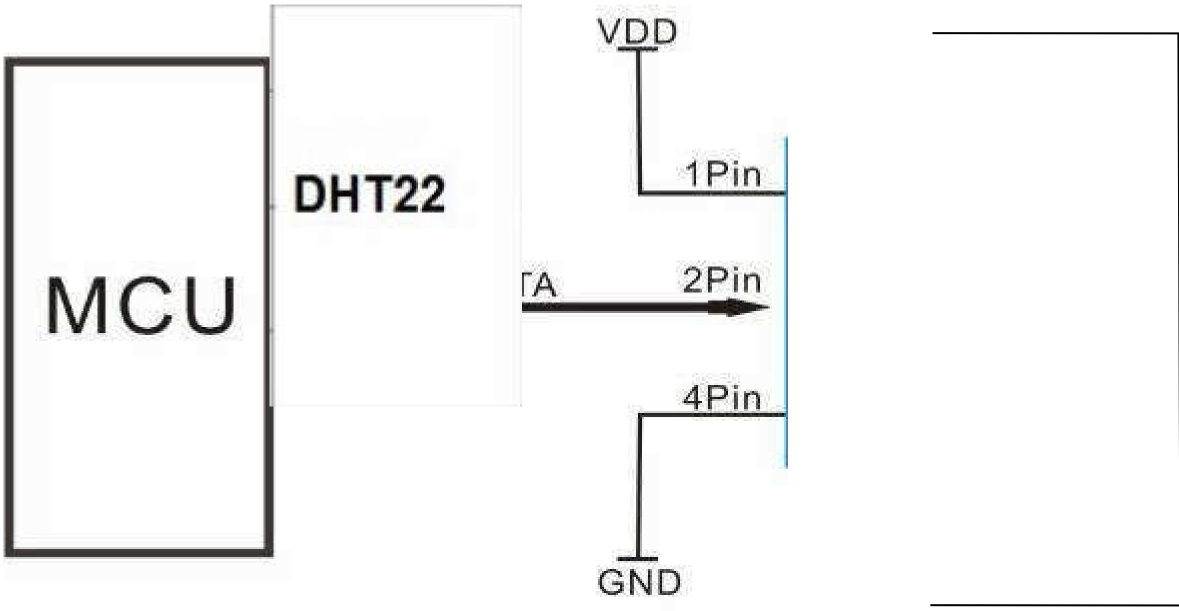
5. Electrical connection diagram:



3Pin---NC, AM2302 is another name for DHT22

6. Operating specifications:

(1) Power and Pins

Power's voltage should be 3.3-6V DC. When power is supplied to sensor, don't send any instruction to the sensor within one second to pass unstable status. One capacitor valued 100nF can be added between VDD and GND for wave filtering.

(2) Communication and signal

Single-bus data is used for communication between MCU and DHT22, it costs 5mS for single time communication.

Data is comprised of integral and decimal part, the following is the formula for data.

DHT22 send out higher data bit firstly!

DATA=8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data+8 bit check-sum

If the data transmission is right, check-sum should be the last 8 bit of "8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data".

When MCU send start signal, DHT22 change from low-power-consumption-mode to running-mode. When MCU finishs sending the start signal, DHT22 will send response signal of 40-bit data that reflect the relative humidity

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and temperature information to MCU. Without start signal from MCU, DHT22 will not give response signal to MCU. One start signal for one time's response data that reflect the relative humidity and temperature information from DHT22. DHT22 will change to low-power-consumption-mode when data collecting finish if it don't receive start signal from MCU again.

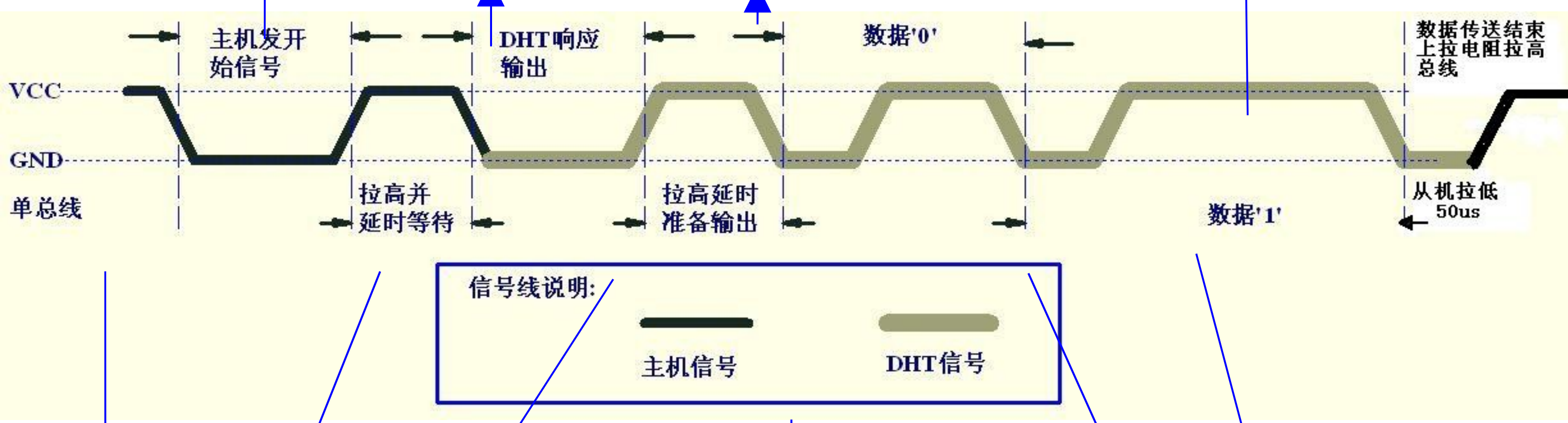
1) Check bellow picture for overall communication process:

Host computer send out start signal.

Sensor send out response signal.

Output data: 1bit"0"

Data transmission finished, and RL pull up bus's voltage for next transmission



Pull up and wait response from sensor

Host's signal

Sensor's signal

Output data: 1bit "1"

Pull up voltage and get ready for sensor's output.

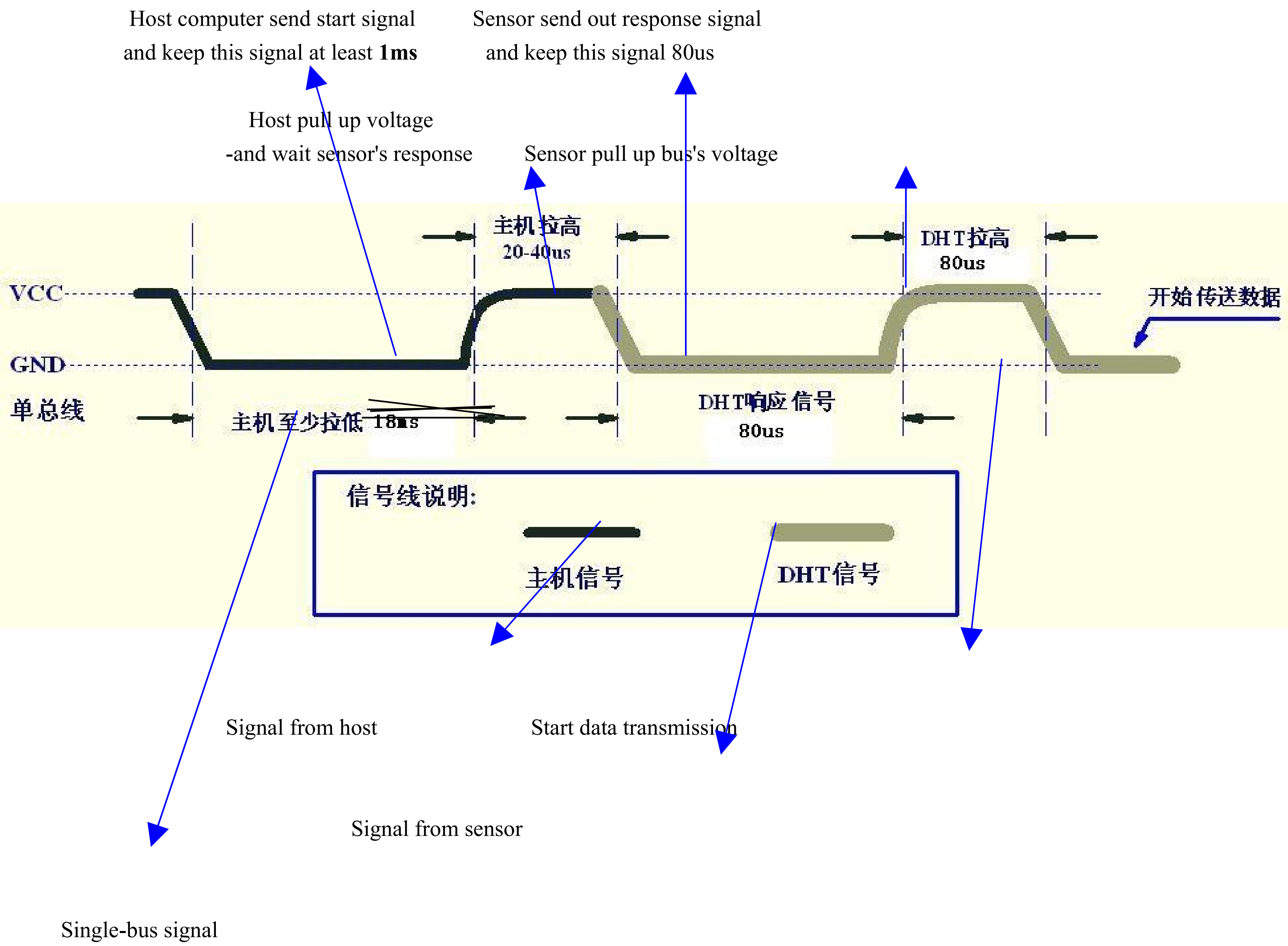
Sensor pull down bus's voltage

Single-bus output

2) Step 1: MCU send out start signal to DHT22

Data-bus's free status is high voltage level. When communication between MCU and DHT22 begin, program of MCU will transform data-bus's voltage level from high to low level and this process must beyond at least 1ms to ensure DHT22 could detect MCU's signal, then MCU will wait 20-40us for DHT22's response.

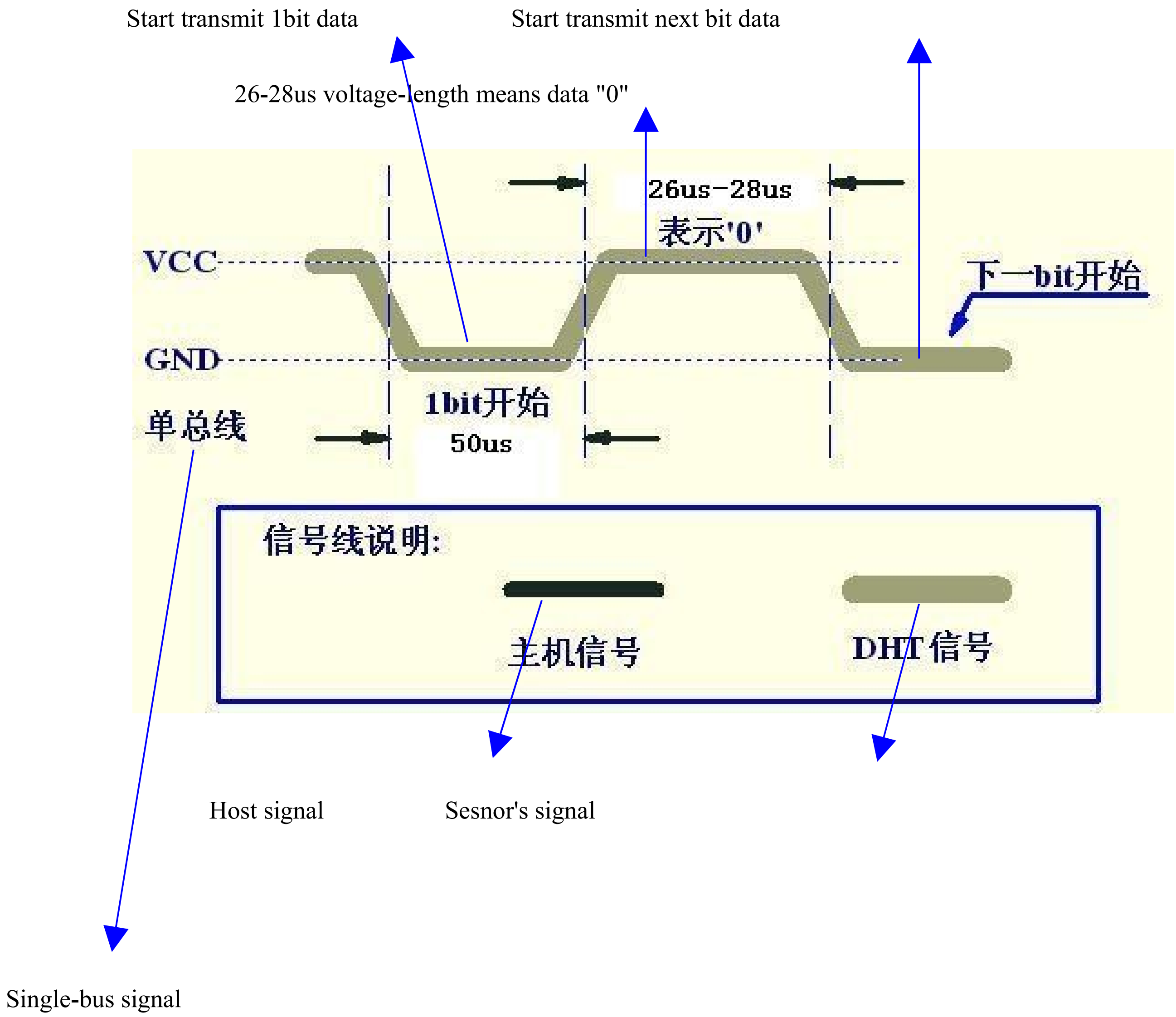
Check bellow picture for step 1:



Step 2: DHT22 send response signal to MCU

When DHT22 detect the start signal, DHT22 will send out low-voltage-level signal and this signal last 80us as response signal, then program of DHT22 transform data-bus's voltage level from low to high level and last 80us for DHT22's preparation to send data.

Check bellow picture for step 2:



Step 3: DHT22 send data to MCU

When DHT22 is sending data to MCU, every bit's transmission begin with low-voltage-level that last 50us, the following high-voltage-level signal's length decide the bit is "1" or "0".

Check bellow picture for step 3:

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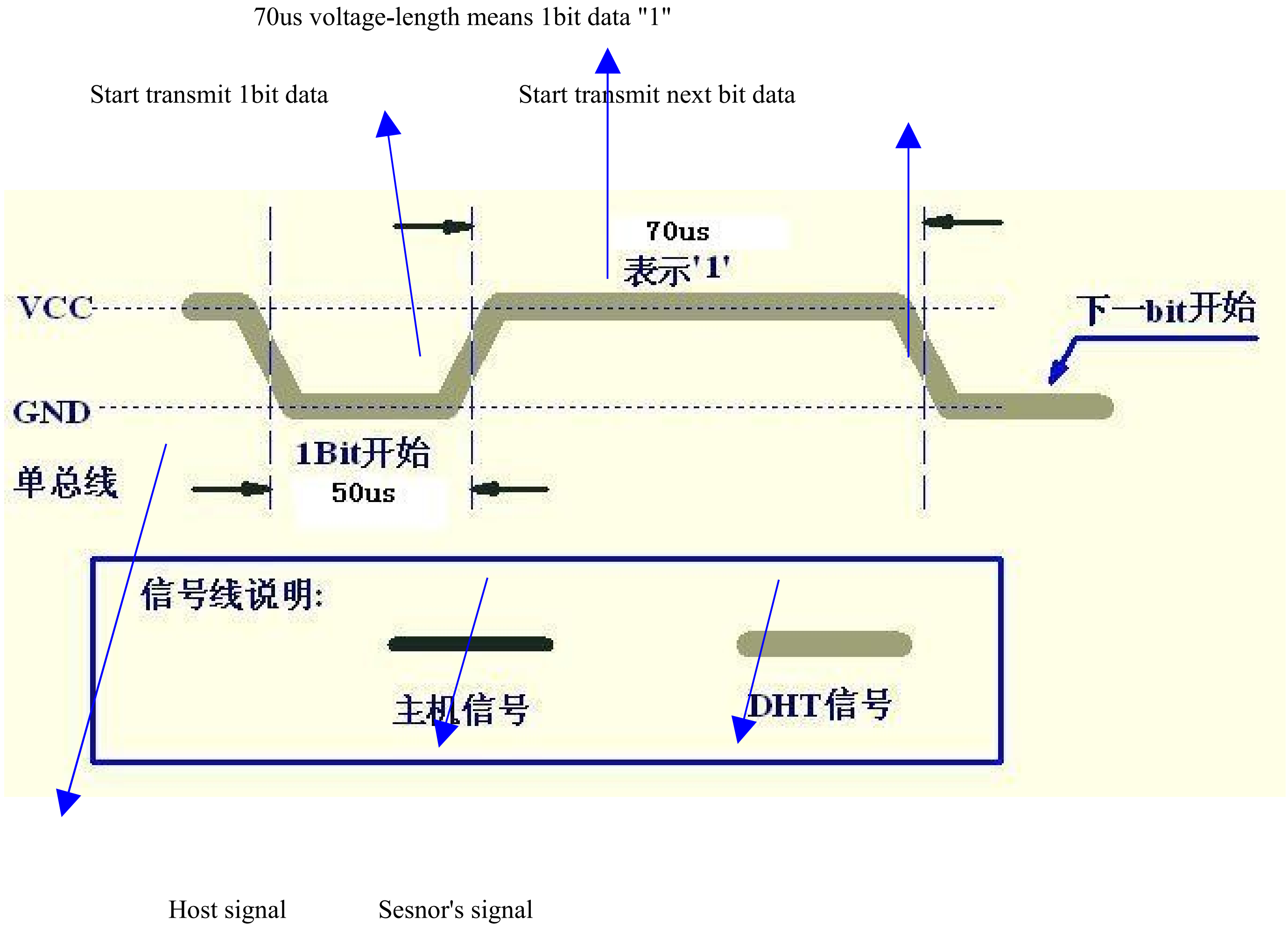

Single-bus signal

If signal from DHT22 is always high-voltage-level, it means DHT22 is not working properly, please check the electrical connection status.

7. Electrical Characteristics:

Item	Condition	Min	Typical	Max	Unit
Power supply	DC	3.3	5	6	V
Current supply	Measuring	1		1.5	mA
	Stand-by	40	Null	50	uA
Collecting period	Second		2		Second

*Collecting period should be : >2 second.

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8. Attentions of application:

(1) Operating and storage conditions

We don't recommend the applying RH-range beyond the range stated in this specification. The DHT22 sensor can recover after working in non-normal operating condition to calibrated status, but will accelerate sensors' aging.

(2) Attentions to chemical materials

Vapor from chemical materials may interfere DHT22's sensitive-elements and debase DHT22's sensitivity.

(3) Disposal when (1) & (2) happens

Step one: Keep the DHT22 sensor at condition of Temperature 50~60Celsius, humidity <10%RH for 2 hours;

Step two: After step one, keep the DHT22 sensor at condition of Temperature 20~30Celsius, humidity >70%RH for 5 hours.

(4) Attention to temperature's affection

Relative humidity strongly depend on temperature, that is why we use temperature compensation technology to ensure accurate measurement of RH. But it's still be much better to keep the sensor at same temperature when sensing.

DHT22 should be mounted at the place as far as possible from parts that may cause change to temperature.

(5) Attentions to light

Long time exposure to strong light and ultraviolet may debase DHT22's performance.

(6) Attentions to connection wires

The connection wires' quality will effect communication's quality and distance, high quality shielding-wire is recommended.

(7) Other attentions

* Welding temperature should be bellow 260Celsius.
* Avoid using the sensor under dew condition.
* Don't use this product in safety or emergency stop devices or any other occasion that failure of DHT22 may cause personal injury.

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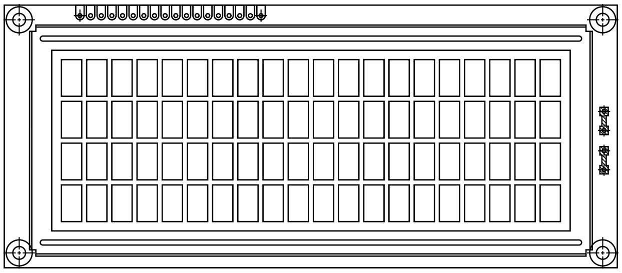
20 x 4 Character LCD



FEATURES

- Type: Character
- Display format: 20 x 4 characters
- Built-in controller: ST 7066 (or equivalent)
- Duty cycle: 1/16
- 5 x 8 dots includes cursor
- + 5 V power supply (also available for + 3 V)
- LED can be driven by pin 1, pin 2, pin 15, pin 16 or A and K
- N.V. optional for + 3 V power supply
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

Pb-free
RoHS COMPLIANT

MECHANICAL DATA

ITEM	STANDARD VALUE	UNIT
Module Dimension	146.0 x 62.5	mm
Viewing Area	123.5 x 43.0	
Dot Size	0.92 x 1.10	
Dot Pitch	0.98 x 1.16	
Mounting Hole	139.0 x 55.5	
Character Size	4.84 x 9.22	

ABSOLUTE MAXIMUM RATINGS

ITEM	SYMBOL	STANDARD VALUE			UNIT
		MIN.	TYP.	MAX.	
Power Supply	V_{DD} to V_{SS}	- 0.3	-	7.0	V
Input Voltage	V_I	- 0.3	-	V_{DD}	

Note

- V_{SS} = 0 V, V_{DD} = 5.0 V

ELECTRICAL CHARACTERISTICS

ITEM	SYMBOL	CONDITION	STANDARD VALUE			UNIT
			MIN.	TYP.	MAX.	
Input Voltage	V_{DD}	V_{DD} = + 5 V	4.7	5.0	5.3	V
		V_{DD} = + 3 V	2.7	3.0	5.3	
Supply Current	I_{DD}	V_{DD} = + 5 V	-	8.0	10.0	mA
Recommended LC Driving Voltage for Normal Temperature Version Module	V_{DD} to V_0	- 20 °C	5.0	5.1	5.7	V
		0 °C	4.6	4.8	5.2	
		25 °C	4.1	4.5	4.7	
		50 °C	3.9	4.2	4.5	
		70 °C	3.7	3.9	4.3	
LED Forward Voltage	V_F	25 °C	-	4.2	4.6	V
LED Forward Current	I_F	25 °C	-	540	1080	mA
EL Power Supply Current	I_{EL}	V_{EL} = 110 V_{AC}, 400 Hz	-	-	5.0	mA

OPTIONS

PROCESS COLOR						BACKLIGHT			
TN	STN Gray	STN Yellow	STN Blue	FSTN B&W	STN Color	None	LED	EL	CCFL
x	x	x	x	x		x	x	x	

For detailed information, please see the "Product Numbering System" document.

DISPLAY CHARACTER ADDRESS CODE

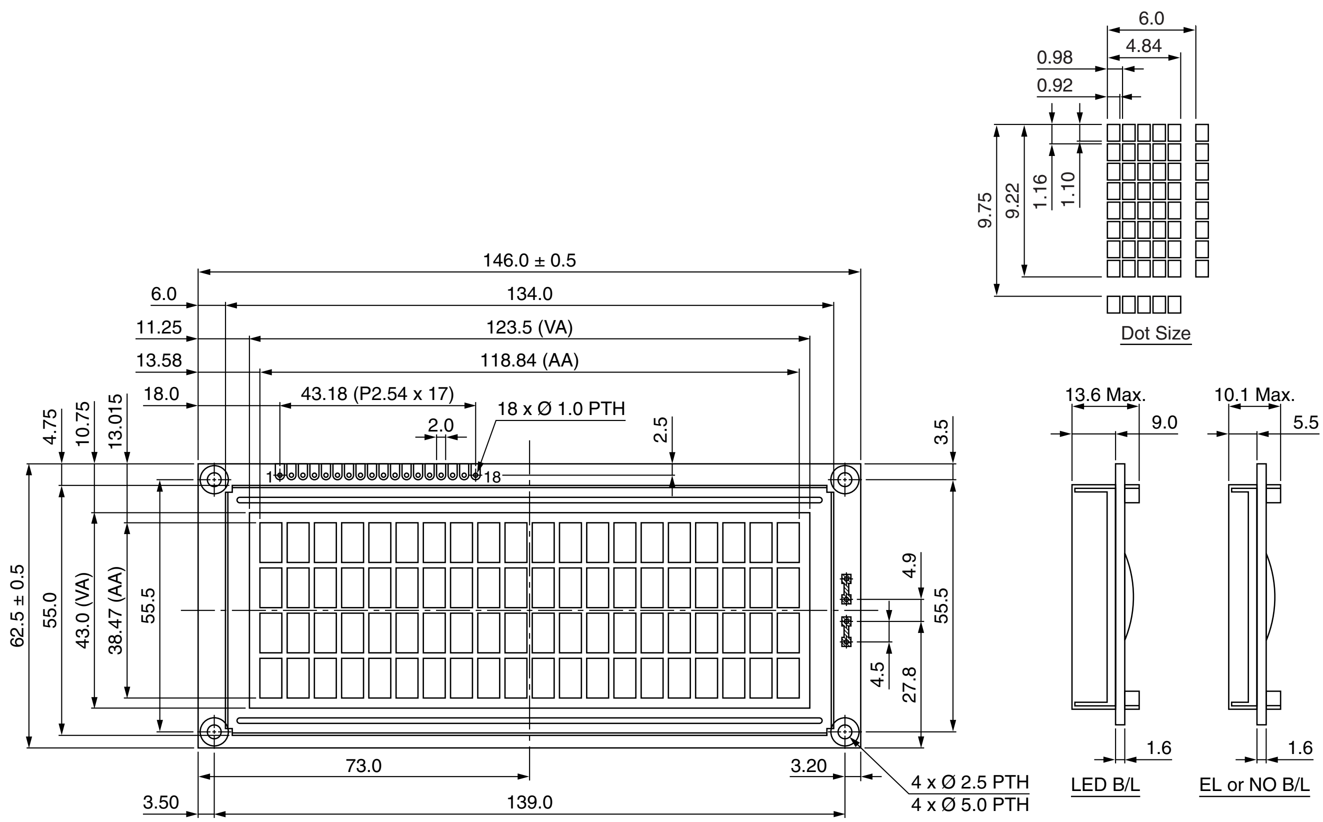
Display Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DD RAM Address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	10	11	12	13
DD RAM Address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F	50	51	52	53
DD RAM Address	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F	20	21	22	23	24	25	26	27
DD RAM Address	54	55	56	57	58	59	5A	5B	5C	5D	5E	5F	60	61	62	63	64	65	66	67

For technical questions, contact: displays@vishay.com

INTERFACE PIN FUNCTION

PIN NO.	SYMBOL	FUNCTION
1	V_{SS}	Ground
2	V_{DD}	+ 3 V or + 5 V
3	V_0	Contrast adjustment
4	RS	H/L register select signal
5	R/$\overline{W}$	H/L read/write signal
6	E	H → L enable signal
7	DB0	H/L data bus line
8	DB1	H/L data bus line
9	DB2	H/L data bus line
10	DB3	H/L data bus line
11	DB4	H/L data bus line
12	DB5	H/L data bus line
13	DB6	H/L data bus line
14	DB7	H/L data bus line
15	A	Power supply for LED (4.2 V)
16	K	Power supply for B/L (0 V)
17	NC/V_{EE}	NC or negative voltage output
18	NC	NC connection

DIMENSIONS in millimeters



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Datasheet

ENGLISH

Stock Nos: 1755034, 1755035, 1755036, 1755037, 1755030, 1755031, 1755038, 1755039, 1755040, 1755041, 1755032, 1755033, 1755042, 1755043, 1755046, 1755047, 1755052, 1755053, 1755044, 1755045, 1755048, 1755049, 1755050, 1755051

IPSU-M12 Series Industrial Pressure Sensor

- ***Piezo-resistive thick film ceramic sensor***
- ***Stainless steel body***
- ***Accuracy <±0.25% FS BFSL***
- ***0-5V or 4-20mA outputs***
- ***Pressure ranges from -14.5 to 5800 psi***
- ***M12 4-pin connector***

The IPSU-M12 series is suitable for use in a wide range of industrial applications. The probe uses a piezo-resistive ceramic sensor, giving excellent media compatibility within a stainless steel housing

The electronics incorporate a microprocessor based amplifier, requiring no adjusting and giving stable electronics, especially for industrial applications..

Each device is temperature compensated, calibrated and supplied with a traceable serial number and calibration data*.

Mating cable and plug assemblies are available.

Electrical Protection

Supply reverse polarity	No damage/no function
Electromagnetic compatibility	CE Compliant

Mechanical Stability

Shock	100g / 11s
Vibration	10g RMS (20 - 2000Hz)

Temperatures & Thermal Effects

Media Temperature	-40ºC to +135ºC
Ambient Temperature	-20ºC to +80ºC
Storage temperature	-40ºC to +125ºC
Compensated temperature range	+20ºC to +80ºC
Thermal Zero Shift (TZS)	<±0.04% /FS/ºC
Thermal Span Shift	<±0.015% /ºC

Performance

Accuracy (Non-Linearity & Hysteresis)		<±0.25% / FS (BFSL)
Setting Errors (offsets)	2-wire	Zero & Full Scale, <±0.5% / FS
	3-wire	Zero & Full Scale, <±0.5% / FS

Material Specifications

Housing	316L Stainless Steel
"O" ring seals	Viton
Diaphragm	Ceramic Al_2O_3 96%
Media wetted parts	Housing & connection, "O" ring seal, diaphragm
Weight	Approx 100g
Installation position	Any
Operational Life	> 100x 10^6 cycles
Insulation resistance	> 50MOhms at 50Vdc
Environmental protection	IP67 (only when used with a similarly rated connector)

Pressure Ranges and Passive mV/V Outputs

Nominal Pressure, Gauge,	psi	15	30	75	150	300	750	1500	3750	6000
Compound range	psi	-7.5 to 0	-7.5 to 30	-15 to 75	-15 to 1235	-15 to 285	-15 to 360			
Permissible Overpressure	psi	30	60	150	300	600	1500	3000	6000	9750
Burst Pressure	psi	60	75	180	375	750	1800	3750	7500	9750

Output Signals and Supply Voltages

Wire system	Output	Supply Voltage	Connection Pin Nos		
2-wire	4-20mA	9-32Vdc	+ve Supply Pin 1	-ve Supply Pin 2	Ground Earth Pin
3-wire	0-5Vdc	9-32Vdc	+ve Supply Pin 1	-ve Supply Pin 2	
			+ve Output Pin 3	Ground Earth Pin 4	

Made in the UK

Specifications are subject to change without prior notice.

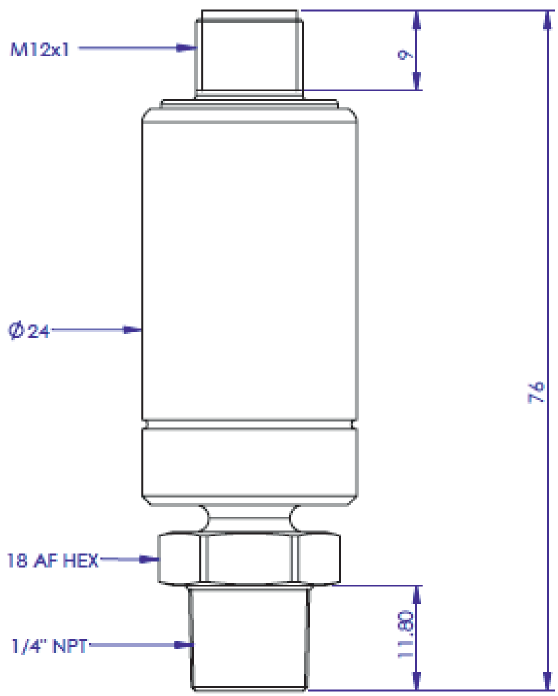
**Calibration data is supplied as a sticker affixed to the product packaging - do not discard*

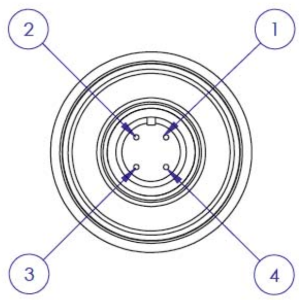
IPSU-M12 Series Industrial Pressure Sensor

RS Stock No.	Range	Output
1755034	0-15 psi G	4-20mA
1755035	0-15 psi G	0-5V
1755036	0-30 psi G	4-20mA
1755037	0-30 psi G	0-5V
1755030	-14.5 to +150 psi G	4-20mA
1755031	-14.5 to +150 psi G	0-5V
1755038	0-75 psi G	4-20mA
1755039	0-75 psi G	0-5V
1755040	0-100 psi G	4-20mA
1755041	0-100 psi G	0-5V
1755032	-14.5 to +350 psi G	4-20mA
1755033	-14.5 to +350 psi G	0-5V
1755042	0-150 psi G	4-20mA
1755043	0-150 psi G	0-5V
1755046	0-300 psi G	4-20mA
1755047	0-300 psi G	0-5V
1755052	0-750 psi G	4-20mA
1755053	0-750 psi G	0-5V
1755044	0-1500 psi SG*	4-20mA
1755045	0-1500 psi SG*	0-5V
1755048	0-3600 psi SG*	4-20mA
1755049	0-3600 psi SG*	0-5V
1755050	0-5800 psi SG*	4-20mA
1755051	0-5800 psi SG*	0-5V

* sealed gauge

Mechanical Dimensions





Made in the UK

Specifications are subject to change without prior notice.

Restricted data sheet

BMP180

Digital pressure sensor

Bosch Sensortec

BOSCH

Invented for life

BMP180 Data sheet

Document revision	2.8
Document release date	May 7th, 2015
Document number	BST-BMP180-DS000-12
Technical reference code(s)	0 273 300 244
Notes	Data in this document are subject to change without notice. Product photos and pictures are for illustration purposes only and may differ from the real product's appearance.

BMP180

DIGITAL PRESSURE SENSOR

Key features

Pressure range:	300 ... 1100hPa (+9000m ... -500m relating to sea level)
Supply voltage:	1.8 ... 3.6V (V_{DD}) 1.62V ... 3.6V (V_{DDIO})
Package:	LGA package with metal lid Small footprint: 3.6mm x 3.8mm Super-flat: 0.93mm height
Low power:	5μA at 1 sample / sec. in standard mode
Low noise:	0.06hPa (0.5m) in ultra low power mode 0.02hPa (0.17m) advanced resolution mode

- Temperature measurement included
- I^2C interface
- Fully calibrated
- Pb-free, halogen-free and RoHS compliant,
- MSL 1

Typical applications

- Enhancement of GPS navigation (dead-reckoning, slope detection, etc.)
- In- and out-door navigation
- Leisure and sports
- Weather forecast
- Vertical velocity indication (rise/sink speed)

BMP180 general description

The BMP180 is the function compatible successor of the BMP085, a new generation of high precision digital pressure sensors for consumer applications.

The ultra-low power, low voltage electronics of the BMP180 is optimized for use in mobile phones, PDAs, GPS navigation devices and outdoor equipment. With a low altitude noise of merely 0.25m at fast conversion time, the BMP180 offers superior performance. The I^2C interface allows for easy system integration with a microcontroller.

The BMP180 is based on piezo-resistive technology for EMC robustness, high accuracy and linearity as well as long term stability.

Robert Bosch is the world market leader for pressure sensors in automotive applications. Based on the experience of over 400 million pressure sensors in the field, the BMP180 continues a new generation of micro-machined pressure sensors.

Index of Contents

1. Electrical characteristics

If not stated otherwise, the given values are ±3-Sigma values over temperature/voltage range in the given operation mode. All values represent the new parts specification; additional solder drift is shown separately.

Table 1: Operating conditions, output signal and mechanical characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Units
Operating temperature	T_A	operational	-40		+85	°C
		full accuracy	0		+65	
Supply voltage	V_{DD}	ripple max. 50mVpp	1.8	2.5	3.6	V
			1.62	2.5	3.6	
Supply current @ 1 sample / sec. 25°C	I_{DDLOW}	ultra low power mode		3		μA
	I_{DDSTD}	standard mode		5		μA
	I_{DDHR}	high resolution mode		7		μA
	I_{DDUHR}	Ultra high res. mode		12		μA
	I_{DDAR}	Advanced res. mode		32		μA
Peak current	I_{peak}	during conversion		650		μA
Standby current	I_{DDSBM}	@ 25°C		0.1	4[1]	μA
Relative accuracy pressure V_{DD} = 3.3V		950 . . . 1050 hPa @ 25 °C		±0.12		hPa
				±1.0		m
		700 ... 900hPa 25 . . . 40 °C		±0.12		hPa
				±1.0		m
Absolute accuracy pressure V_{DD} = 3.3V		300 . . . 1100 hPa 0 . . . +65 °C	-4.0	-1.0*	+2.0	hPa
		300 . . . 1100 hPa -20 . . . 0 °C	-6.0	-1.0*	+4.5	hPa
Resolution of output data		pressure		0.01		hPa
		temperature		0.1		°C
Noise in pressure		see table on page 12-13				
Absolute accuracy temperature V_{DD} = 3.3V		@ 25 °C	-1.5	±0.5	+1.5	°C
		0 . . . +65 °C	-2.0	±1.0	+2.0	°C

[1] at 85°C

Conversion time pressure	$t_{c\_p\_low}$	ultra low power mode		3	4.5	ms
	$t_{c\_p\_std}$	standard mode		5	7.5	ms
	$t_{c\_p\_hr}$	high resolution mode		9	13.5	ms
	$t_{c\_p\_luhr}$	ultra high res. mode		17	25.5	ms
	$t_{c\_p\_ar}$	Advanced res. mode		51	76.5	ms
Conversion time temperature	t_{C_temp}	standard mode		3	4.5	ms
Serial data clock	f_{SCL}				3.4	MHz
Solder drifts		Minimum solder height 50µm	-0.5		+2	hPa
Long term stability**		12 months		±1.0		hPa

* The typical value is: -1±1
** Long term stability is specified in the full accuracy operating pressure range 0 … 65°C

2. Absolute maximum ratings

Table 2: Absolute maximum ratings

Parameter	Condition	Min	Max	Units
Storage temperature		-40	+85	°C
Supply voltage	all pins	-0.3	+4.25	V
ESD rating	HBM, R = 1.5kΩ, C = 100pF		±2	kV
Overpressure			10,000	hPa

The BMP180 has to be handled as Electrostatic Sensitive Device (ESD).

Figure 1: ESD

3. Operation

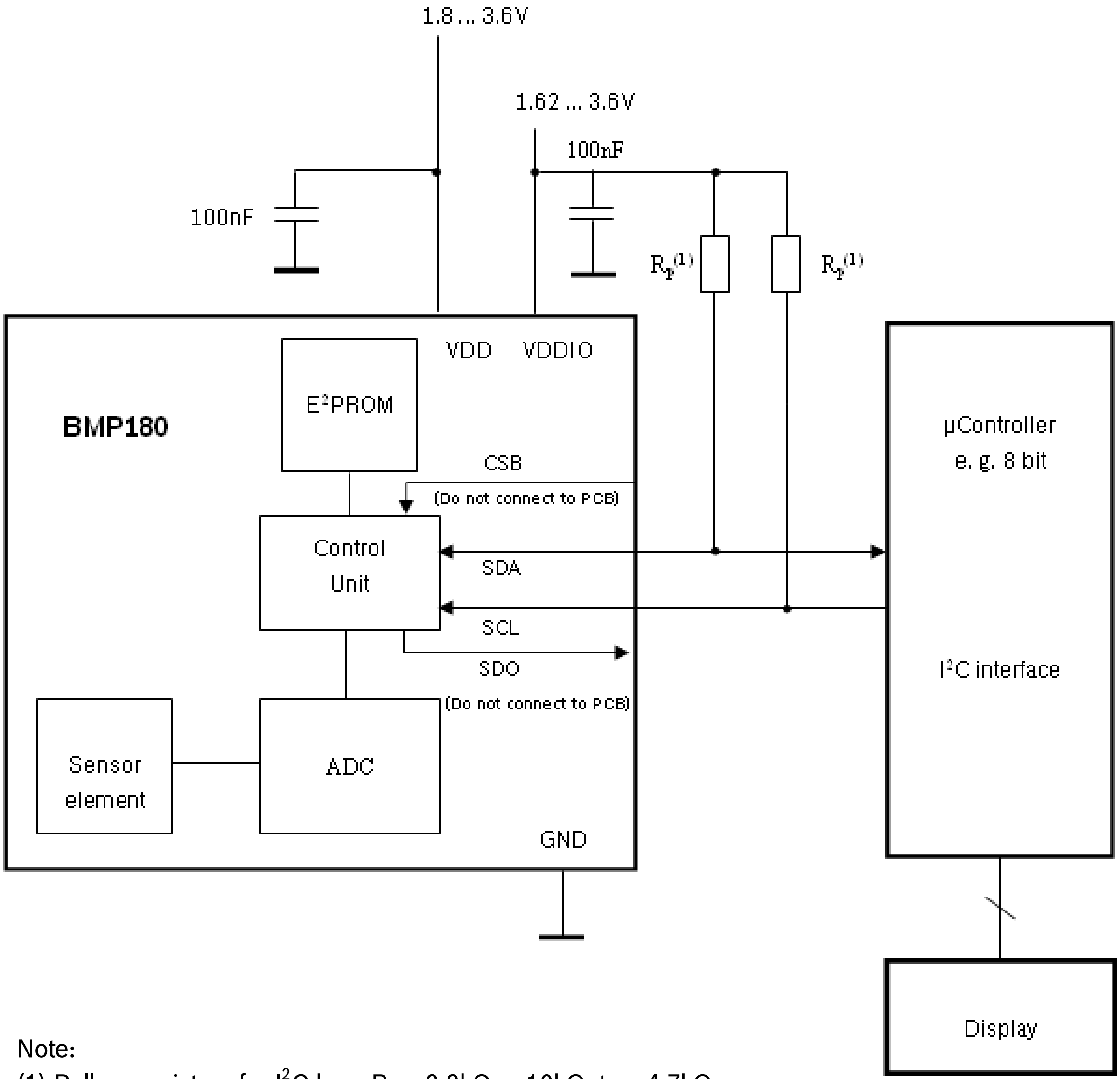
3.1 General description

The BMP180 is designed to be connected directly to a microcontroller of a mobile device via the I^2C bus. The pressure and temperature data has to be compensated by the calibration data of the E^2PROM of the BMP180.

3.2 General function and application schematics

The BMP180 consists of a piezo-resistive sensor, an analog to digital converter and a control unit with E^2PROM and a serial I^2C interface. The BMP180 delivers the uncompensated value of pressure and temperature. The E^2PROM has stored 176 bit of individual calibration data. This is used to compensate offset, temperature dependence and other parameters of the sensor.

- UP = pressure data (16 to 19 bit)
- UT = temperature data (16 bit)



Note:
(1) Pull-up resistors for I^2C bus, R_p = 2.2kΩ ... 10kΩ, typ. 4.7kΩ

Figure 2: Typical application circuit

3.3 Measurement of pressure and temperature

For all calculations presented here an ANSI C code is available from Bosch Sensortec ("BMP180 _API").

The microcontroller sends a start sequence to start a pressure or temperature measurement. After converting time, the result value (UP or UT, respectively) can be read via the I^2C interface. For calculating temperature in °C and pressure in hPa, the calibration data has to be used. These constants can be read out from the BMP180 E^2PROM via the I^2C interface at software initialization.

The sampling rate can be increased up to 128 samples per second (standard mode) for dynamic measurement. In this case, it is sufficient to measure the temperature only once per second and to use this value for all pressure measurements during the same period.

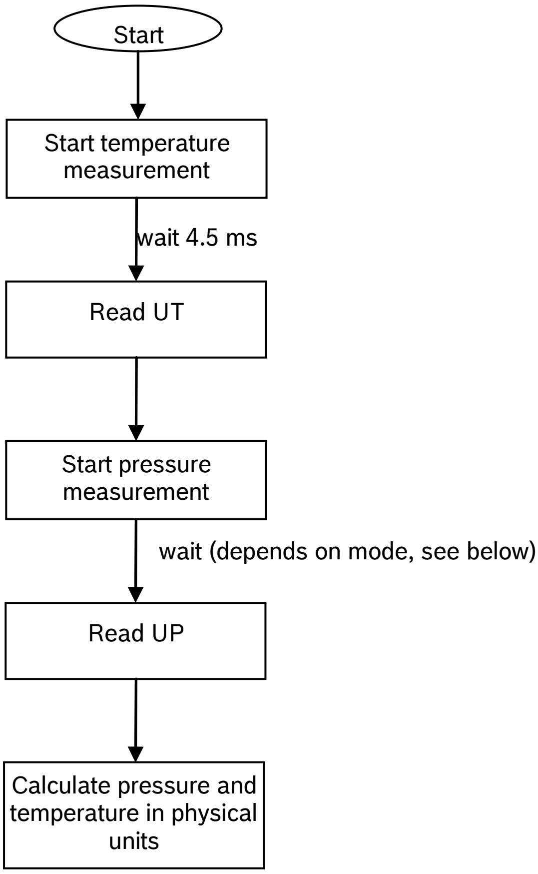


Figure 3: Measurement flow BMP180

3.3.1 Hardware pressure sampling accuracy modes

By using different modes the optimum compromise between power consumption, speed and resolution can be selected, see below table.

Table 3: Overview of BMP180 hardware accuracy modes, selected by driver software via the variable *oversampling_setting*

Mode	**Parameter** *oversampling_setting*	**Internal number of samples**	**Conversion time pressure max. [ms]**	**Avg. current @ 1 sample/s typ. [μA]**	**RMS noise typ. [hPa]**	**RMS noise typ. [m]**
ultra low power	0	1	4.5	3	0.06	0.5
standard	1	2	7.5	5	0.05	0.4
high resolution	2	4	13.5	7	0.04	0.3
ultra high resolution	3	8	25.5	12	0.03	0.25

For further information on noise characteristics see the relevant application note "Noise in pressure sensor applications".

All modes can be performed at higher speeds, e.g. up to 128 times per second for standard mode, with the current consumption increasing proportionally to the sample rate.

3.3.2 Software pressure sampling accuracy modes

For applications where a low noise level is critical, averaging is recommended if the lower bandwidth is acceptable. Oversampling can be enabled using the software API driver (with OSR = 3).

Table 4: Overview of BMP180 software accuracy mode, selected by driver software via the variable *software_oversampling_setting*

Mode	Parameter *oversampling_setting*	software_oversampling_setting	Conversion time pressure max. [ms]	Avg. current @ 1 sample/s typ. [µA]	RMS noise typ. [hPa]	RMS noise typ. [m]
Advanced resolution	3	1	76.5	32	0.02	0.17

3.4 Calibration coefficients

The 176 bit E^2PROM is partitioned in 11 words of 16 bit each. These contain 11 calibration coefficients. Every sensor module has individual coefficients. Before the first calculation of temperature and pressure, the master reads out the E^2PROM data.
The data communication can be checked by checking that none of the words has the value 0 or 0xFFFF.

Table 5: Calibration coefficients

	BMP180 reg adr	
Parameter	**MSB**	**LSB**
AC1	0xAA	0xAB
AC2	0xAC	0xAD
AC3	0xAE	0xAF
AC4	0xB0	0xB1
AC5	0xB2	0xB3
AC6	0xB4	0xB5
B1	0xB6	0xB7
B2	0xB8	0xB9
MB	0xBA	0xBB
MC	0xBC	0xBD
MD	0xBE	0xBF

3.5 Calculating pressure and temperature

The mode (ultra low power, standard, high, ultra high resolution) can be selected by the variable *oversampling_setting* (0, 1, 2, 3) in the C code.

Calculation of true temperature and pressure in steps of 1Pa (= 0.01hPa = 0.01mbar) and temperature in steps of 0.1°C.

The following figure shows the detailed algorithm for pressure and temperature measurement.

This algorithm is available to customers as reference C source code ("BMP180_ API") from Bosch Sensortec and via its sales and distribution partners. **Please contact your Bosch Sensortec representative for details.**

Calculation of pressure and temperature for BMP180

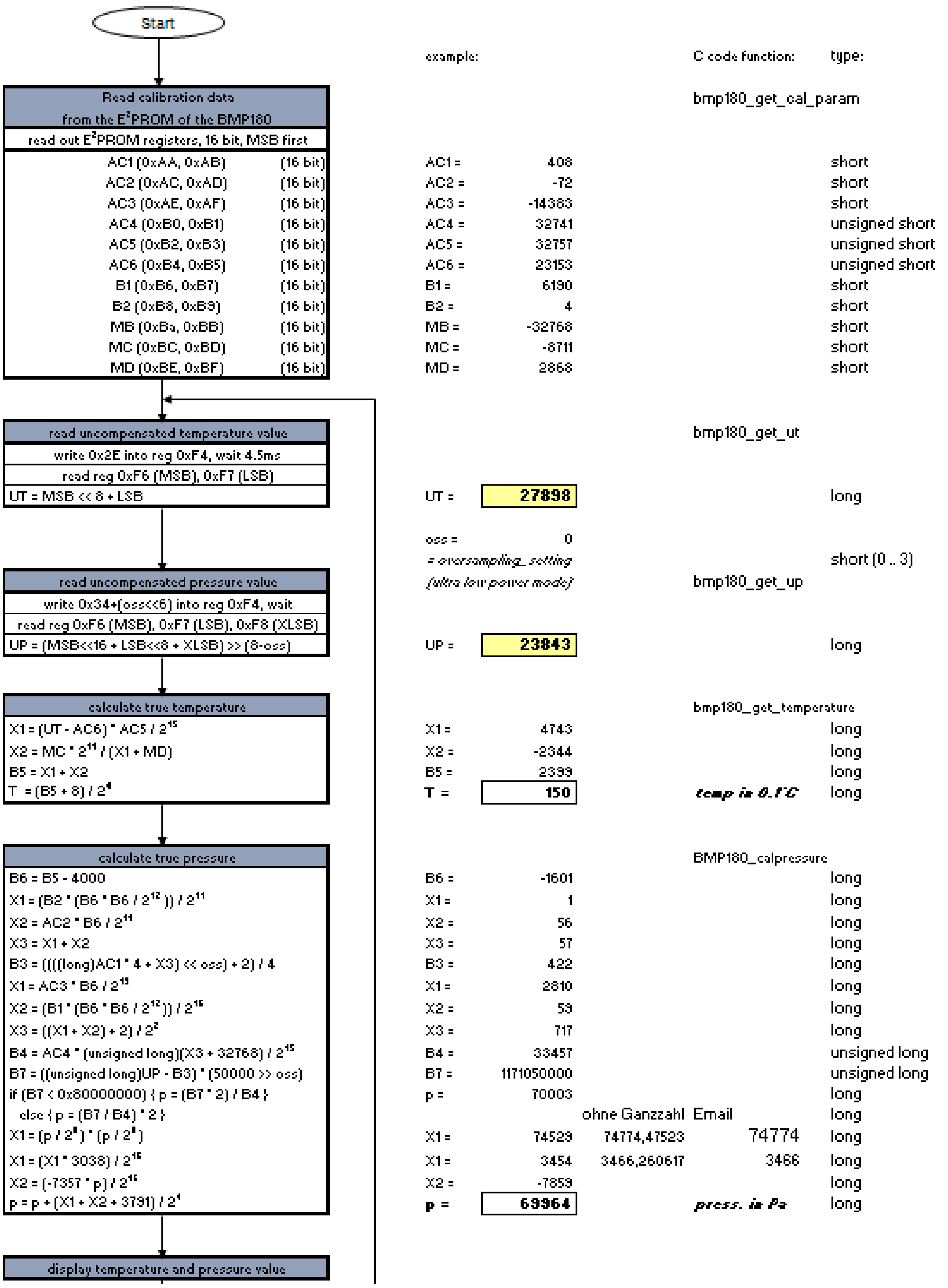


Figure 4: Algorithm for pressure and temperature measurement

3.6 Calculating absolute altitude

With the measured pressure p and the pressure at sea level p_0 e.g. 1013.25hPa, the altitude in meters can be calculated with the international barometric formula:

$$altitude = 44330 * \left(1 - \left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right)$$

Thus, a pressure change of Δp = 1hPa corresponds to 8.43m at sea level.

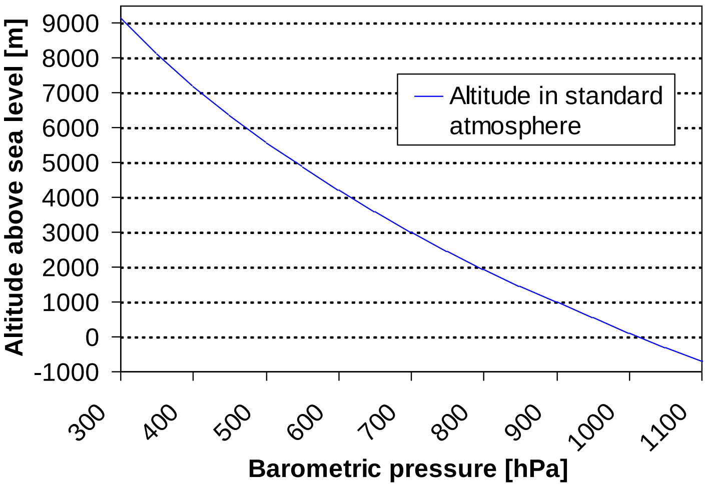


Figure 5: Transfer function: Altitude over sea level – Barometric pressure

3.7 Calculating pressure at sea level

With the measured pressure *p* and the absolute altitude the pressure at sea level can be calculated:

$$p_0 = \frac{p}{\left(1 - \frac{altitude}{44330}\right)^{5.255}}$$

Thus, a difference in altitude of Δaltitude = 10m corresponds to 1.2hPa pressure change at sea level.

4. Global Memory Map

The memory map below shows all externally accessible data registers which are needed to operate BMP180. The left columns show the memory addresses. The columns in the middle depict the content of each register bit. The colors of the bits indicate whether they are read-only, write-only or read- and writable. The memory is volatile so that the writable content has to be re-written after each power-on.
Not all register addresses are shown. These registers are reserved for further Bosch factory testing and trimming.

Register Name	Register Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Reset
out_xlsb	F8h	adc_out_xlsb<7:3					0	0	0	00h
out_lsb	F7h	adc_out_msb<7:0>								00h
out_msb	F6h	adc_out_lsb<7:0								80h
ctrl_meas	F4h	oss<1:0>		sco	measurement					00h
soft	E0h	reset								00h
id	D0h	id<7:0>								55h
calib21 downto calib0	BFh *downto* AAh	calib21<7:0>*downto* calib0<7:0>								n/a

Registers:	Control	Calibration	Dat	
Type:	registers	registers	registers	Fixed

Figure 6: Memory map

Measurement control (register F4h <4:0>): Controls measurements. Refer to Figure 6 for usage details.

Sco (register F4h <5>): Start of conversion. The value of this bit stays “1” during conversion and is reset to “0” after conversion is complete (data registers are filled).

Oss (register F4h <7:6>): controls the oversampling ratio of the pressure measurement (00b: single, 01b: 2 times, 10b: 4 times, 11b: 8 times).

Soft reset (register E0h): Write only register. If set to 0xB6, will perform the same sequence as power on reset.

Chip-id (register D0h): This value is fixed to 0x55 and can be used to check whether communication is functioning.

After conversion, data registers can be read out in any sequence (i.e. MSB first or LSB first). Using a burst read is not mandatory.

5. I^2C Interface

- I^2C is a digital two wire interface
- Clock frequencies up to 3.4Mbit/sec. (I^2C standard, fast and high-speed mode supported)
- SCL and SDA needs a pull-up resistor, typ. 4.7kOhm to V_{DDIO}
  (one resistor each for all the I^2C bus)

The I^2C bus is used to control the sensor, to read calibration data from the E^2PROM and to read the measurement data when A/D conversion is finished. SDA (serial data) and SCL (serial clock) have open-drain outputs.

For detailed I^2C-bus specification please refer to:
http://www.nxp.com/acrobat_download/literature/9398/39340011.pdf

5.1 I^2C specification

Table 6: Electrical parameters for the I^2C interface

Parameter	Symbol	Min.	Typ	Max.	Units
Clock input frequency	f_{SCL}			3.4	MHz
Input-low level	V_{IL}	0		0.2 * V_{DDIO}	V
Input-high level	V_{IH}	0.8 * V_{DDIO}		V_{DDIO}	V
Voltage output low level @ V_{DDIO} = 1.62V, I_{OL} = 3mA	V_{OL}			0.3	V
SDA and SCL pull-up resistor	$R_{pull-up}$	2.2		10	kOhm
SDA sink current @ V_{DDIO} = 1.62V, V_{OL} = 0.3V	I_{SDA_sink}		9		mA
Start-up time after power-up, before first communication	t_{Start}	10			Ms

5.2 Device and register address

The BMP180 module address is shown below. The LSB of the device address distinguishes between read (1) and write (0) operation, corresponding to address 0xEF (read) and 0xEE (write).

Table 7: BMP180 addresses

A7	A6	A5	A4	A3	A2	A1	W/R
1	1	1	0	1	1	1	0/1

5.3 I²C protocol

The I²C interface protocol has special bus signal conditions. Start (S), stop (P) and binary data conditions are shown below. At start condition, SCL is high and SDA has a falling edge. Then the slave address is sent. After the 7 address bits, the direction control bit R/W selects the read or write operation. When a slave device recognizes that it is being addressed, it should acknowledge by pulling SDA low in the ninth SCL (ACK) cycle.
At stop condition, SCL is also high, but SDA has a rising edge. Data must be held stable at SDA when SCL is high. Data can change value at SDA only when SCL is low.
Even though V_{DDIO} can be powered on before V_{DD}, there is a chance of excessive power consumption (a few mA) if this sequence is used, and the state of the output pins is undefined so that the bus can be locked. Therefore, V_{DD} *must* be powered before V_{DDIO} unless the limitations above are understood and not critical.

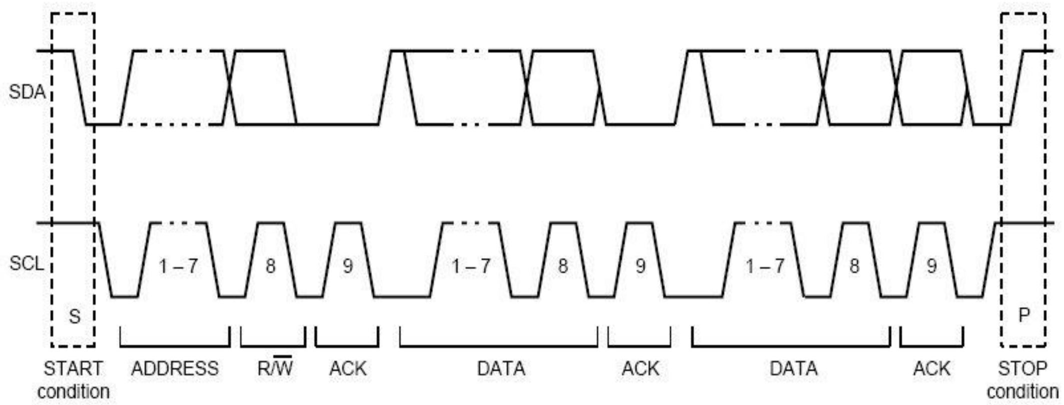


Figure 7: I²C protocol

5.4 Start temperature and pressure measurement

The timing diagrams to start the measurement of the temperature value UT and pressure value UP are shown below. After start condition the master sends the device address write, the register address and the control register data. The BMP180 sends an acknowledgement (ACKS) every 8 data bits when data is received. The master sends a stop condition after the last ACKS.

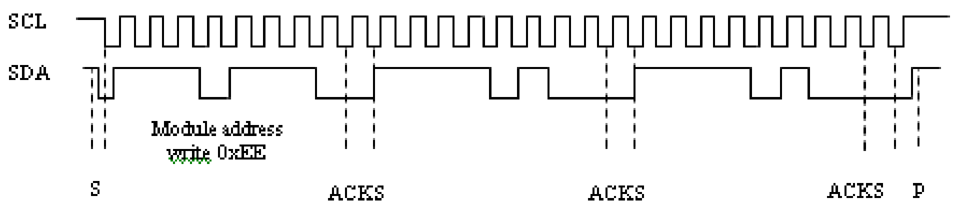


Figure 8: Timing diagram for starting pressure measurement

Abbreviations:

S	Start
P	Stop
ACKS	Acknowledge by Slave
ACKM	Acknowledge by Master
NACKM	Not Acknowledge by Master

Table 8: Control registers values for different internal oversampling_setting (oss)

Measurement	Control register value (register address 0xF4)	Max. conversion time [ms]
Temperature	0x2E	4.5
Pressure (oss = 0)	0x34	4.5
Pressure (oss = 1)	0x74	7.5
Pressure (oss = 2)	0xB4	13.5
Pressure (oss = 3)	0xF4	25.5

5.5 Read A/D conversion result or E^2PROM data

To read out the temperature data word UT (16 bit), the pressure data word UP (16 to 19 bit) and the E^2PROM data proceed as follows:

After the start condition the master sends the module address write command and register address. The register address selects the read register:

E^2PROM data registers 0xAA to 0xBF
Temperature or pressure value UT or UP 0xF6 (MSB), 0xF7 (LSB), optionally 0xF8 (XLSB)

Then the master sends a restart condition followed by the module address read that will be acknowledged by the BMP180 (ACKS). The BMP180 sends first the 8 MSB, acknowledged by the master (ACKM), then the 8 LSB. The master sends a "not acknowledge" (NACKM) and finally a stop condition.

Optionally for ultra high resolution, the XLSB register with address 0xF8 can be read to extend the 16 bit word to up to 19 bits; refer to the application programming interface (API) software rev. 1.1 (“BMP180_ API”, available from Bosch Sensortec).

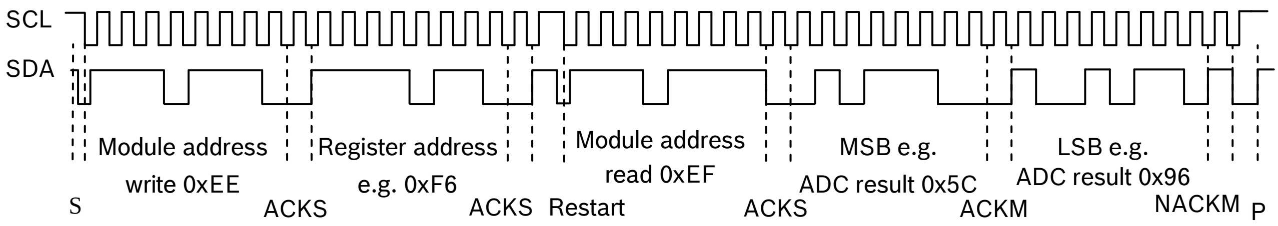


Figure 9: Timing diagram read 16 bit A/D conversion result

6. Package

6.1 Pin configuration

Picture shows the device in top view. Device pins are shown here transparently only for orientation purposes.

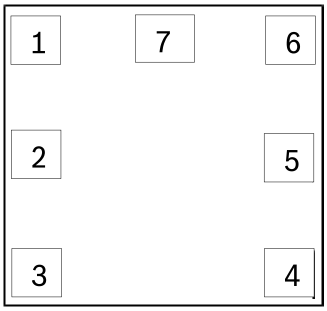


Figure 10: Layout pin configuration BMP180

Table 9: Pin configuration BMP180

in No	Name	Function
1	CSB*	Chip select
2	VDD	Power supply
3	VDDIO	Digital power supply
4	SDO*	SPI output
5	SCL	I2C serial bus clock input
6	SDA	I2C serial bus data (or SPI input)
7	GND	Ground

* A pin compatible product variant with SPI interface is possible upon customer's request. For I^2C (standard case) CSB and SDO are not used, they have to be left open.
All pins have to be soldered to the PCB for symmetrical stress input even though they are not connected internally.

6.2 Outline dimensions

The sensor housing is a 7Pin LGA package with metal lid. Its dimensions are 3.60mm (±0.1 mm) x 3.80mm (±0.1 mm) x 0.93mm (±0.07 mm).

Note: All dimensions are in mm.

6.2.1 Bottom view

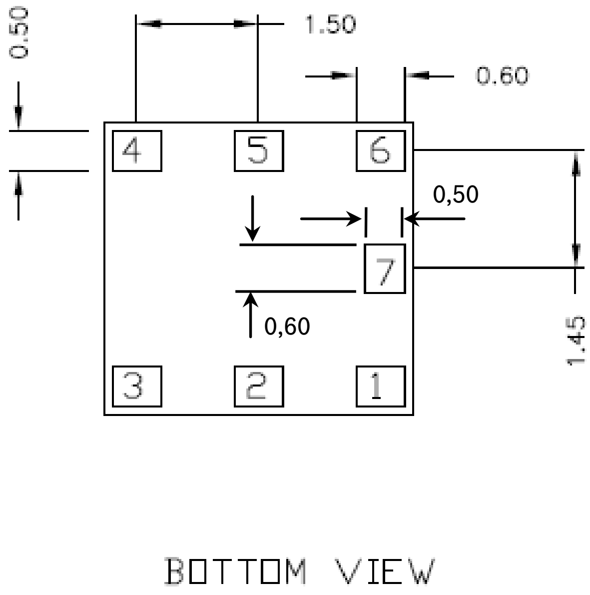


Figure 11: Bottom view BMP180

6.2.2 Top view

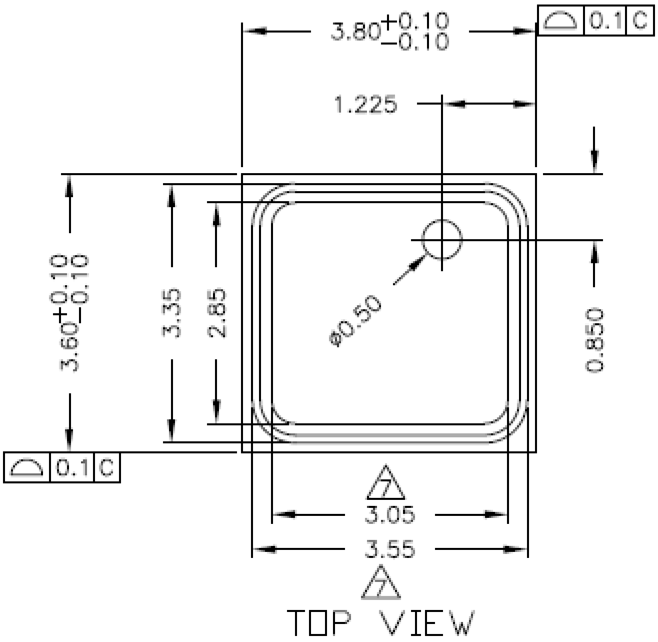


Figure 12: Top view BMP180

6.2.3 Side view

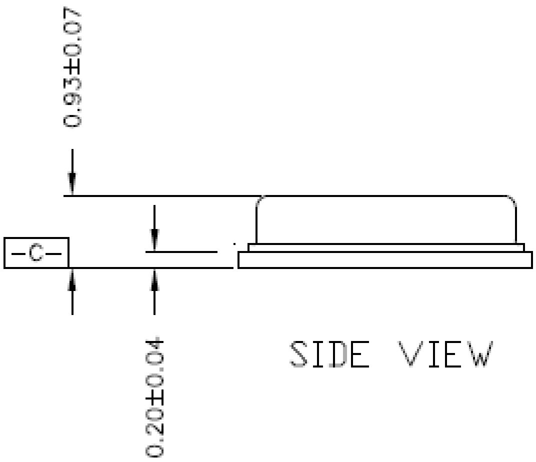


Figure 13: Side view BMP180

6.3 Moisture sensitivity level and soldering

The BMP180 is classified MSL 1 (moisture sensitivity level) according to IPC/JEDEC standards J-STD-020D and J-STD-033A.

The device can be soldered Pb-free with a peak temperature of 260°C for 20 to 40 sec. The minimum height of the solder after reflow shall be at least 50µm. This is required for good mechanical decoupling between the sensor device and the printed circuit board (PCB).

To ensure good solder-ability, the devices shall be stored at room temperature (20°C).

The soldering process can lead to an offset shift.

6.4 RoHS compliancy

The BMP180 sensor meets the requirements of the EC directive "Restriction of hazardous substances (RoHS)", please refer also to:

"Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment".

The BMP180 sensor is also halogen-free.

6.5 Mounting and assembly recommendations

In order to achieve the specified performance for you design, the following recommendations and the “Handling, soldering & mounting instructions BMP180” should be taken into consideration when mounting a pressure sensor on a printed-circuit board (PCB):

- The clearance above the metal lid shall be 0.1mm at minimum.
- For the device housing appropriate venting needs to be provided in case the ambient pressure shall be measured.
- Liquids shall not come into direct contact with the device.
- During operation the sensor is sensitive to light, which can influence the accuracy of the measurement (photo-current of silicon).
- The BMP180 shall not the placed close the fast heating parts. In case of gradients > 3°C/sec. it is recommended to follow Bosch Sensortec application note ANP004, "Correction of errors induced by fast temperature changes". Please contact your Bosch Sensortec representative for details.

7. Legal disclaimer

7.1 Engineering samples

Engineering Samples are marked with an asterisk (*) or (e). Samples may vary from the valid technical specifications of the product series contained in this data sheet. They are therefore not intended or fit for resale to third parties or for use in end products. Their sole purpose is internal client testing. The testing of an engineering sample may in no way replace the testing of a product series. Bosch Sensortec assumes no liability for the use of engineering samples. The Purchaser shall indemnify Bosch Sensortec from all claims arising from the use of engineering samples.

7.2 Product use

Bosch Sensortec products are developed for the consumer goods industry. They may only be used within the parameters of this product data sheet. They are not fit for use in life-sustaining or security sensitive systems. Security sensitive systems are those for which a malfunction is expected to lead to bodily harm or significant property damage. In addition, they are not fit for use in products which interact with motor vehicle systems.

The resale and/or use of products are at the purchaser's own risk and his own responsibility. The examination of fitness for the intended use is the sole responsibility of the Purchaser.

The purchaser shall indemnify Bosch Sensortec from all third party claims arising from any product use not covered by the parameters of this product data sheet or not approved by Bosch Sensortec and reimburse Bosch Sensortec for all costs in connection with such claims.

The purchaser must monitor the market for the purchased products, particularly with regard to product safety, and inform Bosch Sensortec without delay of all security relevant incidents.

7.3 Application examples and hints

With respect to any examples or hints given herein, any typical values stated herein and/or any information regarding the application of the device, Bosch Sensortec hereby disclaims any and all warranties and liabilities of any kind, including without limitation warranties of non-infringement of intellectual property rights or copyrights of any third party. The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics. They are provided for illustrative purposes only and no evaluation regarding infringement of intellectual property rights or copyrights or regarding functionality, performance or error has been made.

8. Document history and modification

Rev. No	Chapter	Description of modifications/changes	Date
1.0		First edition for description of serial production material – Preliminary version	
1.1	5.1	New nomenclature of pin configuration	27 July 2010
1.2	5	Design change in package – hole in Lid and without slit	13 September 2010
1.3	3.2 5.1	- Standardizing pin naming over Bosch Sensortec products – typical application circuit - Optimizing pin description, SPI description	15 December 2010
2.0	1	- Non-preliminary version - Verifying parameter through characterization	28 January 2011
2.1	3.2 4 5.3 6.1 6.2.1	- Declaration of SDO and CSB pins in the typical application circuit - Adding global memory map and bits description - Power-up sequence - Description of used interfaces - Dimension pin7	1 April 2011
2.2	6.1	Correction of the pin configuration (editorial change)	14 April 2011
2.3	3.3	Optimizing noise performance	25 May 2011
2.4	6.3	Removed shelf-life constraints	26 January 2012
	page 2	Comparison removed	
	5.1	Voltage output low level added	
	5.3	Power on sequence of V_{DD} and V_{DDIO} defined	
2.5	1	Added max values for supply current for restricted version	15 Feb 2013
	1	Added max value for standby current for restricted version	5 Apr 2013
	Figure 4	Update of calculation of algorithm for pressure and temperature measurement	
	Page 2	Changed wording from “ultra high resolution mode” to “advanced resolution mode”	
2.6	Page 26	Changed document referral from ANP015 to BST-MPS-AN004-00	17 Jan 2014
2.7	3.5	New equation for B3	26 Aug 2014
2.8	Page 26	Updated RoHS directive to 2011/65/EU effective 8 June 2011	07 May 2015

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Revision_2.7_082014
Document number: BST-BMP180-DS000-11

INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I²C Interface

1 Features

- Senses Bus Voltages from 0 to 26 V
- Reports Current, Voltage, and Power
- 16 Programmable Addresses
- High Accuracy: 0.5% (Maximum) Over Temperature (INA219B)
- Filtering Options
- Calibration Registers
- SOT23-8 and SOIC-8 Packages

2 Applications

- Servers
- Telecom Equipment
- Notebook Computers
- Power Management
- Battery Chargers
- Welding Equipment
- Power Supplies
- Test Equipment

3 Description

The INA219 is a current shunt and power monitor with an I^2C- or SMBUS-compatible interface. The device monitors both shunt voltage drop and bus supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts of current in amperes. An additional multiplying register calculates power in watts. The I^2C- or SMBUS-compatible interface features 16 programmable addresses.

The INA219 is available in two grades: A and B. The B grade version has higher accuracy and higher precision specifications.

The INA219 senses across shunts on buses that can vary from 0 to 26 V. The device uses a single 3- to 5.5-V supply, drawing a maximum of 1 mA of supply current. The INA219 operates from –40°C to 125°C.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA219	SOIC (8)	3.91 mm × 4.90 mm
	SOT-23 (8)	1.63 mm × 2.90 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic

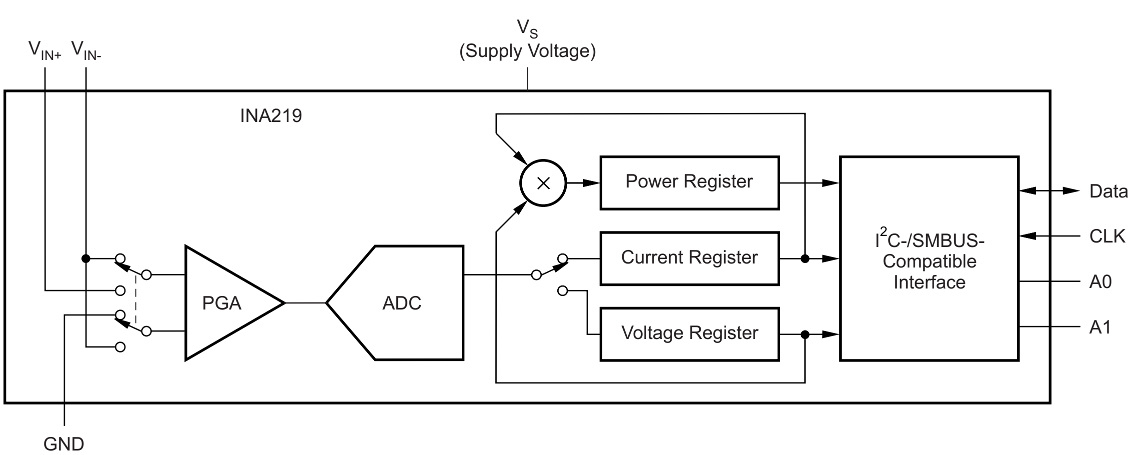


Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision F (September 2011) to Revision G — **Page**

- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1
- Updated *Bus Timing Diagram Definitions* table. I^2C timing table values were previously based on simulation and not characterized 6

Changes from Revision E (September 2010) to Revision F — **Page**

- Changed step 5 and step 6 values in Table 8 26

Changes from Revision D (September 2010) to Revision E — **Page**

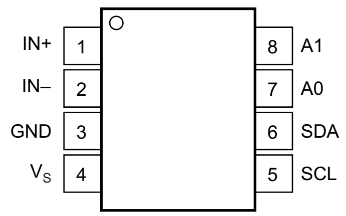
- Updated *Packaging Information* table 3

5 Related Products

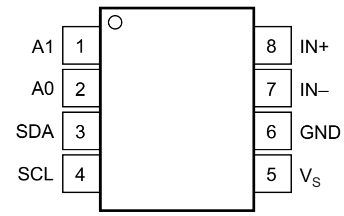
DEVICE	DESCRIPTION
INA209	Current/power monitor with watchdog, peak-hold, and fast comparator functions
INA210, INA211, INA212, INA213, INA214	Zerø-drift, low-cost, analog current shunt monitor series in small package

6 Pin Configuration and Functions

DCN Package
8-Pin SOT-23
Top View



D Package
8-Pin SOIC
Top View



Pin Functions

PIN			I/O	DESCRIPTION
NAME	SOT-23	SOIC		
IN+	1	8	Analog Input	Positive differential shunt voltage. Connect to positive side of shunt resistor.
IN–	2	7	Analog Input	Negative differential shunt voltage. Connect to negative side of shunt resistor. Bus voltage is measured from this pin to ground.
GND	3	6	Analog	Ground
V_S	4	5	Analog	Power supply, 3 to 5.5 V
SCL	5	4	Digital Input	Serial bus clock line
SDA	6	3	Digital I/O	Serial bus data line
A0	7	2	Digital Input	Address pin. Table 1 shows pin settings and corresponding addresses.
A1	8	1	Digital Input	Address pin. Table 1 shows pin settings and corresponding addresses.

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
V_S	Supply voltage		6	V
Analog Inputs IN+, IN–	Differential (V_{IN+} – $V_{IN–}$)(2)	–26	26	V
	Common-mode(V_{IN+} + $V_{IN–}$) / 2	-0.3	26	V
SDA		GND – 0.3	6	V
SCL		GND – 0.3	V_S + 0.3	V
Input current into any pin			5	mA
Open-drain digital output current			10	mA
Operating temperature		–40	125	°C
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) V_{IN+} and $V_{IN–}$ may have a differential voltage of –26 to 26 V; however, the voltage at these pins must not exceed the range –0.3 to 26 V.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	±4000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2)	±750	
		Machine Model (MM)	±200	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	NOM	MAX	UNIT
V_{CM}		12		V
V_S		3.3		V
T_A	–25		85	ºC

7.4 Thermal Information

THERMAL METRIC(1)		INA219		UNIT
		D (SOIC)	DCN (SOT)	
		8 PINS	8 PINS	
$R_{θJA}$	Junction-to-ambient thermal resistance	111.3	135.4	°C/W
$R_{θJC(top)}$	Junction-to-case (top) thermal resistance	55.9	68.1	°C/W
$R_{θJB}$	Junction-to-board thermal resistance	52	48.9	°C/W
$ψ_{JT}$	Junction-to-top characterization parameter	10.7	9.9	°C/W
$ψ_{JB}$	Junction-to-board characterization parameter	51.5	48.4	°C/W
$R_{θJC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

7.5 Electrical Characteristics:

At T_A = 25°C, V_S = 3.3 V, V_{IN+} = 12V, V_{SHUNT} = (V_{IN+} – $V_{IN–}$) = 32 mV, PGA = /1, and BRNG(1) = 1, unless otherwise noted.

PARAMETER		TEST CONDITIONS	INA219A			INA219B			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
INPUT									
V_{SHUNT}	Full-scale current sense (input) voltage range	PGA = /1	0		±40	0		±40	mV
		PGA = /2	0		±80	0		±80	mV
		PGA = /4	0		±160	0		±160	mV
		PGA = /8	0		±320	0		±320	mV
	Bus voltage (input voltage) range(2)	BRNG = 1	0		32	0		32	V
		BRNG = 0	0		16	0		16	V
CMRR	Common-mode rejection	V_{IN+} = 0 to 26 V	100	120		100	120		dB
V_{OS}	Offset voltage, RTI(3)	PGA = /1		±10	±100		±10	±50(4)	μV
		PGA = /2		±20	±125		±20	±75(4)	μV
		PGA = /4		±30	±150		±30	±75(4)	μV
		PGA = /8		±40	±200		±40	±100(4)	μV
	vs Temperature	T_A = –25°C to 85°C		0.1			0.1		μV/°C
PSRR	vs Power Supply	V_S = 3 to 5.5 V		10			10		μV/V
	Current sense gain error			±40			±40		m%
	vs Temperature	T_A = –25°C to 85°C		1			1		m%/°C
	IN+ pin input bias current	Active mode		20			20		μA
	IN– pin input bias current || $V_{IN–}$ pin input impedance	Active mode		20 || 320			20 || 320		μA || kΩ
	IN+ pin input leakage(5)	Power-down mode		0.1	±0.5		0.1	±0.5	μA
	IN– pin input leakage(5)	Power-down mode		0.1	±0.5		0.1	±0.5	μA
DC ACCURACY									
	ADC basic resolution			12			12		bits
	Shunt voltage, 1 LSB step size			10			10		μV
	Bus voltage, 1 LSB step size			4			4		mV
	Current measurement error			±0.2%	±0.5%		±0.2%	±0.3%(4)	
	over Temperature	T_A = –25°C to 85°C			±1%			±0.5%(4)	
	Bus voltage measurement error			±0.2%	±0.5%		±0.2%	±0.5%	
	over Temperature	T_A = –25°C to 85°C			±1%			±1%	
	Differential nonlinearity			±0.1			±0.1		LSB
ADC TIMING									
	ADC conversion time	12 bit		532	586		532	586	μs
		11 bit		276	304		276	304	μs
		10 bit		148	163		148	163	μs
		9 bit		84	93		84	93	μs
	Minimum convert input low time		4			4			μs
SMBus									
SMBus timeout(6)				28	35		28	35	ms
DIGITAL INPUTS (SDA as Input, SCL, A0, A1)									
	Input capacitance			3			3		pF
	Leakage input current	0 ≤ V_{IN} ≤ V_S		0.1	1		0.1	1	μA
	V_{IH} input logic level		0.7 (V_S)		6	0.7 (V_S)		6	V
	V_{IL} input logic level		–0.3		0.3 (V_S)	–0.3		0.3 (V_S)	V

(1) BRNG is bit 13 of the Configuration register 00h in Figure 19.
(2) This parameter only expresses the full-scale range of the ADC scaling. In no event should more than 26 V be applied to this device.
(3) Referred-to-input (RTI)
(4) Indicates improved specifications of the INA219B.
(5) Input leakage is positive (current flowing into the pin) for the conditions shown at the top of the table. Negative leakage currents can occur under different input conditions.
(6) SMBus timeout in the INA219 resets the interface any time SCL or SDA is low for over 28 ms.

Electrical Characteristics: (continued)

At T_A = 25°C, V_S = 3.3 V, V_{IN+} = 12V, V_{SHUNT} = (V_{IN+} – $V_{IN–}$) = 32 mV, PGA = /1, and BRNG[(1)] = 1, unless otherwise noted.

PARAMETER	TEST CONDITIONS	INA219A			INA219B			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	
Hysteresis			500			500		mV
OPEN-DRAIN DIGITAL OUTPUTS (SDA)								
Logic 0 output level	I_{SINK} = 3 mA		0.15	0.4		0.15	0.4	V
High-level output leakage current	V_{OUT} = V_S		0.1	1		0.1	1	μA
POWER SUPPLY								
Operating supply range		3		5.5	3		5.5	V
Quiescent current			0.7	1		0.7	1	mA
Quiescent current, power-down mode			6	15		6	15	μA
Power-on reset threshold			2			2		V

7.6 Bus Timing Diagram Definitions[(1)]

		FAST MODE		HIGH-SPEED MODE		UNIT
		MIN	MAX	MIN	MAX	
$f_{(SCL)}$	SCL operating frequency	0.001	0.4	0.001	2.56	MHz
$t_{(BUF)}$	Bus free time between STOP and START condition	1300		160		ns
$t_{(HDSTA)}$	Hold time after repeated START condition. After this period, the first clock is generated.	600		160		ns
$t_{(SUSTA)}$	Repeated START condition setup time	600		160		ns
$t_{(SUSTO)}$	STOP condition setup time	600		160		ns
$t_{(HDDAT)}$	Data hold time	0	900	0	90	ns
$t_{(SUDAT)}$	Data setup time	100		10		ns
$t_{(LOW)}$	SCL clock LOW period	1300		250		ns
$t_{(HIGH)}$	SCL clock HIGH period	600		60		ns
t_F DA	Data fall time		300		150	ns
t_FCL	Clock fall time		300		40	ns
t_RCL	Clock rise time		300		40	ns
t_RCL	Clock rise time for SCLK ≤ 100kHz		1000			ns

(1) Values based on a statistical analysis of a one-time sample of devices. Minimum and maximum values are not ensured and not production tested.

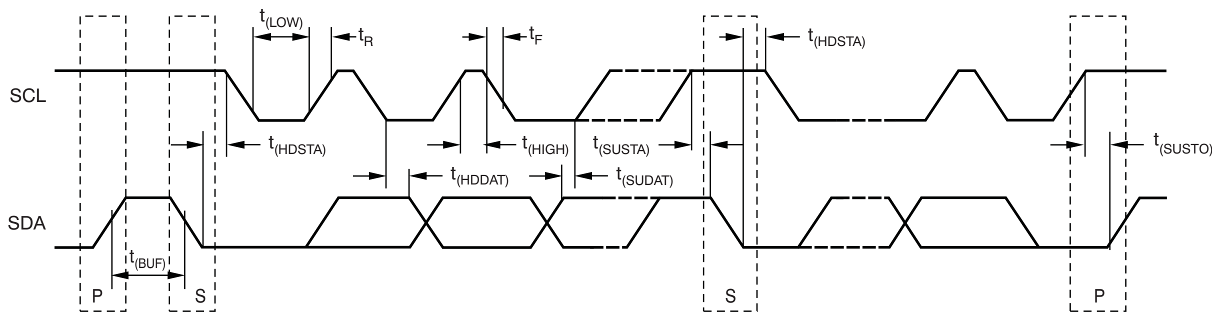


Figure 1. Bus Timing Diagram

7.7 Typical Characteristics

At T_A = 25°C, V_S = 3.3 V, V_{IN+} = 12 V, V_{SHUNT} = (V_{IN+} – $V_{IN–}$) = 32 mV, PGA = /1, and BRNG = 1, unless otherwise noted.

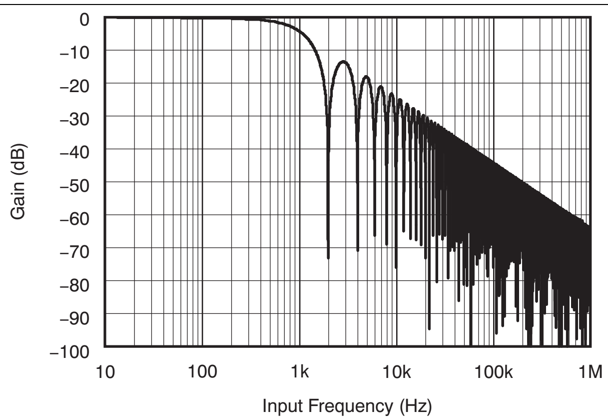


Figure 2. Frequency Response

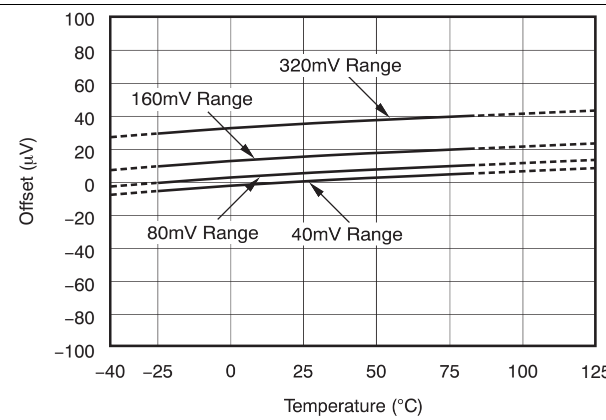


Figure 3. ADC Shunt Offset vs Temperature

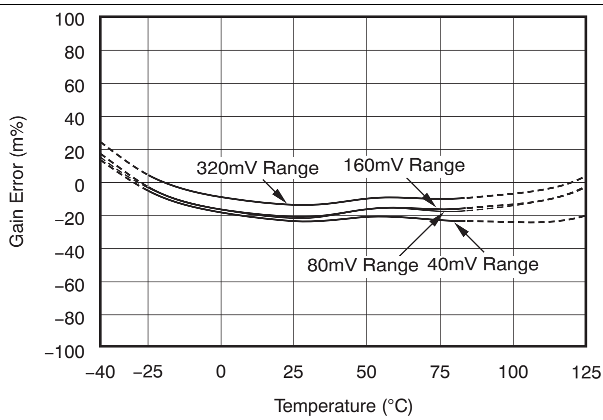


Figure 4. ADC Shunt Gain Error vs Temperature

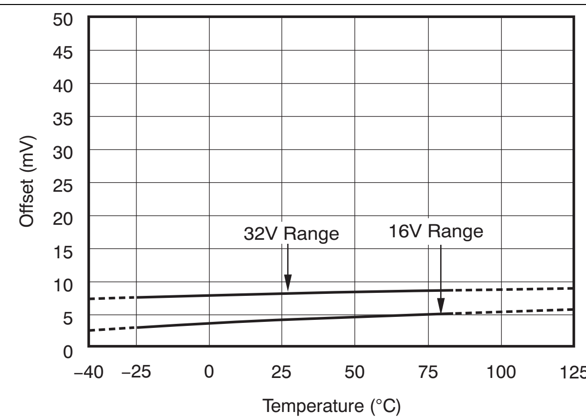


Figure 5. ADC Bus Voltage Offset vs Temperature

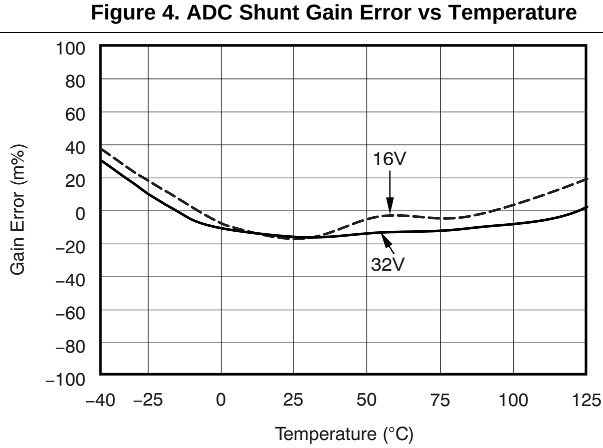


Figure 6. ADC Bus Gain Error vs Temperature

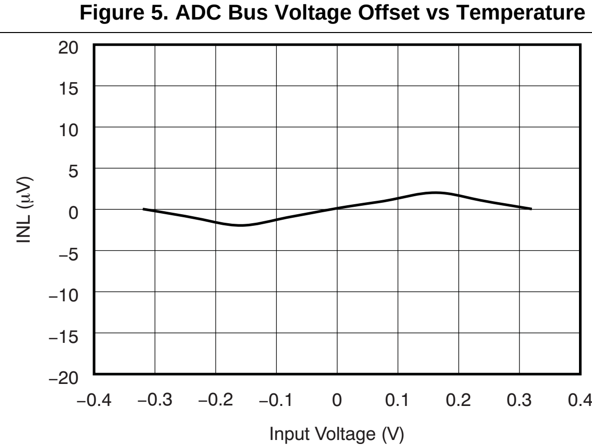


Figure 7. Integral Nonlinearity vs Input Voltage

Typical Characteristics (continued)

At T_A = 25°C, V_S = 3.3 V, V_{IN+} = 12 V, V_{SHUNT} = (V_{IN+} – $V_{IN–}$) = 32 mV, PGA = /1, and BRNG = 1, unless otherwise noted.

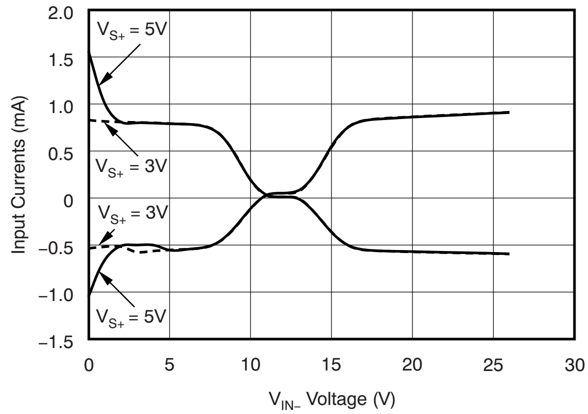


Figure 8. Input Currents With Large Differential Voltages(V_{IN+} at 12 V, Sweep Of $V_{IN–}$)

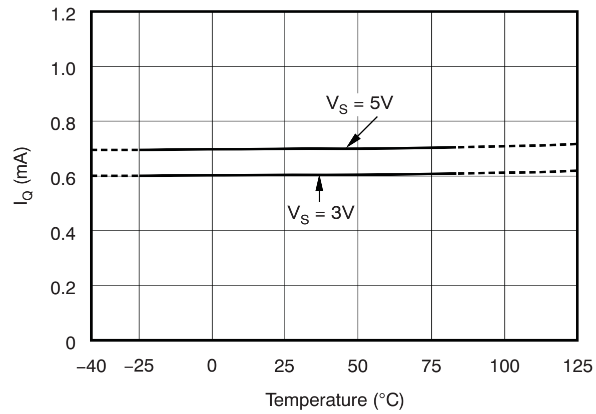


Figure 9. Active I_Q vs Temperature

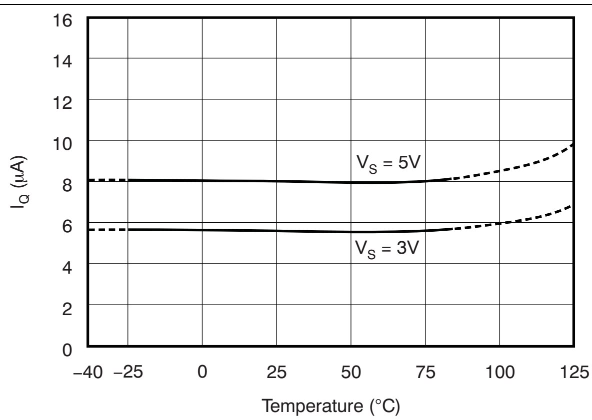


Figure 10. Shutdown I_Q vs Temperature

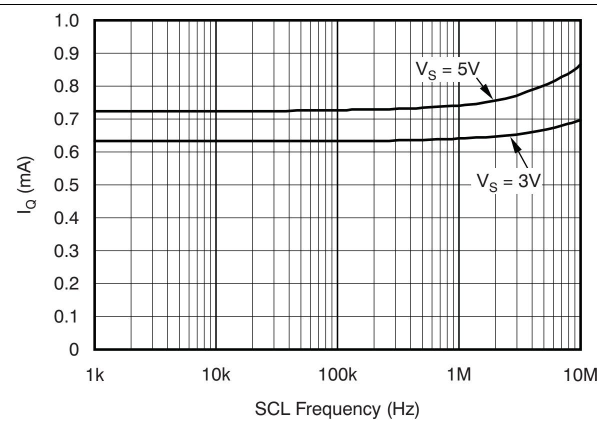


Figure 11. Active I_Q vs I^2C Clock Frequency

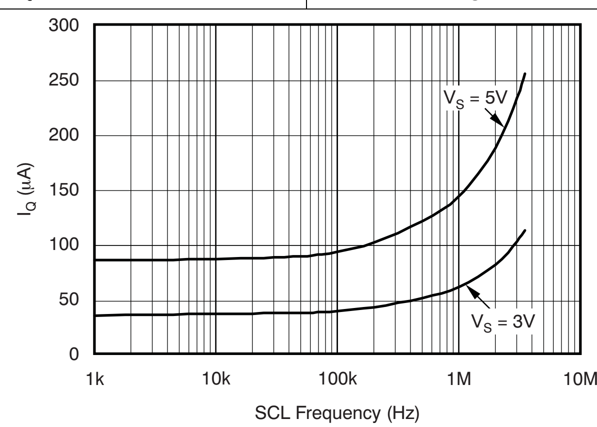


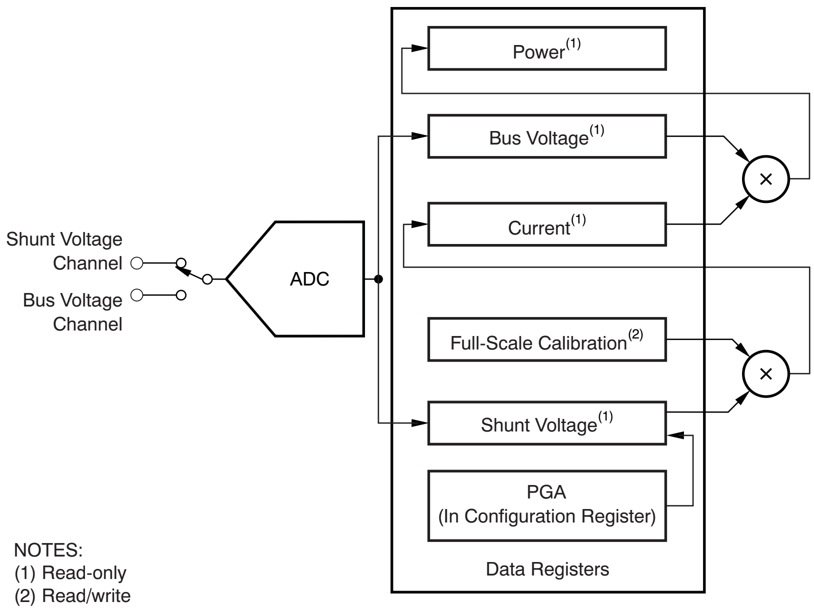
Figure 12. Shutdown I_Q vs I^2C Clock Frequency

8 Detailed Description

8.1 Overview

The INA219 is a digital current sense amplifier with an I^{2}C- and SMBus-compatible interface. It provides digital current, voltage, and power readings necessary for accurate decision-making in precisely-controlled systems. Programmable registers allow flexible configuration for measurement resolution as well as continuous-versus-triggered operation. Detailed register information appears at the end of this data sheet, beginning with Table 2. See the *Functional Block Diagram* section for a block diagram of the INA219 device.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Basic ADC Functions

The two analog inputs to the INA219, IN+ and IN–, connect to a shunt resistor in the bus of interest. The INA219 is typically powered by a separate supply from 3 to 5.5 V. The bus being sensed can vary from 0 to 26 V. There are no special considerations for power-supply sequencing (for example, a bus voltage can be present with the supply voltage off, and vice-versa). The INA219 senses the small drop across the shunt for shunt voltage, and senses the voltage with respect to ground from IN– for the bus voltage. Figure 13 shows this operation.

When the INA219 is in the normal operating mode (that is, MODE bits of the Configuration register are set to 111), it continuously converts the shunt voltage up to the number set in the shunt voltage averaging function (Configuration register, SADC bits). The device then converts the bus voltage up to the number set in the bus voltage averaging (Configuration register, BADC bits). The Mode control in the Configuration register also permits selecting modes to convert only voltage or current, either continuously or in response to an event (triggered).

All current and power calculations are performed in the background and do not contribute to conversion time; conversion times shown in the *Electrical Characteristics:* can be used to determine the actual conversion time.

Power-Down mode reduces the quiescent current and turns off current into the INA219 inputs, avoiding any supply drain. Full recovery from Power-Down requires 40 µs. ADC Off mode (set by the Configuration register, MODE bits) stops all conversions.

Writing any of the triggered convert modes into the Configuration register (even if the desired mode is already programmed into the register) triggers a single-shot conversion. Table 6 lists the triggered convert mode settings.

Feature Description (continued)

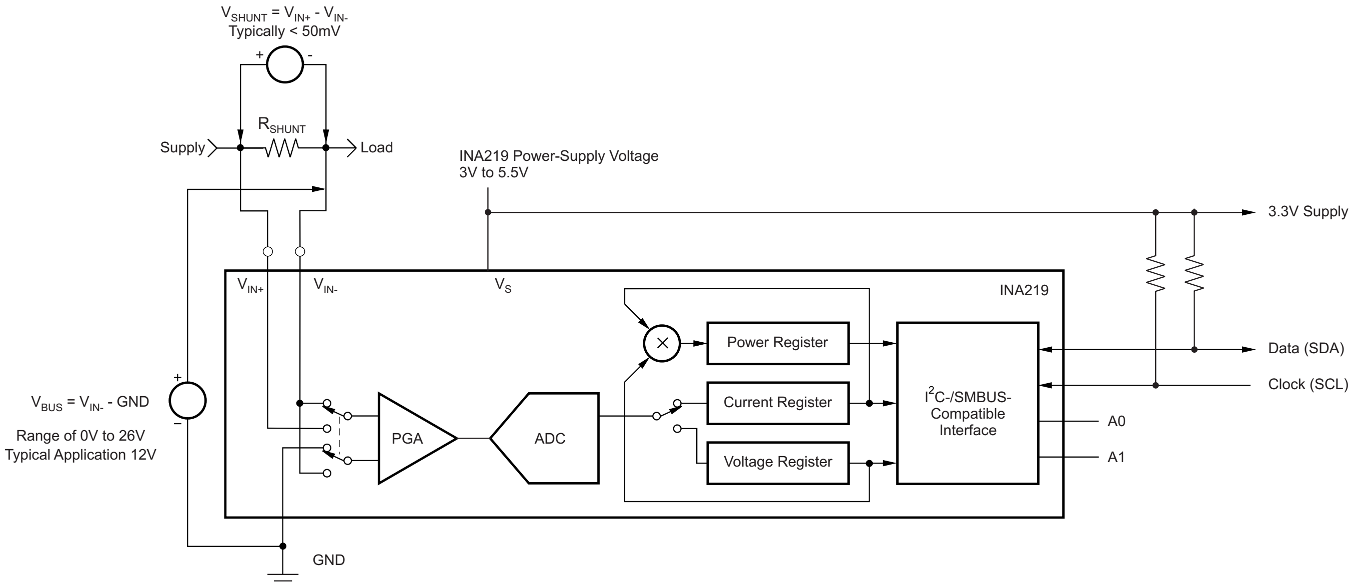


Figure 13. INA219 Configured for Shunt and Bus Voltage Measurement

Although the INA219 can be read at any time, and the data from the last conversion remain available, the conversion ready bit (Status register, CNVR bit) is provided to help coordinate one-shot or triggered conversions. The conversion ready bit is set after all conversions, averaging, and multiplication operations are complete.

The conversion ready bit clears under any of these conditions:

- Writing to the Configuration register, except when configuring the MODE bits for power down or ADC off (disable) modes
- Reading the Status register
- Triggering a single-shot conversion with the convert pin

8.3.1.1 Power Measurement

Current and bus voltage are converted at different points in time, depending on the resolution and averaging mode settings. For instance, when configured for 12-bit and 128 sample averaging, up to 68 ms in time between sampling these two values is possible. Again, these calculations are performed in the background and do not add to the overall conversion time.

8.3.1.2 PGA Function

If larger full-scale shunt voltages are desired, the INA219 provides a PGA function that increases the full-scale range up to 2, 4, or 8 times (320 mV). Additionally, the bus voltage measurement has two full-scale ranges: 16 or 32 V.

8.3.1.3 Compatibility With TI Hot Swap Controllers

The INA219 is designed for compatibility with hot swap controllers such the TI TPS2490. The TPS2490 uses a high-side shunt with a limit at 50 mV; the INA219 full-scale range of 40 mV enables the use of the same shunt for current sensing below this limit. When sensing is required at (or through) the 50-mV sense point of the TPS2490, the PGA of the INA219 can be set to /2 to provide an 80-mV full-scale range.

8.4 Device Functional Modes

8.4.1 Filtering and Input Considerations

Measuring current is often noisy, and such noise can be difficult to define. The INA219 offers several options for filtering by choosing resolution and averaging in the Configuration register. These filtering options can be set independently for either voltage or current measurement.

The internal ADC is based on a delta-sigma (ΔΣ) front-end with a 500-kHz (±30%) typical sampling rate. This architecture has good inherent noise rejection; however, transients that occur at or very close to the sampling rate harmonics can cause problems. Because these signals are at 1 MHz and higher, they can be dealt with by incorporating filtering at the input of the INA219. The high frequency enables the use of low-value series resistors on the filter for negligible effects on measurement accuracy. In general, filtering the INA219 input is only necessary if there are transients at exact harmonics of the 500-kHz (±30%) sampling rate (>1 MHz). Filter using the lowest possible series resistance and ceramic capacitor. Recommended values are 0.1 to 1 µF. Figure 14 shows the INA219 with an additional filter added at the input.

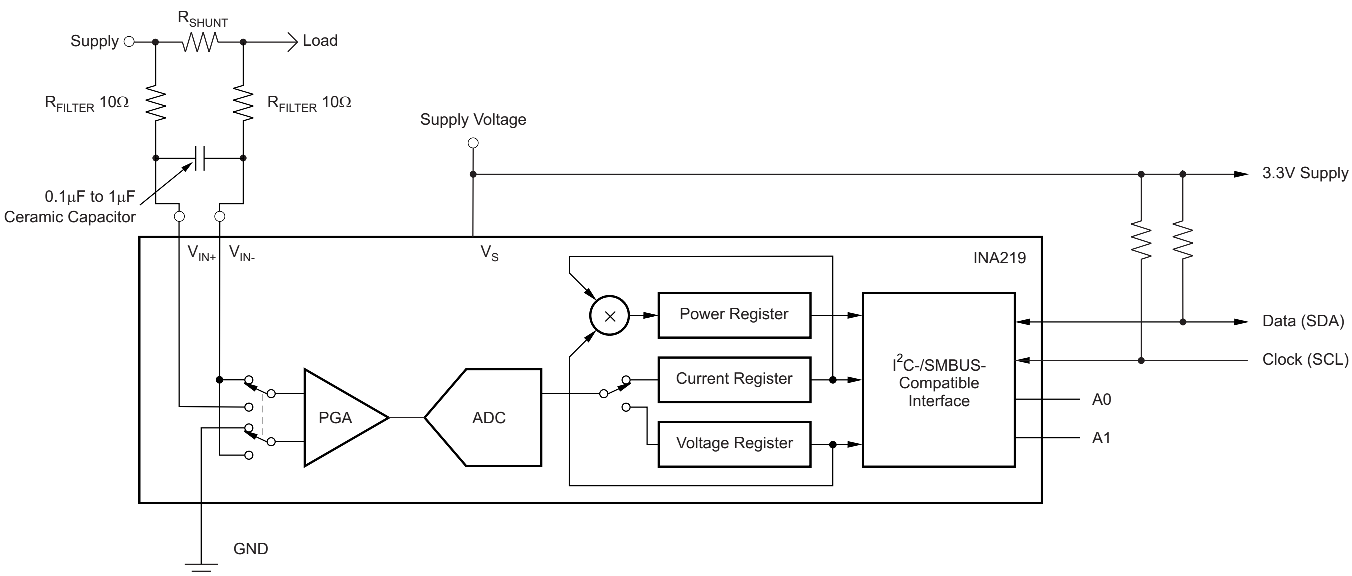


Figure 14. INA219 With Input Filtering

Overload conditions are another consideration for the INA219 inputs. The INA219 inputs are specified to tolerate 26 V across the inputs. A large differential scenario might be a short to ground on the load side of the shunt. This type of event can result in full power-supply voltage across the shunt (as long the power supply or energy storage capacitors support it). It must be remembered that removing a short to ground can result in inductive kickbacks that could exceed the 26-V differential and common-mode rating of the INA219. Inductive kickback voltages are best dealt with by zener-type transient-absorbing devices combined with sufficient energy storage capacitance.

In applications that do not have large energy storage electrolytics on one or both sides of the shunt, an input overstress condition may result from an excessive dV/dt of the voltage applied to the input. A hard physical short is the most likely cause of this event, particularly in applications with no large electrolytics present. This problem occurs because an excessive dV/dt can activate the ESD protection in the INA219 in systems where large currents are available. Testing has demonstrated that the addition of 10-Ω resistors in series with each input of the INA219 sufficiently protects the inputs against dV/dt failure up to the 26-V rating of the INA219. These resistors have no significant effect on accuracy.

8.5 Programming

An important aspect of the INA219 device is that it measure current or power if it is programmed based on the system. The device measures both the differential voltage applied between the IN+ and IN- input pins and the voltage at IN- pin. In order for the device to report both current and power values, the user must program the resolution of the Current Register (04h) and the value of the shunt resistor (R_{SHUNT}) present in the application to develop the differential voltage applied between the input pins. Both the Current_LSB and shunt resistor value are used in the calculation of the Calibration Register value that the device uses to calculate the corresponding current and power values based on the measured shunt and bus voltages.

After programming the Calibration Register, the Current Register (04h) and Power Register (03h) update accordingly based on the corresponding shunt voltage and bus voltage measurements. Until the Calibration Register is programmed, the Current Register (04h) and Power Register (03h) remain at zero.

8.5.1 Programming the Calibration Register

The Calibration Register is calculated based on Equation 1. This equation includes the term Current_LSB, which is the programmed value for the LSB for the Current Register (04h). The user uses this value to convert the value in the Current Register (04h) to the actual current in amperes. The highest resolution for the Current Register (04h) can be obtained by using the smallest allowable Current_LSB based on the maximum expected current as shown in Equation 2. While this value yields the highest resolution, it is common to select a value for the Current_LSB to the nearest round number above this value to simplify the conversion of the Current Register (04h) and Power Register (03h) to amperes and watts respectively. The R_{SHUNT} term is the value of the external shunt used to develop the differential voltage across the input pins. The Power Register (03h) is internally set to be 20 times the programmed Current_LSB see Equation 3.

$$\text{Cal} = \text{trunc}\left[\frac{0.04096}{\text{Current\_LSB} \times R_{SHUNT}}\right]$$

where

- 0.04096 is an internal fixed value used to ensure scaling is maintained properly (1)

$$\text{Current\_LSB} = \frac{\text{Maximum Expected Current}}{2^{15}} \quad (2)$$

$$\text{Power\_LSB} = 20\ \text{Current\_LSB} \quad (3)$$

Shunt voltage is calculated by multiplying the Shunt Voltage Register contents with the Shunt Voltage LSB of 10 µV.

The Bus Voltage register bits are not right-aligned. In order to compute the value of the Bus Voltage, Bus Voltage Register contents must be shifted right by three bits. This shift puts the BD0 bit in the LSB position so that the contents can be multiplied by the Bus Voltage LSB of 4-mV to compute the bus voltage measured by the device.

After programming the Calibration Register, the value expected in the Current Register (04h) can be calculated by multiplying the Shunt Voltage register contents by the Calibration Register and then dividing by 4096 as shown in Equation 4. To obtain a value in amperes the Current register value is multiplied by the programmed Current_LSB.

$$\text{Current Register} = \frac{\text{Shunt Voltage Register} \times \text{Calibration Register}}{4096} \quad (4)$$

The value expected in the Power register (03h) can be calculated by multiplying the Current register value by the Bus Voltage register value and then dividing by 5000 as shown in Equation 5. Power Register content is multiplied by Power LSB which is 20 times the Current_LSB for a power value in watts.

$$\text{Power Register} = \frac{\text{Current Register} \times \text{Bus Voltage Register}}{5000} \quad (5)$$

Programming (continued)

8.5.2 Programming the Power Measurement Engine

8.5.2.1 Calibration Register and Scaling

The Calibration Register enables the user to scale the Current Register (04h) and Power Register (03h) to the most useful value for a given application. For example, set the Calibration Register such that the largest possible number is generated in the Current Register (04h) or Power Register (03h) at the expected full-scale point. This approach yields the highest resolution using the previously calculated minimum Current_LSB in the equation for the Calibration Register. The Calibration Register can also be selected to provide values in the Current Register (04h) and Power Register (03h) that either provide direct decimal equivalents of the values being measured, or yield a round LSB value for each corresponding register. After these choices have been made, the Calibration Register also offers possibilities for end user system-level calibration. After determining the exact current by using an external ammeter, the value of the Calibration Register can then be adjusted based on the measured current result of the INA219 to cancel the total system error as shown in Equation 6.

$$\text{Corrected\_Full\_Scale\_Cal} = \text{trunc}\left[\frac{\text{Cal} \times \text{MeasShuntCurrent}}{\text{INA219\_Current}}\right] \tag{6}$$

8.5.3 Simple Current Shunt Monitor Usage (No Programming Necessary)

The INA219 can be used without any programming if it is only necessary to read a shunt voltage drop and bus voltage with the default 12-bit resolution, 320-mV shunt full-scale range (PGA = /8), 32-V bus full-scale range, and continuous conversion of shunt and bus voltage.

Without programming, current is measured by reading the shunt voltage. The Current register and Power register are only available if the Calibration register contains a programmed value.

8.5.4 Default Settings

The default power-up states of the registers are shown in the *Register Details* section of this data sheet. These registers are volatile, and if programmed to other than default values, must be re-programmed at every device power-up. Detailed information on programming the Calibration register specifically is given in the section, *Programming the Calibration Register*.

8.5.5 Bus Overview

The INA219 offers compatibility with both I^2C and SMBus interfaces. The I^2C and SMBus protocols are essentially compatible with one another.

The I^2C interface is used throughout this data sheet as the primary example, with SMBus protocol specified only when a difference between the two systems is being addressed. Two bidirectional lines, SCL and SDA, connect the INA219 to the bus. Both SCL and SDA are open-drain connections.

The device that initiates the transfer is called a *master*, and the devices controlled by the master are *slaves*. The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates START and STOP conditions.

To address a specific device, the master initiates a START condition by pulling the data signal line (SDA) from a HIGH to a LOW logic level while SCL is HIGH. All slaves on the bus shift in the slave address byte on the rising edge of SCL, with the last bit indicating whether a read or write operation is intended. During the ninth clock pulse, the slave being addressed responds to the master by generating an Acknowledge and pulling SDA LOW.

Data transfer is then initiated and eight bits of data are sent, followed by an *Acknowledge* bit. During data transfer, SDA must remain stable while SCL is HIGH. Any change in SDA while SCL is HIGH is interpreted as a START or STOP condition.

Once all data have been transferred, the master generates a STOP condition, indicated by pulling SDA from LOW to HIGH while SCL is HIGH. The INA219 includes a 28-ms timeout on its interface to prevent locking up an SMBus.

Programming (continued)

8.5.5.1 Serial Bus Address

To communicate with the INA219, the master must first address slave devices through a slave address byte. The slave address byte consists of seven address bits, and a direction bit indicating the intent of executing a read or write operation.

The INA219 has two address pins, A0 and A1. Table 1 describes the pin logic levels for each of the 16 possible addresses. The state of pins A0 and A1 is sampled on every bus communication and should be set before any activity on the interface occurs. The address pins are read at the start of each communication event.

Table 1. INA219 Address Pins and Slave Addresses

A1	A0	SLAVE ADDRESS
GND	GND	1000000
GND	V_{S+}	1000001
GND	SDA	1000010
GND	SCL	1000011
V_{S+}	GND	1000100
V_{S+}	V_{S+}	1000101
V_{S+}	SDA	1000110
V_{S+}	SCL	1000111
SDA	GND	1001000
SDA	V_{S+}	1001001
SDA	SDA	1001010
SDA	SCL	1001011
SCL	GND	1001100
SCL	V_{S+}	1001101
SCL	SDA	1001110
SCL	SCL	1001111

8.5.5.2 Serial Interface

The INA219 operates only as a slave device on the I^2C bus and SMBus. Connections to the bus are made through the open-drain I/O lines SDA and SCL. The SDA and SCL pins feature integrated spike suppression filters and Schmitt triggers to minimize the effects of input spikes and bus noise. The INA219 supports the transmission protocol for fast (1- to 400-kHz) and high-speed (1-kHz to 2.56-MHz) modes. All data bytes are transmitted most significant byte first.

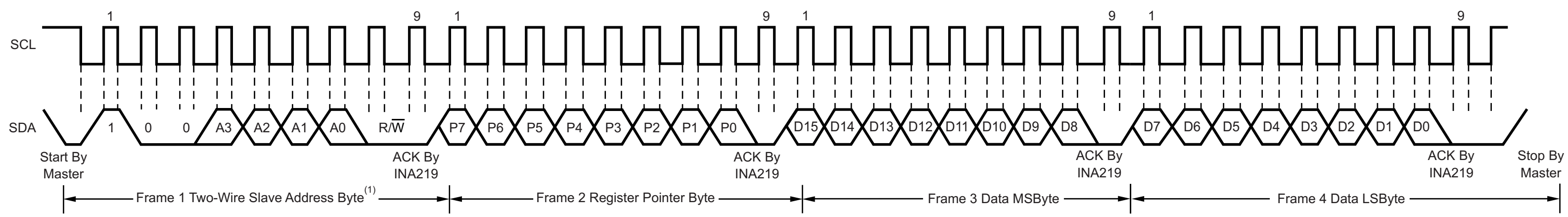
8.5.6 Writing to and Reading from the INA219

Accessing a particular register on the INA219 is accomplished by writing the appropriate value to the register pointer. Refer to Table 2 for a complete list of registers and corresponding addresses. The value for the register pointer as shown in Figure 18 is the first byte transferred after the slave address byte with the R/$\overline{W}$ bit LOW. Every write operation to the INA219 requires a value for the register pointer.

Writing to a register begins with the first byte transmitted by the master. This byte is the slave address, with the R/$\overline{W}$ bit LOW. The INA219 then acknowledges receipt of a valid address. The next byte transmitted by the master is the address of the register to which data will be written. This register address value updates the register pointer to the desired register. The next two bytes are written to the register addressed by the register pointer. The INA219 acknowledges receipt of each data byte. The master may terminate data transfer by generating a START or STOP condition.

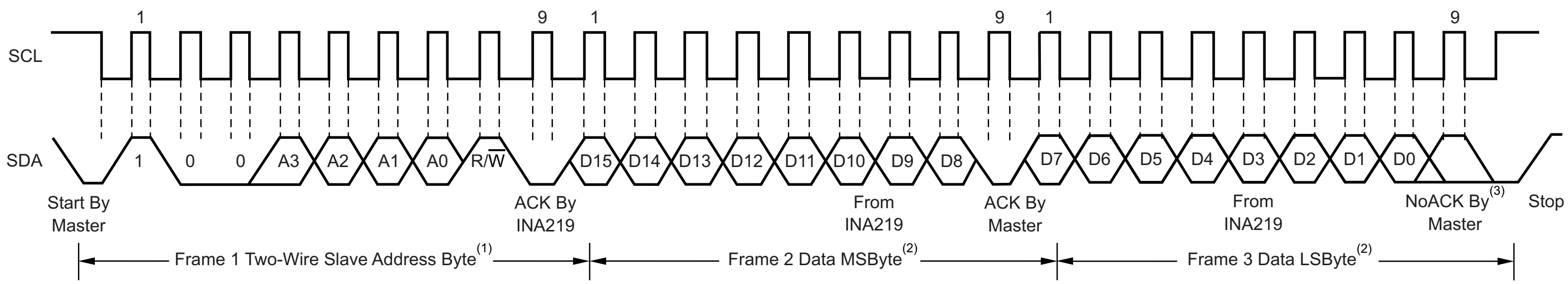
When reading from the INA219, the last value stored in the register pointer by a write operation determines which register is read during a read operation. To change the register pointer for a read operation, a new value must be written to the register pointer. This write is accomplished by issuing a slave address byte with the R/$\overline{W}$ bit LOW, followed by the register pointer byte. No additional data are required. The master then generates a START condition and sends the slave address byte with the R/$\overline{W}$ bit HIGH to initiate the read command. The next byte is transmitted by the slave and is the most significant byte of the register indicated by the register pointer. This byte is followed by an *Acknowledge* from the master; then the slave transmits the least significant byte. The master acknowledges receipt of the data byte. The master may terminate data transfer by generating a *Not-Acknowledge* after receiving any data byte, or generating a START or STOP condition. If repeated reads from the same register are desired, it is not necessary to continually send the register pointer bytes; the INA219 retains the register pointer value until it is changed by the next write operation.

Figure 15 and Figure 16 show write and read operation timing diagrams, respectively. Note that register bytes are sent most-significant byte first, followed by the least significant byte. Figure 17 shows the timing diagram for the SMBus Alert response operation. Figure 18 shows a typical register pointer configuration.



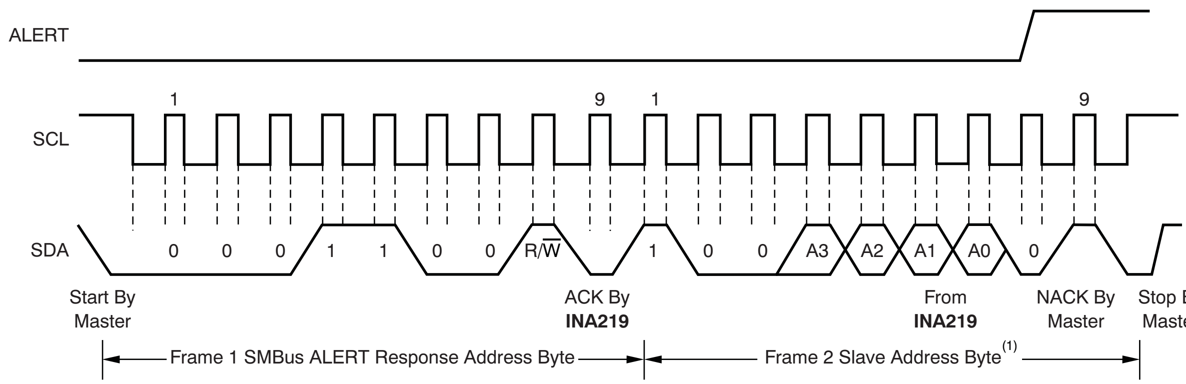
NOTE (1): The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 1.

Figure 15. Timing Diagram for Write Word Format



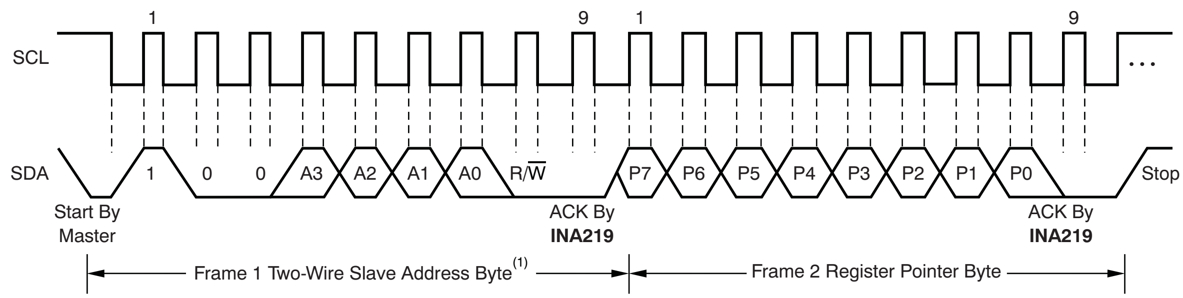
NOTES: (1) The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 1.
(2) Read data is from the last register pointer location. If a new register is desired, the register pointer must be updated. See Figure 19.
(3) ACK by Master can also be sent.

Figure 16. Timing Diagram for Read Word Format



NOTE (1): The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 1.

Figure 17. Timing Diagram for SMBus Alert



NOTE (1): The value of the Slave Address Byte is determined by the settings of the A0 and A1 pins. Refer to Table 1.

Figure 18. Typical Register Pointer Set

8.5.6.1 High-Speed I²C Mode

When the bus is idle, both the SDA and SCL lines are pulled high by the pull-up devices. The master generates a start condition followed by a valid serial byte containing high-speed (HS) master code *00001XXX*. This transmission is made in fast (400 kbps) or standard (100 kbps) (F/S) mode at no more than 400 kbps. The INA219 does not acknowledge the HS master code, but does recognize it and switches its internal filters to support 2.56 Mbps operation.

The master then generates a repeated start condition (a repeated start condition has the same timing as the start condition). After this repeated start condition, the protocol is the same as F/S mode, except that transmission speeds up to 2.56 Mbps are allowed. Instead of using a stop condition, repeated start conditions should be used to secure the bus in HS-mode. A stop condition ends the HS-mode and switches all the internal filters of the INA219 to support the F/S mode. For bus timing, see *Bus Timing Diagram Definitions*(1) and Figure 1.

8.5.6.2 Power-Up Conditions

Power-up conditions apply to a software reset through the RST bit (bit 15) in the Configuration register, or the I²C bus General Call Reset.

(1) Values based on a statistical analysis of a one-time sample of devices. Minimum and maximum values are not ensured and not production tested.

8.6 Register Maps

8.6.1 Register Information

The INA219 uses a bank of registers for holding configuration settings, measurement results, maximum/minimum limits, and status information. Table 2 summarizes the INA219 registers; *Functional Block Diagram* shows registers.

Register contents are updated 4 μs after completion of the write command. Therefore, a 4-μs delay is required between completion of a write to a given register and a subsequent read of that register (without changing the pointer) when using SCL frequencies in excess of 1 MHz.

Table 2. Summary of Register Set

POINTER ADDRESS	REGISTER NAME	FUNCTION	POWER-ON RESET		TYPE(1)
HEX			BINARY	HEX	
00	Configuration	All-register reset, settings for bus voltage range, PGA Gain, ADC resolution/averaging.	00111001 10011111	399F	R/$\overline{W}$
01	Shunt voltage	Shunt voltage measurement data.	Shunt voltage	—	R
02	Bus voltage	Bus voltage measurement data.	Bus voltage	—	R
03	Power(2)	Power measurement data.	00000000 00000000	0000	R
04	Current(2)	Contains the value of the current flowing through the shunt resistor.	00000000 00000000	0000	R
05	Calibration	Sets full-scale range and LSB of current and power measurements. Overall system calibration.	00000000 00000000	0000	R/$\overline{W}$

(1) Type: **R** = Read only, **R/$\overline{W}$** = Read/Write.
(2) The Power register and Current register default to 0 because the Calibration register defaults to 0, yielding a zero current value until the Calibration register is programmed.

8.6.2 Register Details

All INA219 16-bit registers are actually two 8-bit bytes through the I²C interface.

8.6.2.1 Configuration Register (address = 00h) [reset = 399Fh]

Figure 19. Configuration Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RST	—	BRNG	PG1	PG0	BADC 4	BADC 3	BADC 2	BADC 1	SADC 4	SADC 3	SADC 2	SADC 1	MODE 3	MODE 2	MODE 1
R/W-0	R/W-0	R/W-1	R/W-1	R/W-1	R/W-0	R/W-0	R/W-1	R/W-1	R/W-0	R/W-0	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 3. Bit Descriptions

RST:	**Reset Bit**
Bit 15	Setting this bit to '1' generates a system reset that is the same as power-on reset. Resets all registers to default values; this bit self-clears.
BRNG:	**Bus Voltage Range**
Bit 13	0 = 16V FSR 1 = 32V FSR (default value)
PG:	**PGA (Shunt Voltage Only)**
Bits 11, 12	Sets PGA gain and range. Note that the PGA defaults to ÷8 (320mV range). Table 4 shows the gain and range for the various product gain settings.

Table 4. PG Bit Settings(1)

PG1	PG0	GAIN	Range
0	0	1	±40 mV
0	1	/2	±80 mV
1	0	/4	±160 mV
1	1	/8	±320 mV

(1) Shaded values are default.

BADC:	**BADC Bus ADC Resolution/Averaging**
Bits 7–10	These bits adjust the Bus ADC resolution (9-, 10-, 11-, or 12-bit) or set the number of samples used when averaging results for the Bus Voltage Register (02h).

SADC: **SADC Shunt ADC Resolution/Averaging**

Bits 3–6 These bits adjust the Shunt ADC resolution (9-, 10-, 11-, or 12-bit) or set the number of samples used when averaging results for the Shunt Voltage Register (01h).
BADC (Bus) and SADC (Shunt) ADC resolution/averaging and conversion time settings are shown in Table 5.

Table 5. ADC Settings(1)

ADC4	ADC3	ADC2	ADC1	Mode/Samples	Conversion Time
0	X(2)	0	0	9 bit	84 μs
0	X(2)	0	1	10 bit	148 μs
0	X(2)	1	0	11 bit	276 μs
0	X(2)	1	1	12 bit	532 μs
1	0	0	0	12 bit	532 μs
1	0	0	1	2	1.06 ms
1	0	1	0	4	2.13 ms
1	0	1	1	8	4.26 ms
1	1	0	0	16	8.51 ms
1	1	0	1	32	17.02 ms
1	1	1	0	64	34.05 ms
1	1	1	1	128	68.10 ms

(1) Shaded values are default.
(2) X = Don't care

MODE: **Operating Mode**

Bits 0–2 Selects continuous, triggered, or power-down mode of operation. These bits default to continuous shunt and bus measurement mode. The mode settings are shown in Table 6.

Table 6. Mode Settings(1)

MODE3	MODE2	MODE1	MODE
0	0	0	Power-down
0	0	1	Shunt voltage, triggered
0	1	0	Bus voltage, triggered
0	1	1	Shunt and bus, triggered
1	0	0	ADC off (disabled)
1	0	1	Shunt voltage, continuous
1	1	0	Bus voltage, continuous
1	1	1	Shunt and bus, continuous

(1) Shaded values are default.

8.6.3 Data Output Registers

8.6.3.1 Shunt Voltage Register (address = 01h)

The Shunt Voltage register stores the current shunt voltage reading, V_{SHUNT}. Shunt Voltage register bits are shifted according to the PGA setting selected in the Configuration register (00h). When multiple sign bits are present, they will all be the same value. Negative numbers are represented in 2's complement format. Generate the 2's complement of a negative number by complementing the absolute value binary number and adding 1. Extend the sign, denoting a negative number by setting the MSB = 1. Extend the sign to any additional sign bits to form the 16-bit word.

Example: For a value of V_{SHUNT} = –320 mV:

1. Take the absolute value (include accuracy to 0.01 mV) → 320.00
2. Translate this number to a whole decimal number → 32000
3. Convert it to binary → 111 1101 0000 0000

4. Complement the binary result : 000 0010 1111 1111
5. Add 1 to the Complement to create the Two's Complement formatted result → 000 0011 0000 0000
6. Extend the sign and create the 16-bit word: 1000 0011 0000 0000 = 8300h (Remember to extend the sign to all sign-bits, as necessary based on the PGA setting.)

At PGA = /8, full-scale range = ±320 mV (decimal = 32000). For V_{SHUNT} = +320 mV, Value = 7D00h; For V_{SHUNT} = –320 mV, Value = 8300h; and LSB = 10µV.

Figure 20. Shunt Voltage Register at PGA = /8

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SIGN	SD14_8	SD13_8	SD12_8	SD11_8	SD10_8	SD9_8	SD8_8	SD7_8	SD6_8	SD5_8	SD4_8	SD3_8	SD2_8	SD1_8	SD0_8

At PGA = /4, full-scale range = ±160 mV (decimal = 16000). For V_{SHUNT} = +160 mV, Value = 3E80h; For V_{SHUNT} = –160 mV, Value = C180h; and LSB = 10µV.

Figure 21. Shunt Voltage Register at PGA = /4

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SIGN	SIGN	SD13_4	SD12_4	SD11_4	SD10_4	SD9_4	SD8_4	SD7_4	SD6_4	SD5_4	SD4_4	SD3_4	SD2_4	SD1_4	SD0_4

At PGA = /2, full-scale range = ±80 mV (decimal = 8000). For V_{SHUNT} = +80 mV, Value = 1F40h; For V_{SHUNT} = –80 mV; Value = E0C0h; and LSB = 10µV.

Figure 22. Shunt Voltage Register at PGA = /2

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SIGN	SIGN	SIGN	SD12_2	SD11_2	SD10_2	SD9_2	SD8_2	SD7_2	SD6_2	SD5_2	SD4_2	SD3_2	SD2_2	SD1_2	SD0_2

At PGA = /1, full-scale range = ±40 mV (decimal = 4000). For V_{SHUNT} = +40 mV, Value = 0FA0h; For V_{SHUNT} = –40 mV, Value = F060h; and LSB = 10µV.

Figure 23. Shunt Voltage Register at PGA = /1

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SIGN	SIGN	SIGN	SIGN	SD11_1	SD10_1	SD9_1	SD8_1	SD7_1	SD6_1	SD5_1	SD4_1	SD3_1	SD2_1	SD1_1	SD0_1

Table 7. Shunt Voltage Register Format(1)

V_{SHUNT} Reading (mV)	Decimal Value	PGA = /8 (D15:D0)	PGA = /4 (D15:D0)	PGA = /2 (D15:D0)	PGA = /1 (D15:D0)
320.02	32002	0111 1101 0000 0000	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
320.01	32001	0111 1101 0000 0000	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
320.00	32000	0111 1101 0000 0000	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
319.99	31999	0111 1100 1111 1111	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
319.98	31998	0111 1100 1111 1110	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
⋮	⋮	⋮	⋮	⋮	⋮
160.02	16002	0011 1110 1000 0010	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
160.01	16001	0011 1110 1000 0001	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
160.00	16000	0011 1110 1000 0000	0011 1110 1000 0000	0001 1111 0100 0000	0000 1111 1010 0000
159.99	15999	0011 1110 0111 1111	0011 1110 0111 1111	0001 1111 0100 0000	0000 1111 1010 0000
159.98	15998	0011 1110 0111 1110	0011 1110 0111 1110	0001 1111 0100 0000	0000 1111 1010 0000
⋮	⋮	⋮	⋮	⋮	⋮
80.02	8002	0001 1111 0100 0010	0001 1111 0100 0010	0001 1111 0100 0000	0000 1111 1010 0000
80.01	8001	0001 1111 0100 0001	0001 1111 0100 0001	0001 1111 0100 0000	0000 1111 1010 0000
80.00	8000	0001 1111 0100 0000	0001 1111 0100 0000	0001 1111 0100 0000	0000 1111 1010 0000
79.99	7999	0001 1111 0011 1111	0001 1111 0011 1111	0001 1111 0011 1111	0000 1111 1010 0000
79.98	7998	0001 1111 0011 1110	0001 1111 0011 1110	0001 1111 0011 1110	0000 1111 1010 0000
⋮	⋮	⋮	⋮	⋮	⋮
40.02	4002	0000 1111 1010 0010	0000 1111 1010 0010	0000 1111 1010 0010	0000 1111 1010 0000
40.01	4001	0000 1111 1010 0001	0000 1111 1010 0001	0000 1111 1010 0001	0000 1111 1010 0000
40.00	4000	0000 1111 1010 0000	0000 1111 1010 0000	0000 1111 1010 0000	0000 1111 1010 0000
39.99	3999	0000 1111 1001 1111	0000 1111 1001 1111	0000 1111 1001 1111	0000 1111 1001 1111
39.98	3998	0000 1111 1001 1110	0000 1111 1001 1110	0000 1111 1001 1110	0000 1111 1001 1110
⋮	⋮	⋮	⋮	⋮	⋮
0.02	2	0000 0000 0000 0010	0000 0000 0000 0010	0000 0000 0000 0010	0000 0000 0000 0010
0.01	1	0000 0000 0000 0001	0000 0000 0000 0001	0000 0000 0000 0001	0000 0000 0000 0001
0	0	0000 0000 0000 0000	0000 0000 0000 0000	0000 0000 0000 0000	0000 0000 0000 0000
–0.01	–1	1111 1111 1111 1111	1111 1111 1111 1111	1111 1111 1111 1111	1111 1111 1111 1111
–0.02	–2	1111 1111 1111 1110	1111 1111 1111 1110	1111 1111 1111 1110	1111 1111 1111 1110
⋮	⋮	⋮	⋮	⋮	⋮
–39.98	–3998	1111 0000 0110 0010	1111 0000 0110 0010	1111 0000 0110 0010	1111 0000 0110 0010
–39.99	–3999	1111 0000 0110 0001	1111 0000 0110 0001	1111 0000 0110 0001	1111 0000 0110 0001
–40.00	–4000	1111 0000 0110 0000	1111 0000 0110 0000	1111 0000 0110 0000	1111 0000 0110 0000
–40.01	–4001	1111 0000 0101 1111	1111 0000 0101 1111	1111 0000 0101 1111	1111 0000 0110 0000
–40.02	–4002	1111 0000 0101 1110	1111 0000 0101 1110	1111 0000 0101 1110	1111 0000 0110 0000
⋮	⋮	⋮	⋮	⋮	⋮
–79.98	–7998	1110 0000 1100 0010	1110 0000 1100 0010	1110 0000 1100 0010	1111 0000 0110 0000
–79.99	–7999	1110 0000 1100 0001	1110 0000 1100 0001	1110 0000 1100 0001	1111 0000 0110 0000
–80.00	–8000	1110 0000 1100 0000	1110 0000 1100 0000	1110 0000 1100 0000	1111 0000 0110 0000
–80.01	–8001	1110 0000 1011 1111	1110 0000 1011 1111	1110 0000 1100 0000	1111 0000 0110 0000
–80.02	–8002	1110 0000 1011 1110	1110 0000 1011 1110	1110 0000 1100 0000	1111 0000 0110 0000
⋮	⋮	⋮	⋮	⋮	⋮
–159.98	–15998	1100 0001 1000 0010	1100 0001 1000 0010	1110 0000 1100 0000	1111 0000 0110 0000
–159.99	–15999	1100 0001 1000 0001	1100 0001 1000 0001	1110 0000 1100 0000	1111 0000 0110 0000
–160.00	–16000	1100 0001 1000 0000	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–160.01	–16001	1100 0001 0111 1111	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–160.02	–16002	1100 0001 0111 1110	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
⋮	⋮	⋮	⋮	⋮	⋮
–319.98	–31998	1000 0011 0000 0010	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–319.99	–31999	1000 0011 0000 0001	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–320.00	–32000	1000 0011 0000 0000	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–320.01	–32001	1000 0011 0000 0000	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000
–320.02	–32002	1000 0011 0000 0000	1100 0001 1000 0000	1110 0000 1100 0000	1111 0000 0110 0000

(1) Out-of-range values are shown in gray shading.

8.6.3.2 Bus Voltage Register (address = 02h)

The Bus Voltage register stores the most recent bus voltage reading, V_{BUS}.

At full-scale range = 32 V (decimal = 8000, hex = 1F40), and LSB = 4 mV.

Figure 24. Bus Voltage Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BD12	BD11	BD10	BD9	BD8	BD7	BD6	BD5	BD4	BD3	BD2	BD1	BD0	—	CNVR	OVF

At full-scale range = 16 V (decimal = 4000, hex = 0FA0), and LSB = 4 mV.

CNVR: **Conversion Ready**

Bit 1: Although the data from the last conversion can be read at any time, the INA219 Conversion Ready bit (CNVR) indicates when data from a conversion is available in the data output registers. The CNVR bit is set after all conversions, averaging, and multiplications are complete. CNVR will clear under the following conditions:

1.) Writing a new mode into the Operating Mode bits in the Configuration Register (except for Power-Down or Disable)

2.) Reading the Power Register

OVF: **Math Overflow Flag**

Bit 0: The Math Overflow Flag (OVF) is set when the Power or Current calculations are out of range. It indicates that current and power data may be meaningless.

8.6.3.3 Power Register (address = 03h) [reset = 00h]

Full-scale range and LSB are set by the Calibration register. See the *Programming the Calibration Register*.

Figure 25. Power Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PD15	PD14	PD13	PD12	PD11	PD10	PD9	PD8	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

The Power register records power in watts by multiplying the values of the current with the value of the bus voltage according to the equation Equation 5:

8.6.3.4 Current Register (address = 04h) [reset = 00h]

Full-scale range and LSB depend on the value entered in the Calibration register. See *Programming the Calibration Register* for more information. Negative values are stored in 2's complement format.

Figure 26. Current Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSIGN	CD14	CD13	CD12	CD11	CD10	CD9	CD8	CD7	CD6	CD5	CD4	CD3	CD2	CD1	CD0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

The value of the Current register is calculated by multiplying the value in the Shunt Voltage register with the value in the Calibration register according to the Equation 4:

8.6.4 Calibration Register

8.6.4.1 Calibration Register (address = 05h) [reset = 00h]

Current and power calibration are set by bits FS15 to FS1 of the Calibration register. Note that bit FS0 is not used in the calculation. This register sets the current that corresponds to a full-scale drop across the shunt. Full-scale range and the LSB of the current and power measurement depend on the value entered in this register. See the *Programming the Calibration Register*. This register is suitable for use in overall system calibration. Note that the 0 POR values are all default.

Figure 27. Calibration Register(1)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FS15	FS14	FS13	FS12	FS11	FS10	FS9	FS8	FS7	FS6	FS5	FS4	FS3	FS2	FS1	FS0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

(1) FS0 is a *void* bit and will always be 0. It is not possible to write a 1 to FS0. CALIBRATION is the value stored in FS15:FS1.

9 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

The INA219 is a current shunt and power monitor with an I^2C- and SMBus-compatible interface. The device monitors both a shunt voltage drop and bus supply voltage. Programmable calibration value, combined with an internal multiplier, enable readouts of current and power.

9.2 Typical Application

Figure 28 shows a typical application circuit for the INA219. Use a 0.1-μF ceramic capacitor for power-supply bypassing, placed as closely as possible to the supply and ground pins.

The input filter circuit consisting of R_{F1}, R_{F2}, and C_F is not necessary in most applications. If the need for filtering is unknown, reserve board space for the components and install 0-Ω resistors for R_{F1} and R_{F2} and leave C_F unpopulated, unless a filter is needed (see *Filtering and Input Considerations*).

The pull-up resistors shown on the SDA and SCL lines are not needed if there are pullup resistors on these same lines elsewhere in the system. Resistor values shown are typical: consult either the I^2C or SMBus specification to determine the acceptable minimum or maximum values and also refer to the *Specifications* for Output Current Limitations.

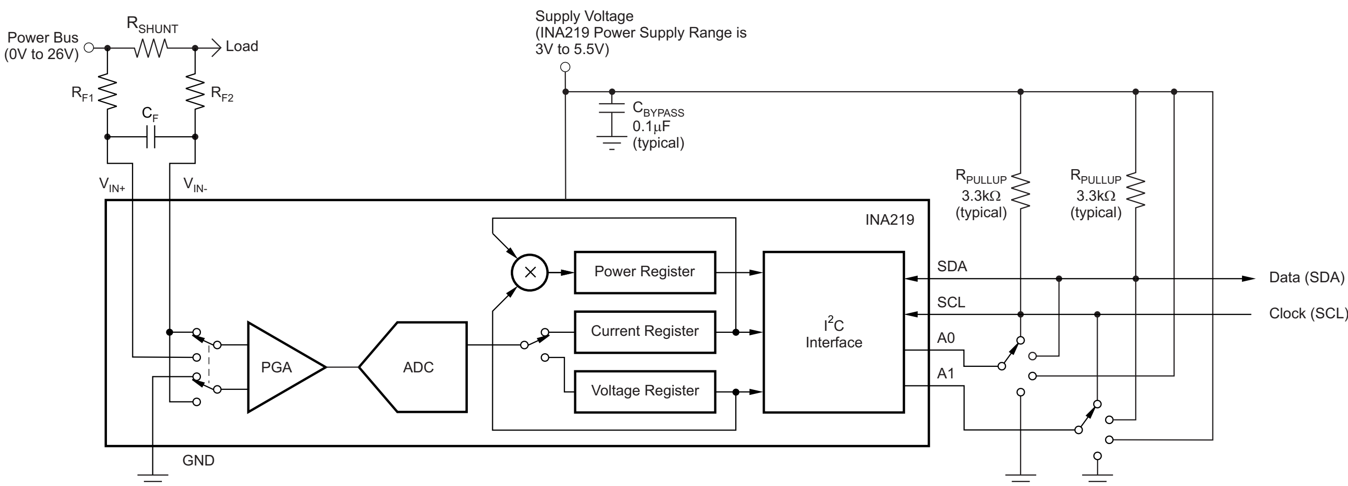


Figure 28. Typical Application Circuit

9.2.1 Design Requirements

The INA219 measures the voltage across a current-sensing resistor (R_{SHUNT}) when current passes through the resistor. The device also measures the bus supply voltage, and calculates power when calibrated. This section goes through the steps to program the device for power measurements, and shows the register results Table 8.

The Conditions for the example circuit is: Maximum expected load current = 15 A, Nominal load current = 10 A, V_{CM} = 12 V, R_{SHUNT} = 2 mΩ, V_{SHUNT} FSR = 40 mV (PGA = /1), and BRNG = 0 (VBUS range = 16 V).

9.2.2 Detailed Design Procedure

Figure 29 shows a nominal 10-A load that creates a differential voltage of 20 mV across a 2-mΩ shunt resistor. The common mode is at 12 volts and the voltage present at the IN– pin is equal to the common-mode voltage minus the differential drop across the resistor.

Typical Application (continued)

For this example, the minimum-current LSB is calculated to be 457.78 µA/bit, assuming a maximum expected current of 15 A using Equation 2. This value is rounded up to 1 mA/bit and is chosen for the current LSB. Setting the current LSB to this value allows for sufficient precision while serving to simplify the math as well. Using Equation 1 results in a calibration value of 20480 (5000h). This value is then programmed into the Calibration register.

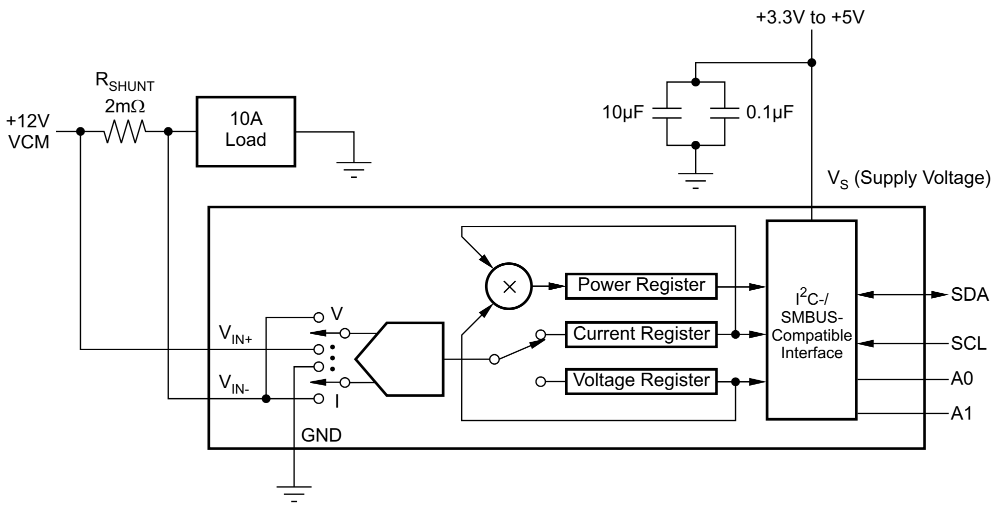


Figure 29. Example Circuit Configuration

The bus voltage is internally measured at the IN– pin to calculate the voltage level delivered to the load. The Bus Voltage register bits are not right-aligned; therefore, they must be shifted right by three bits. Multiply the shifted contents by the 4-mV LSB to compute the bus voltage measured by the device in volts. The shifted value of the Bus Voltage register contents is equal to BB3h, the decimal equivalent of 2995. This value of 2995 is multiplied by the 4-mV LSB, and results in a value of 11.98 V. As shown, the voltage at the IN– pin is 11.98 V. For a 40-mV, full-scale range, this small difference is not a significant deviation from the 12-V common-mode voltage. However, at larger full-scale ranges, this deviation can be much larger.

The Current register content is internally calculated using Equation 4, and the result of 10000 (2710h) is automatically loaded into the register. Current in amperes is equal to 1 mA/bit times 10000, and results in a 10-A load current.

The Power register content is internally calculated using Equation 5 and the result of 5990 (1766h) is automatically loaded into the register. Multiplying this result by the Power register LSB 20 × 10^{-3}(20 times 1 × 10^{-3} current LSB using Equation 3), results in a power calculation of 5990 × 20 mW/bit, and equals 119.8 W. This result matches what is expected for this register. A calculation for the power delivered to the load uses 11.98 V (12 VCM – 20-mV shunt drop) multiplied by the load current of 10 A to give a 119.8-W result.

9.2.2.1 Register Results for the Example Circuit

Table 8 shows the register readings for the Calibration example.

Table 8. Register Results(1)

REGISTER NAME	ADDRESS	CONTENTS	ADJ	DEC	LSB	VALUE
Configuration	00h	019Fh				
Shunt	01h	07D0h		2000	10 µV	20 mV
Bus	02h	5D98h	0BB3	2995	4 mV	11.98 V
Calibration	05h	5000h		20480		
Current	04h	2710h		10000	1 mA	10.0 A
Power	03h	1766h		5990	20 mW	119.8 W

(1) Conditions: load = 10 A, V_{CM} = 12 V, R_{SHUNT} = 2 mΩ, V_{SHUNT} FSR = 40 mV, and V_{BUS} = V_{IN-}, BRNG = 0 (VBUS range = 16 V).

10 Power Supply Recommendations

The input circuitry of the device can accurately measure signals on common-mode voltages beyond its power supply voltage, V_S. For example, the voltage applied to the V_S power supply terminal can be 5 V, whereas the load power-supply voltage being monitored (the common-mode voltage) can be as high as 26 V. Note also that the device can withstand the full 0-V to 26-V range at the input terminals, regardless of whether the device has power applied or not.

Place the required power-supply bypass capacitors as close as possible to the supply and ground terminals of the device to ensure stability. A typical value for this supply bypass capacitor is 0.1 µF. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise.

11 Layout

11.1 Layout Guidelines

Connect the input pins (IN+ and IN–) to the sensing resistor using a Kelvin connection or a 4-wire connection. These connection techniques ensure that only the current-sensing resistor impedance is detected between the input pins. Poor routing of the current-sensing resistor commonly results in additional resistance present between the input pins. Given the very low ohmic value of the current-sensing resistor, any additional high-current carrying impedance causes significant measurement errors. Place the power-supply bypass capacitor as close as possible to the supply and ground pins.

11.2 Layout Example

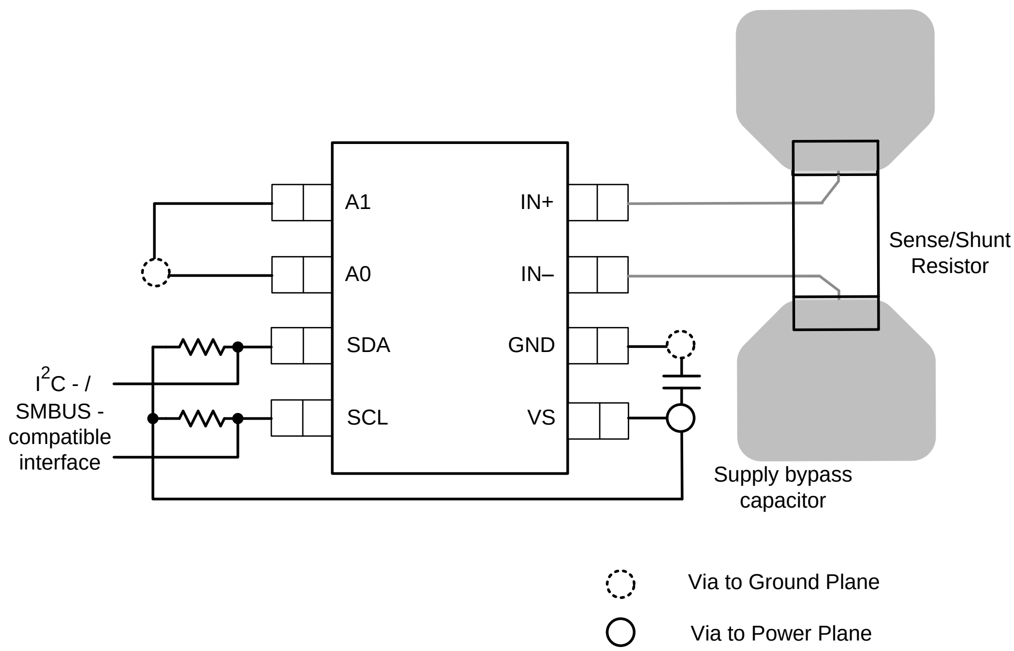


Figure 30. Recommended Layout

12 Device and Documentation Support

12.1 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.2 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

12.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

12.4 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA219AID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	NIPDAU	Level-1-260C-UNLIM	-40 to 125	I219A	Samples
INA219AIDCNR	ACTIVE	SOT-23	DCN	8	3000	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	A219	Samples
INA219AIDCNT	ACTIVE	SOT-23	DCN	8	250	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	A219	Samples
INA219AIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-1-260C-UNLIM	-40 to 125	I219A	Samples
INA219BID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	NIPDAU	Level-1-260C-UNLIM	-40 to 125	I219B	Samples
INA219BIDCNR	ACTIVE	SOT-23	DCN	8	3000	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	B219	Samples
INA219BIDCNT	ACTIVE	SOT-23	DCN	8	250	Green (RoHS & no Sb/Br)	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	B219	Samples
INA219BIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	NIPDAU	Level-1-260C-UNLIM	-40 to 125	I219B	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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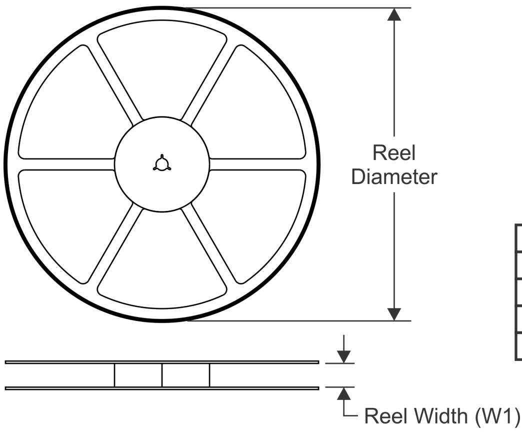
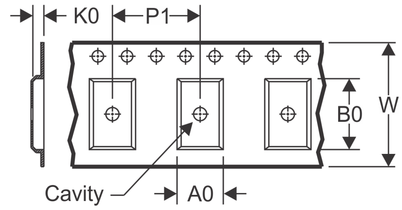
TAPE AND REEL INFORMATION

REEL DIMENSIONS

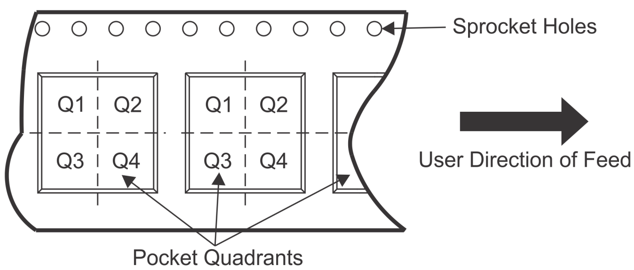


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

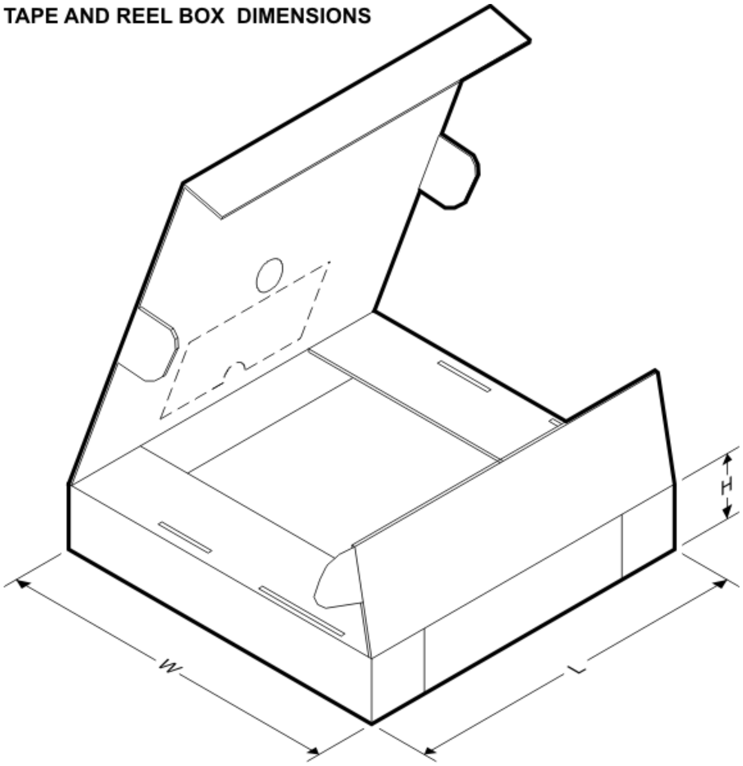
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA219AIDCNR	SOT-23	DCN	8	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA219AIDCNT	SOT-23	DCN	8	250	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA219AIDR	SOIC	D	8	2500	330.0	12.5	6.4	5.2	2.1	8.0	12.0	Q1
INA219BIDCNR	SOT-23	DCN	8	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA219BIDCNT	SOT-23	DCN	8	250	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
INA219BIDR	SOIC	D	8	2500	330.0	12.5	6.4	5.2	2.1	8.0	12.0	Q1

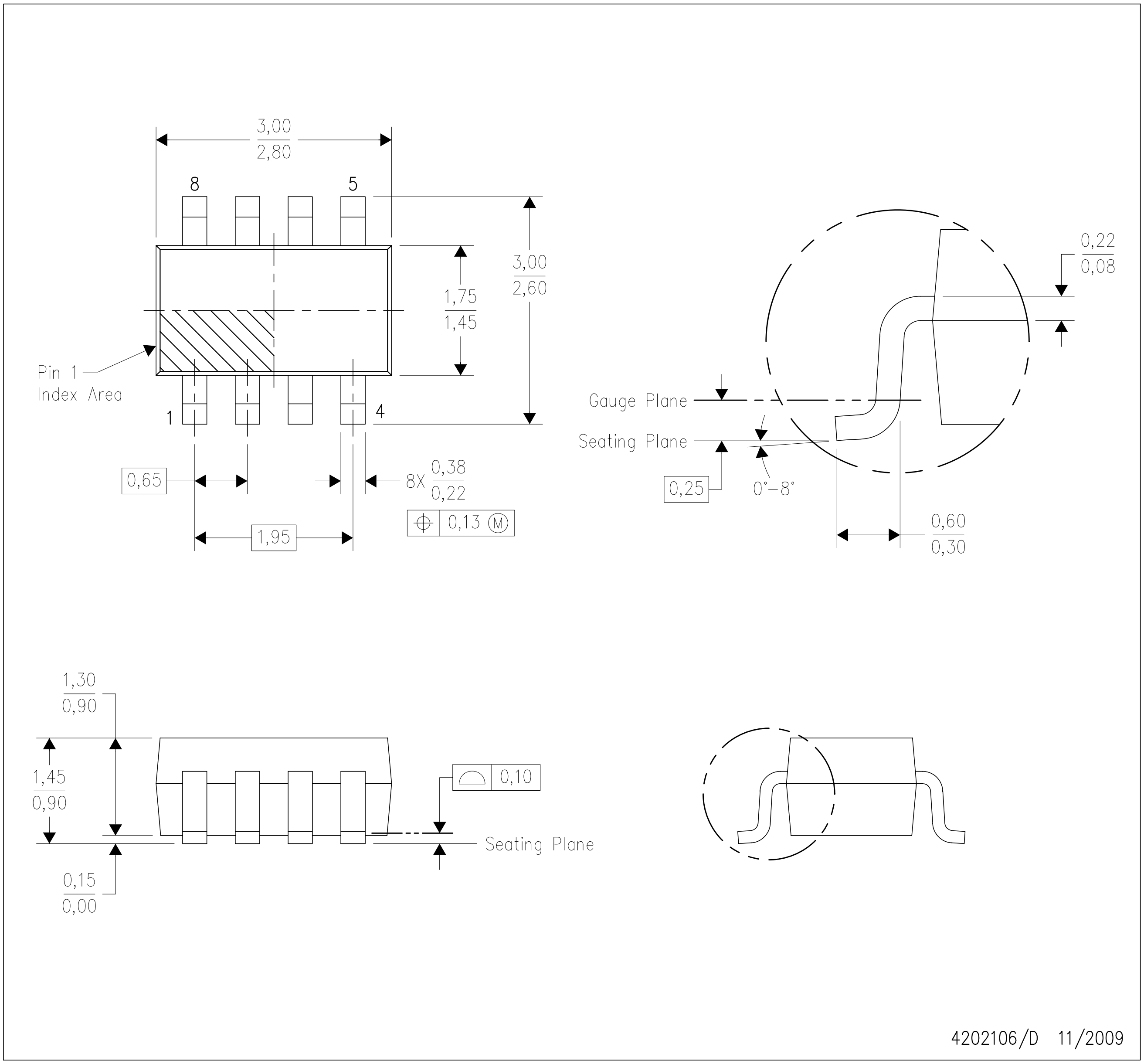
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

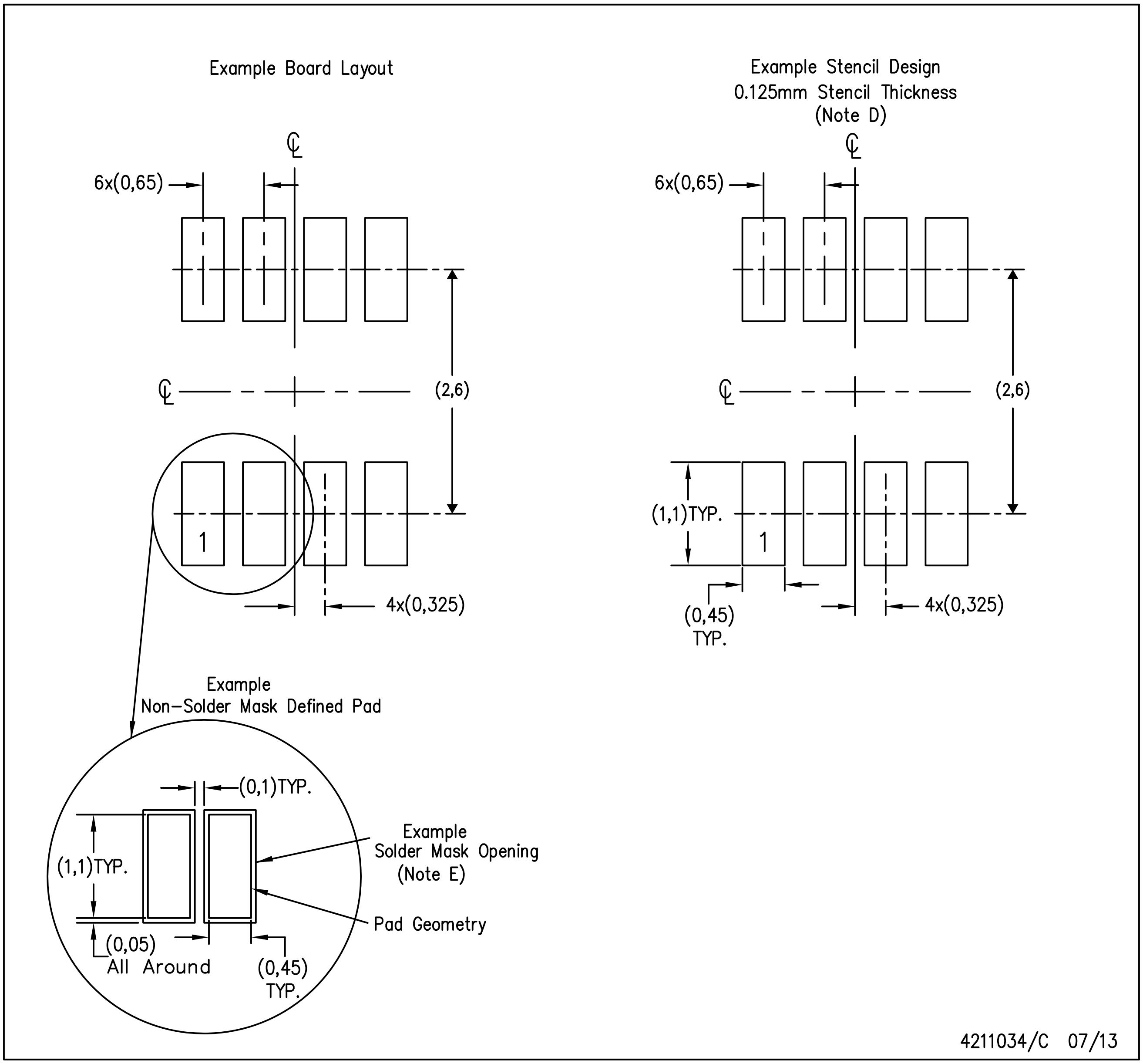
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA219AIDCNR	SOT-23	DCN	8	3000	195.0	200.0	45.0
INA219AIDCNT	SOT-23	DCN	8	250	195.0	200.0	45.0
INA219AIDR	SOIC	D	8	2500	340.5	338.1	20.6
INA219BIDCNR	SOT-23	DCN	8	3000	195.0	200.0	45.0
INA219BIDCNT	SOT-23	DCN	8	250	195.0	200.0	45.0
INA219BIDR	SOIC	D	8	2500	340.5	338.1	20.6

DCN (R-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE (DIE DOWN)



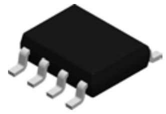
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Package outline exclusive of metal burr & dambar protrusion/intrusion.
- D. Package outline inclusive of solder plating.
- E. A visual index feature must be located within the Pin 1 index area.
- F. Falls within JEDEC MO-178 Variation BA.
- G. Body dimensions do not include flash or protrusion. Mold flash and protrusion shall not exceed 0.25 per side.

DCN (R-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE (DIE DOWN)



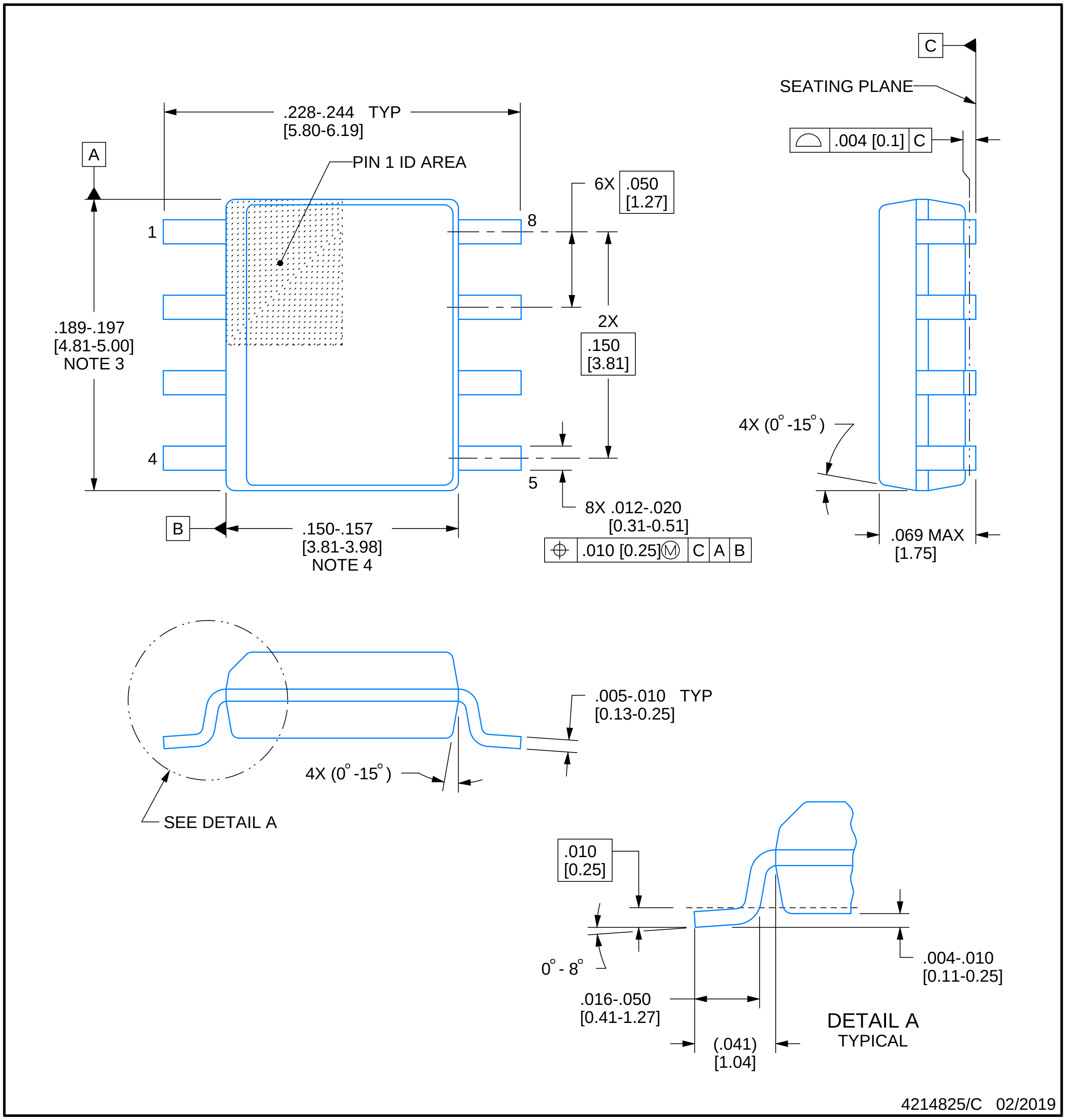
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

D0008A



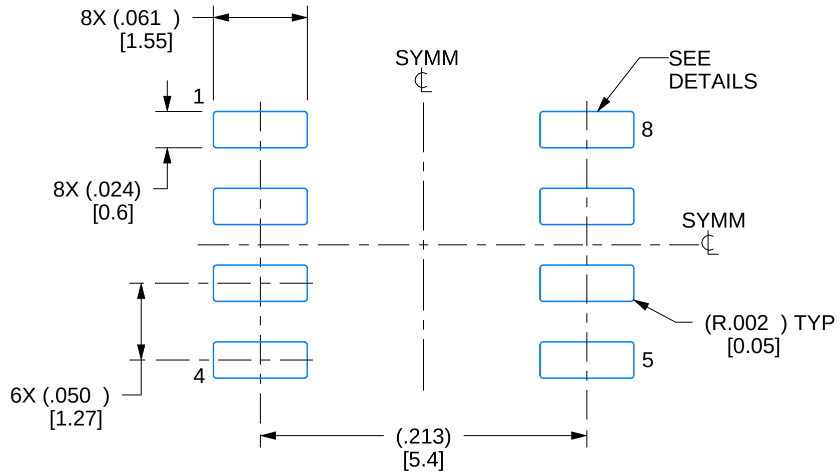
SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

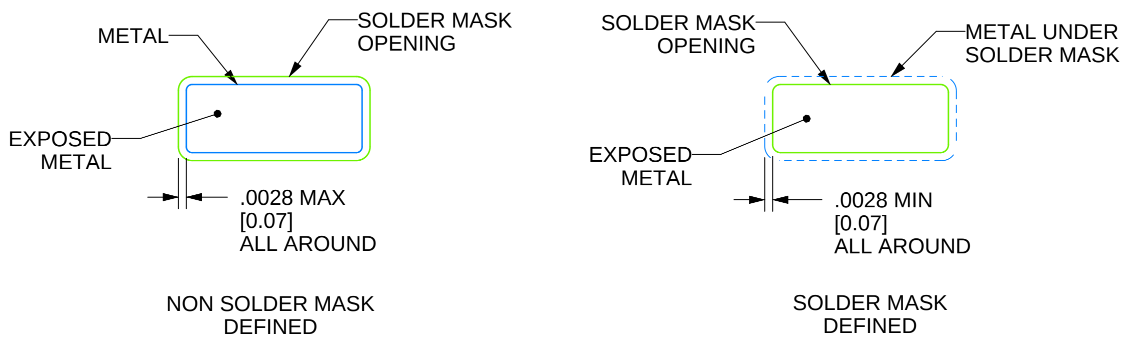


NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X

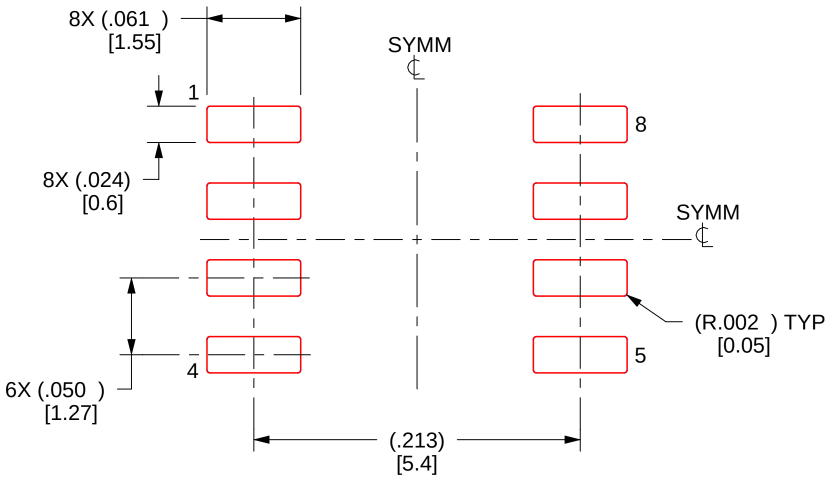


SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

LM340, LM340A and LM7805 Family Wide V_{IN} 1.5-A Fixed Voltage Regulators

1 Features

- Output Current up to 1.5 A
- Available in Fixed 5-V, 12-V, and 15-V Options
- Output Voltage Tolerances of ±2% at T_J = 25°C (LM340A)
- Line Regulation of 0.01% / V of at 1-A Load (LM340A)
- Load Regulation of 0.3% / A (LM340A)
- Internal Thermal Overload, Short-Circuit and SOA Protection
- Available in Space-Saving SOT-223 Package
- Output Capacitance Not Required for Stability

2 Applications

- Industrial Power Supplies
- SMPS Post Regulation
- HVAC Systems
- AC Inventors
- Test and Measurement Equipment
- Brushed and Brushless DC Motor Drivers
- Solar Energy String Invertors

3 Description

The LM340 and LM7805 Family monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.5-A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

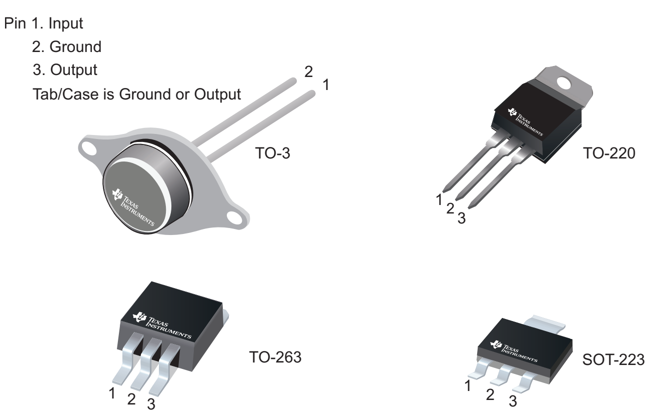
LM7805 is also available in a higher accuracy and better performance version (LM340A). Refer to LM340A specifications in the *LM340A Electrical Characterisitcs* table.

Device Information(1)

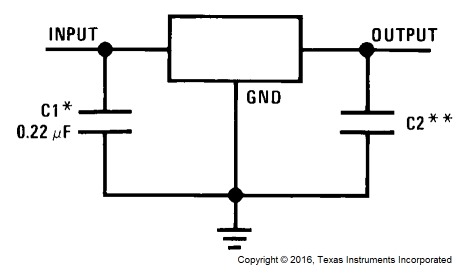
PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM340x LM7805 Family	DDPAK/TO-263 (3)	10.18 mm × 8.41 mm
	SOT-223 (4)	6.50 mm × 3.50 mm
	TO-220 (3)	14.986 mm × 10.16 mm
	TO-3 (2)	38.94 mm x 25.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Available Packages



Fixed Output Voltage Regulator



*Required if the regulator is located far from the power supply filter.
**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1-µF, ceramic disc).

Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

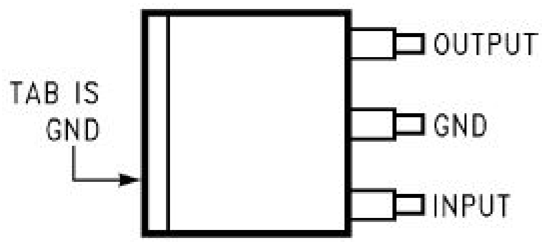
Changes from Revision K (November 2015) to Revision L	Page
• Changed pinout number order for the TO-220 and SOT-223 packages from: 2, 3, 1 to: 1, 2, 3	1

Changes from Revision J (December 2013) to Revision K	Page
• Added *ESD Ratings* table, *Thermal Information* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	1
• Deleted obsolete LM140 and LM7808C devices from the data sheet	1
• Changed Figure 13 caption from *Line Regulation 140AK-5.0* to *Line Regulation LM340,*	11
• Changed Figure 14 caption from *Line Regulation 140AK-5.0* to *Line Regulation LM340,*	11

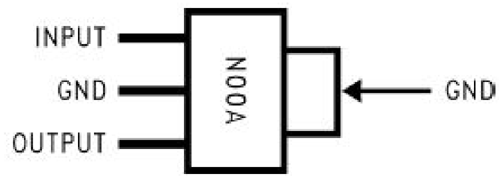
Changes from Revision I (March 2013) to Revision J	Page
• Changed 0.5 from typ to max	5

5 Pin Configuration and Functions

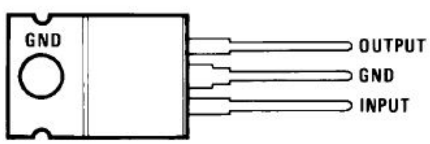
LM7805 and LM7812 KTT Package
3-Pin DDPAK/TO-263
Top View



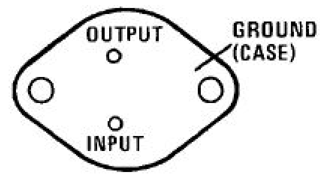
LM7805 DCY Package
4-Pin SOT-223
Side View



LM7805, LM7812, and LM7815 NDE Package
3-Pin TO-220
Top View



LM340K-5.0 NDS Package
2-Pin TO-3
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
INPUT	1	I	Input voltage pin
GND	2	I/O	Ground pin
OUTPUT	3	O	Output voltage pin

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)(2)

		MIN	MAX	UNIT
DC input voltage			35	V
Internal power dissipation(3)		Internally Limited		
Maximum junction temperature			150	°C
Lead temperature (soldering, 10 sec.)	TO-3 package (NDS)		300	°C
	Lead temperature 1,6 mm (1/16 in) from case for 10 s		230	°C
Storage temperature		−65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.
(3) The maximum allowable power dissipation at any ambient temperature is a function of the maximum junction temperature for operation (T_{JMAX} = 125°C or 150°C), the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature (T_A). $P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature rises above T_{JMAX} and the electrical specifications do not apply. If the die temperature rises above 150°C, the device goes into thermal shutdown. For the TO-3 package (NDS), the junction-to-ambient thermal resistance (θ_{JA}) is 39°C/W. When using a heat sink, θ_{JA} is the sum of the 4°C/W junction-to-case thermal resistance (θ_{JC}) of the TO-3 package and the case-to-ambient thermal resistance of the heat sink. For the TO-220 package (NDE), θ_{JA} is 54°C/W and θ_{JC} is 4°C/W. If SOT-223 is used, the junction-to-ambient thermal resistance is 174°C/W and can be reduced by a heat sink (see Applications Hints on heat sinking).If the DDPAK\TO-263 package is used, the thermal resistance can be reduced by increasing the PCB copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more inches of copper area, θ_{JA} is 32°C/W.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM)(1)	±2000	V

(1) ESD rating is based on the human-body model, 100 pF discharged through 1.5 kΩ.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Temperature (T_A)	LM340A, LM340	0	125	°C

6.4 Thermal Information

THERMAL METRIC(1)		LM340, LM7805 Family				UNIT
		NDE (TO-220)	KTT (DDPAK/TO-263)	DCY (SOT-223)	NDS (TO-3)	
		3 PINS	3 PINS	4 PINS	2 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	23.9	44.8	62.1	39	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	16.7	45.6	44	2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	5.3	24.4	10.7	—	°C/W
ψ_{JT}	Junction-to-top characterization parameter	3.2	11.2	2.7	—	°C/W
ψ_{JB}	Junction-to-board characterization parameter	5.3	23.4	10.6	—	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	1.7	1.5	—	—	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

6.5 LM340A Electrical Characteristics, V_O = 5 V, V_I = 10 V

I_{OUT} = 1 A, 0°C ≤ T_J ≤ 125°C (LM340A) unless otherwise specified(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Output voltage	T_J = 25°C		4.9	5	5.1	V
		P_D ≤ 15 W, 5 mA ≤ I_O ≤ 1 A 7.5 V ≤ V_{IN} ≤ 20 V		4.8		5.2	V
ΔV_O	Line regulation	7.5 V ≤ V_{IN} ≤ 20 V	T_J = 25°C		3	10	mV
			Over temperature, I_O = 500 mA			10	mV
		8 V ≤ V_{IN} ≤ 12 V	T_J = 25°C			4	mV
			Over temperature			12	mV
ΔV_O	Load regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5 A		10	25	mV
			250 mA ≤ I_O ≤ 750 mA			15	mV
		Over temperature, 5 mA ≤ I_O ≤ 1 A				25	mV
I_Q	Quiescent current	T_J = 25°C				6	mA
		Over temperature				6.5	mA
ΔI_Q	Quiescent current change	T_J = 25°C, I_O = 1 A 7.5 V ≤ V_{IN} ≤ 20 V				0.8	mA
		Over temperature, 5 mA ≤ I_O ≤ 1 A				0.5	mA
		Over temperature, I_O = 500 mA 8 V ≤ V_{IN} ≤ 25 V				0.8	mA
V_N	Output noise voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple rejection	f = 120 Hz 8 V ≤ V_{IN} ≤ 18 V	T_J = 25°C, , I_O = 1 A	68	80		dB
			Over temperature, I_O = 500 mA	68			dB
R_O	Dropout voltage	T_J = 25°C, I_O = 1 A			2		V
	Output resistance	f = 1 kHz			8		mΩ
	Short-circuit current	T_J = 25°C			2.1		A
	Peak output current	T_J = 25°C			2.4		A
	Average TC of V_O	Min, T_J = 0°C, I_O = 5 mA			−0.6		mV/°C
V_{IN}	Input voltage required to maintain line regulation	T_J = 25°C		7.5			V

(1) All characteristics are measured with a 0.22-µF capacitor from input to ground and a 0.1-µF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

6.6 LM340 / LM7805 Electrical Characteristics, V_O = 5 V, V_I = 10 V

0°C ≤ T_J ≤ 125°C unless otherwise specified(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Output voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1 A		4.8	5	5.2	V
		P_D ≤ 15 W, 5 mA ≤ I_O ≤ 1 A 7.5 V ≤ V_{IN} ≤ 20 V		4.75		5.25	V
ΔV_O	Line regulation	I_O = 500 mA	T_J = 25°C 7V ≤ V_{IN} ≤ 25V		3	50	mV
			Over temperature 8V ≤ V_{IN} ≤ 20V			50	mV
		I_O ≤ 1 A	T_J = 25°C 7.5V ≤ V_{IN} ≤ 20V			50	mV
			Over temperature 8V ≤ V_{IN} ≤ 12V			25	mV
ΔV_O	Load regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5 A		10	50	mV
			250 mA ≤ I_O ≤ 750 mA			25	mV
		Over temperature, 5 mA ≤ I_O ≤ 1 A				50	mV
I_Q	Quiescent current	I_O ≤ 1 A	T_J = 25°C			8	mA
			Over temperature			8.5	mA
ΔI_Q	Quiescent current change	0°C ≤ T_J ≤ 125°C, 5 mA ≤ I_O ≤ 1 A			0.5		mA
		7 V ≤ V_{IN} ≤ 20 V	T_J = 25°C, I_O ≤ 1 A			1	mA
			Over temperature, I_O ≤ 500 mA			1	mA
V_N	Output noise voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple rejection	f = 120 Hz 8 V ≤ V_{IN} ≤ 18 V	T_J = 25°C, I_O ≤ 1 A	62	80		dB
			Over temperature, I_O ≤ 500 mA	62			dB
R_O	Dropout voltage	T_J = 25°C, I_O = 1 A			2		V
	Output resistance	f = 1 kHz			8		mΩ
	Short-circuit current	T_J = 25°C			2.1		A
	Peak output current	T_J = 25°C			2.4		A
	Average TC of V_{OUT}	Over temperature, I_O = 5 mA			−0.6		mV/°C
V_{IN}	Input voltage required to maintain line regulation	T_J = 25°C, I_O ≤ 1 A		7.5			V

(1) All characteristics are measured with a 0.22-μF capacitor from input to ground and a 0.1-μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

6.7 LM340 / LM7812 Electrical Characteristics, V_O = 12 V, V_I = 19 V

0°C ≤ T_J ≤ 125°C unless otherwise specified(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Output voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1 A		11.5	12	12.5	V
		P_D ≤ 15 W, 5 mA ≤ I_O ≤ 1 A 14.5 V ≤ V_{IN} ≤ 27 V		11.4		12.6	V
ΔV_O	Line regulation	I_O = 500 mA	T_J = 25°C 14.5V ≤ V_{IN} ≤ 30V		4	120	mV
			Over temperature 15V ≤ V_{IN} ≤ 27V			120	mV
		I_O ≤ 1 A	T_J = 25°C 14.6V ≤ V_{IN} ≤ 27V			120	mV
			Over temperature 16V ≤ V_{IN} ≤ 22V			60	mV
ΔV_O	Load regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5 A		12	120	mV
			250 mA ≤ I_O ≤ 750 mA			60	mV
		Over temperature, 5 mA ≤ I_O ≤ 1 A				120	mV
I_Q	Quiescent current	I_O ≤ 1 A	T_J = 25°C			8	mA
			Over temperature			8.5	mA
ΔI_Q	Quiescent current change	5 mA ≤ I_O ≤ 1 A			0.5		mA
		T_J = 25°C, I_O ≤ 1 A 14.8 V ≤ V_{IN} ≤ 27 V				1	mA
		Over temperature, I_O ≤ 500 mA 14.5 V ≤ V_{IN} ≤ 30 V				1	mA
V_N	Output noise voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			75		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple rejection	f = 120 Hz 15 V ≤ V_{IN} ≤ 25 V	T_J = 25°C, I_O ≤ 1 A	55	72		dB
			Over temperature, I_O ≤ 500 mA,	55			dB
R_O	Dropout voltage	T_J = 25°C, I_O = 1 A			2		V
	Output resistance	f = 1 kHz			18		mΩ
	Short-circuit current	T_J = 25°C			1.5		A
	Peak output current	T_J = 25°C			2.4		A
	Average TC of V_{OUT}	Over temperature, I_O = 5 mA			−1.5		mV/°C
V_{IN}	Input voltage required to maintain line regulation	T_J = 25°C, I_O ≤ 1 A		14.6			V

(1) All characteristics are measured with a 0.22-μF capacitor from input to ground and a 0.1-μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

6.8 LM340 / LM7815 Electrical Characteristics, V_O = 15 V, V_I = 23 V

0°C ≤ T_J ≤ 125°C unless otherwise specified(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Output voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1 A		14.4	15	15.6	V
		P_D ≤ 15 W, 5 mA ≤ I_O ≤ 1 A 17.5 V ≤ V_{IN} ≤ 30 V		14.25		15.75	V
ΔV_O	Line regulation	I_O = 500 mA	T_J = 25°C 17.5 V ≤ V_{IN} ≤ 30 V		4	150	mV
			Over temperature 18.5 V ≤ V_{IN} ≤ 30 V			150	mV
		I_O ≤ 1 A	T_J = 25°C 17.7 V ≤ V_{IN} ≤ 30 V			150	mV
			Over temperature 20 V ≤ V_{IN} ≤ 26 V			75	mV
ΔV_O	Load regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5 A		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			75	mV
		Over temperature, 5 mA ≤ I_O ≤ 1 A,				150	mV
I_Q	Quiescent current	I_O ≤ 1 A	T_J = 25°C			8	mA
			Over temperature			8.5	mA
ΔI_Q	Quiescent current change	5 mA ≤ I_O ≤ 1 A			0.5		mA
		T_J = 25°C, I_O ≤ 1 A 17.9 V ≤ V_{IN} ≤ 30 V				1	mA
		Over temperature, I_O ≤ 500 mA 17.5 V ≤ V_{IN} ≤ 30 V				1	mA
V_N	Output noise voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple rejection	f = 120 Hz 18.5 V ≤ V_{IN} ≤ 28.5 V	T_J = 25°C, I_O ≤ 1 A	54	70		dB
			Over temperature, I_O ≤ 500 mA,	54			dB
R_O	Dropout voltage	T_J = 25°C, I_O = 1 A			2		V
	Output resistance	f = 1 kHz			19		mΩ
	Short-circuit current	T_J = 25°C			1.2		A
	Peak output current	T_J = 25°C			2.4		A
	Average TC of V_{OUT}	Over temperature, I_O = 5 mA			−1.8		mV/°C
V_{IN}	Input voltage required to maintain line regulation	T_J = 25°C, I_O ≤ 1 A		17.7			V

(1) All characteristics are measured with a 0.22-µF capacitor from input to ground and a 0.1-µF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

6.9 Typical Characteristics

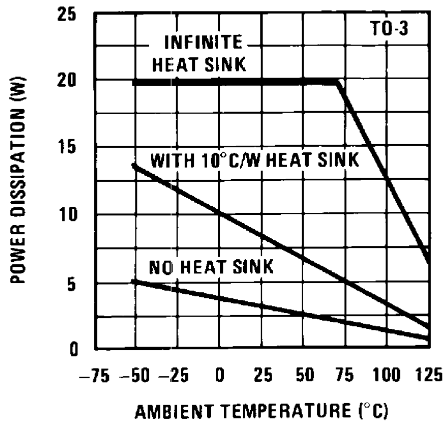


Figure 1. Maximum Average Power Dissipation

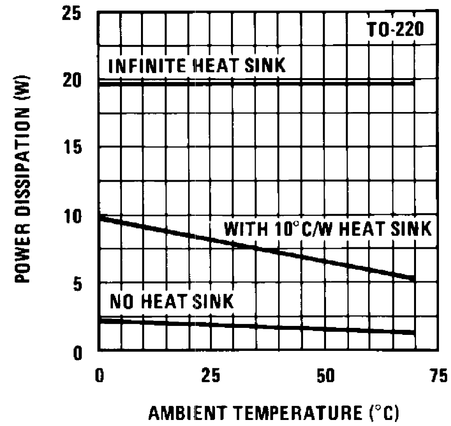


Figure 2. Maximum Average Power Dissipation

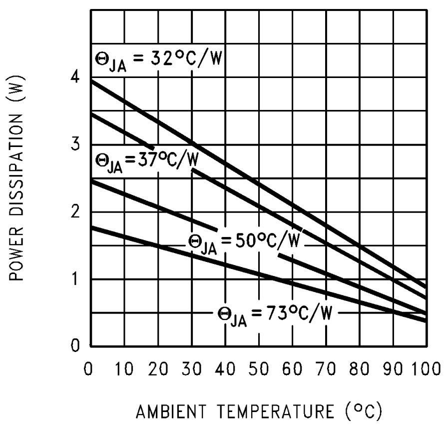
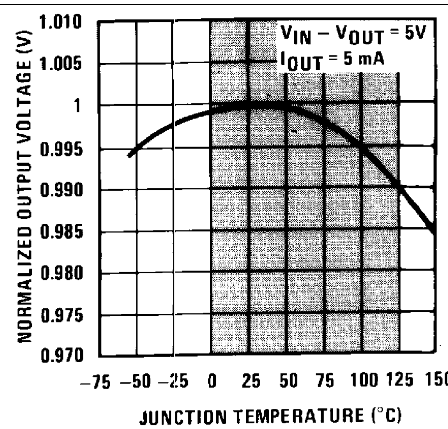


Figure 3. Maximum Power Dissipation (DDPAK/TO-263)



Shaded area refers to LM340A/LM340, LM7805, LM7812 and LM7815.

Figure 4. Output Voltage (Normalized to 1 V at T_J = 25°C)

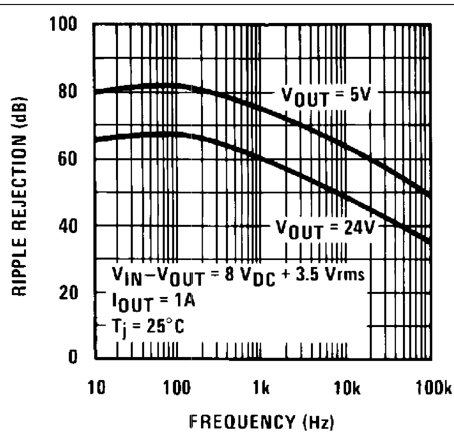


Figure 5. Ripple Rejection

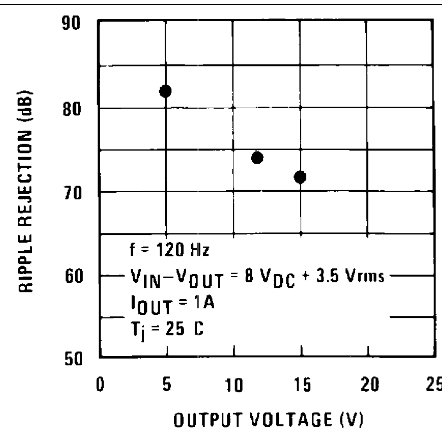


Figure 6. Ripple Rejection

Typical Characteristics (continued)

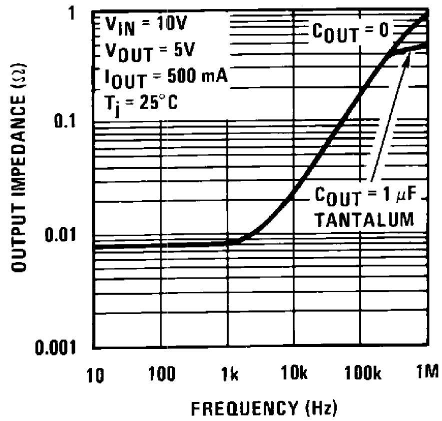


Figure 7. Output Impedance

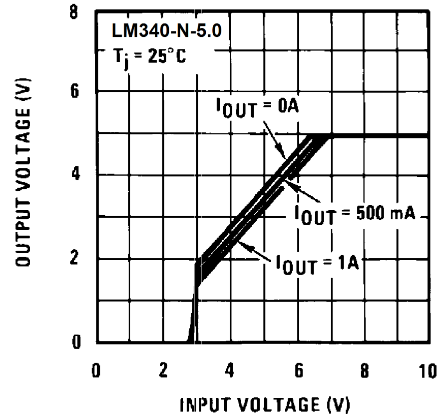
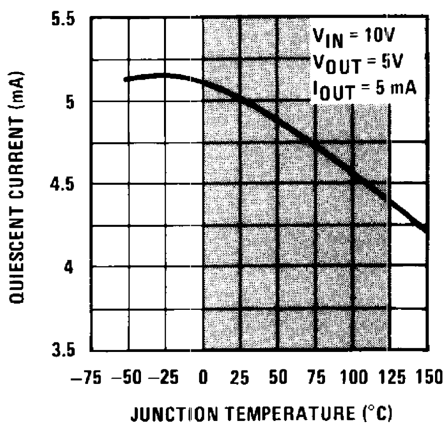


Figure 8. Dropout Characteristics



Shaded area refers to LM340A/LM340, LM7805, LM7812, and LM7815.

Figure 9. Quiescent Current

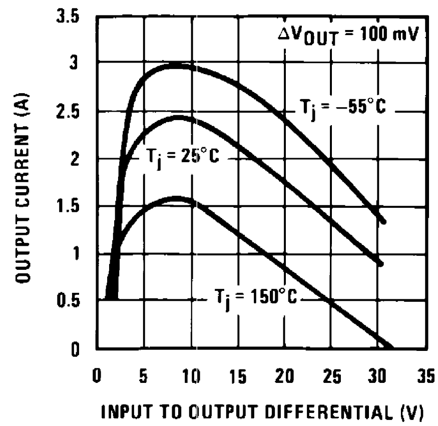
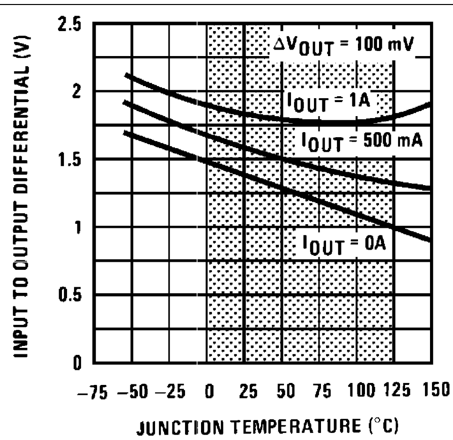


Figure 10. Peak Output Current



Shaded area refers to LM340A/LM340, LM7805, LM7812, and LM7815.

Figure 11. Dropout Voltage

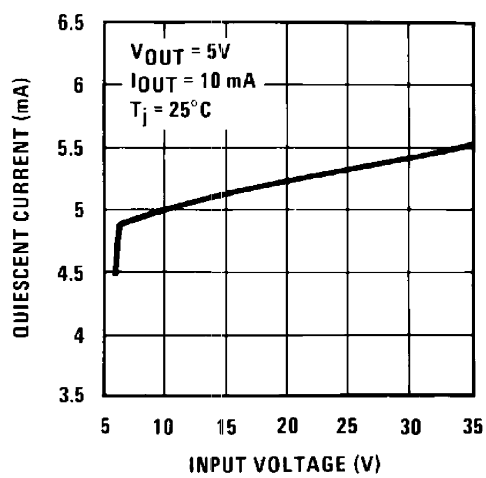
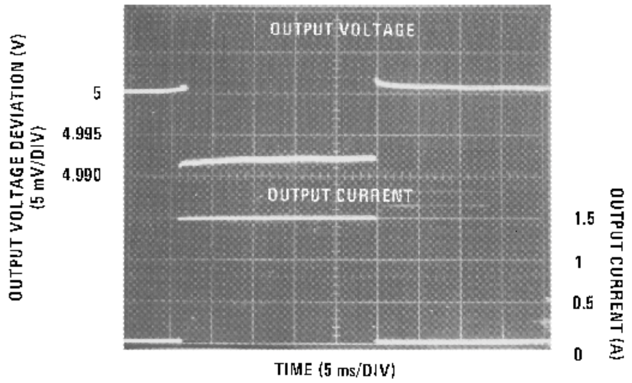


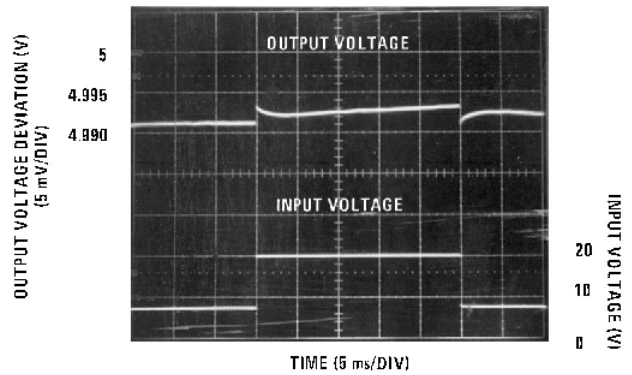
Figure 12. Quiescent Current

Typical Characteristics (continued)



I_{OUT} = 1 A, T_A = 25°C

Figure 13. Line Regulation LM340



V_{IN} = 10 V, T_A = 25°C

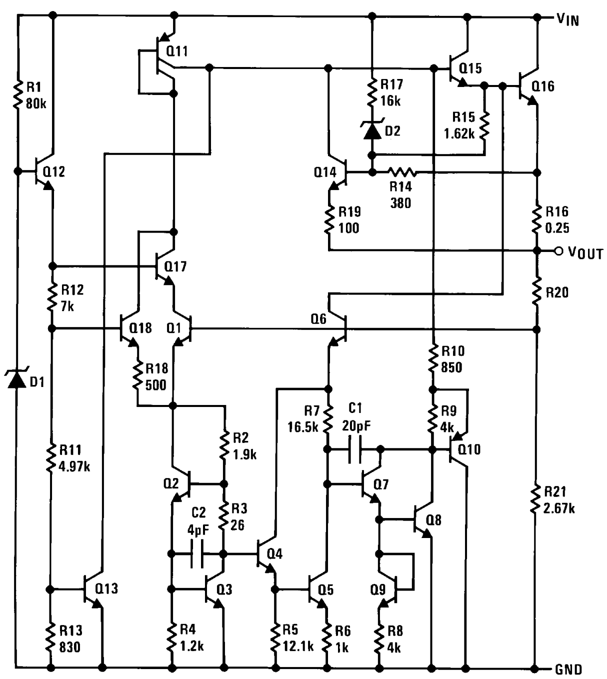
Figure 14. Line Regulation LM340

7 Detailed Description

7.1 Overview

The LM340 and LM7805 devices are a family of fixed output positive voltage regulators with outputs ranging from 3 V to 15 V. They accept up to 35 V of input voltage and with proper heat dissipation can provide over 1.5 A of current. With a combination of current limiting, thermal shutdown, and safe area protection, these regulators eliminate any concern of damage. These features paired with excellent line and load regulation make the LM340 and LM7805 Family versatile solutions to a wide range of power management designs. Although the LM340 and LM7805 Family were designed primarily as fixed-voltage regulators, these devices can be used with external component for adjustable voltage and current.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Output Current

With proper considerations, the LM340 and LM7805 Family can exceed 1.5-A output current. Depending on the desired package option, the effective junction-to-ambient thermal resistance can be reduced through heat sinking, allowing more power to be dissipated in the device.

7.3.2 Current Limiting Feature

In the event of a short circuit at the output of the regulator, each device has an internal current limit to protect it from damage. The typical current limits for the LM340 and LM7805 Family is 2.4 A.

7.3.3 Thermal Shutdown

Each package type employs internal current limiting and thermal shutdown to provide safe operation area protection. If the junction temperature is allowed to rise to 150°C, the device will go into thermal shutdown.

7.4 Device Functional Modes

There are no functional modes for this device.

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The LM340x and LM7805 series is designed with thermal protection, output short-circuit protection, and output transistor safe area protection. However, as with any IC regulator, it becomes necessary to take precautions to assure that the regulator is not inadvertently damaged. The following describes possible misapplications and methods to prevent damage to the regulator.

8.1.1 Shorting the Regulator Input

When using large capacitors at the output of these regulators, a protection diode connected input to output (Figure 15) may be required if the input is shorted to ground. Without the protection diode, an input short causes the input to rapidly approach ground potential, while the output remains near the initial V_{OUT} because of the stored charge in the large output capacitor. The capacitor will then discharge through a large internal input to output diode and parasitic transistors. If the energy released by the capacitor is large enough, this diode, low current metal, and the regulator are destroyed. The fast diode in Figure 15 shunts most of the capacitors discharge current around the regulator. Generally no protection diode is required for values of output capacitance ≤ 10 μF.

8.1.2 Raising the Output Voltage Above the Input Voltage

Because the output of the device does not sink current, forcing the output high can cause damage to internal low current paths in a manner similar to that just described in *Shorting the Regulator Input*.

8.1.3 Regulator Floating Ground

When the ground pin alone becomes disconnected, the output approaches the unregulated input, causing possible damage to other circuits connected to V_{OUT}. If ground is reconnected with power ON, damage may also occur to the regulator. This fault is most likely to occur when plugging in regulators or modules with on card regulators into powered up sockets. The power must be turned off first, the thermal limit ceases operating, or the ground must be connected first if power must be left on. See Figure 16.

8.1.4 Transient Voltages

If transients exceed the maximum rated input voltage of the device, or reach more than 0.8 V below ground and have sufficient energy, they will damage the regulator. The solution is to use a large input capacitor, a series input breakdown diode, a choke, a transient suppressor or a combination of these.

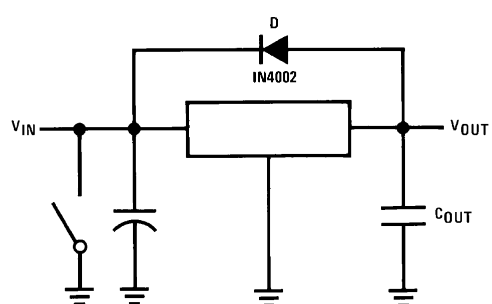


Figure 15. Input Short

Application Information (continued)

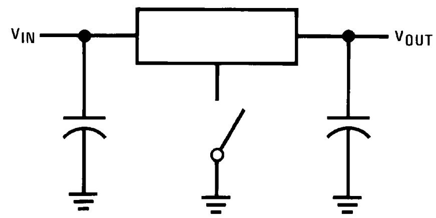


Figure 16. Regulator Floating Ground

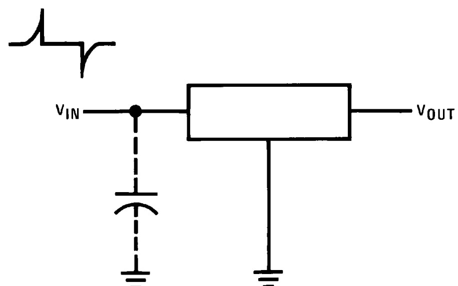


Figure 17. Transients

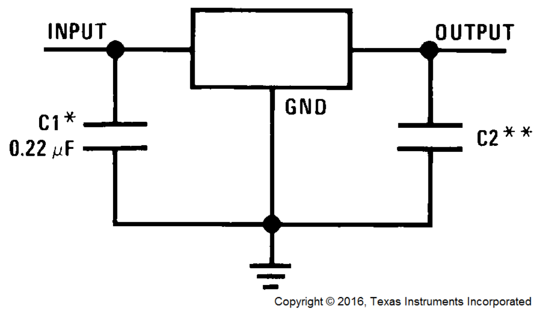
When a value for $\theta_{(H–A)}$ is found, a heat sink must be selected that has *a value that is less than or equal to this number.*

$\theta_{(H–A)}$ is specified numerically by the heat sink manufacturer in this catalog or shown in a curve that plots temperature rise vs power dissipation for the heat sink.

8.2 Typical Applications

8.2.1 Fixed Output Voltage Regulator

The LM340x and LM7805 Family devices are primarily designed to provide fixed output voltage regulation. The simplest implementation of LM340x and LM7805 Family is shown in Figure 18.



*Required if the regulator is located far from the power supply filter.
**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1-μF, ceramic disc).

Figure 18. Fixed Output Voltage Regulator

8.2.1.1 Design Requirements

The device component count is very minimal. Although not required, TI recommends employing bypass capacitors at the output for optimum stability and transient response. These capacitors must be placed as close as possible to the regulator. If the device is located more than 6 inches from the power supply filter, it is required to employ input capacitor.

Typical Applications (continued)

8.2.1.2 Detailed Design Procedure

The output voltage is set based on the device variant. LM340x and LM7805 Family are available in 5-V, 12-V and 15-V regulator options.

8.2.1.3 Application Curve

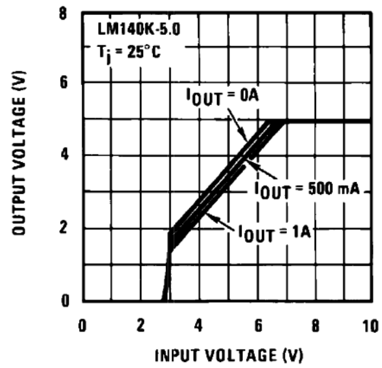
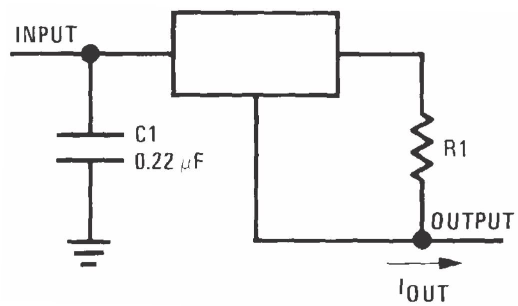


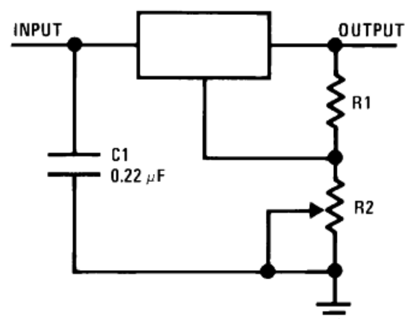
Figure 19. V_{OUT} vs V_{IN}, V_{OUT} = 5 V

8.3 System Examples



I_{OUT} = V2–3 / R1 + I_Q
ΔI_Q = 1.3 mA over line and load changes.

Figure 20. Current Regulator



V_{OUT} = 5 V + (5 V/R1 + I_Q) R2 5 V/R1 > 3 I_Q,
load regulation (L_r) ≈ [(R1 + R2)/R1] (L_r of LM340-5).

Figure 21. Adjustable Output Regulator

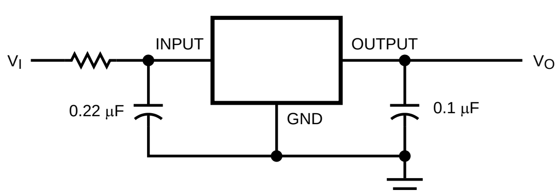


Figure 22. High Input Voltage Circuit With Series Resistor

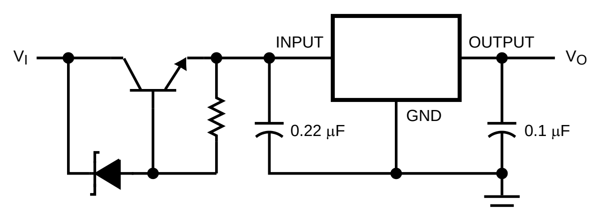
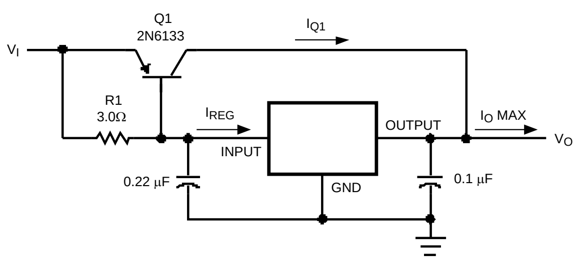


Figure 23. High Input Voltage Circuit implementation With Transistor

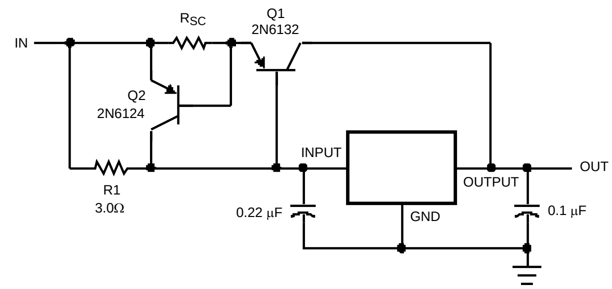
System Examples (continued)



$\beta(Q1) \geq I_{O\ Max} / I_{REG\ Max}$

$R1 = 0.9 / I_{REG} = \beta_{(Q1)} V_{BE(Q1)} / I_{REG\ Max\ (\beta\ +1)} - I_{O\ Max}$

Figure 24. High Current Voltage Regulator



$R_{SC} = 0.8 / I_{SC}$

$R1 = \beta V_{BE(Q1)} / I_{REG\ Max} (\beta +1) - I_{O\ Max}$

Figure 25. High Output Current With Short-Circuit Protection

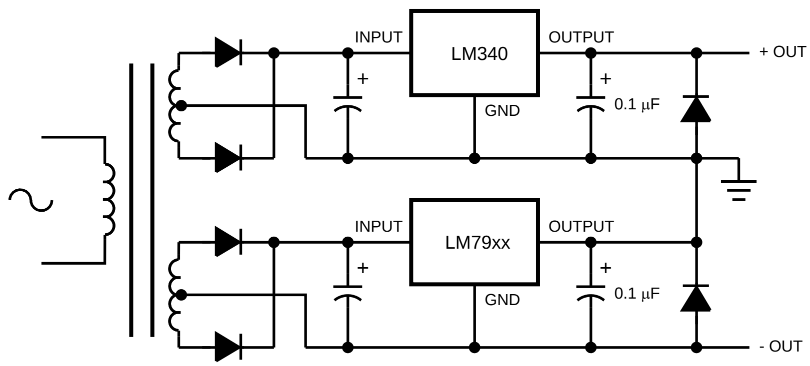


Figure 26. LM340 Used With Negative Regulator LM79xx

9 Power Supply Recommendations

The LM340 is designed to operate from a wide input voltage up to 35 V. Please refer to electrical characteristics tables for the minimum input voltage required for line/load regulation. If the device is more than six inches from the input filter capacitors, an input bypass capacitor, 0.1 μF or greater, of any type is needed for stability.

10 Layout

10.1 Layout Guidelines

Some layout guidelines must be followed to ensure proper regulation of the output voltage with minimum noise. Traces carrying the load current must be wide to reduce the amount of parasitic trace inductance. To improve PSRR, a bypass capacitor can be placed at the OUTPUT pin and must be placed as close as possible to the IC. All that is required for the typical fixed output regulator application circuit is the LM340x/LM7805 Family IC and a 0.22-µF input capacitor if the regulator is placed far from the power supply filter. A 0.1-µF output capacitor is recommended to help with transient response. In cases when VIN shorts to ground, an external diode must be placed from VOUT to VIN to divert the surge current from the output capacitor and protect the IC.

10.2 Layout Example

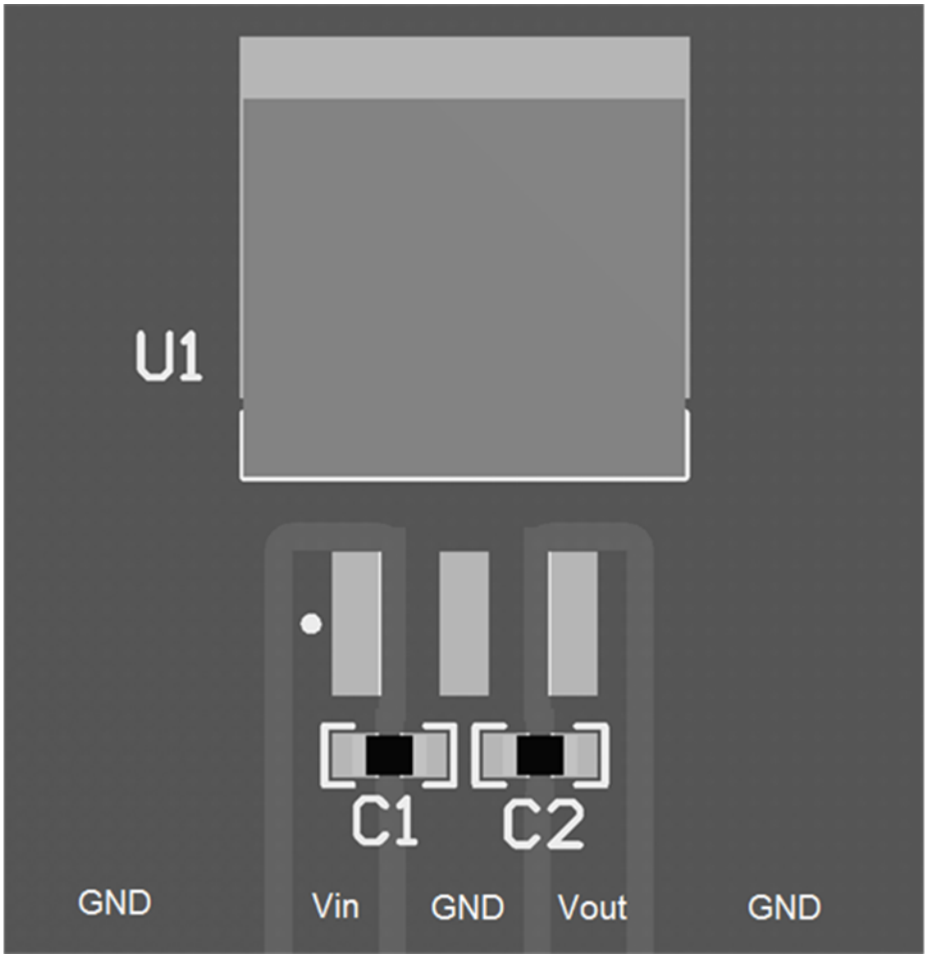


Figure 27. Layout Example DDPAK

Layout Example (continued)

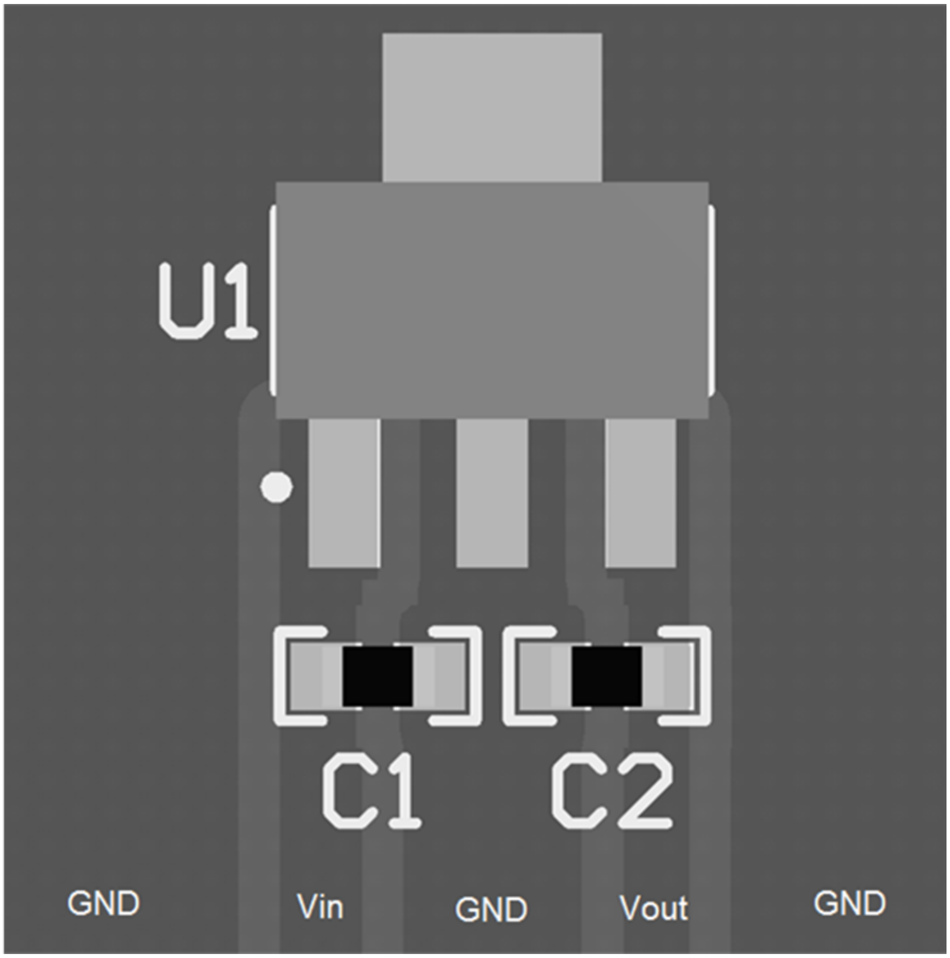


Figure 28. Layout Example SOT-223

10.3 Heat Sinking DDPAK/TO-263 and SOT-223 Package Parts

Both the DDPAK/TO-263 (KTT) and SOT-223 (DCY) packages use a copper plane on the PCB and the PCB itself as a heat sink. To optimize the heat sinking ability of the plane and PCB, solder the tab of the plane.

Figure 29 shows for the DDPAK/TO-263 the measured values of $\theta_{(J-A)}$ for different copper area sizes using a typical PCB with 1-oz copper *and no solder mask over the copper area used for heat sinking*.

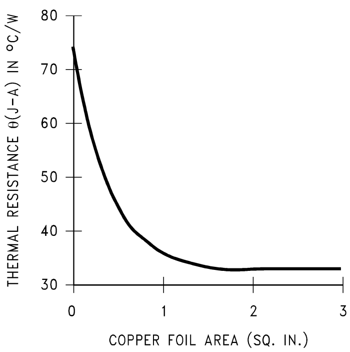


Figure 29. $\theta_{(J-A)}$ vs Copper (1 Ounce) Area for the DDPAK/TO-263 Package

Heat Sinking DDPAK/TO-263 and SOT-223 Package Parts (continued)

As shown in Figure 29, increasing the copper area beyond 1 square inch produces very little improvement. It should also be observed that the minimum value of $\theta_{(J-A)}$ for the DDPAK/TO-263 package mounted to a PCB is 32°C/W.

As a design aid, Figure 30 shows the maximum allowable power dissipation compared to ambient temperature for the DDPAK/TO-263 device (assuming $\theta_{(J-A)}$ is 35°C/W and the maximum junction temperature is 125°C).

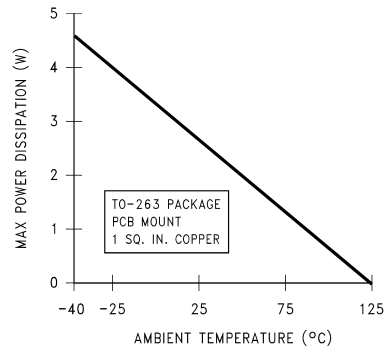


Figure 30. Maximum Power Dissipation vs T_{AMB} for the DDPAK/TO-263 Package

Figure 31 and Figure 32 show the information for the SOT-223 package. Figure 31 assumes a $\theta_{(J-A)}$ of 74°C/W for 1-oz. copper and 51°C/W for 2-oz. copper and a maximum junction temperature of 125°C.

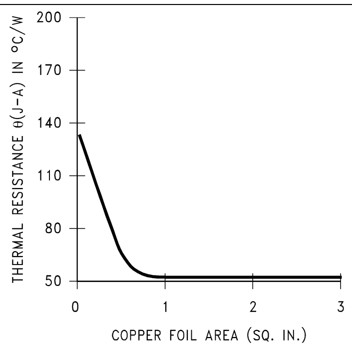


Figure 31. $\theta_{(J-A)}$ vs Copper (2 Ounce) Area for the SOT-223 Package

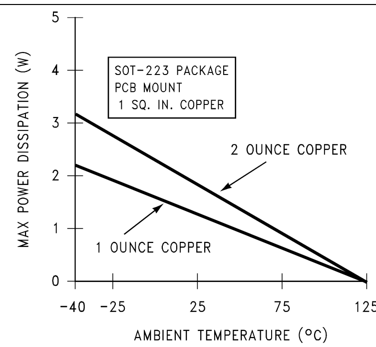


Figure 32. Maximum Power Dissipation vs T_{AMB} for the SOT-223 Package

See *AN-1028 LMX2370 PLLatinum Dual Freq Synth for RF Pers Comm LMX2370 2.5GHz/1.2GHz* (SNVA036) for power enhancement techniques to be used with the SOT-223 package.

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation, see the following:

- *AN-1028 LMX2370 PLLatinum Dual Freq Synth for RF Pers Comm LMX2370 2.5GHz/1.2GHz* (SNVA036)
- *LM140K Series 3-Terminal Positive Regulators* (SNVS994)

11.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 1. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
LM340	Click here	Click here	Click here	Click here	Click here
LM340A	Click here	Click here	Click here	Click here	Click here
LM7805	Click here	Click here	Click here	Click here	Click here
LM7812	Click here	Click here	Click here	Click here	Click here
LM7815	Click here	Click here	Click here	Click here	Click here

11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.4 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.5 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.6 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.7 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM340AT-5.0	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 70	LM340AT 5.0 P+	
LM340AT-5.0/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	0 to 125	LM340AT 5.0 P+	Samples
LM340K-5.0	ACTIVE	TO-3	NDS	2	50	TBD	Call TI	Call TI	0 to 125	LM340K -5.0 7805P+	Samples
LM340K-5.0/NOPB	ACTIVE	TO-3	NDS	2	50	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	0 to 125	LM340K -5.0 7805P+	Samples
LM340MP-5.0	NRND	SOT-223	DCY	4	1000	TBD	Call TI	Call TI	0 to 70	N00A	
LM340MP-5.0/NOPB	ACTIVE	SOT-223	DCY	4	1000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 125	N00A	Samples
LM340MPX-5.0/NOPB	ACTIVE	SOT-223	DCY	4	2000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 125	N00A	Samples
LM340S-12/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -12 P+	Samples
LM340S-5.0	NRND	DDPAK/ TO-263	KTT	3	45	TBD	Call TI	Call TI	0 to 70	LM340S -5.0 P+	
LM340S-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -5.0 P+	Samples
LM340SX-12/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -12 P+	Samples
LM340SX-5.0	NRND	DDPAK/ TO-263	KTT	3	500	TBD	Call TI	Call TI	0 to 70	LM340S -5.0 P+	
LM340SX-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -5.0 P+	Samples
LM340T-12	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 70	LM340T12 7812 P+	
LM340T-12/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM		LM340T12 7812 P+	Samples
LM340T-15	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 70	LM340T15 7815 P+	
LM340T-15/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	0 to 125	LM340T15 7815 P+	Samples
LM340T-5.0	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 70	LM340T5	

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
										7805 P+	
LM340T-5.0/LF01	ACTIVE	TO-220	NDG	3	45	Green (RoHS & no Sb/Br)	SN	Level-4-260C-72 HR	0 to 125	LM340T5 7805 P+	Samples
LM340T-5.0/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	0 to 125	LM340T5 7805 P+	Samples
LM7805CT	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 125	LM340T5 7805 P+	
LM7805CT/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	0 to 125	LM340T5 7805 P+	Samples
LM7805MP/NOPB	ACTIVE	SOT-223	DCY	4	1000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 125	N00A	Samples
LM7805MPX/NOPB	ACTIVE	SOT-223	DCY	4	2000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 125	N00A	Samples
LM7805S/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -5.0 P+	Samples
LM7805SX/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -5.0 P+	Samples
LM7812CT/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	-40 to 125	LM340T12 7812 P+	Samples
LM7812S/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -12 P+	Samples
LM7812SX/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	SN	Level-3-245C-168 HR	0 to 125	LM340S -12 P+	Samples
LM7815CT/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	SN	Level-1-NA-UNLIM	0 to 125	LM340T15 7815 P+	Samples
LM78S40CN/NOPB	ACTIVE	PDIP	NFG	16	25	Pb-Free (RoHS)	SN	Level-1-NA-UNLIM	0 to 70	LM78S40CN	Samples
LM78S40N/NOPB	ACTIVE	PDIP	NFG	16	25	Pb-Free (RoHS)	SN	Level-1-NA-UNLIM	0 to 125	LM78S40N	Samples

(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] **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

[4] There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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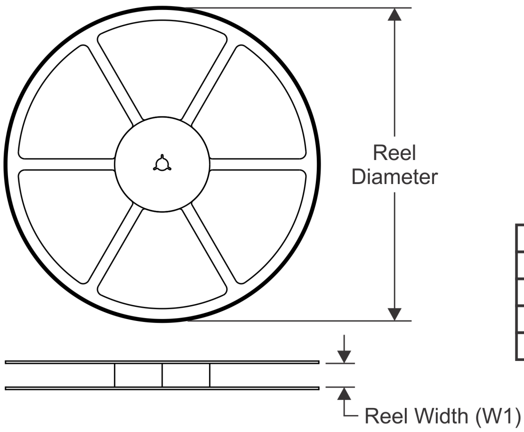
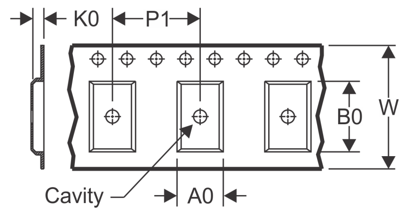
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

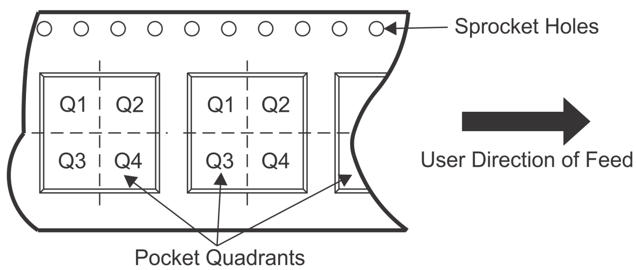


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

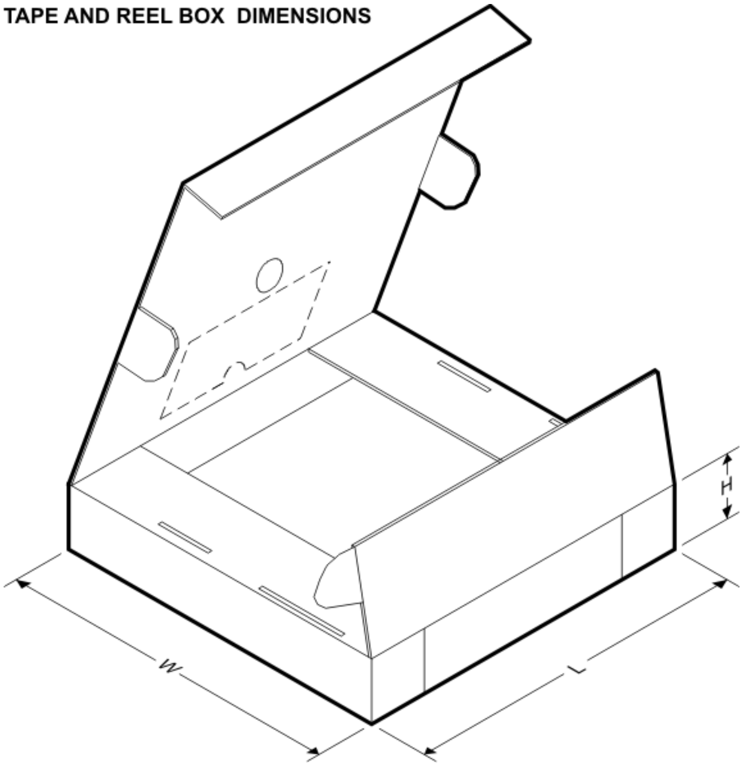
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM340MP-5.0	SOT-223	DCY	4	1000	330.0	16.4	7.0	7.5	2.2	12.0	16.0	Q3
LM340MP-5.0/NOPB	SOT-223	DCY	4	1000	330.0	16.4	7.0	7.5	2.2	12.0	16.0	Q3
LM340MPX-5.0/NOPB	SOT-223	DCY	4	2000	330.0	16.4	7.0	7.5	2.2	12.0	16.0	Q3
LM340SX-12/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM340SX-5.0	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM340SX-5.0/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM7805MP/NOPB	SOT-223	DCY	4	1000	330.0	16.4	7.0	7.5	2.2	12.0	16.0	Q3
LM7805MPX/NOPB	SOT-223	DCY	4	2000	330.0	16.4	7.0	7.5	2.2	12.0	16.0	Q3
LM7805SX/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM7812SX/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2

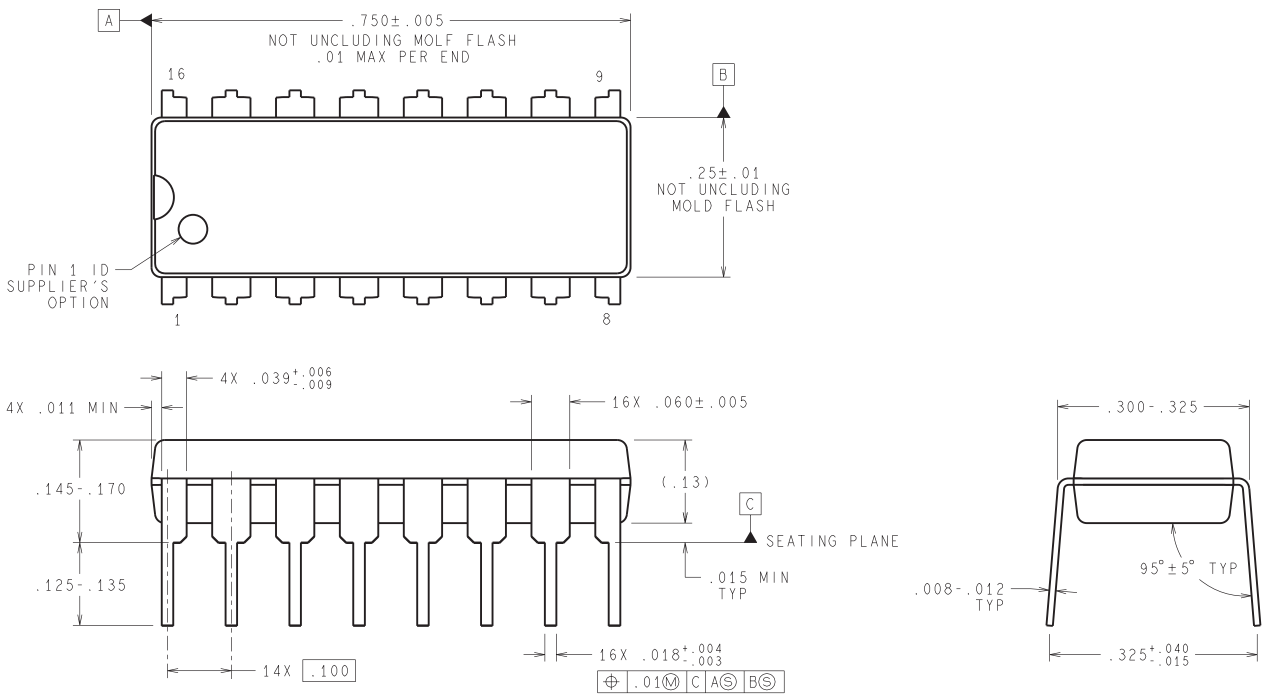
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM340MP-5.0	SOT-223	DCY	4	1000	367.0	367.0	35.0
LM340MP-5.0/NOPB	SOT-223	DCY	4	1000	367.0	367.0	35.0
LM340MPX-5.0/NOPB	SOT-223	DCY	4	2000	367.0	367.0	35.0
LM340SX-12/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM340SX-5.0	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM340SX-5.0/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM7805MP/NOPB	SOT-223	DCY	4	1000	367.0	367.0	35.0
LM7805MPX/NOPB	SOT-223	DCY	4	2000	367.0	367.0	35.0
LM7805SX/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM7812SX/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0

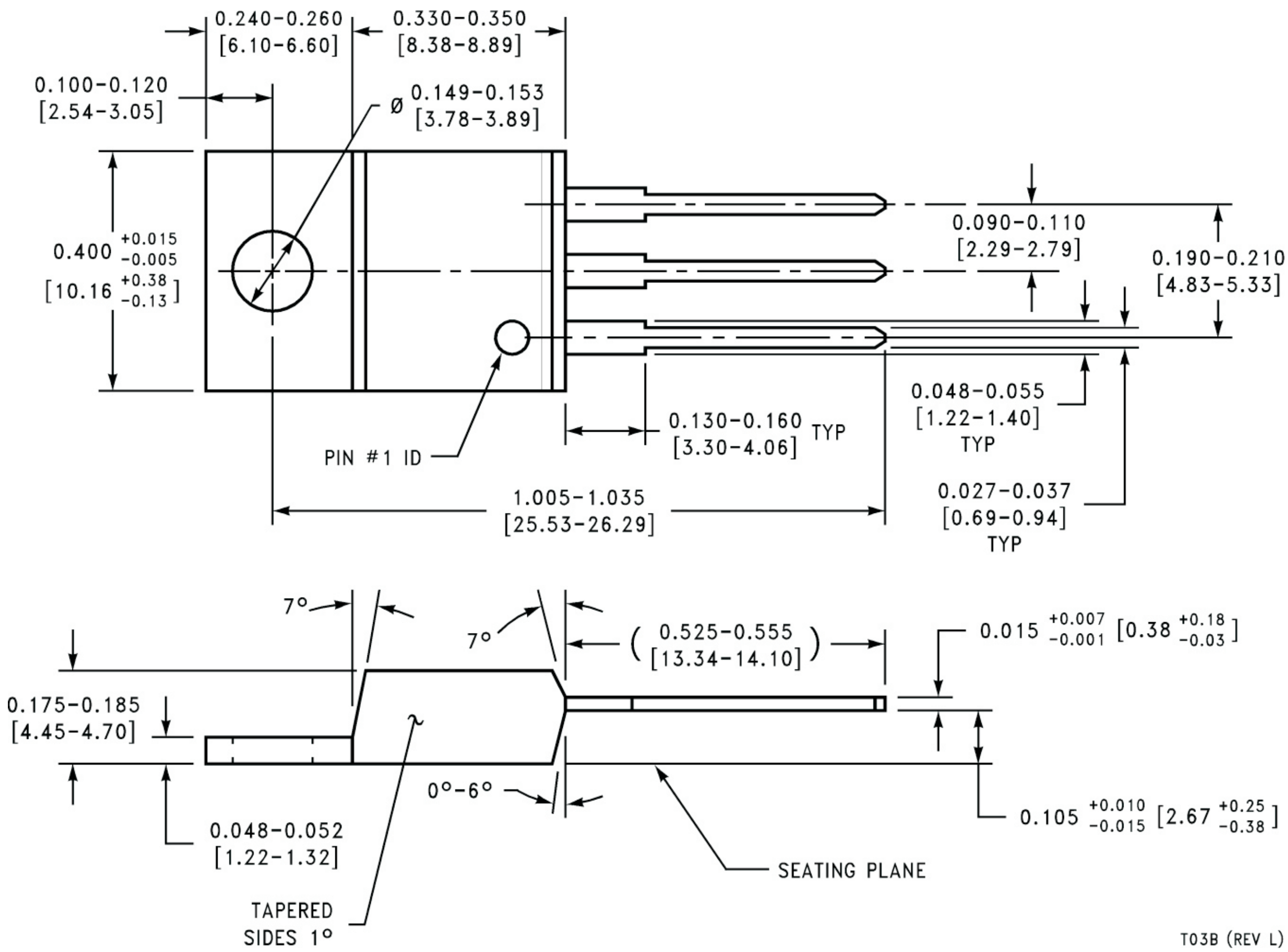
NFG0016E



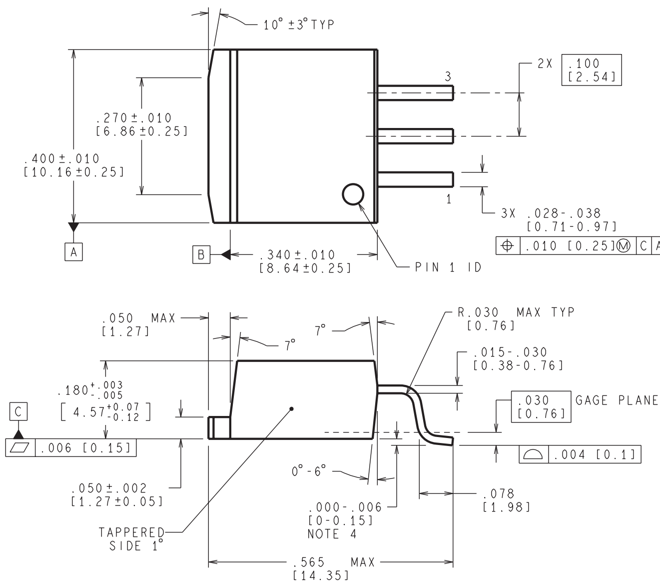
DIMENSIONS ARE IN INCHES
DIMENSIONS IN ( ) FOR REFERENCE ONLY

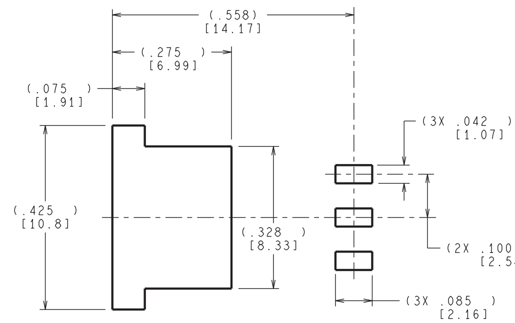
N16E (Rev G)

NDE0003B

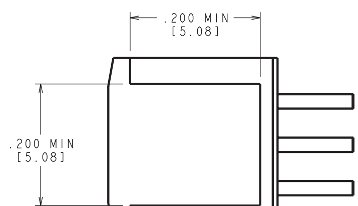

0.240–0.260
[6.10–6.60]
0.330–0.350
[8.38–8.89]
0.100–0.120
[2.54–3.05]
Ø 0.149–0.153
[3.78–3.89]
0.400 +0.015 −0.005
[10.16 +0.38 −0.13]
0.090–0.110
[2.29–2.79]
0.190–0.210
[4.83–5.33]
0.048–0.055
[1.22–1.40]
TYP
0.130–0.160 TYP
[3.30–4.06]
PIN #1 ID
1.005–1.035
[25.53–26.29]
0.027–0.037
[0.69–0.94]
TYP
7°
7°
(0.525–0.555
[13.34–14.10])
0.015 +0.007 −0.001 [0.38 +0.18 −0.03]
0.175–0.185
[4.45–4.70]
0°–6°
0.105 +0.010 −0.015 [2.67 +0.25 −0.38]
0.048–0.052
[1.22–1.32]
SEATING PLANE
TAPERED
SIDES 1°
T03B (REV L)

KTT0003B





LAND PATTERN RECOMMENDATION

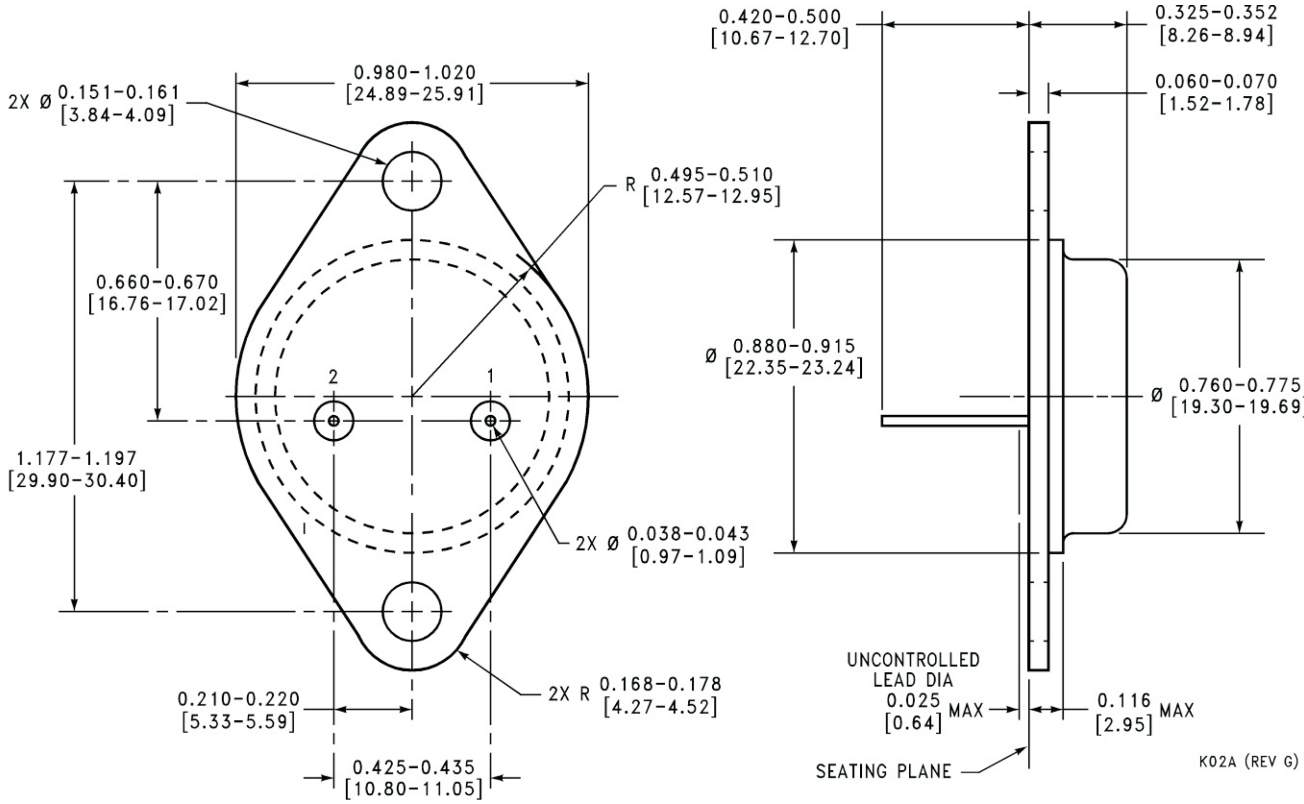


CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY

TS3B (Rev F)

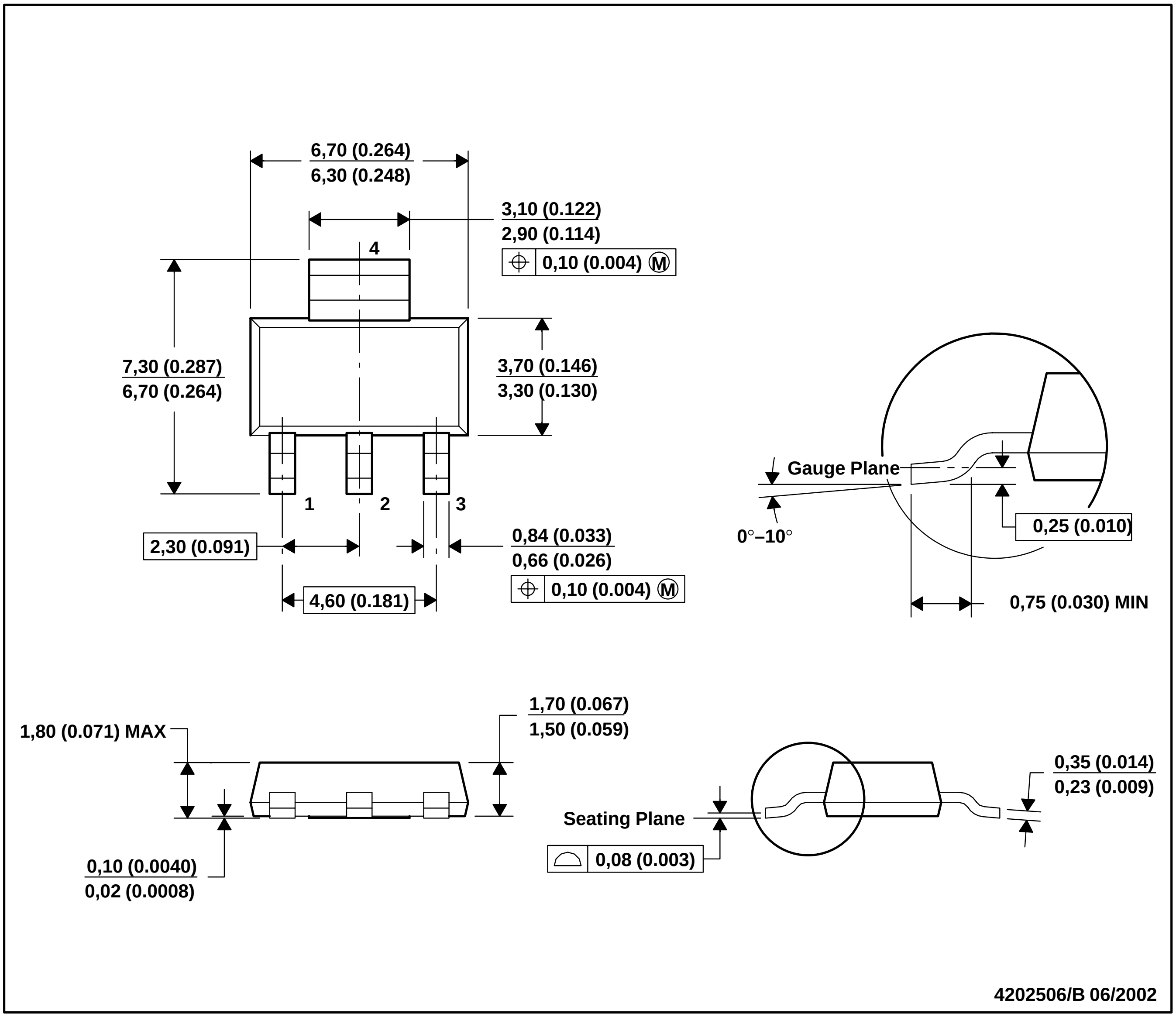
BOTTOM SIDE OF PACKAGE

NDS0002A



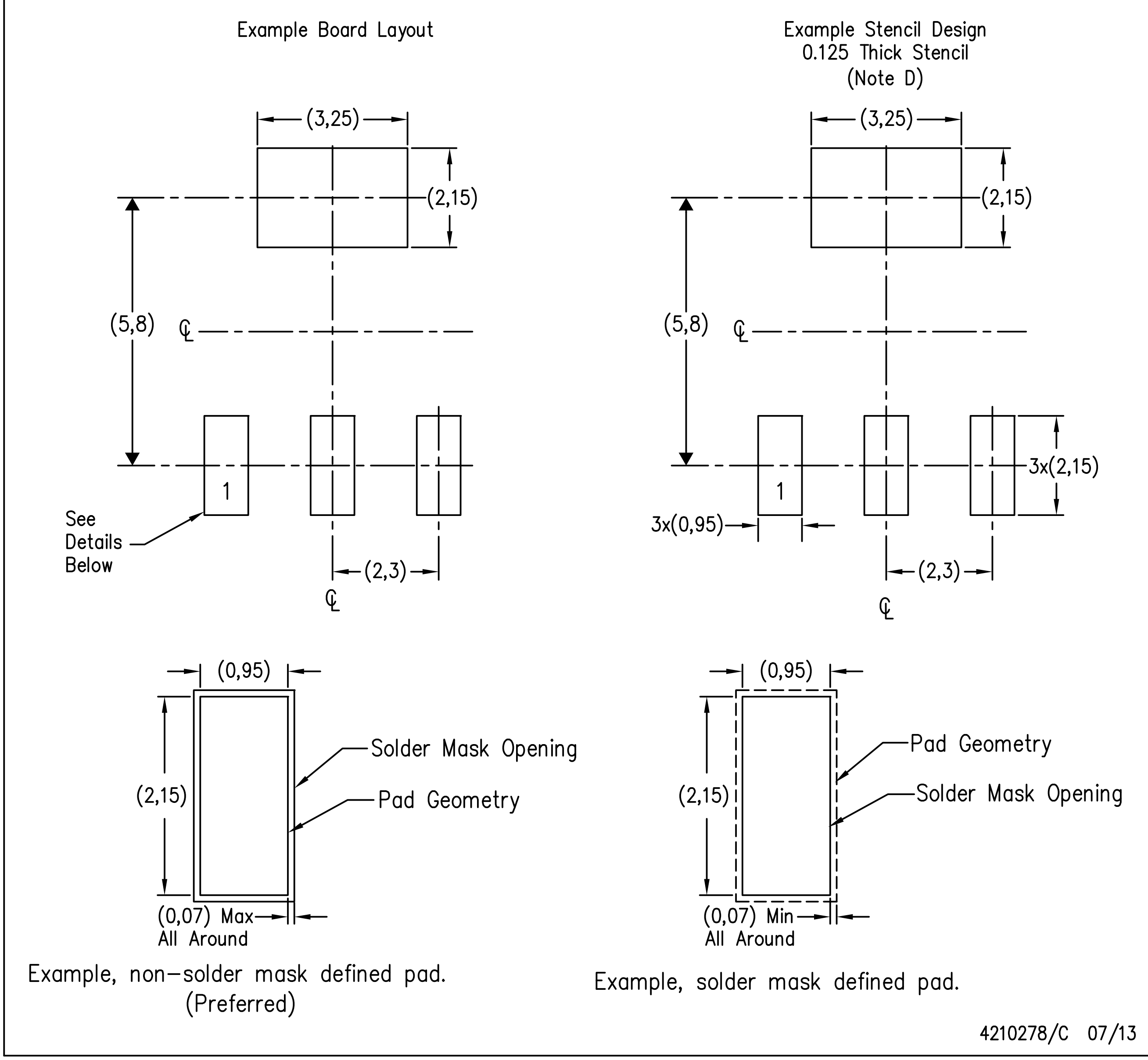
2X Ø 0.151-0.161 [3.84-4.09]
0.980-1.020 [24.89-25.91]
R 0.495-0.510 [12.57-12.95]
0.660-0.670 [16.76-17.02]
1.177-1.197 [29.90-30.40]
2
1
2X Ø 0.038-0.043 [0.97-1.09]
2X R 0.168-0.178 [4.27-4.52]
0.210-0.220 [5.33-5.59]
0.425-0.435 [10.80-11.05]
0.420-0.500 [10.67-12.70]
0.325-0.352 [8.26-8.94]
0.060-0.070 [1.52-1.78]
Ø 0.880-0.915 [22.35-23.24]
Ø 0.760-0.775 [19.30-19.69]
UNCONTROLLED LEAD DIA
0.025 [0.64] MAX
0.116 [2.95] MAX
SEATING PLANE
K02A (REV G)

DCY (R-PDSO-G4) **PLASTIC SMALL-OUTLINE**



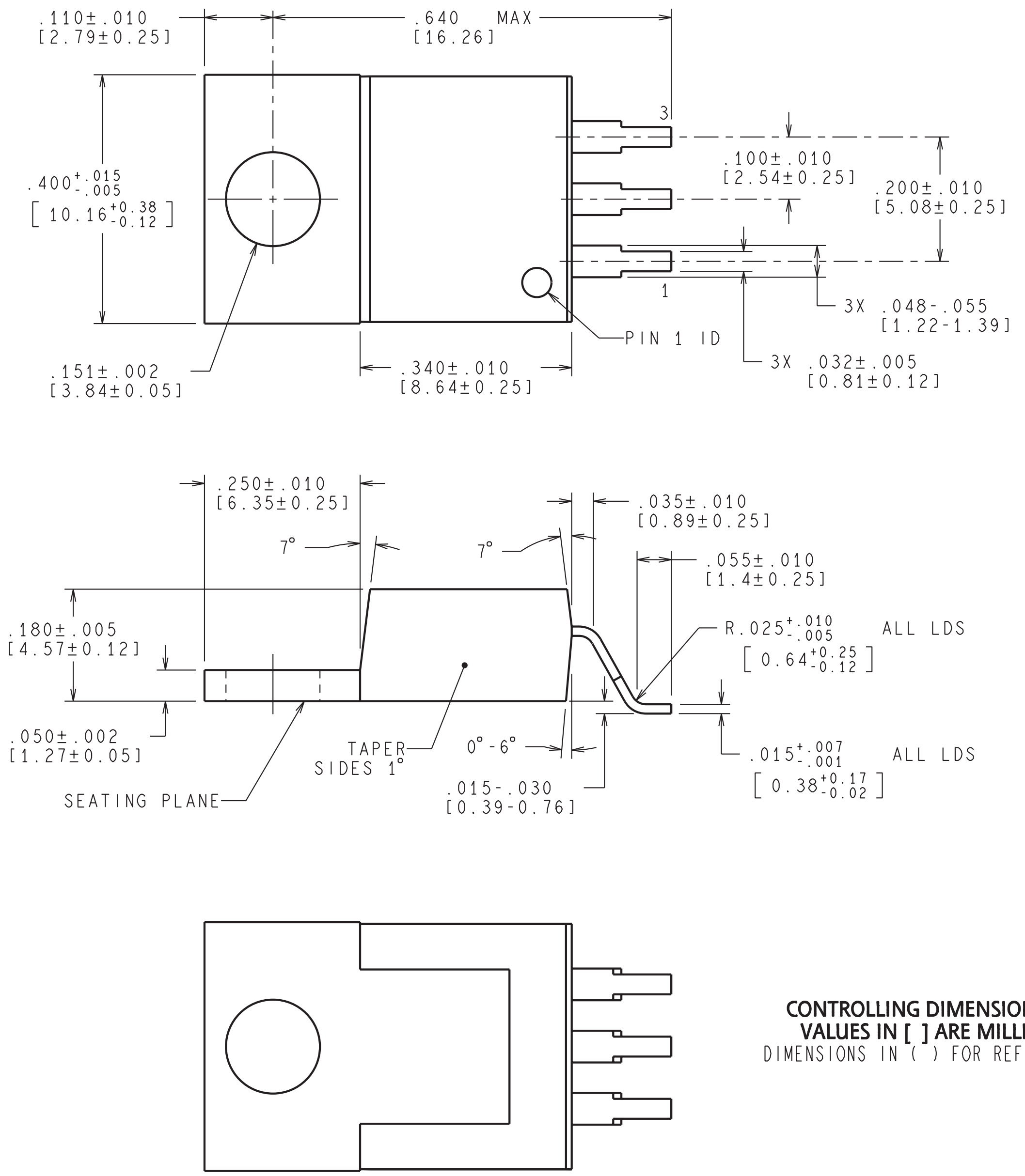
NOTES: A. All linear dimensions are in millimeters (inches).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. Falls within JEDEC TO-261 Variation AA.

DCY (R–PDSO–G4) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil recommendations. Refer to IPC 7525 for stencil design considerations.

NDG0003F



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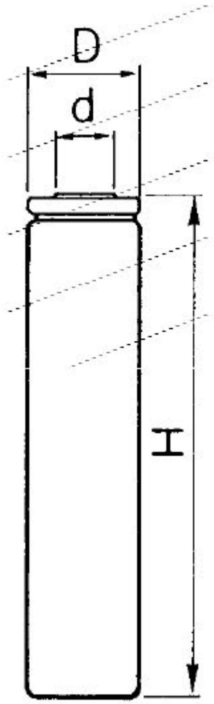
VALUES IN [ ] ARE MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY

T03F (Rev B)

IMPORTANT NOTICE AND DISCLAIMER

Cell Type NCR18650B

Specifications

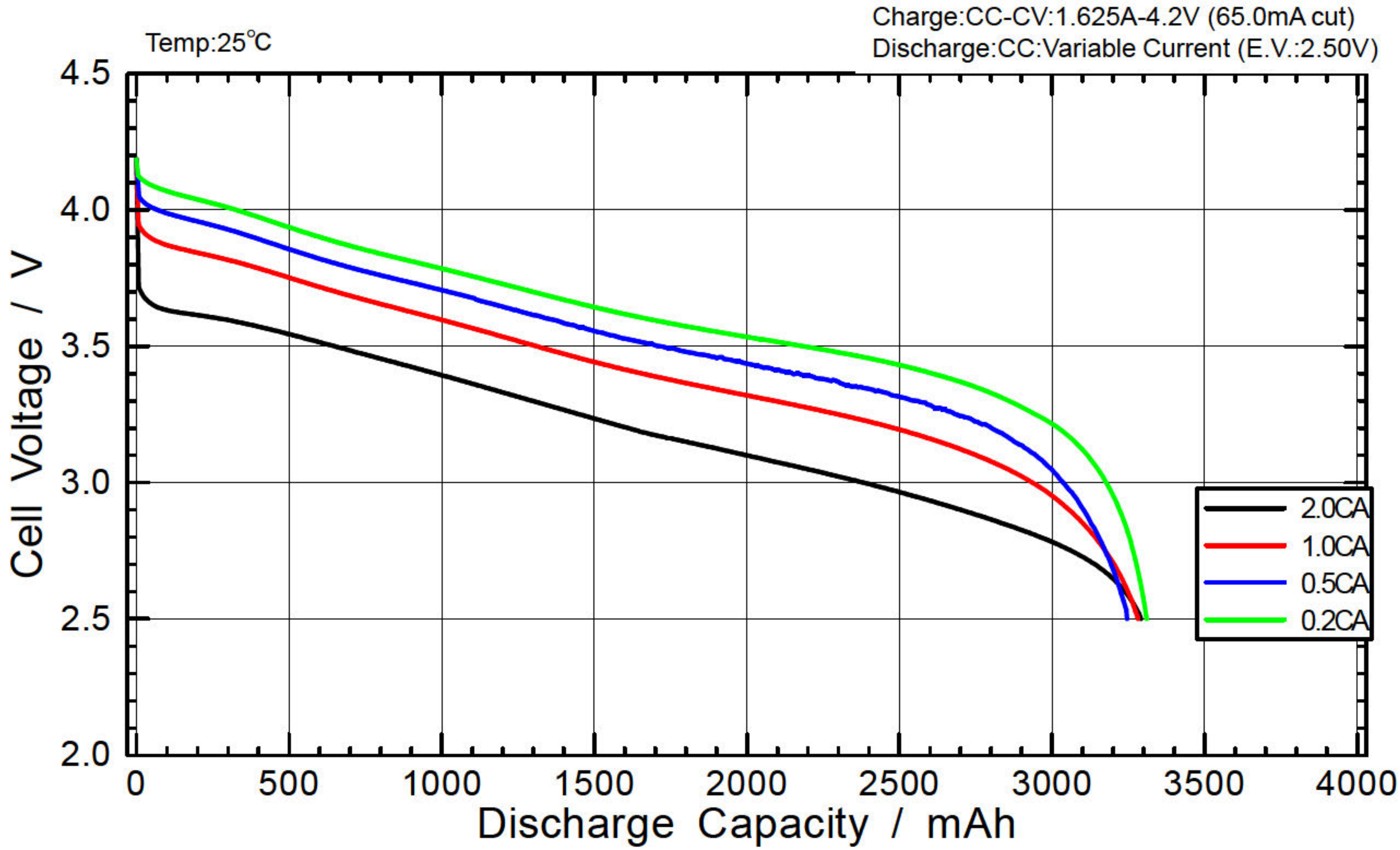


Dimensions(Typ.) of Bare Cell		
	H	64.93mm
	D	18.2mm
	d	7.9mm

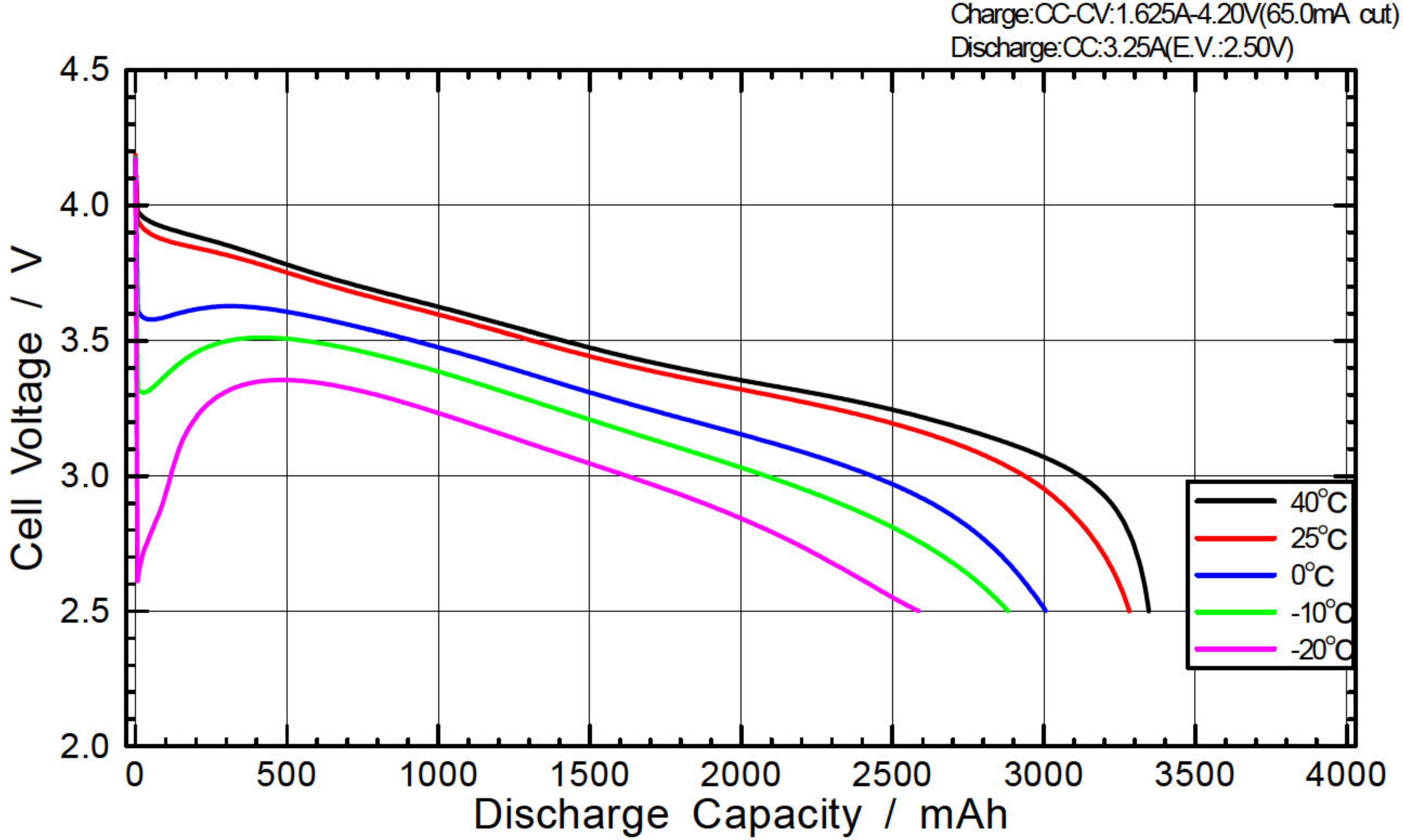
Discharged State after Assembling

Rated Capacity (at 20℃)		Min.3200mAh
Nominal Capacity (at 25℃)		Min.3250mAh
		Typ.3350mAh
Nominal Voltage		3.6V
Charging Method		Constant Current -Constant Voltage
Charging Voltage		4.2V
Charging Current		Std.1625mA
Charging Time		4.0hrs.
Ambient Temperature	Charge	+10～+45℃
	Discharge	-20～+60℃
	Storage	-20～+50℃
Weight (Max.)		47.5g
Dimensions (Max.) Maximum size without tube	(D)	18.25mm
	(H)	65.10mm
Volumetric Energy Density		676Wh/l
Gravimetric Energy Density		243Wh/kg

Discharge Rate Characteristics for NCR18650B



Discharge Temperature Characteristics for NCR18650B



Charge Characteristics for NCR18650B