DISEÑO E IMPLEMENTACIÓN DE SISTEMA DE MONITOREO PARA EQUIPO FERMENTADOR DE CAFÉ

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FACULTAD DE INGENÍERIA
PROGRAMA DE INGENIERIA ELECTRÓNICA
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Proyecto de grado presentado como requisito para optar al título de Ingeniero Electrónico

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A **JOSE ONIAS Y MIRIAM**, gran fortuna tener a los obreros
de la vida como maestros y como padres.
A **MIS HERMANOS**, en la cumbre prometida los estoy esperando
AL **ALMA MATER**, por fundamentar el individuo que soy y encausar mi
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A todas aquellas personas que hicieron parte de mí
formación como persona y como profesional

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GLOSARIO

FERMENTACIÓN: proceso de transformación de un sustrato orgánico producido por enzimas de bacterias, levaduras u hongos en el cual se pueden liberar gases o no. La transformación se realiza mediante reacciones de oxidación-reducción catalizadas por enzimas a través de las cuales muchos microorganismos pueden obtener energía y, como productos residuales, alcoholes y ácidos orgánicos.

LABVIEW: entorno de desarrollo de programación en lenguaje gráfico.

MYSQL: es un sistema de gestión de bases de datos (SGBD) multiusuario, multiplataforma y de código abierto.

SENSOR: un sensor es un dispositivo capaz de detectar magnitudes físicas o químicas, llamadas variables de instrumentación, y transformarlas en variables eléctricas.

CAFÉ: se denomina *café* a la bebida (infusión) que se obtiene a partir de las semillas tostadas y molidas de los frutos de la planta de *café* o cafeto (*Coffea*).

PH: la palabra pH es la abreviatura de "*pondus Hydrogenium*". Esto significa literalmente el peso del hidrógeno. El pH es un indicador del número de iones de hidrógeno que dan como resultado la acidez o alcalinidad de una disolución.

TEMPERATURA: la temperatura es una medida del calor o energía térmica de las partículas en una sustancia.

HUMEDAD: agua u otro líquido que impregna la superficie o el interior de un cuerpo, o presente en el aire en forma de vapor.

PIC (Peripheral Interface Controller): familia de microcontroladores fabricados por Microchip Technology Inc. y derivados del PIC1650, originalmente desarrollado por la división de microelectrónica de General Instrument.

RESUMEN

El proyecto consiste en el diseño e implementación de un sistema de monitoreo de un fermentador de café, se instaló un lote de sensores que permiten obtener en tiempo real las condiciones en que se encuentra el grano de café en fermentación en cuanto a temperatura, humedad, pH y peso teniendo con estos datos suficiente información para determinar cuando el proceso está terminado y pasar al lavado del café.

Se desarrolla una interfaz en Labview 2010, la cual cuenta con la visualización y la evolución de las variables medidas, así como la gestión de la base de datos creada en MYSQL, con opciones de crear, deshacer y exportar a excel la información de los registros para su posterior análisis. Se incorporó el monitoreo remoto en internet donde se tendrá le interfaz con toda la información y el estado del proceso.

El dispositivo se equipo con tecnología Zigbee para comunicarse con el computador, este instrumento trabaja bajo el estándar IEEE 802.15.4 de redes inalámbricas de área personal, permite que el fermentador sea portátil en un rango de 1000 metros con línea de vista y 500 metros en interiores.

Palabras claves: Labview, MYSQL, IEEE, Monitoreo, Fermentador, Café

ABSTRACT

The project is about designing and implementing of a monitoring system for a coffee fermenter. This machine has got a batch of sensors that allow getting real-time temperature, humidity, pH and weight conditions during fermentation process. These data are enough information to determine the ending process in order to start the washing coffee process.

The interface was developed in Labview 2010, which shows the evolution of the measured variables, also, a database created in MySQL, which has the options to create and export to excel the record information for analysis. This work has remote monitoring internet where users can access to all the information and status of the process.

The device is equipped with Zigbee technology to communicate with the computer, this instrument works on the IEEE 802.15.4 standard for wireless personal area networks, allows the fermenter being portable in a range of 1000 meters with a line of view and 500 meters indoor.

Keywords: Labview, MYSQL, IEEE, Monitoring, Fermenter, Coffee

INTRODUCCIÓN

Tradicionalmente el café ha sido el producto de mayor exportación en Colombia y la base de su economía nacional. En este contexto el departamento del Huila como región caficultora en el mes de noviembre del 2011 se ratificó como el primer productor de café en el país, con un 16.01% de la producción nacional. Sin embargo una de las principales dificultades que enfrenta el gremio es que solo el 56% de los caficultores cuentan con asistencia técnica (Diario del Huila., 2011, versión web), esta es una de las grandes premisas para el desarrollo del proyecto de monitoreo de fermentación de café.

El proceso de fermentado es una de la etapas más delicadas en el beneficio del café, este procedimiento es la licuefacción del mucilago por medio de enzimas y bacterias, que hacen que a medida que la descomposición avanza el PH disminuye, la temperatura en la pila de fermentación aumenta, el grano pierde peso. Cuando no se realiza un seguimiento a estas variables puede ocurrir una sobre fermentación dando como resultado cafés de baja calidad con sabores como: vinagre, guayaba, rancio, piña madura, condiciones que devalúan el precio del grano.

El equipo implementado, cuenta con un tanque de fermentación ubicado sobre una plataforma de pesaje que posee cuatro celdas de carga que monitorean el comportamiento másico del grano. Se instaló un lote de sensores que proporcionan la evolución de las diferentes variables que intervienen en al proceso como son PH, temperatura y humedad relativa. Toda la información recolectada por los sensores es enviada vía inalámbrica hasta un ordenador donde se desarrollo una aplicación en Labview la cual nos permite una completa administración de la información ya que cuenta con opciones para almacenar, visualizar, graficar y generar reportes a excel de las tablas para un análisis posterior.

El equipo desarrollado contribuirá al conocimiento detallado del proceso de fermentación y a tomar una mejor decisión del momento en que se debe llevar el grano al lavado para obtener cafés de alta calidad y de cualidades que se pueden manipular ya que podemos hacer que el café se fermente más o menos de una forma controlada buscando la incidencia de una manera cuantitativa de la fermentación en el procesado del café.

Este fermentador fortalecerá la investigación de grupos que buscan siempre mejorar la calidad en los granos, para así obtener mayores ingresos y ser competitivos en mercados nacionales e internacionales.

1. OBJETIVOS

1.1 OBJETIVO GENERAL

Diseñar e implementar un sistema de monitoreo de equipo fermentador de café para el programa de Ingeniería Agrícola de la Universidad Surcolombiana.

1.2 OBJETIVOS ESPECÍFICOS

- ✓ Instalar un lote de sensores de bajo costo y altas prestaciones para monitorear temperatura, PH, humedad relativa y comportamiento másico del café en fermentación.

- ✓ Diseñar un sistema de alarma ajustable para las variables monitoreadas según las necesidades del usuario.

- ✓ Diseñar e implementar una tarjeta electrónica para adquisición y transmisión de datos bajo estándar IEEE 802.15.4 para redes inalámbricas de área personal.

- ✓ Diseñar e implementar software que permita visualizar, generar reportes y almacenar en una base de datos los valores de las variables monitoreadas.

2. MARCO TEÓRICO

2.1 EL CAFÉ

La planta de café pertenece a la familia *Rubiaceae,* la cual comprende 500 géneros y más de 6000 especies, son plantas tropicales y se encuentran en los estratos más bajos de los bosques. *Coffea* es el género de las rubíaceas (*Rubiaceae*) más importante económicamente y está dividida en cinco subsecciones así: de acuerdo a la altura de los árboles (*Nanocoffea*), grosor de la hoja *(Pachycoffea*), color del fruto (*Erythrocoffea, Melanocoffea*) y la distribución geográfica (*Mozambicoffea*), este género contiene alrededor de 100 especies entre estas *Coffea Arabica (Arabica)* (Figura 1) *y Coffea canephora (Robusta),* las cuales representan el 70% y 80% respectivamente del café comercial (Charrier A-Berthaut J,1985) (Bolívar - Forero, C.P., 2009).

Figura 1. Planta de café. (*Coffea arabica*).

Fuente:http://www.taringa.net/posts/imagenes/1501385/Cafe___mmm-que-rico-asi-comienza-todo.html

El fruto del café es una drupa, es de forma ovalada ligeramente aplanada, está compuesto por dos semillas plano convexas separado por el surco. El fruto es de color verde inicialmente luego se torna amarillo y finalmente rojo, aunque algunas variedades maduran de color amarillo.
El tiempo que transcurre desde la florescencia hasta la madures del fruto depende de cada especie:

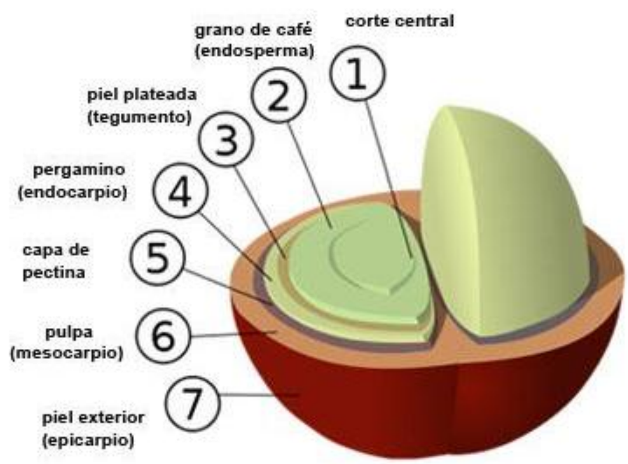
Tabla 1. Tiempo de maduración del grano.

ESPECIE	TIEMPO
Coffe arábica	6-8 meses
Coffe canephora	9-11 meses
Coffe liberica	11-14 meses

Fuente:http://academic.uprm.edu/mmonroig/id53.htm

Partes que componen el grano (Figura 2):

Epicarpio (cutícula, cascara, pulpa). Parte exterior del fruto de color rojo o amarillo en su madurez que cubre y protege las demás partes de la cereza.
Mesocarpio (mucílago, baba). Cubierta de consistencia gelatinosa que cubre las almendras, de color cremoso.
Endocarpio (pergamino, cascarilla). Parte corácea de color crema a marrón que envuelve la semilla.
Espermoderma (película plateada). Cubre la semilla o almendra (tegumento seminal).
Endospermo. Semilla propiamente constituida.
Embrión. Localizado en la superficie convexa de la semilla y representado por un hipocotíleo y dos cotiledones.
Figura 2. Estructura interna del fruto y grano del café.



Fuente:http://irati.pnte.cfnavarra.es/multiblog/gangsval/2012/05/14/estructura-del-fruto-y-grano-del-cafeto/

En Colombia entre las principales variedades de café que se cultivan se encuentra: *Caturra, Borbón, Variedad Colombia, Variedad Castilla,* todas estas pertenecen a la especie *Coffea arabica,* las cuales producen cafés suaves (Bolívar - Forero, C.P., 2009). En el país el café se cultiva en zonas ubicadas entre los 1 y 11° de latitud Norte, 74 a 78° latitud Oeste y altitudes de los 1000 a 2000 msnm, su ubicación geográfica corresponde a los departamentos de Antioquia, Boyacá, Caldas, Cauca, Cesar, Cundinamarca, La Guajira, Huila, Magdalena, Nariño, Norte de Santander, Quindío Risaralda, Santander, Tolima y Valle del Cauca, en su mayoría, áreas de la región Andina (Roa, G. et al., 1999)

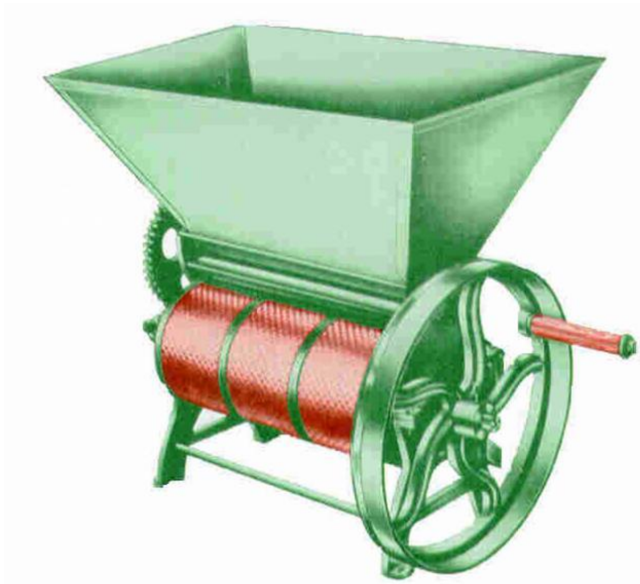
2.1.1 Beneficio Húmedo del Café.

2.1.1.1 Cosecha. La variedad de café, el clima, las precipitaciones tiene influencia directa en la maduración del grano y por lo tanto en el tiempo y tipo de método de recolección que se debe utilizar. Es de suma importancia que los granos maduros predominen en un 80% porque son estos los que poseen una composición química óptima para generar sabores ya aromas característicos de alta calidad y pureza durante el tostado. Los frutos verdes dan cualidades que interfieren en la calidad de la bebida además son demasiado duros para separarlos del árbol lo que causa caída de ramas, hojas que demoran los procesos de post-cosecha. Los granos sobre maduros producen alcoholes que proveen fuertes características sensoriales a la bebida (Henao Cuellar, 2007).

Los métodos de recolección dependen del territorio y del proceso de maduración del grano. En Colombia el fruto madura de forma gradual durante todo el año y es por esta razón que se utiliza el método de desprender las cerezas de forma manual, para lo cual se debe utilizar mano de obra calificada, este método proporciona ventajas a los métodos mecánicos, en la calidad de los frutos recolectados, pero es mucho más costoso y de mucho más tiempo ya que se debe recorrer todo el árbol buscando los granos maduros listos para su cosecha.

2.1.1.2 Despulpado. Proceso por el cual se elimina la piel exterior (epicarpio), esto se realiza de forma mecánica. La despulpadora (Figura.3) ejerce presión sobre la cereza madura obligando a la separación de la cascara de la drupa de café. Las despulpadores deben estar correctamente calibradas para evitar que la almendra sea destruida por las partes fijas, cilíndricas y rotatorias de las cuales se compone. Además estas deben estar completamente limpias libre de suciedad que altere la calidad del café despulpado.

Figura 3. Despulpadora de café.



Fuente: http://bogotacity.olx.com.co/despulpadoras-frutas-despulpadoras-cafe-laminadoras-caucho-peladoras-pollos-rolleras-etc-iid-313380574

2.1.1.3 Fermentación. En la fermentación se elimina el mucílago.

Mucílago. El mucílago es una capa de aproximadamente 0,5 a 2 mm de espesor que está fuertemente adherida a la cáscara del grano de café. Desde el punto de vista físico, el mucílago es un sistema coloidal líquido, liofílico, siendo por lo tanto un hidrogel. Químicamente, el mucílago contiene agua, pectinas, azúcares y ácidos orgánicos. Durante la maduración del grano de café el pectato de calcio, localizado en la laminilla media y la protopectina de la pared celular, es convertido en pectinas. Esta transformación o hidrólisis de las protopectinas resulta en la desintegración de la pared celular, dejando un plasma celular libre. En este plasma, además de pectinas, se encuentran azúcares y ácidos orgánicos derivados del metabolismo y la conversión del almidón (Carbonell y Vilanova, 1974).

Tabla 2. Porcentaje de la composición química del mucílago.

Sustancias pécticas totales	35,8 %
Azúcares totales medios	45,8 %
Azúcares reductores	30,0 %
Azúcares no reductores	20,0
Celulosa=cenizas	17,0%

Fuente: Carbonell y Vilanova, 1974

El proceso de fermentación lo que busca es la descomposición del mucílago para que pueda ser retirado con facilidad en la etapa de lavado, este proceso generalmente se realiza en tanques de hormigón o tanque tina (Figura 4)

Figura 4. Tanque tina fermentado y lavado de café.

Fuente: http://www.cebar.net/e-COMMERCE/ver_detalle.php?id=218

Es de los momentos más delicados y cruciales en el procesado del café para lograr un producto de alta calidad es la fermentación, procedimiento por el cual el mucílago que recubre el grano experimenta una licuefacción por medio de enzimas propias del grano y otras enzimas extracelulares producidas por microorganismos presentes en el proceso, a medida que la fermentación avanza, la formación de ácidos hace que el PH baje de un valor de 6.0 que posee en mucilago fresco, hasta un valor de 4.0 a 4.5 donde está listo para su lavado y posterior secado. El tiempo de fermento depende de factores como la temperatura, los tanques, el oxigeno presente, lo cual ayuda a la proliferación de las enzimas, bacterias, levaduras que aceleran la licuefacción del mucílago.

Problemas que genera la fermentación en la calidad

Según Calvert, K. (2008) la carrera se da entra la acción microbiológica de las bacterias por deshacer el mucílago y las levaduras y mohos por continuar con el proceso de fermentación y si no se lava afectan el sabor de la bebida. Lo que se busca es una mayor cantidad de bacterias benignas al proceso, por lo cual se debe mantener buenos niveles de oxigeno, en el momento en que el tanque se solidifica y se queda sin agua que contenga oxigeno, el movimiento se pierde y la masa de café se vuelve anaeróbica, llevando a la proliferación de levaduras y mohos que causan distintos daños a las cualidades organolépticas del grano.

- **Sabor Fructuoso y Café Agrio.** Al quedar los tanques si oxigeno las bacterias no pueden digerir el mucílago, dando paso a las levaduras que lo convierten en alcohol y los sabores fructuosos se establecerán, los alcoholes se convertirán en ácidos tipo vinagre lo cual se traduce en un café agrio. El sabor fructuoso según Calvert, K. (2008) no está ligado el tiempo de fermentación, sino al hecho de que termine o no la fermentación, si el café se termina en 8 horas comenzara a tener un sabor fructuoso a partir de 12 horas, en las primeras horas de sobrefermento se puede recuperar el café, pero no hay lavado que salve un sobrefermento de mucho tiempo.

- **Notas Florales vinosas y sabor a grama.** Las notas más notorias son las dejadas por levaduras, mientras los alcoholes son solubles y volátiles para removerse con el lavado, existen otros mucho más aceitosos como los aldehídos, cetonas (aceites) y perfumados a base de químicos y estos pueden filtrarse a través de la corteza del pergamino y contaminarlo y aparecerán al momento de tostar el café. Si el comprador los desea, son bueno, sino tratara de bajar el precio Calvert, K. (2008).
- **Sabor a Cebolla.** El sabor a cebolla, por ejemplo, surge cuando la relación entre azúcares solubles y pectinas menos solubles se vuelve muy baja. El crecimiento inicial de bacterias positivas se da por los altos niveles de azúcares presentes en el mucílago maduro. Sin embargo, si se está utilizando demasiada agua fresca para despulpado, o más particularmente si se utilizan los cultivos Agar (galactosa que es un azúcar llamada galactosa), entonces la mayoría de estos azúcares solubles se lavan antes que se complete la fermentación, y las bacterias positivas iníciales pueden ser reemplazadas no solo por levaduras pero también por otras bacterias que producen mayores ácidos, como los propiónicos y los butíricos, los cuales provocan el sabor a cebolla Calvert, K. (2008).

Humedad en el café

El asunto de la humedad se puede ilustrar con lo ocurrido en nuestro cuerpo que evapora líquidos de nuestro cuerpo; pero es debajo de la piel que se da el efecto de enfriamiento y solamente un vapor gaseoso es lo que emanamos. Sin embargo, al limitar el flujo de aire alrededor de nosotros e incrementar su humedad relativa y envolverse en una capa plástica en casos extremos, en este caso perderíamos la misma cantidad de humedad, pero se verá en la piel como el líquido que llamamos sudor, y prácticamente no tendrá efecto enfriador. El sudor, sin embargo, está lejos de ser agua pura. Es una solución de sales, azúcares y otros nutrientes solubles, que se depositan en la superficie de la piel, y que es alimento ideal para los microrganismos. El olor desagradable que emana de nosotros y esa sensación “pegajosa” que sentimos cuando no estamos limpios, son el resultado de la actividad microbiana.

El café que se deja en agua por periodos de tiempo demasiado prolongados, está sujeto a este mismo proceso. Como hay agua tanto fuera como dentro del grano, la transferencia de azúcares y sales solubles a través de la superficie del grano también puede darse, incluso más rápidamente que el sudar. Algunas fuentes indican una figura de una pérdida del 1-2% del peso del café verde por cada día que el café está en contacto innecesario con el agua. Por esto mismo, los tiempos de fermentación deberían ser tan cortos como sea posible. Sin embargo, no elimine ninguno de estos procesos, ni el lavado ni el enjuague, o habrá una pérdida aún mayor en la calidad por otras causas (Calvert, K. 2008).

2.1.1.4 Lavado. El lavado posterior a la fermentación remueve toda la parte restante del mucilago, además de prevenir una subsecuente proliferación de microrganismos y así detener la fermentación. Este procedimiento se realiza en los tanques de fermentación (Figura 4), de esta forma se lavan los tanques y al mismo tiempo el café. Se añade agua potable muy limpia y manualmente se lleva a cabo una delicada agitación para no dañar los granos de café.

Al momento de drenar el tanque el café pergamino húmedo reduce su humedad hasta un 60-53%, lo que ayuda para el secado posterior.

2.1.1.5 Secado. El secado es un proceso de gran importancia en la cadena de producción de alimentos, ya que el contenido de humedad es, sin duda, la característica más importante para determinar si el grano corre el riesgo de deteriorarse durante el almacenamiento. El secado se realiza para inhibir la germinación de las semillas, reducir el contenido de humedad de los granos hasta un nivel que impida el crecimiento de los hongos y evitar las reacciones de deterioración. Una definición clara y completa del secado puede ser la siguiente: "es el método universal de acondicionar los granos por medio de la eliminación del agua hasta un nivel que permita su equilibrio con el aire ambiente, de tal forma que preserve su aspecto, sus características de alimentos, su calidad nutritiva y la viabilidad de la semilla" (Rivera, 2000).

Dentro de los procesos productivos del café el secado es la etapa del beneficio que tiene como finalidad disminuir el contenido de humedad del grano, hasta un porcentaje tal, que permita su almacenamiento seguro sin adquirir mal olor o sabor. La Resolución No 5 de 2002 del Comité Nacional de Cafeteros para la comercialización del café pergamino seco, establece un contenido final de humedad entre el 10 y el 12%.

2.1.2 Beneficio Seco del Café. El Beneficio seco no se utiliza en el país, este solo tiene los siguientes pasos para llegar al café pergamino.

- Recolección
- Secado
- Molido
- Ensacado
- Almacenamiento

A diferencia del beneficio húmedo, este método toma directamente las cerezas maduras y las coloca en los silos, donde la capa exterior el mucílago y la almendra se secan como una sola. Luego en el molino se extrae el café pergamino que está listo para su comercialización, estos cafés son fuertes, muy ácidos en sus cualidades aromáticas, lo que hace su uso cada vez menos usados, aunque a diferencia del beneficio húmedo no se despulpa ni se requiere fermentación.

2.2 CELDA DE CARGA

Las celdas de carga sensores electrónicos de peso o transductores cuyo propósito es convertir el peso aplicado a una señal eléctrica y transmitirla a indicador de peso o a un computador para ser procesada.

Figura 5. Celdas de carga

Fuente: http://www.automatizando.com.co/tension%20y%20fuerza.htm

2.2.1 Tipos de celdas de carga. Encontramos distintas configuraciones para la construcción, las cuales se dividen en los siguientes tipos de celdas de carga

- **Viga de flexión** (Figura 6)**.** Para pesaje de tanques y control de procesos industriales. Presentan una construcción de bajo perfil para su integración en las áreas restringidas

Figura 6. Celda de carga tipo viga.

Fuente: http://www.omega.com/ppt/pptsc_lg.asp?ref=LC501&Nav=

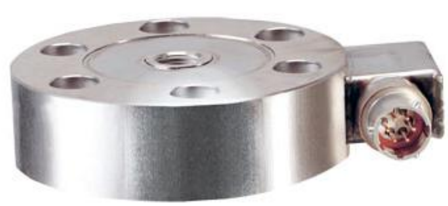
- **Compresión** (Figura 7). Las celdas de carga de compresión a menudo tienen un diseño de botones integral. Son ideales para el montaje en espacios reducidos. Ofrecen una excelente estabilidad a largo plazo.

Figura 7. Celda de carga de compresión.

Fuente: http://www.omega.com/ppt/pptsc_lg.asp?ref=LCGD&Nav=

- **Plataforma y punto único** (Figura 8)**.** Las celdas de carga plataforma y de un solo punto se utilizan para sistemas de pesaje comercial e industrial. Ellas proporcionan lecturas exactas, independientemente de la posición de la carga en la plataforma.

Figura 8. Celda de carga plataforma y punto único.



Fuente: http://www.omega.com/ppt/pptsc_lg.asp?ref=lchd&nav=

- **S-Beam** (Figura 9)**.** Celdas de carga S-Beam deben su nombre a su forma de S. celdas de carga S-Beam pueden proporcionar una salida bajo tensión o compresión. Las aplicaciones incluyen el nivel del tanque, tolvas y básculas para camiones.

Figura 9. Celda de carga tipo S-Beam.

Fuente: http://www.omega.com/ppt/pptsc_lg.asp?ref=lc101&nav=

- **Compresión/Tensión** (Figura 10)**.** Se utiliza con frecuencia en el monitoreo de líneas de fuerza

Figura 10. Celda de carga tipo compresión/tensión

Fuente: http://www.omega.com/ppt/pptsc_lg.asp?ref=LC402&Nav=

- **Monocelda** (Figura 11)**.** Estas monoceldas se utilizan en básculas, pesaje de tolvas, control de procesos, pesaje en cintas transportadoras, envasadoras y controladoras dinámicas de peso. Las monoceldas insensibles al momento físico permiten pesar cargas descentradas y simplifican el diseño de los sistemas de pesaje, puesto que controlan con todas las fuerzas y momentos sin perder rendimiento.

Figura 11. Celda de carga mono-celda

*Fuente:*http://co.mt.com/lac/es/home/products/Industrial_Weighing_Solutions/load_cells_and_weigh_modules/single_point_LC/MT1241_aluminum.html

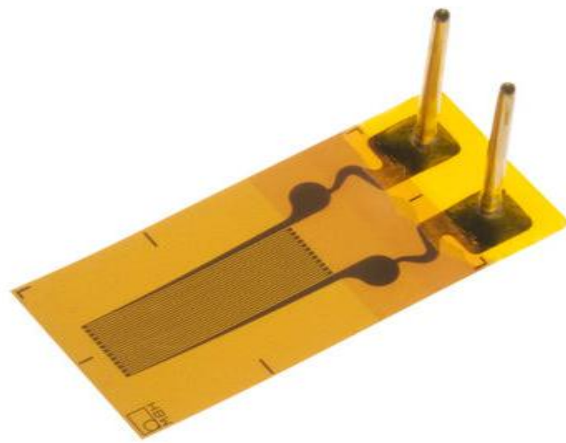
2.2.2 Galga Extensiométrica. Una galga extensiométrica es un sensor formado por un hilo muy fino y distribuido en varios tramos en paralelo (Figura 12). Su funcionamiento se basa en el cambio de su resistencia eléctrica cuando varía su longitud. Están basados en el efecto piezorresistivo. Ésta es la propiedad que tienen ciertos materiales para cambiar el valor nominal de su resistencia cuando son sometidos a esfuerzos, presión, carga, torque, cambios de posición.

El sensor está constituido básicamente por una base muy delgada no conductora, sobre la cual va adherido un hilo metálico muy fino, de forma que la mayor parte de su longitud está distribuido paralelamente a una dirección determinada (Figura 12).

Las galgas son transductores pasivos, esto quiere decir que necesitan una fuente de energía eléctrica para medir las variaciones, que aplicados sobre un material, permiten evaluar la fuerza ejercida sobre él a partir de la deformación resultante. Así, fuerzas de comprensión, tracción o torsión aplicadas sobre la viga, generan deformaciones que son transmitidas a la galga, respondiendo ésta con una variación a su propia resistencia eléctrica. La unidad de medida de la galga es el e (épsilon) y expresa la deformación producida en un material. Es una medida adimensional y enuncia la relación que existe entre el incremento de la longitud medida y la longitud inicial. Ecuación 1.

Ecuación 1. $$\varepsilon = \frac{\Delta l}{l}$$

Figura 12. Galga extensiométrica de estructura integrada



Fuente: http://www.directindustry.es/prod/hbm/galgas-extensiometricas-de-estructura-integrada-6017-252932.html

2.2.3 Características de una galga extensiométrica. Características de una galga extensiométrica son las siguientes

Anchura y Longitud: Dichos parámetros nos proporcionan las características constructivas de la galga. Nos permite escoger el tamaño del sensor que más se adecúe a nuestras necesidades.

Peso. Esta característica nos define el peso de la galga. Este suele ser del orden de gramos. En aplicaciones de mucha exactitud el peso puede influir en la medida de la deformación.

Tensión medible. Es el rango de variación de longitud de la galga, cuando ésta se somete a una deformación. Este rango viene expresado en un tanto por cien respecto a la longitud de la galga.

Temperatura de funcionamiento. Es aquella temperatura para la cual el funcionamiento de la galga se encuentra dentro de los parámetros proporcionados por el fabricante.

Resistencia de la galga: Es la resistencia de la galga cuando ésta no está sometida a ninguna deformación. Es la resistencia de referencia y suele acompañarse de un porcentaje de variación.

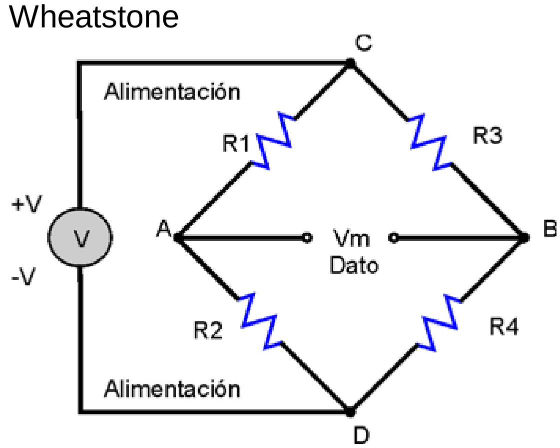
Factor de galga. Factor de galga o factor de sensibilidad de la galga es una constante K característica de cada galga. Determina la sensibilidad de ésta. Este factor es función de muchos parámetros, pero especialmente de la aleación empleada en la fabricación.

Coeficiente de temperatura del factor de galga: La temperatura influye notablemente en las características. A su vez, cualquier variación en estas características influye en el factor de galga. Este coeficiente se mide en %/ºC, que es la variación porcentual del valor nominal del factor de galga respecto al incremento de temperatura.

Prueba de fatiga. Esta característica nos indica el número de contracciones o deformaciones a una determinada tensión que puede soportar la galga sin romperse.
Material de la lámina. Esta característica nos define el material del que está hecho el hilo conductor o el material semiconductor.
Material de la base. Esta característica nos define el material del que está constituida la base no conductora de la galga.
Factor de expansión lineal. Representa un error que se produce en la magnitud de salida en ausencia de señal de entrada, es decir, en ausencia de deformación. Este error depende de la temperatura ambiente a la que está sometida la galga.

2.2.4 Acondicionamiento de señal en galgas extensiométricas. Para detectar los cambios en la resistencia que se producen en las galgas, necesitamos un circuito, que sometido a una corriente eléctrica de cómo resultado una medida que permita definir el estado de deformación de la galga, para este fin se utiliza el puente de Wheatstone (Figura 13) (Montesinos Lara, 2010).

Figura 13. Puente de Wheatstone

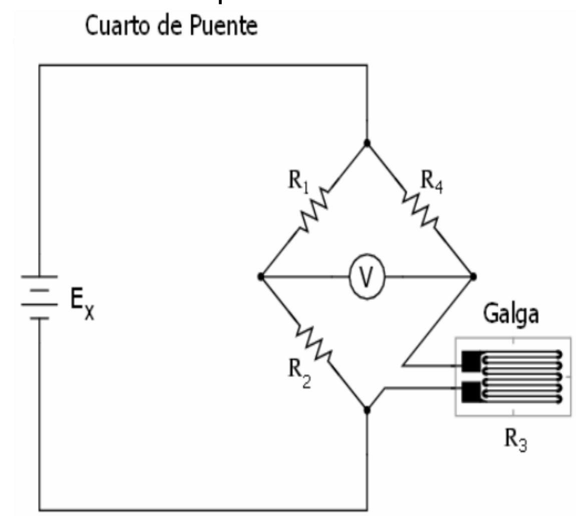


Fuente: http://tpmi-26.blogspot.es/

Para medir la deformación que se puede producir en la estructura a evaluar, el puente de Wheatstone se puede diseñar de tres maneras diferentes: con una, con dos y con cuatro galgas. Estos montajes se denominan como montaje en cuarto de puente, semipuente y puente completo respectivamente. Para ello, hay que tener en cuenta un parámetro muy importante, ya que nos puede dar valores erróneos a la salida de tensión. Este parámetro es la temperatura, ya que una variación de ésta produce también una variación en la resistencia) (Montesinos Lara, 2010).

- **Configuración de un cuarto de puente**. Cuando se utiliza solo una galga y resistores completando el puente, la configuración se denomina cuarto de puente. En esta configuración los cables conductores que conectan la galga con el puente deben de ser del mismo calibre y si se puede, deben de trenzarse para evitar diferencia de temperatura entre ellos. La figura 4 muestra esta configuración.

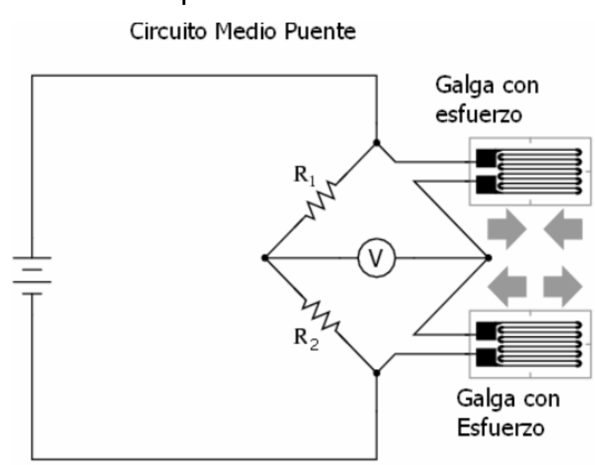
Figura 14. Configuración cuarto de puente



Fuente:http://fit.um.edu.mx/jorgemp/clases/ingbiomedica/unidad3/ManualSensores2007.pdf

- **Configuración de un medio puente**. Si se emplean dos galgas (Figura 15) que experimentan deformaciones de igual magnitud pero de signo opuesto, al disponerlas de la forma indicada en las figuras, se obtiene una relación lineal entre el voltaje de salida y la deformación y la sensibilidad de la medición se dobla.

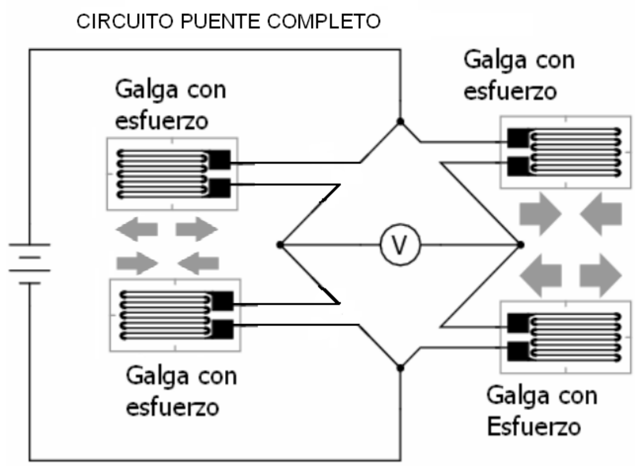
Figura 15. Configuración medio puente.



Fuente:http://fit.um.edu.mx/jorgemp/clases/ingbiomedica/unidad3/ManualSensores2007.pdf

- **Configuración puente completo.** En esta, los cuatro brazos del puente son utilizados y la sensibilidad del puente aumenta considerablemente, siendo el voltaje de salida cuatro veces el de una configuración de un cuarto de puente. La figura 16 muestra una configuración de puente de Wheatstone completó. Esta configuración se usa cuando el punto donde se efectúa la medición esta retirado de los instrumentos de medición y también cuando las condiciones ambientales son sumamente cambiantes. Su uso principal es en transductores donde se requiere leer unidades diferentes a las de deformación (presión, carga, etc.).

Figura 16. Configuración puente completo.



Fuente:http://fit.um.edu.mx/jorgemp/clases/ingbiomedica/unidad3/ManualSensores2007.pdf

2.2.5 Limitaciones de las galgas extensiométricas. Los factores que hay que tener en cuenta para el uso de las galgas son (Montesinos Lara, 2010).

- El esfuerzo aplicado no debe llevar a la galga fuera de su límite elástico de deformaciones (4% de la longitud de la galga), es decir, no se debe salir de la zona de funcionamiento ya que tendríamos una lectura errónea.
- El esfuerzo debe ser transmitido íntegramente en la galga. La deformación de la galga debe ser la de la pieza, es decir, el sensor debe estar perfectamente adherida.
- Hay que tener en cuenta la sensibilidad transversal, es decir, la galga debe colocarse en la dirección adecuada ya que se puede tener valores de medida indeseables.
- La temperatura influye directamente sobre la galga. Para compensar sus efectos se puede utilizar galgas pasivas o auto compensadas.
- La unión de materiales distintos pueden generar pequeñas diferencias de potencial, para ello, la galga debe estar totalmente aislada.
- Tener en cuenta el calentamiento de la galga por la disipación de su potencia.

2.3 PESAJE

2.3.1 Pesaje simple y multipunto. Existen diferentes tipos de pesaje entre ellos tenemos.

- **Pesaje de un punto simple:** Las celdas de carga de punto simple pueden ser utilizadas para diseños de plataforma, usualmente en sistemas de baja capacidad.

- **Dos puntos de pesaje:** Pueden ser utilizados en plataformas delgadas más largas, por ejemplo una celda de carga en cada extremo.

- **Tres puntos de pesaje:** Frecuentemente utilizadas en el pesaje de cilindros verticales. Utilizando tres puntos es menos complicado nivelar.

- **Cuatro puntos de pesaje:** Típicamente utilizados en básculas de plataforma de alta capacidad y contenedores rectangulares.

- **Más de cuatro puntos:** Generalmente utilizados en contendores ó plataformas de muy alta capacidad.

- **Uso de pivotes y celdas de carga:** algunas celdas de carga están diseñadas para ser utilizados en pivotes. El uso de pivotes no es recomendado a menos que la exactitud no sea muy importante. Si un pivote es utilizado, se debe tomar en cuenta un diseño mecánico que permita una adecuada y lineal transferencia de la carga a las celdas en el sistema. Cualquier fricción en el pivote causará una baja respuesta y mediciones sin repetitividad.

2.3.2 Acerca de la sensibilidad (mV/V). Cuando una celda de carga es adquirida, usualmente viene acompañada de una documentación con los detalles de las especificaciones incluida la sensibilidad de la señal de salida por voltios de excitación ó mV/V. generalmente la salida de la celda deberá ser aproximadamente de 0 mV con cero carga, sin embargo, pueden tener un pequeño voltaje offset.

La mayoría de los cambios que originan dicho voltaje de desviación, dependen del cambio en la resistencia de la celda de carga cuando el voltaje de exitacion es aplicado.

El parámetro mV/V es una característica de sensibilidad de la celda de carga e indica la magnitud de milivoltios que ha de entregar por cada voltio de alimentación (generalmente DC). Por ejemplo, una celda de carga con una capacidad nominal de 250 Kg puede tener una sensibilidad nominal de salida de 2.357mV/V, es decir, que si el voltaje de excitación es 10V, ella podrá entregar a la salida un rango de voltaje de 0mV sin carga hasta 23.57mV con la carga completa, tendremos un peso equivalente de 250Kg.

2.4 PH

Ciganda, L.M., 2004 Afirma que las reacciones más importantes son probablemente las que tienen lugar en disolución acuosa. Todas las reacciones biológicas, y gran número de las efectuadas en laboratorio, se realizan en el seno del agua.
Una sustancia en dilución acuosa se disocia en fragmentos menores (iones) y se establece un equilibrio entre la especie no disociada y sus partes componentes. Una vez establecido el equilibrio, la unión de ambos iones para reconstruir el compuesto se produce con la velocidad precisa para compensar la disociación. La expresión de la constante de equilibrio, K_{eq}, para la disociación del agua es:

Ecuación 2. $$K_{eq} = \frac{[H^+][OH^-]}{H_2O}$$

Donde los corchetes representan las concentraciones en moles por litro.

En disoluciones razonablemente diluidas, el valor de $[H_2O]$, es prácticamente constante. La cantidad de agua que se consume o se forma durante una reacción química es pequeña, en comparación con la cantidad total de agua presente. Por ello la ecuación 2. Puede escribirse como:

Ecuación 3. $$K_a = [H^+][OH^-]$$

Esta constante de equilibrio, K_a, se llama *producto iónico* del agua y varía con la temperatura. Su valor es $1,0 * 10^{-14}$, a 25 ºC. En el agua pura las concentraciones de H^+ y OH^- valen cada una $1,0 * 10^{-7}$. Si se añade un ácido al agua, la concentración de hidrogeniones (H^+) aumenta sobre el valor $1,0 * 10^{-7}$, pero como el producto iónico permanece igual a $1,0 * 10^{-14}$, la concentración de aniones hidroxilo (OH^-) desciende por debajo de $1,0 * 10^{-7}$. De modo análogo, cuando se añade una base al agua, la concentración de cationes (H^+) disminuye.

Puesto que las potencias grandes de diez son incómodas de manejar, se ha introducido una notación logarítmica, llamada *escala de pH.* El símbolo pH significa “potencia negativa de la concentración de ión hidrógeno.” El pH es el logaritmo cambiado de signo de $[H^+]$:

Ecuación 4. $$pH = -\log_{10}[H^+]$$

Como cualquier medida, el pH posee una escala propia que indica con exactitud un valor. La escala va de pH = 0 a pH= 14; el pH 7 es el que simboliza la neutralidad. Si el pH es < 7 la solución es considerada ácida; por el contrario, si el pH es > 7, la solución se considera alcalina. Mientras más ácida la solución, más cerca del 0 estará; y mientras más básica o alcalina el resultado se aproximará a 14 (Ciganda, L.M., 2004).

2.4.1 Electrodo de pH. El electrodo de vidrio (Figura 17) actualmente constituye la pieza fundamental en la medición electrométrica del pH. Junto con el electrodo de calomel, se encuentran ampliamente difundidos y a la fecha no existe otro sistema para la medición electrométrica que tenga la misma versatilidad y precisión. El principio bajo el cual trabaja el electrodo de vidrio fue descubierto, en forma accidental por McInnes y Dole, cuando observaron que el vidrio que empleaban en sus investigaciones mostraba cierta sensibilidad a las variaciones de pH. Una vez hecho su descubrimiento, procedieron a investigar una composición más adecuada de vidrio, que es la base de los electrodos empleados hoy día (Ruíz Ramírez, J.E. 2010).

Figura 17. Electrodo de pH

Fuente: http://limacallao.olx.com.pe/electrodo-para-ph-metro-cuerpo-epoxico-uso-general-conexion-bnc-iid-246028035

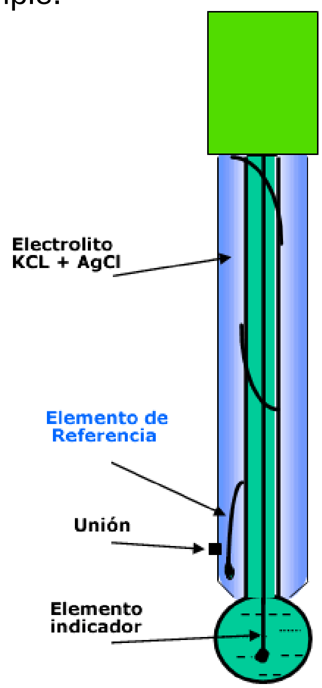
2.4.2 Clasificación de los Electrodos de pH. Existen dos clases de electrodos para medir pH

- **Electrodo de unión simple**

En esta configuración el elemento de referencia se encuentra directamente en el electrolito (KCL 3,5M + AgCl) y posee un solo punto de unión antes de que el electrolito haga contacto con el medio (Figura 18)

Es un electrodo de respuesta rápida, pero de más fácil contaminación.

Figura 18. Electrodo unión simple.



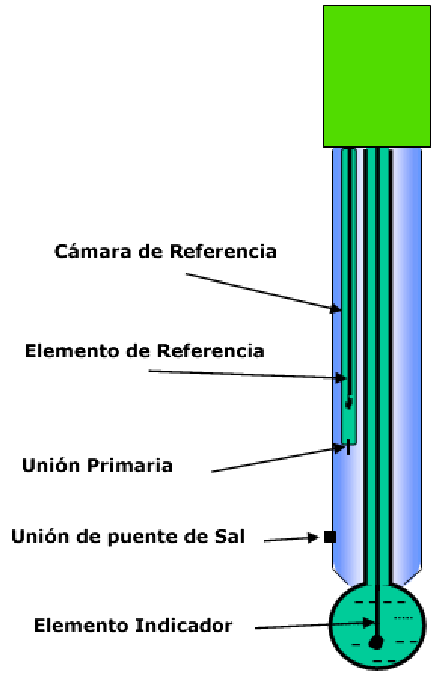
Fuente: http://www.hannacolombia.com/articulos-de-interes/articulos/item/157-eleccion-del-electrodo-de-ph

- **Electrodo de unión doble**

En este electrodo el elemento de referencia se encuentra en una cámara, aislado, recibe su nombre debido a que posee una unión primaria entre la cámara de referencia-electrolito y una segunda entre el electrolito-medio llamada unión de puente de sal (Figura 19).

El electrodo utiliza el electrolito KCL 3,5M y es un electrodo más lento que el de unión simple, pero al estar aislada la cámara de referencia es más difícil que se contamine el elemento de referencia.

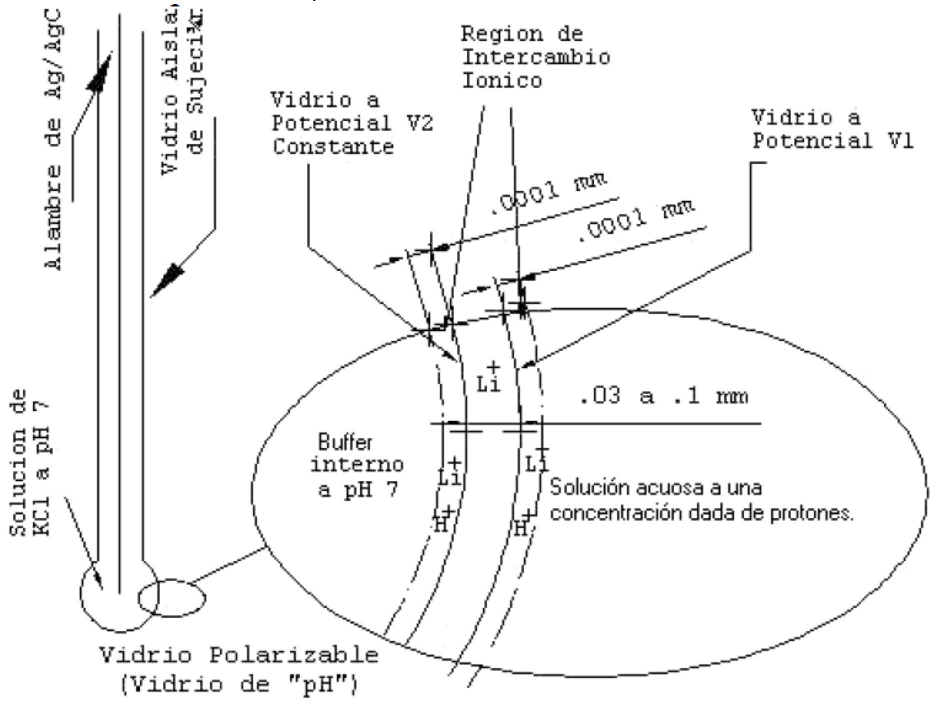
Figura 19. Electrodo unión doble.



Fuente: http://www.hannacolombia.com/articulos-de-interes/articulos/item/157-eleccion-del-electrodo-de-ph

2.4.3 Funcionamiento Electrodo de pH. El cuerpo del electrodo es de vidrio común (o plástico), no conductor de cargas eléctricas mientras que el bulbo, extremo sensible del electrodo, se construye con este vidrio de formulación especial, conocido como "vidrio sensible al pH" (en realidad, es vidrio polarizable). El vidrio de pH es conductor de cargas eléctricas porque tiene óxido de litio dentro del cristal, además de óxido de sílice, de calcio y algunos otros. Según se puede observar en la figura. 20, la estructura del vidrio es tal que permite el intercambio de iones litio por iones de hidrógeno en solución acuosa, de modo que se forma una capa (fina) hidratada. Se crea así un potencial (del orden milivoltios) a través de la interface creada entre el vidrio (en el "seno" del vidrio) y la solución acuosa. El voltaje creado hacia el interior del bulbo es constante porque se mantiene su pH constante (mediante una solución buffer de pH 7) de modo que la diferencia de potencial depende sólo del pH del medio externo. La incorporación de un alambre (usualmente de Ag/AgCl) permite conducir este potencial hasta un amplificador (Ciganda, L.M., 2004).

Figura 20. Electrodo de vidrio, membrana intercambiadora de iones.



Fuente: http://cabierta.uchile.cl/libros/l_herrera/iq54a/instru.htm#Electrodo para la medición de actividad de H+ (pH)

El sistema actual de medición de pH es, por excelencia, el electrodo combinado. Su nombre deriva de la práctica inicial en que el electrodo sensor de (H+) estaba separado del electrodo de referencia; la combinación de ambos en una sola estructura llevó a su nombre actual. Sin embargo, la práctica industrial sigue utilizando electrodos de referencia y de pH separados, porque permite señales más confiables y procedimientos de manutención que, en ciertos casos, resultan más controlables y de menor costo (Ruíz Ramírez, J.E. 2010).

De cualquier forma, la diferencia de potencial será dada por la ecuación de Nernst, ver ecuación 5.

Ecuación 5.
$$E_H = E_{ref} + \frac{2.3\,RT}{NF}\; pH$$

Donde E_H es el potencial (en voltios) detectado a través de la membrana de vidrio, E_{ref} es el potencial del electrodo de referencia, y $\frac{2.3\,RT}{NF}$ es el **factor de Nernst**, que depende de la constante de los gases (R), la constante de Faraday (F), la carga del ión (Nión), que para el pH vale 1, y la temperatura en grados

Kelvin (T). El comportamiento del electrodo depende de la temperatura. Por eso es importante que a la hora de calibrar el pH-metro siempre esperemos a que las disoluciones patrón sacadas de la nevera se pongan a temperatura ambiente.

Como a 25ºC el factor de Nernst vale aproximadamente 0,0591 y el potencial de referenciase considera igual a cero, la ecuación de Nernst queda reducida a

Ecuación 6. $$E_H = 0{,}0591 * pH$$

2.5 TEMPERATURA

La temperatura es una medida del calor o energía térmica de las partículas en una sustancia. En resumen, la temperatura es una medida de la energía media de las moléculas en una sustancia y no depende del tamaño o tipo del objeto que las contenga (RUÍZ RAMÍREZ, J.E. 2010).

Para determinar la temperatura se ha diseñado distintos instrumentos que utilizan distintas características de los elementos, como variación de resistencia, deformación, semiconductores, dilatación etc.

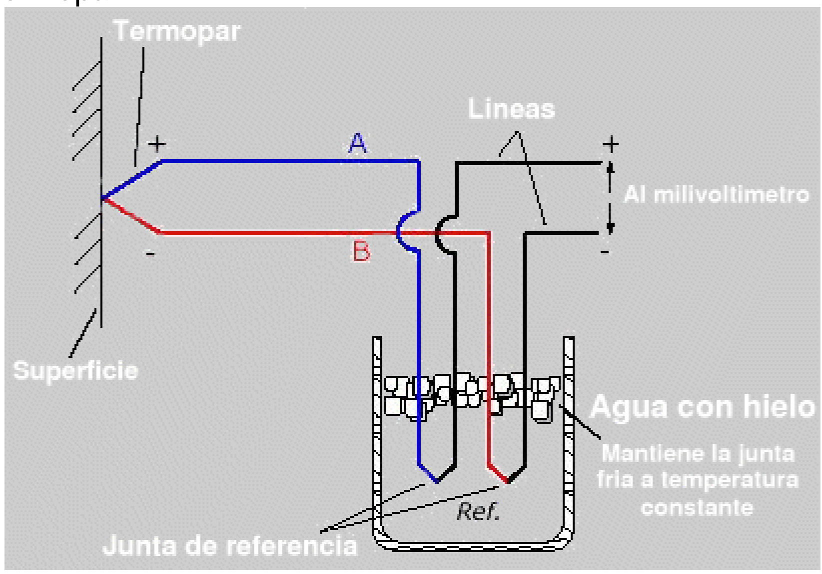
Se encuentran comúnmente:

- RTD (Sensores de Temperatura resistivos), dentro de ellos encontramos el Pt-100.
- Termopares
- Termómetros de Vidrio,
- Termómetro Bimetálico,
- Sensores de Temperatura en Circuito Integrado. (Semiconductores)

Describimos el funcionamiento de dos tipos de sensores de temperatura, los cuales pueden ser utilizados en el sistema que vamos a implementar.

2.5.1 Termopares. Cuando dos metales se unen, en la unión se produce una diferencia de potencial. Ésta depende de los metales utilizados y la temperatura de la unión. Un termopar (Figura 21) es un circuito completo con dos uniones de este tipo. Si ambas uniones están a la misma temperatura, no existe una fuerza electromotriz (f.e.m) neta. En cambio, si la temperatura es diferente, si se produce una f.e.m. Por lo general una de las dos uniones se mantiene a 0ºC (Ruíz Ramírez, J.E. 2010).

Figura 21. Termopar



Fuente: http://www.sabelotodo.org/electrotecnia/termopar.html

En la Tabla 3 se muestran los termopares de uso más común, los intervalos de temperatura en los que se usan, sensibilidad y características.

Tabla 3. Código de colores para termopares

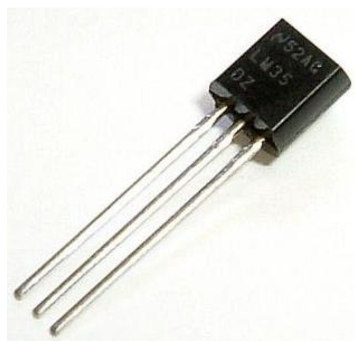
Termopar Tipo	Aleación	Rango	IEC 584	ANSI 43710
K	Niquel-Cromo Niquel-Aluminio	-150 a 1100°C		
J	Hierro Cobre-Niquel	-40 a 700°C		
T	Cobre Cobre-Niquel	-200 a 350°C		
E	Niquel-Cromo Cobre-Niquel	-150 a 800°C		
N	Niquel-Cromo Niquel-Silicio	-150 a 1100°C		
S	Platino Platino-Rodio10%	0 a 1550°C		
R	Platino Platino-Rodio13%	0 a 1600°C		
B	Platino-Rodio6% Platino-Rodio30%	0 a 1700°C		

Fuente:http://www.maikontrol.com/temperatura/sondas-de-temperatura/33-informacion-tecnica-sobre-termopares/64-tabla-de-colores-para-termopares.html

2.5.2 Sensores de Temperatura en Circuito Integrado. Tiene una gran ventaja respecto a los demás, obviamente para el uso que se pretende dar, que es sensar la temperatura en el proceso de fermentación. Algunas ventajas son: el tamaño del circuito integrado, el costo moderado, y la mejor ventaja es que se puede diseñar su rango de operación para valores de tensión que un microcontrolador estándar pueda manejar (Mendoza Livia, W.R., 2011).

La serie LM35 corresponde a un sensor de temperatura de precisión en un circuito integrado, cuya salida de tensión es linealmente proporcional a la temperatura en grados Celsius. Su salida en grados centígrados le da una ventaja a la hora del tratamiento de su señal, ya que esta unidad es la preferida en las diferentes aplicaciones. Este sensor tiene una salida con una precisión calibrada de 1º Centígrado y un rango que abarca desde -55º a +150ºC. La salida lineal equivale a 10mV/ºC.

Figura 22. Sensor LM35.



Fuente: http://articulo.mercadolibre.cl/MLC-403282949-lm35dz-lm35-temperatura-sensor-ic0-a-100degc-_JM

Características:
- Calibrado directamente en º Celsius.
- Escala de factor lineal.
- Exactitud garantizada 0.5ºC (a +25ºC).
- Rango entre -55º a +150ºC.
- Conveniente para aplicaciones remotas.
- Opera entre 4 y 30 Voltios.
- Baja corriente de alimentación (60µA).
- Bajo costo.
- Baja impedancia de salida.

El LM35 se puede usar fácilmente, en la misma forma que otros circuitos integrados, puede ser pegado a una superficie y su temperatura estará aproximadamente a 0.01ºC de la temperatura de la superficie. Esto supone que la temperatura del aire es la misma de la superficie, en caso de no ser así la temperatura en el sensor se hará intermedia (Góngora Ruiz, M.A. et al. 2010).

2.6 HUMEDAD

La humedad es la cantidad de líquido presente en un cuerpo o en el ambiente. La humedad se presenta a nivel molecular y se relaciona con la cantidad de moléculas de agua contenida en una determinada sustancia. Se puede expresar en forma absoluta o relativa. La humedad relativa es la relación porcentual entre la cantidad de vapor de agua real que contiene el aire y la que necesitaría contener para saturarse a temperatura constante, por ejemplo, una humedad relativa del 70% quiere decir que de la totalidad de vapor de agua (el 100%) que podría contener el aire a esta temperatura, solo tiene el 70%.

2.7 ESTANDAR ZIGBEE

ZigBee es un estándar de comunicaciones inalámbricas diseñado por la ZigBee Alliance (Figura 23). No es una tecnología, sino un conjunto estandarizado de soluciones que pueden ser implementadas por cualquier fabricante. ZigBee está basado en el estándar IEEE 802.15.4 de redes inalámbricas de área personal (wireless personal área network, WPAN) y tiene como objetivo las aplicaciones que requieren comunicaciones seguras con baja tasa de envío de datos y maximización de la vida útil de sus baterías (Valverde Rebaza, J.C., 2007).

Figura 23. Logo Zigbee Alliance

Fuente: http://www.autoevolution.com/news-image/new-charging-standard-coming-from-zigbee-and-sae-30639-1.html

2.7.1 Características de Zigbee.

Citadas por Valverde Rebaza, J.C. (2007) algunas característica son.

- ZigBee opera en las bandas libres ISM (Industrial, Scientific & Medical) de 2.4 GHz, 868 MHz (Europa) y 915 MHz (Estados Unidos).

- Tiene una velocidad de transmisión de 250 Kbps y un rango de cobertura de 10 a 75 metros.
- A pesar de coexistir en la misma frecuencia con otro tipo de redes como WiFi o Bluetooth su desempeño no se ve afectado, esto debido a su baja tasa de transmisión y, a características propias del estándar IEEE 802.15.4.

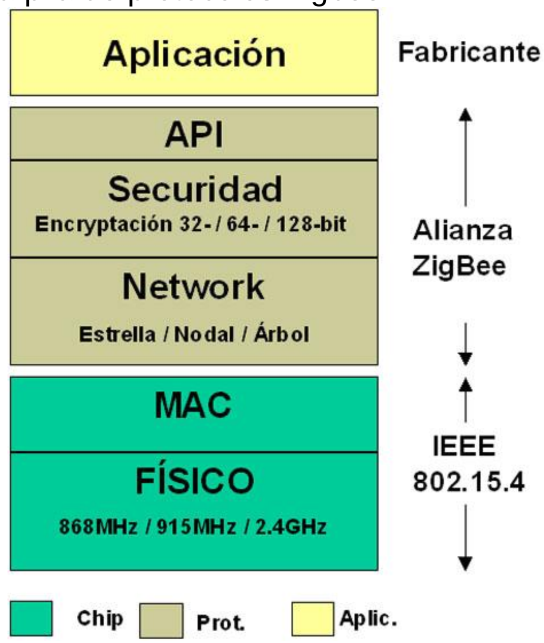
- Capacidad de operar en redes de gran densidad, esta característica ayuda a aumentar la confiabilidad de la comunicación, ya que entre más nodos existan dentro de una red, entonces, mayor número de rutas alternas existirán para garantizar que un paquete llegue a su destino.
- Cada red ZigBee tiene un identificador de red único, lo que permita que coexistan varias redes en un mismo canal de comunicación sin ningún problema. Teóricamente pueden existir hasta 16000 redes diferentes en un mismo canal y cada red puede estar constituida por hasta 65 000 nodos, obviamente estos límites se ven truncados por algunas restricciones físicas (memoria disponible, ancho de banda, etc.).
- Es un protocolo de comunicación multi-salto, es decir, que se puede establecer comunicación entre dos nodos aun cuando estos se encuentren fuera del rango de transmisión, siempre y cuando existan otros nodos intermedios que los interconecten, de esta manera, se incrementa el área de cobertura de la red.
- Su topología de malla (MESH) permite a la red auto recuperarse de problemas en la comunicación aumentando su confiabilidad.

2.7.2 Tipos de dispositivos. El la tecnología Zigbee se tienen tres diferentes dispositivos.

- **Coordinador Zigbee (ZC, Zigbee Coordinator).** Es el dispositivo más importante y más completo en la red. Es el director o sirve como enlace a otras redes. Puede almacenar información y ser centro de confianza para claves de cifrado.
- **Router Zigbee (ZR).** Equipo encargado de interconectar dispositivos separados en la topología de red.
- **Dispositivo final (Zigbee end Device, ZED).** Solo posee la capacidad de comunicarse con los router o coordinadores pero no con otros dispositivos, por esta cualidad consume menos energía y requiere menor memoria por lo que son los más baratos.

2.7.3 Arquitectura. La pila de protocolos Zigbee es similar al modelo OSI, posee diferentes capas independientes una de la otra (Figura 24)

Figura 24. Capas de la pila de protocolos Zigbee



Fuente: http://www.casadomo.com/noticiasDetalle.aspx?idm=10&id=7123&c=6

- La capa de más bajo nivel es la capa física (PHY), que en conjunto con la capa de acceso al medio (MAC), brindan los servicios de transmisión de datos por el aire, punto a punto. Estas dos capas esta descritas en el estándar IEEE 802.15.4–2003. El estándar trabaja sobre las bandas ISM de uso no regulado, dónde se definen hasta 16 canales en el rango de 2.4 GHz, cada una de ellas con un ancho de banda de 5 MHz. Se utilizan radios con un *espectro de dispersión de secuencia directa*, lográndose tasas de transmisión en el aire de hasta 250 Kbps en rangos que oscilan entre los 10 y 75 m, los cuales dependen bastante del entorno (Valverde Rebaza, J.C., 2007).
- La capa de red (NWK) tiene como objetivo principal permitir el correcto uso del subnivel MAC y ofrecer una interfaz adecuada para su uso por parte de la capa de aplicación. En esta capa se brindan los métodos necesarios para: iniciar la red, unirse a la red, enrutar paquetes dirigidos a otros nodos en la red, proporcionar los medios para garantizar la entrega del paquete al destinatario final, filtrar paquetes recibidos, cifrarlos y autentificarlos. Se debe tener en cuenta que el algoritmo de enrutamiento que se usa es el de *enrutamiento de malla*, el cual se basa en el protocolo *Ad Hoc On-Demand Vector Routing – AODV*. Cuando esta capa se encuentra cumpliendo la función de unir o separar dispositivos a través del controlador de red, implementa seguridad, y encamina tramas a sus respectivos destinos; además, la capa de red del controlador de red es responsable de crear una nueva red y asignar direcciones a los dispositivos de la misma. Es en esta capa en donde se

implementan las distintas topologías de red que ZigBee soporta (árbol, estrella y mesh network) (Valverde Rebaza, J.C., 2007).

- La siguiente capa es la de soporte a la aplicación que es el responsable de mantener el rol que el nodo juega en la red, filtrar paquetes a nivel de aplicación, mantener la relación de grupos y dispositivos con los que la aplicación interactúa y simplificar el envío de datos a los diferentes nodos de la red. La capa de Red y de soporte a la aplicación son definidas por la ZigBee Alliance.
- En el nivel conceptual más alto se encuentra la capa de aplicación que no es otra cosa que la aplicación misma y de la que se encargan los fabricantes. Es en esta capa donde se encuentran los ZDO (ZigBee Device Objects) que se encargan de definir el papel del dispositivo en la red, si el actuará como coordinador, router o dispositivo final; la subcapa APS y los objetos de aplicación definidos por cada uno de los fabricantes.

2.7.4 Empaquetamiento y direccionamiento. Según Valverde Rebaza, J.C., (2007) el empaquetamiento se realiza en cuatro tipos de paquetes, datos, ACK, MAC y baliza (Figura 25).

Figura 25. Empaquetamiento y direccionamiento Zigbee

Fuente: http://www.domodesk.com/content.aspx?co=97&t=146&c=43

El paquete de datos tiene una carga de datos de hasta 104 bytes. La trama esta numerada para asegurar que todos los paquetes llegan a su destino. Un campo nos asegura que el paquete se ha recibido sin errores. Esta estructura aumenta la fiabilidad en condiciones complicadas de transmisión.

La estructura de los paquetes ACK, llamada también *paquete de reconocimiento*, es dónde se realiza una realimentación desde el receptor al emisor, de esta manera se confirma que el paquete se ha recibido sin errores. Se puede incluir un *tiempo de silencio* entre tramas, para enviar un pequeño paquete después de la transmisión de cada paquete.

El paquete MAC, se utiliza para el control remoto y la configuración de dispositivos/nodos. Una red centralizada utiliza este tipo de paquetes para configurar la red a distancia.

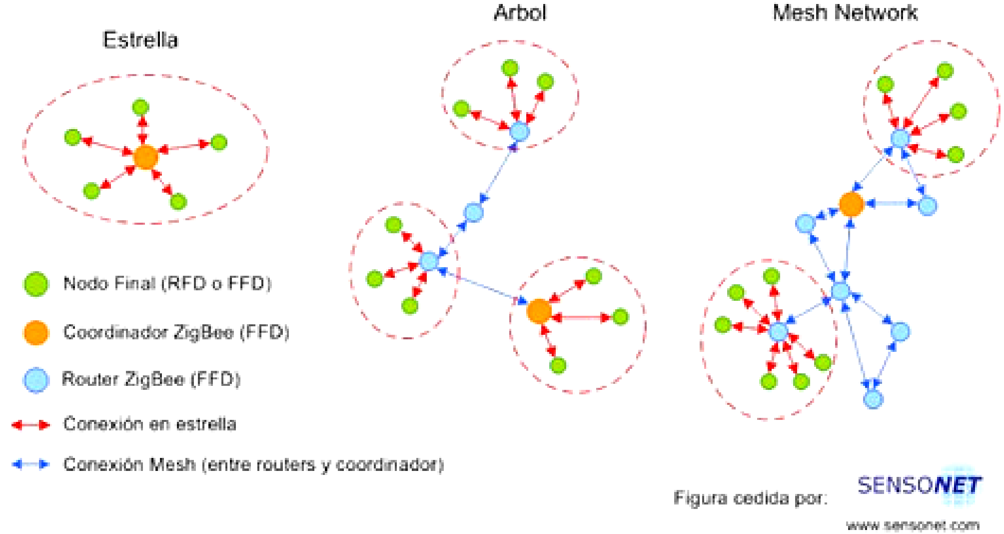
El paquete baliza, se encarga de "*despertar*" los dispositivos que "*escuchan*" y luego vuelven a "*dormirse*" si no reciben nada más. Estos paquetes son importantes para mantener todos los dispositivos y los nodos sincronizados, sin tener que gastar una gran cantidad de batería estando todo el tiempo encendidos.

2.7.5 Topologías, En ZigBee existen tres tipos de topologías: estrella, árbol, y en red mallada (meshnetwork), las cuales pueden observarse en la figura 26. Siempre hay un nodo de red que asume el papel de coordinador central encargado de centralizar la adquisición y las rutas de comunicación entre dispositivos. Además, si se aplica el concepto de Mesh Network, pueden existir coordinadores o routers, alimentados permanentemente en espera de recibir/repetir las tramas de los dispositivos o sensores. Ambos dispositivos son del tipo FFD (Full Functionality Device), debido a que exigen empotrar la mayoría de primitivas definidas por el stack ZigBee.

Los dispositivos que harán la función de sensores, termostatos o mandos a distancia serán de funcionalidad reducida (RFD, Reduced Functionality Device), y serán alimentados por baterías o pilas.

Sin lugar a dudas, una de las mayores aportaciones del ZigBee y el que mayor interés está despertando a las empresas desarrolladoras de productos, es el concepto de red nodal o mesh network por el que cualquier dispositivo ZigBee puede conectarse con otro dispositivo usando a varios de sus compañeros como repetidores. A este se le conoce como enrutado "multi-salto", primero hace llegar la información al nodo ZigBee vecino, el cual puede además ser coordinador de la red, para así llegar al nodo destino, pasando por todos los que sean necesarios. De esta manera cualquier nodo ZigBee puede hacer llegar los datos a cualquier parte de la red inalámbrica siempre y cuando todos los dispositivos tengan un vecino dentro de su rango de cobertura.

Figura 26. Topologías Zigbee

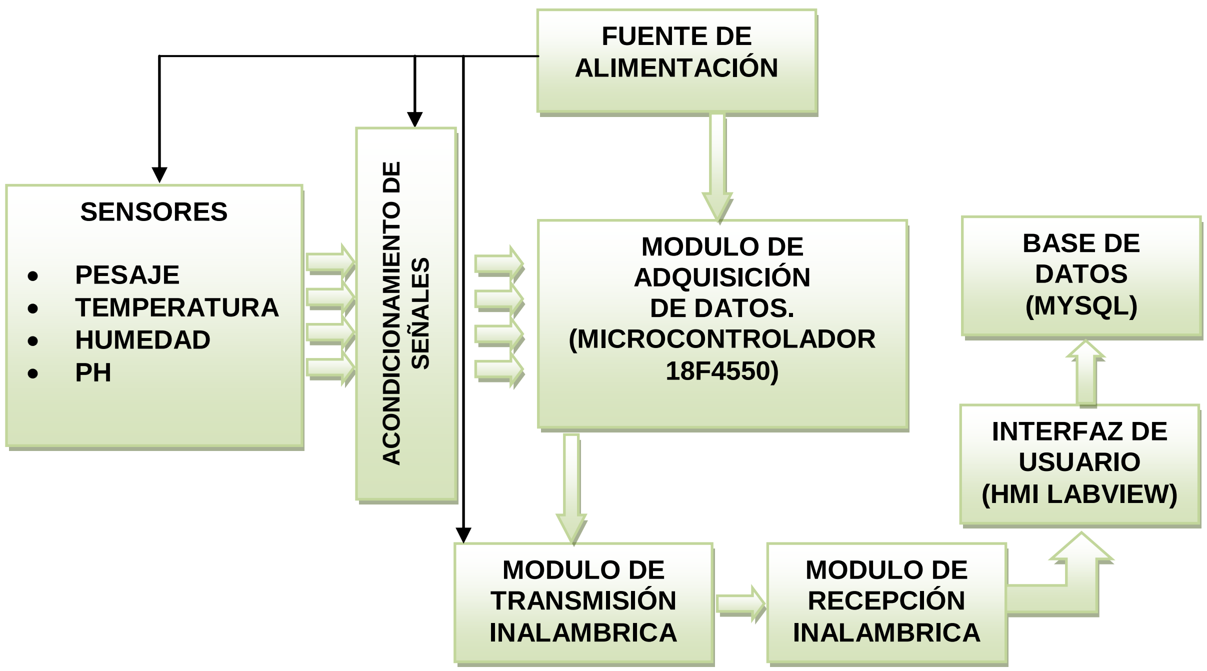


Fuente: http://www.casadomo.com/noticiasDetalle.aspx?idm=10&id=7123&c=6

3. DESARROLLO DEL PROYECTO

El monitoreo completo del equipo de fermentación de café se realizó mediante la instalación de un lote de sensores que proporcionan en tiempo real la evolución de cada una de las variables, un módulo de visualización y almacenamiento de los datos, en la figura 27.se ve el diagrama en bloques.

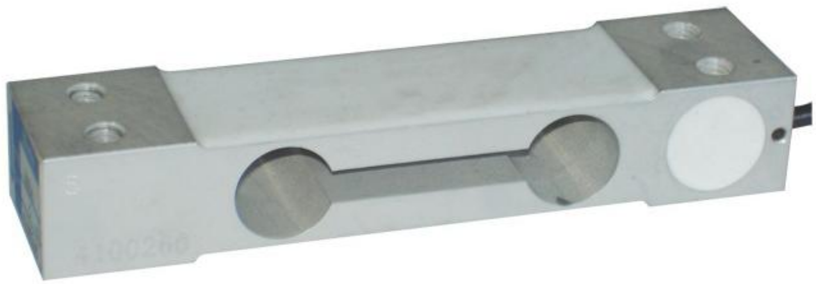
Figura 27. Diagrama de bloques del sistema



3.1 DISEÑO DEL SISTEMA DE PESAJE

3.1.1 Acondicionamiento celdas de carga. Para el diseño de la tarjeta de pesaje se utilizaron cuatro celdas de carga (Figura 27). Cada una con una capacidad nominal de 40Kg. para un total de 160Kg como peso máximo que puede soportar la plataforma.

Figura 28. Celda de carga mono-bloque SP06-AL MV



Fuente:http://www.bci.co/Pesaje/celdas_de_carga/mono_bloque_max200kg/catalogo_sp06/sp06.pdf

Este modelo tiene una salida a plena escala es de 1.8 mV/V, en donde V es el voltaje DC de alimentación de 0-12 VDC (Anexo A. Celda de carga). Para esta aplicación se establece 12 VDC.

Se tiene entonces que para cada sensor, la salida máxima (40Kg) es de 18mV de acuerdo a la ecuación característica de la celda de carga:

$$V_{salida} = V_{cc} * Sensibilidad$$

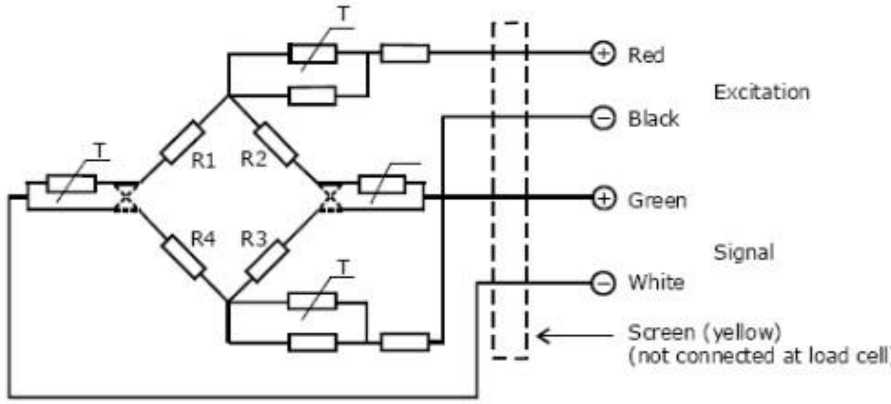
$$V_{salida} = 12V * \frac{1.8mV}{V}$$

$$V_{salida} = 21.6\, mV$$

La temperatura de operación para este sensor es de -10°C a +50°C que es suficiente para el buen funcionamiento de la celda en el área de trabajo.

El modelo SP06-AL MV tiene 4 hilos para la conexión de las señales eléctricas (Figura 28).

Figura 29. Cableado para la celda de carga SP06-AL MV



Fuente:http://www.bci.co/Pesaje/celdas_de_carga/mono_bloque_max200kg/catalogo_sp06/sp06.pdf

3.1.1.1 Amplificadores de instrumentación. Son circuitos que se encargan de amplificar las señales de mili-voltios provenientes de las celdas de carga y de convertir la señal flotante proveniente del puente de cada sensor, en señales referenciadas a tierra para las etapas siguientes. Los amplificadores de instrumentación (A.I.) para cada celda de carga son idénticos (Góngora Ruiz, M.A. et al. 2010).

En esta sección se describen las características, funcionamiento y conexión de un A.I. para cualquiera de los cuatro sensores.

3.1.1.2 Amplificador de instrumentación INA128. El INA128 es un amplificador de instrumentación de alto rendimiento que requiere de un solo resistor externo para conseguir una ganancia de 1 a 1000. La selección de la ganancia está dada por la siguiente fórmula:

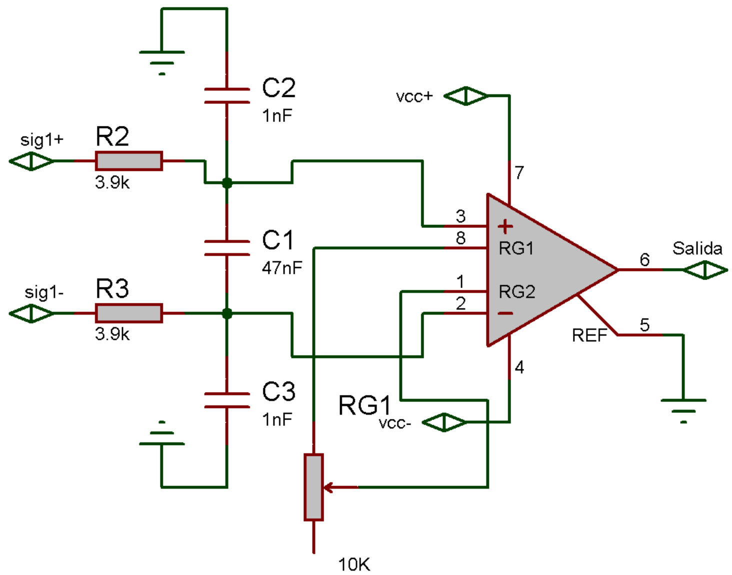
$$R_G = \frac{50K\Omega}{G-1}$$

El rango de voltaje de alimentación es de ±2.25 V a ±18 V. Para este diseño se establece un voltaje dual de alimentación de ±12 V.

El bajo ruido y voltaje offset máximo de 50 µV favorecen a las señales de salida de mili-voltios de las celdas de carga. Tiene excelente respuesta en un ancho de banda de 200 KHz para una ganancia de 100. (Anexo B. INA128)

3.1.1.3 Circuito de amplificación con el INA128. El circuito que amplifica la señal de cada celda de carga se muestra a continuación.

Figura 30. Circuito de amplificación con el INA128



Para contrarrestar el voltaje DC de offset que pueda aparecer en la señal de salida debido a la interferencia de radio-frecuencias, se implementa la red pasa-bajo compuesto por R1, R2, C1, C2 yC3. Estos valores establecen una frecuencia de corte de 416.4 Hz:

$$f_c \frac{1}{2\pi \;\; R_2 + R_3 \;\;\; C_2 + C_3 + C_1}$$

$$f_c \frac{1}{2\pi \;\; 3.9K\Omega + 3.9K\Omega \;\;\; 1000pF + 1000pF + 0.047\mu F}$$

$$f_c = 416.4Hz$$

Para calcular el valor del potenciómetro que establece la ganancia exacta del A.I (RG1, Figura 30) se deben tener en cuenta cada sensor llega a un circuito sumador que entregara una señal ponderada no mayor a 5V hacia el conversor análogo-digital luego de ser filtrada.

Entonces, la ganancia de cada A.I. está limitada para un voltaje de salida máximo de 1.25V de tal manera que la suma de las cuatro sea igual a 5V cuando las cuatro celdas de carga entreguen una señal máxima de 21.6mV (40Kg).

Así, los valores de G y RG, están dados por:

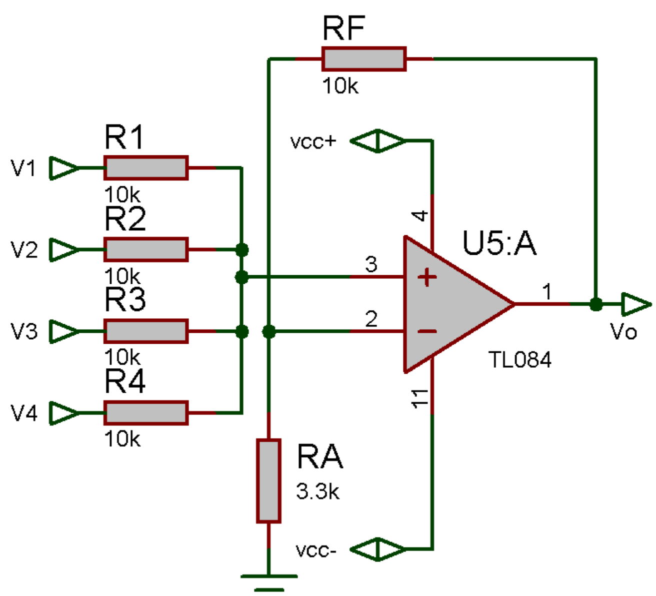
$$G = \frac{1.25V}{21.6mV} = 57.8703$$

$$R_{G1} = \frac{50K\Omega}{56.8703 - 1} \approx 879.192\Omega$$

3.1.1.4 Circuito sumador. Este circuito es el encargado de sumar ponderadamente las cuatro señales provenientes de los amplificadores de instrumentación conectados a cada sensor. De esta manera se obtiene una única señal que representa el peso total.

3.1.1.5 Circuito sumador con el TL084. El circuito encargado de sumar las señales amplificadas provenientes de cada amplificador de instrumentación se muestra en la figura 30.

Figura 31. Circuito sumador con amplificador TL084



Es un sumador no inversor cuya señal de salida está dada por la siguiente ecuación:

$$V_0 = \left(1 + \frac{R_F}{R_A}\right) * (R_1//R_2//R_3//R_4) * \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}\right)$$

Haciendo Rn= R1= R2= R3= R4 la ecuación se reduce a:

$$V_0 = \left(1 + \frac{R_F}{R_A}\right) * \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}\right)$$

Para conseguir una ganancia unitaria en la suma de las señales

$$\frac{R_F}{R_A} = 3$$

Además para hallar un balance de polarización

$$R_F//R_A = R_1//R_2//R_3//R_4$$

$$\frac{3}{4}R_A = \frac{R_F}{4}$$

$$R_F = 3R_A$$

Seguido obtenemos

$$R_F = R_1 = R_2 = R_3 = R_4 = 10K\Omega$$

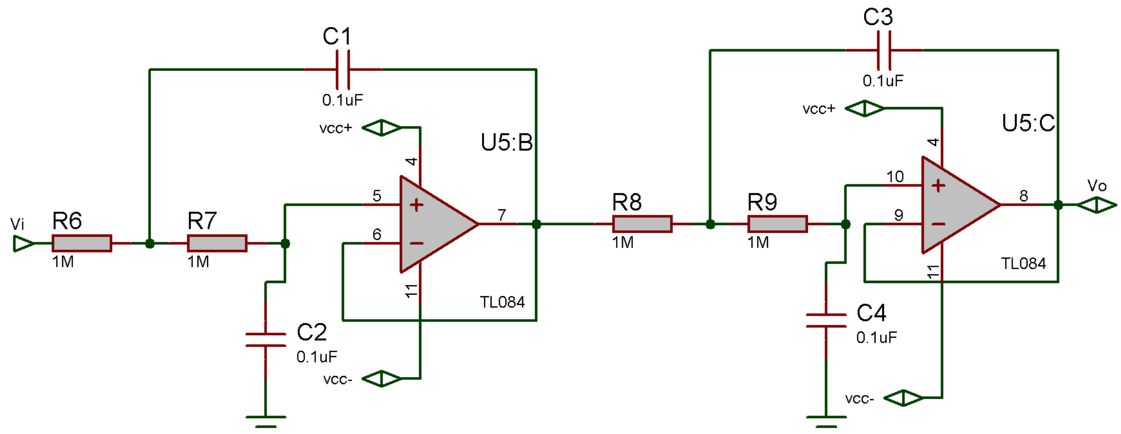
Y con un potenciómetro ajustamos el valor de R_A

$$R_A = \frac{10K\Omega}{3} = 3{,}33K\Omega$$

3.1.1.6 Filtro pasa-bajo. La señal de salida del circuito sumador puede tener algún nivel de ruido proveniente de las mismas celdas de carga que pudieran ser amplificados y sumados, ó niveles de ruido debido a interferencias en cualquier parte del circuito acondicionador, por estas razones, es importante implementar una etapa que filtre al máximo la señal de interés antes de llegar al conversor análogo digital asegurando una correcta medida del peso (Góngora Ruiz, M.A. et al. 2010).

3.1.1.7 Circuito de filtro activo pasa-bajo. Es un filtro pasa-bajo de cuatro polos con una frecuencia de corte de 1.59 Hz, suficiente para filtrar la señal DC proveniente de las celdas de carga. El amplificador operacional seleccionado para este diseño es el TL084. La figura 32 muestra el circuito del filtro:

Figura 32. Filtro pasa-bajo usando amplificador TL084



Las frecuencias de corte de cada una de las etapas del filtro están determinadas por:

$$f_{c1} = \frac{1}{2\pi R_6 * \sqrt{C_1 * C_2}} = \frac{1}{2\pi \ 1M\Omega \ * \ \sqrt{0.1\mu F * 0.1\mu F}} = 1.59Hz$$

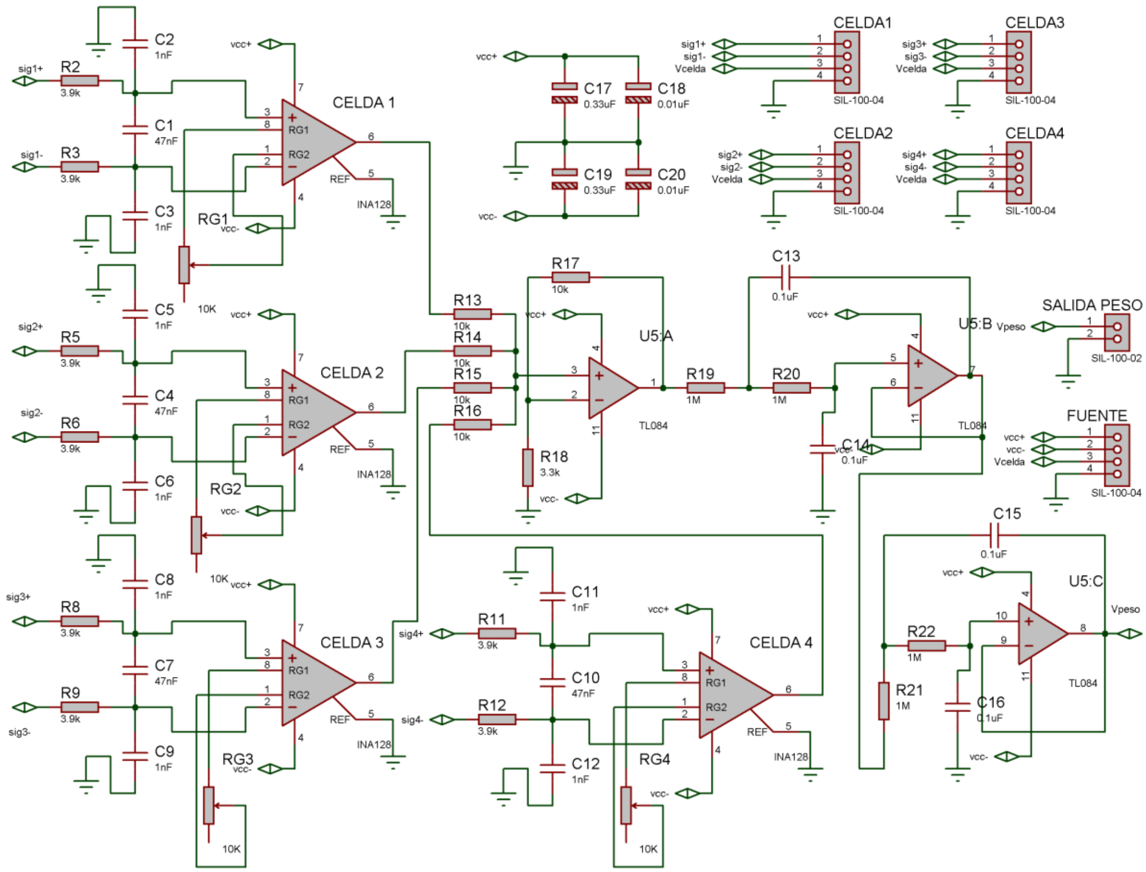
Con $R_6 = R_7$

$$f_{c2} = \frac{1}{2\pi R_8 * \sqrt{C_3 * C_4}} = \frac{1}{2\pi \ 1M\Omega \ * \ \sqrt{0.1\mu F * 0.1\mu F}} = 1.59Hz$$

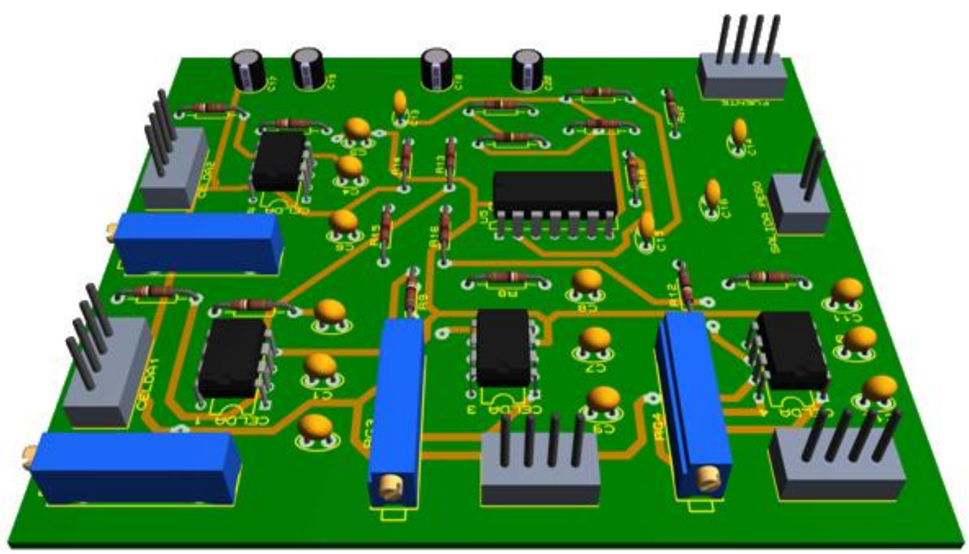
Con $R_8 = R_9$

El circuito final implementado con las cuatro celdas de carga, el sumador y el filtro se puede apreciar en la figura 32.

Figura 33. Acondicionamiento Celdas de carga



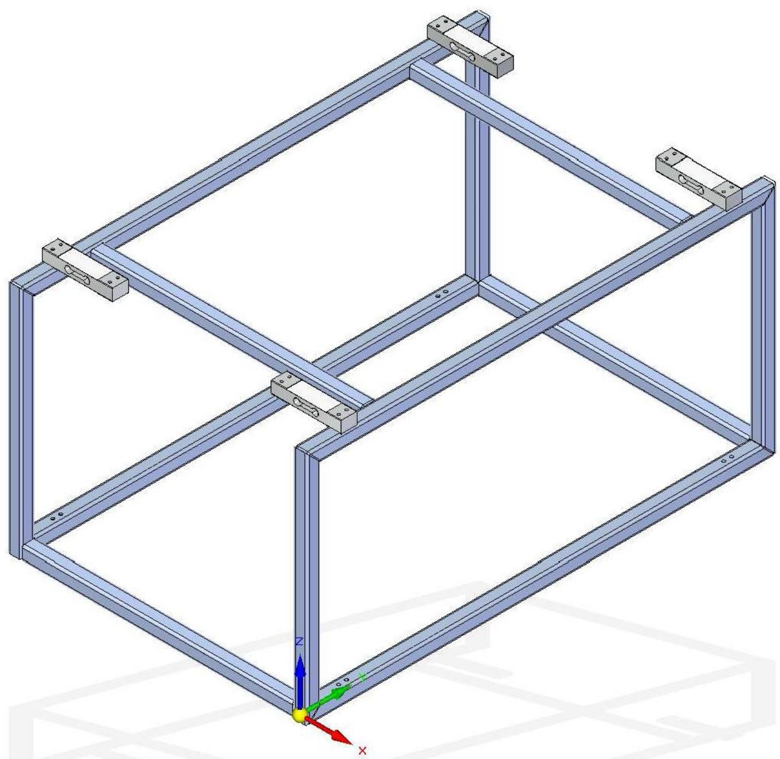
En la figura 33 se puede apreciar la tarjeta de pesaje terminada de manera física.
Figura 34. Tarjeta electrónica de pesaje.



3.1.2 Diseño de la plataforma de pesaje. La plataforma de pesaje se modeló con el software Solid Edge ST3 de la empresa Siemens, el programa permite realizar diseños de estructuras 3D y proporciona las pruebas de esfuerzo a los que son sometidos los materiales de construcción de la plataforma para saber si soportaran el peso con el cual trabajara.

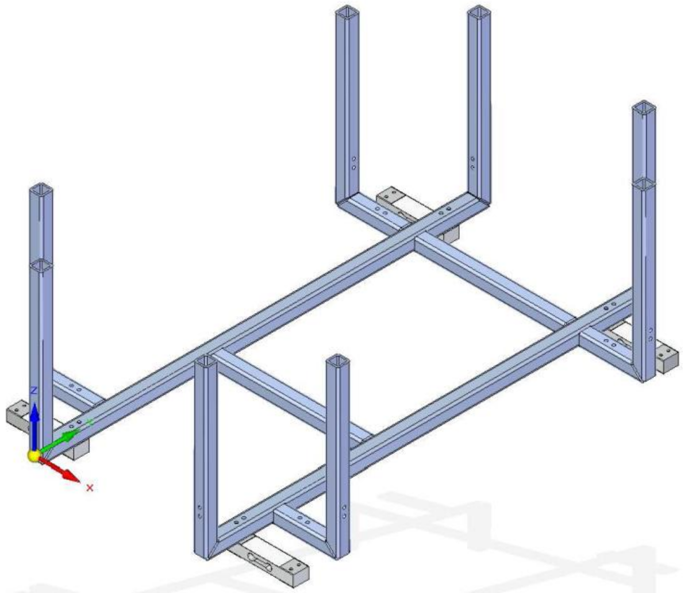
Las celdas de carga para que funcionen adecuadamente se ubicaron en las cuatro esquinas (Figura 34) esto permite que el peso se distribuya de manera uniforme y perpendicular a la superficie de contacto con las celdas de carga.

Figura 35. Ubicación celdas de carga en la plataforma de pesaje



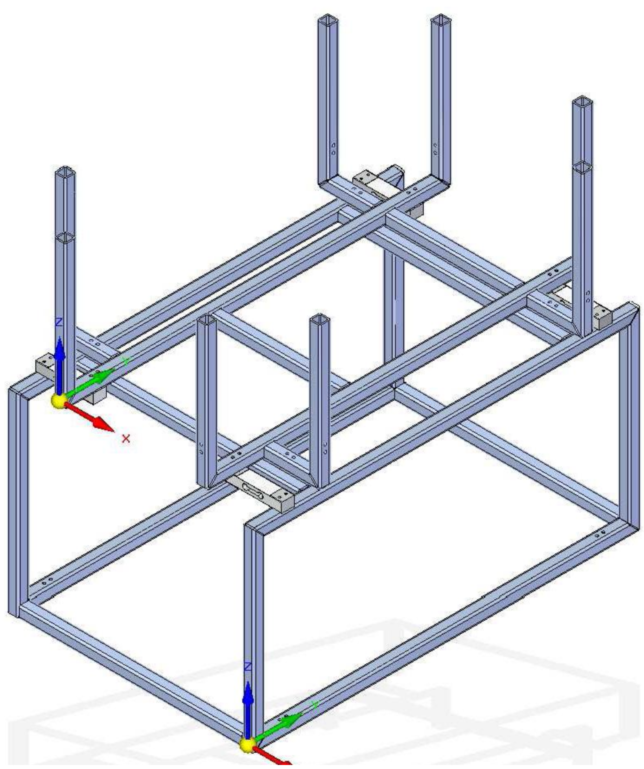
La base sobre la cual se colocara el tanque de fermentación se ubica sobre las cuatro celdas de carga anteriormente visualizadas (Figura 34). Se construyo con ocho tubos verticales formando una canasta (Figura 35), para dar estabilidad a movimientos horizontales que afectan y pueden ocasionar fracturas en las celdas de carga y medidas reales del peso del grano en fermentación

Figura 36. Base tanque de fermentación



La plataforma se construyo en acero estructural en tubería cuadrada de 1” y calibre 1/8”. Su imagen final es como se muestra en la figura 36.

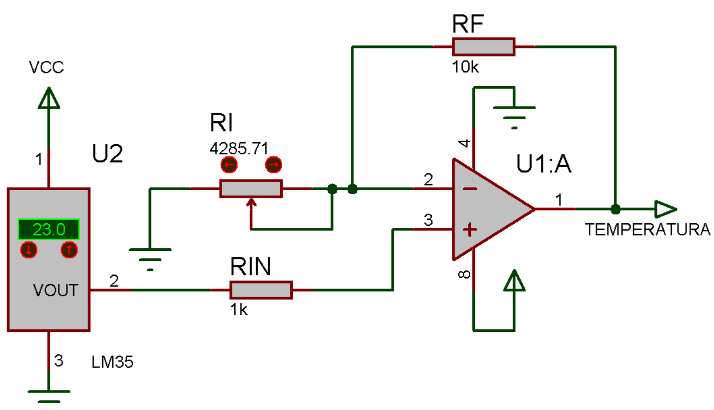
Figura 37. Plataforma de pesaje, prototipo final. Solid Edge ST3



3.2 ACONDICIONAMIENTO SENSOR DE TEMPERATURA

Para obtener la temperatura del proceso se utilizo el sensor LM35 que varia linealmente a una relación de 10mV/°C y la máxima temperatura que soporta es de 150°C (Anexo C. LM35), con esto el mayor voltaje que vamos a tener en la salida del sensor es de 1.5V, se necesita acondicionar este voltaje a los valores del microcontrolador (0-5V) para este fin se hace necesario implementar el circuito de la figura 38.

Figura 38. Circuito de acondicionamiento señal temperatura



La ganancia en un amplificador no inversor está dada por la siguiente relación

Ecuacion 7. $$G = 1 + \frac{R_F}{R_I}$$

Esta debe ser igual a 3.33 para que a la salida del amplificador se tenga valores que correspondan a los niveles de tensión del microcontrolador, G=5V/1.5V, donde 5V (máxima tensión de salida del amplificador) y 1.5V (máxima salida de tensión del sensor LM35). Conociendo la ganancia requerida se calcula las resistencias para configurar el amplificador. Se asume RF=10KΩ y se reemplazan estos valores de G y RF en la ecuación 7 y se despeja RI=4285.71Ω, valor que obtenemos con una resistencia variable (Figura 38).

3.3 ACONDICIONAMIENTO SENSOR DE HUMEDAD

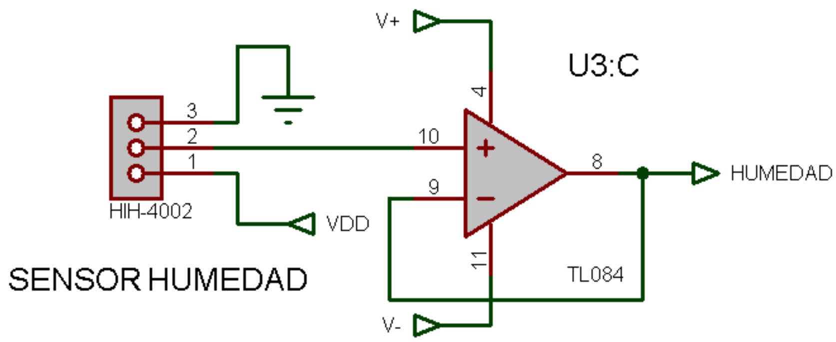
El sensor utilizado fue el HIH-4000-002 (Figura 39), varía su voltaje de salida linealmente con la humedad relativa de 0-100% con una alimentación de 4-5.8Vdc y opera en un rango de temperatura de -40 a 85°C. (Anexo D. HIH-4000)

Figura 39 Sensor de humedad HIH-4000-002

Fuente: http://www.tme.eu/es/katalog/sensores-de-humedad_100525/

El sensor tiene una salida de tensión de 0 a 3.8 voltios máximos, que están dentro de los niveles que el microcontrolador por su puerto análogo puede manejar, así que el sensor es conectado a un seguidor de tensión figura 40, para acoplar impedancias y fijar el voltaje

Figura 40 Acondicionamiento sensor de Humedad HIH-4002



La función para el cálculo de la humedad relativa es proporcionada por el fabricante en la ecuación 8 se puede ver la relación entre voltaje de salida del sensor y la humedad relativa

Ecuación 8. $$V_{0ut} = V_{Fuente}\ 0.0062\ \%RH\ + 0.16$$

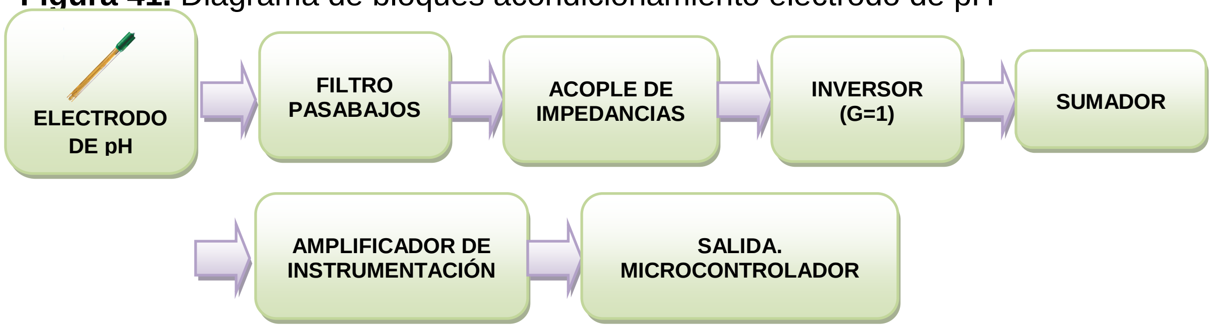
De esta relación se despejo %RH, ecuación 9 para determinar el porcentaje de humedad relativa de 0 a 100%

Ecuación 9. $$\%RH = \frac{V_{0ut}}{V_{Fuente}*0.0062} - \ 0.16$$

3.4 MÓDULO ACONDIONADOR PARA EL ELECTRODO DE PH

En la Figura 41 se muestra un diagrama de bloques del circuito acondicionador de pH

Figura 41. Diagrama de bloques acondicionamiento electrodo de pH



El electrodo que se utilizó fue el PE-11 LUTRON y tienen las características suministradas en la tabla 4.

Tabla 4 Características físicas electrodo de pH PE-11

Especificaciones	**Electrodo PE-11**
Descripción	Electrodo PH combinado
Referencia	Doble, Ag/AgCl
Unión	Cerámica simple
Electrolito	Gel
Intervalo	pH: 0-14
Punta	Esférica
Cuerpo	Plástico
Cable	Coaxial 1m
Conector	BNC

Un electrodo de pH detecta los cambios de potencial (voltaje) causados por la diferencia de acidez en el agua. Por otra parte, estos electrodos son un excelente método para la medida del pH debido a su linealidad, exactitud, inmunidad al color o turbidez de la muestra, bajo costo y rápida respuesta. De forma concreta, un electrodo de pH consiste en una delgada membrana de vidrio sensible a la actividad de los iones H+ presentes en el agua.

Se le llama electrodo de combinación debido a que reúne en un solo cuerpo el electrodo de referencia y el electrodo de pH, el cual mide la diferencia de potencial (voltaje) entre ambos electrodos.

El voltaje en generado por el electrodo de pH esta dado por la ecuación de Nernst ver ecuación 10 y es proporcional a $[H^+]$

Ecuación 10. $$E_{medido} = E_{referencia} - \frac{2.3\ RT}{nF}\ pH$$

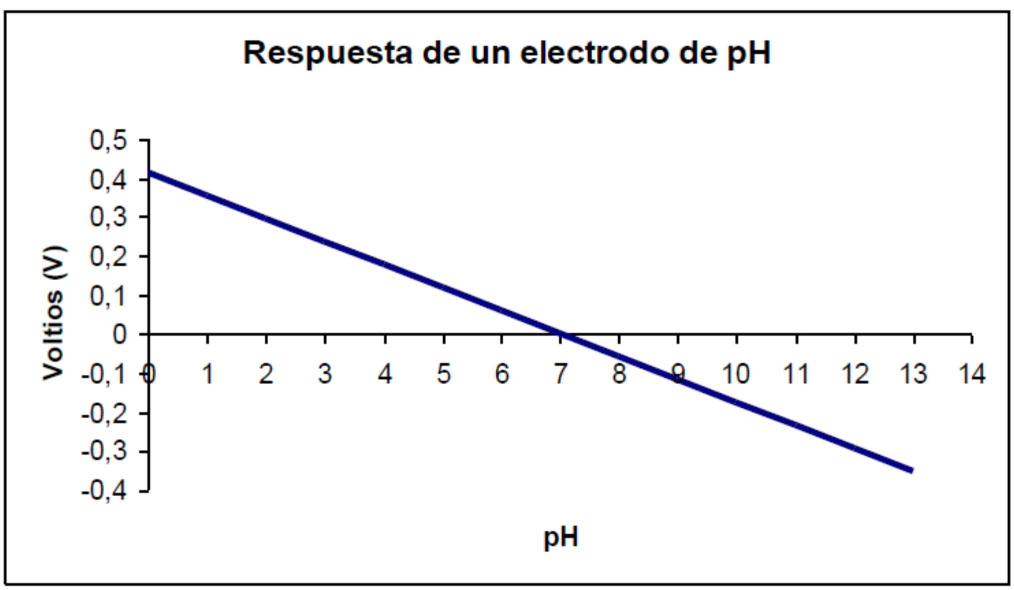
Donde:
E_{medido}, es el potencial (en voltios) detectado a través de la membrana de vidrio.
$E_{referencia}$, es el potencial del electrodo de referencia.
R = constante universal de los gases.
T = temperatura absoluta en grados Kelvin.
n = la carga del ión, que para el pH vale 1.
F = constante de Faraday.
2,3 RT/NF = el factor de Nernst.

Como el factor de Nernst a temperatura de 25°C vale aproximadamente 0.0591 y el potencial de referencia se considera igual a cero la ecuación 10 queda reducida a las ecuación 11

Ecuación 11. $$E_{medido} = 0.0591 * pH$$

La ecuación 11. Establece la relación de 59.1 mV por unidad de pH (a 25°C) en la figura 42 se muestra la curva de un electrodo de pH

Figura 42. Respuesta electrodo. PH vs Voltaje (V)



3.4.1 Diseño del Filtro Pasabajos El filtro Pasabajos permite atenuar el ruido externo al electrodo que altera las medidas reales de este, considerando que la velocidad de respuesta del electrodo por cambios de PH es hasta de 300 ms el filtro tiene una frecuencia de corte de 3.333 Hz

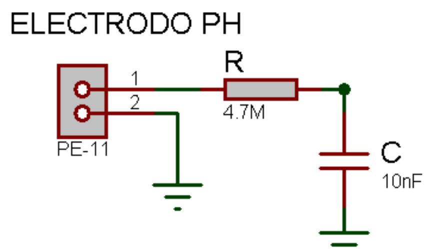
Ecuación 12. $$f = \frac{1}{T} = \frac{1}{300ms} = 3.33\ Hz$$

El cálculo de la frecuencia de corte para se realiza con la siguiente relación

Ecuación 13. $$f_c = \frac{1}{2\pi RC}$$

En la figura 43 se ilustra el filtro diseñado

Figura 43 Filtro pasa bajos a 3.33 Hz



Se selecciona un condensador comercial de 10nF y se calcula el valor de R para una frecuencia de 3.333 Hz, de la ecuación 3.4.3se tiene que:

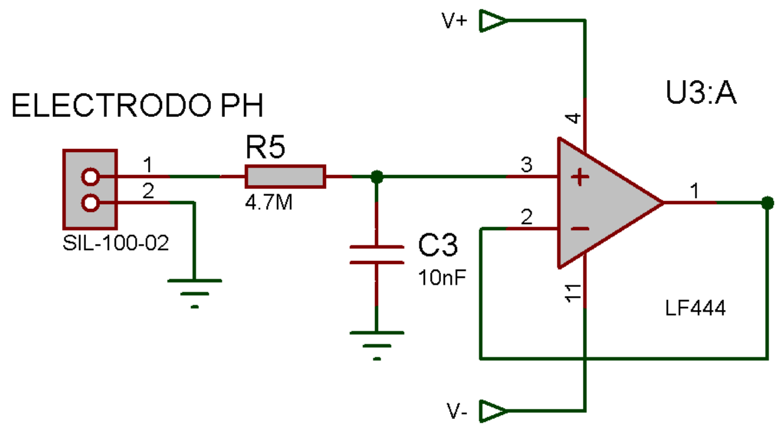
$$R = \frac{1}{2\pi * 3.33 * 10 * 10^{-9}}$$

$$R = 4.7M\Omega$$

Con el filtro se asegura un filtrado de la señal del electrodo PH y queda lista para ser acoplada a la siguiente etapa.

3.4.2 Acople de Impedancias. Para este fin se implemento un seguidor de tensión como se muestra en figura 44

Figura 44 Circuito de acople de Impedancias LF444

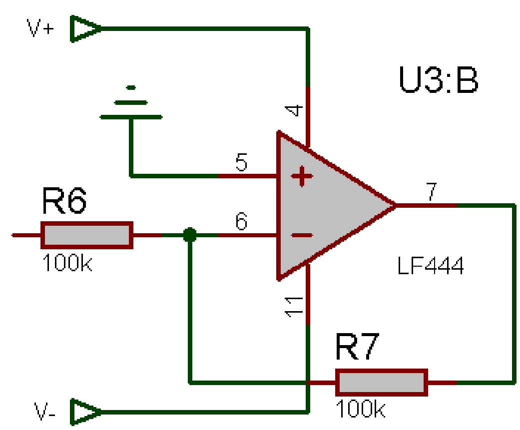


Los electrodos de vidrio tienen una impedancia muy alta de aproximadamente 50 MΩ hasta 500 MΩ por esto se hace necesario un amplificador como el LF444 (Anexo E. LF444) de National Semiconductor que tiene una impedancia de entrada muy alta 10^{12} Ω suficiente para realizar un buen acople con el electrodo de PH.

3.4.3 Diseño del Circuito Inversor de G=1. Este circuito invierte el signo de la señal de salida pero la magnitud es igual a la de la señal de entrada, el diagrama del circuito se observa en la figura 45

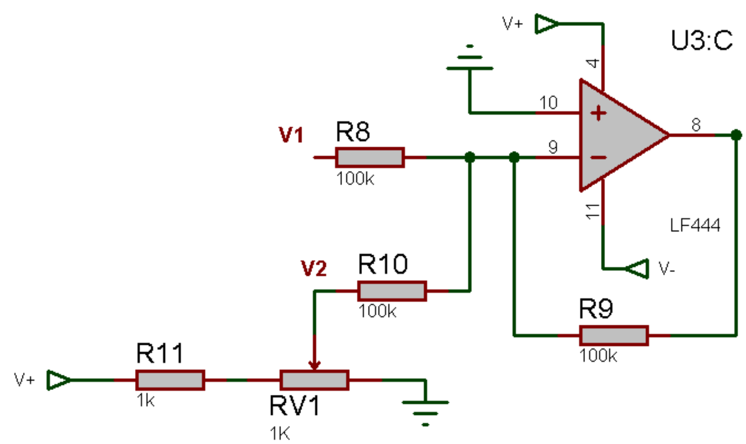
Su función se realiza para cambiar el signo de la señal del seguidor de voltaje de la etapa de acople de impedancias

Figura 45 Circuito inversor con G=1



3.4.4 Diseño del Circuito Sumador. El circuito sumador inversor (Figura 46) suma el voltaje V1 que tiene un rango de -380mV a 380mV del inversor de G=1 con la tensión de referencia V2=380mV generada con un divisor de voltaje, con esto aseguramos una variación a la salida del sumador de inversor es de -760mV a 0mV (Figura 46),

Figura 46 Esquema amplificador INA128



Se ajusto el potenciómetro hasta obtener el voltaje V2=380mV y quedando una resistencia de R=51Ω

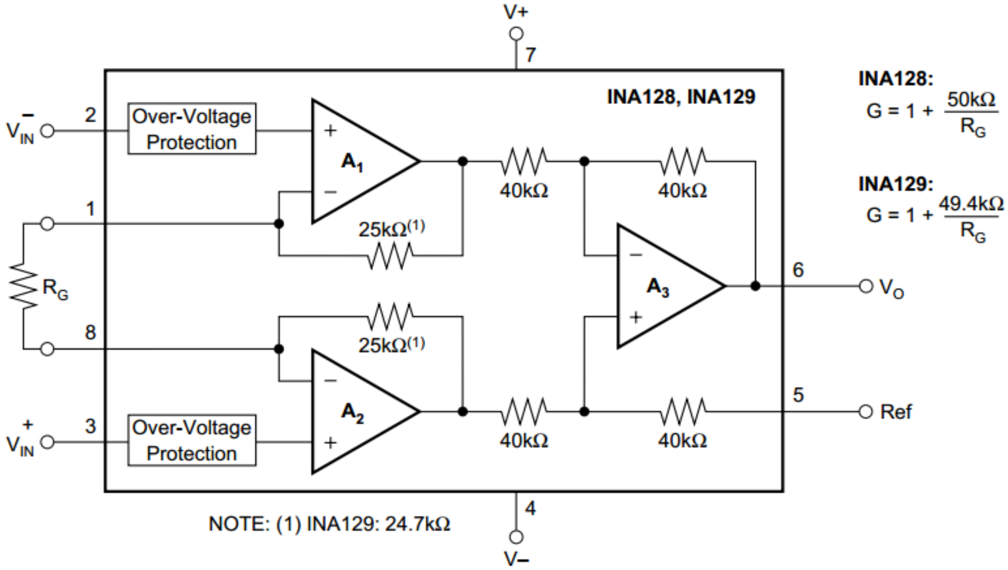
Figura 47 Rango voltaje salida del sumador inversor

3.4.5 Diseño Circuito Amplificador. Para esta etapa se utilizo el amplificador de instrumentación INA128, es un dispositivo que ofrece una alta precisión, bajo costo, posee un ancho de banda de 200KHz a G=100, su ganancia se puede ajustar solo con una resistencia de 1 a 10000, voltaje de offset de 50µV, funciona con alimentaciones de ±2,25V a ±18V máximo de ±40V.

Para más información ver Anexo B

A continuación se ilustra un esquema del INA128

Figura 48 Esquema amplificador INA128



Fuente: http://www.datasheetcatalog.org/datasheet/BurrBrown/mXrttty.pdf

Como se necesita que la salida del amplificador varié en un rango de 0-5 voltios para los niveles de tensión del microcontrolador, se procede a calcular la ganancia necesaria para este fin.

Vmáx_out=5V en la salida y en la entrada Vmáx_in es de 760mV entonces se tiene que.

$$G = \frac{Vmáx\_out}{Vmáx\_in} = \frac{5V}{760mV} = 6.6$$

Para calcular RG se utiliza la fórmula del INA128

Ecuación 14. $$G = 1 + \frac{50K\Omega}{RG}$$

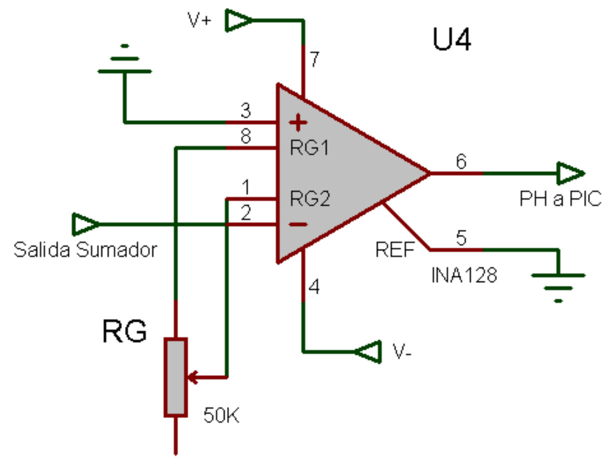
De la ecuación 14, se tiene que:

$$RG = \frac{50K\Omega}{G - 1}$$

Reemplazando G=6.6 se tiene que RG=8.928KΩ

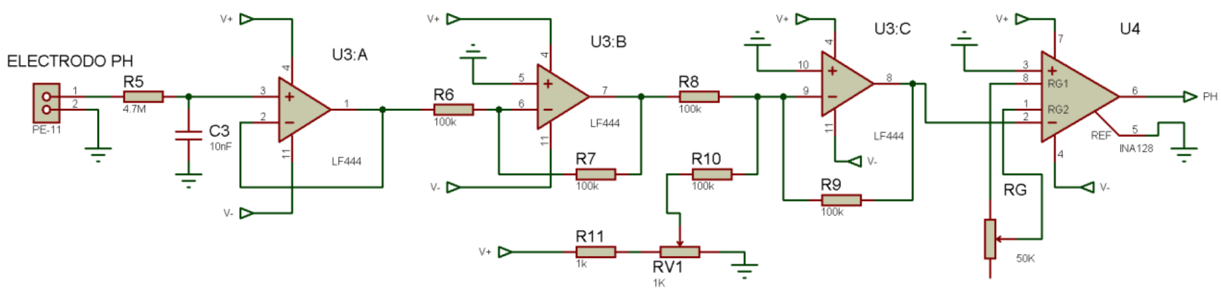
Diseñando el esquema del circuito se utiliza un potenciómetro de 50KΩ para ajustar la resistencia RG (Figura 48)

Figura 49 Circuito Amplificador INA128



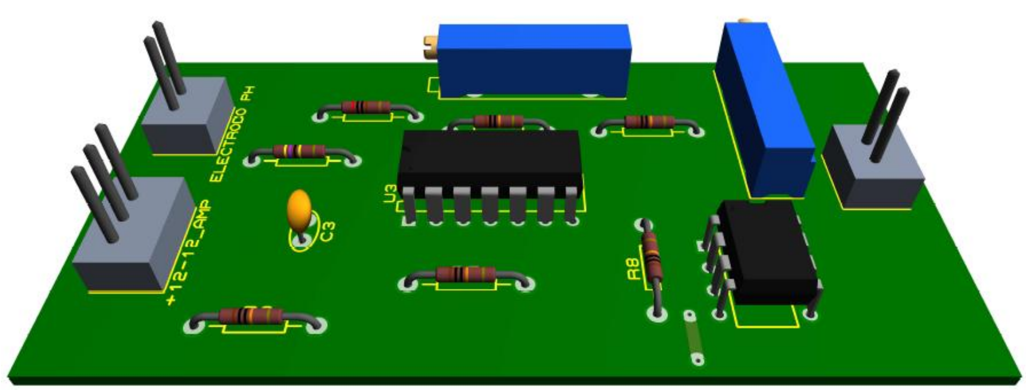
El circuito completo del acondicionamiento del electrodo de PH se presenta en la figura 49

Figura 50 Circuito de acondicionamiento electrodo PH



La tarjeta implementada se muestra en la figura 51

Figura 51 Tarjeta acondicionamiento electrodo PH



3.5 DISEÑO FUENTE DE ALIMENTACIÓN

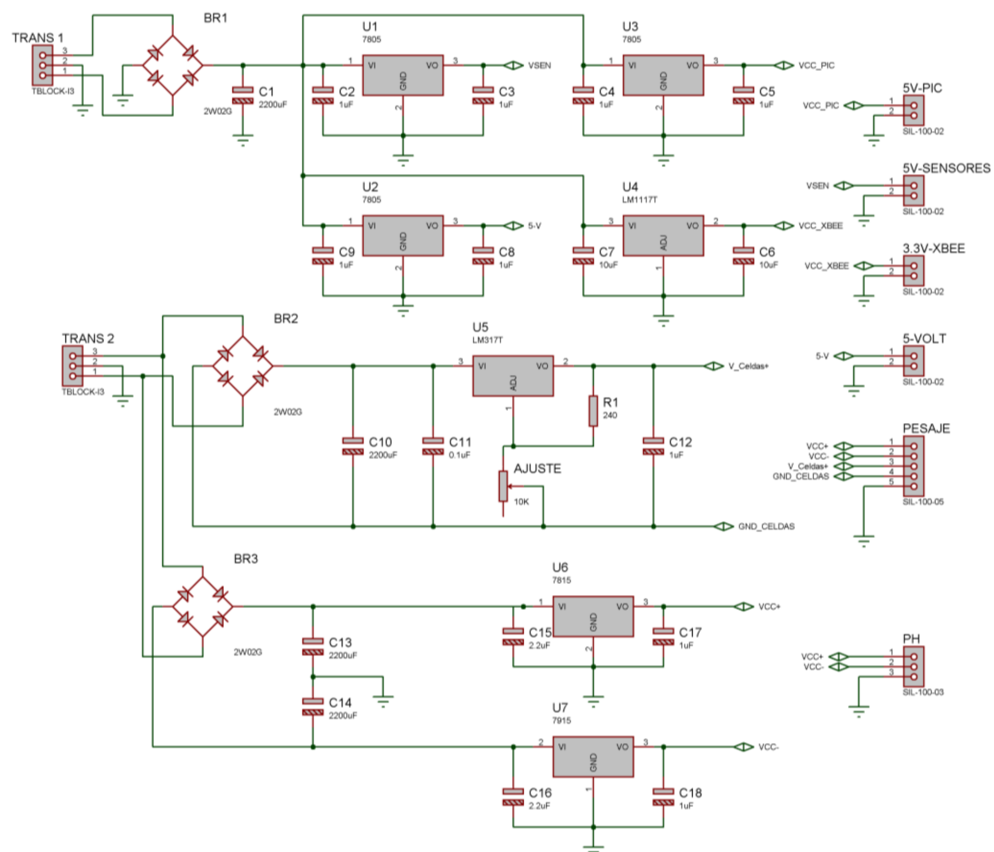
Se implemento una fuente regulada que proporciona los voltajes necesarios para el óptimo funcionamiento del sistema, en la tabla 4 se presentan los dispositivos, los voltajes de operación y los reguladores utilizados en el diseño de la fuente.

Tabla 5. Voltajes, fuente de alimentación

DISPOSITIVO	VOLTAJE OPERACIÓN	REGULADOR
Microcontrolador	5 Voltios	LM7805
Zigbee	3.3 Voltios	LM1117T
Celdas de Carga	10 Voltios	LM317T
Amplificadores +	+15 Voltios	L7815
Amplificadores -	-15 Voltios	L7915
Sensores	5 Voltios	LM7805

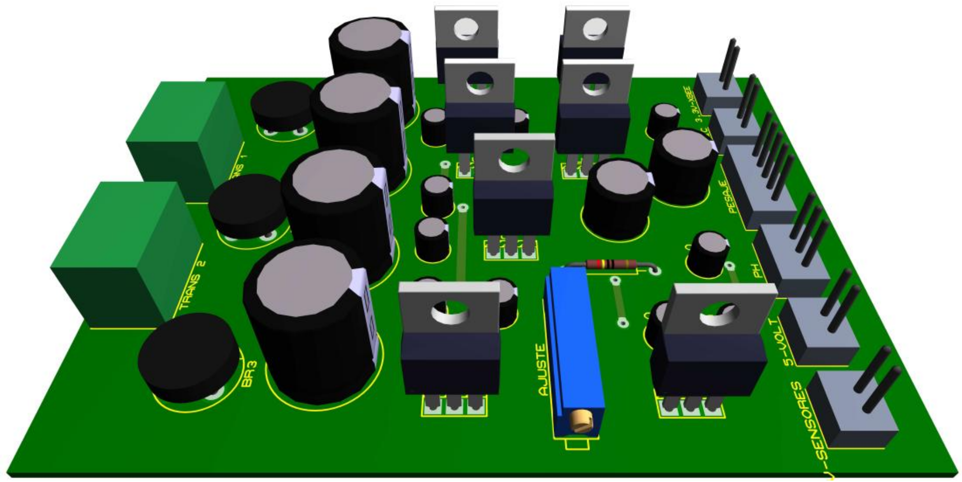
El esquemático que se diseño se presenta en la figura 52

Figura 52. Esquemático fuente de alimentación



La tarjeta implementada se ilustra en la figura 53

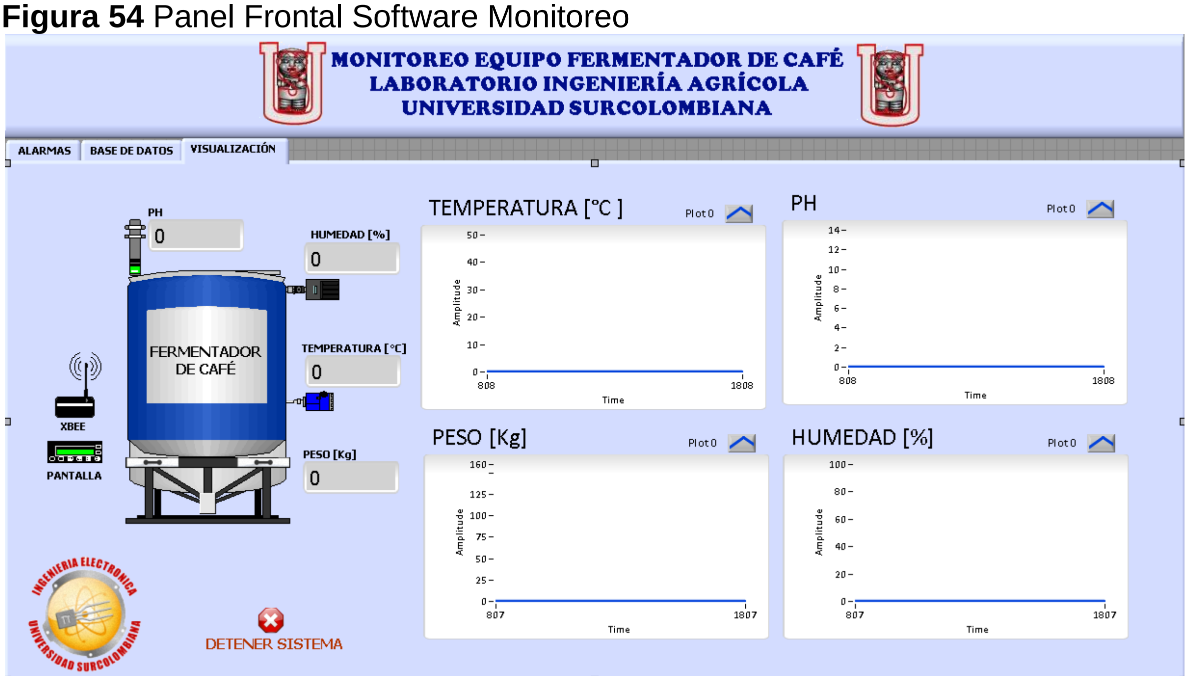
Figura 53. Tarjeta fuente de alimentación



3.6 SOFTWARE DE MONITOREO Y ALMACENAMIENTO EN BASE DE DATOS MYSQL Y LABVIEW.

El sistema cuenta con un programa de monitoreo desarrollado en Labview el cual es un software de programación gráfica que permite crear aplicaciones muy amigables al usuario y de un fácil manejo. En la figura 54 se aprecia el panel frontal. (Anexo F. Programa Monitoreo Labview)

Figura 54 Panel Frontal Software Monitoreo



El programa tiene tres ventanas de configuración

3.6.1 Ventana de Alarmas En la figura 55 se observa dicha ventana, esta provee información de estado de los sensores, si estos están funcionando adecuadamente. Tiene la opción para configurar el envío de correos electrónicos según el intervalo de tiempo que se programe para ver el estado de la fermentación, en el email se adjunta un archivo texto con el sumario de todas las medidas almacenadas.
Tiene una alarma para dar la señal de que el proceso de fermentación ha terminado con el grado de PH deseado el cual se programa inicialmente en un valor de 0-14. En el momento en que el proceso termine se genera una alarma visual y sonora indicando que el fermentado ha finalizo.

Figura 55 Panel de Alarmas

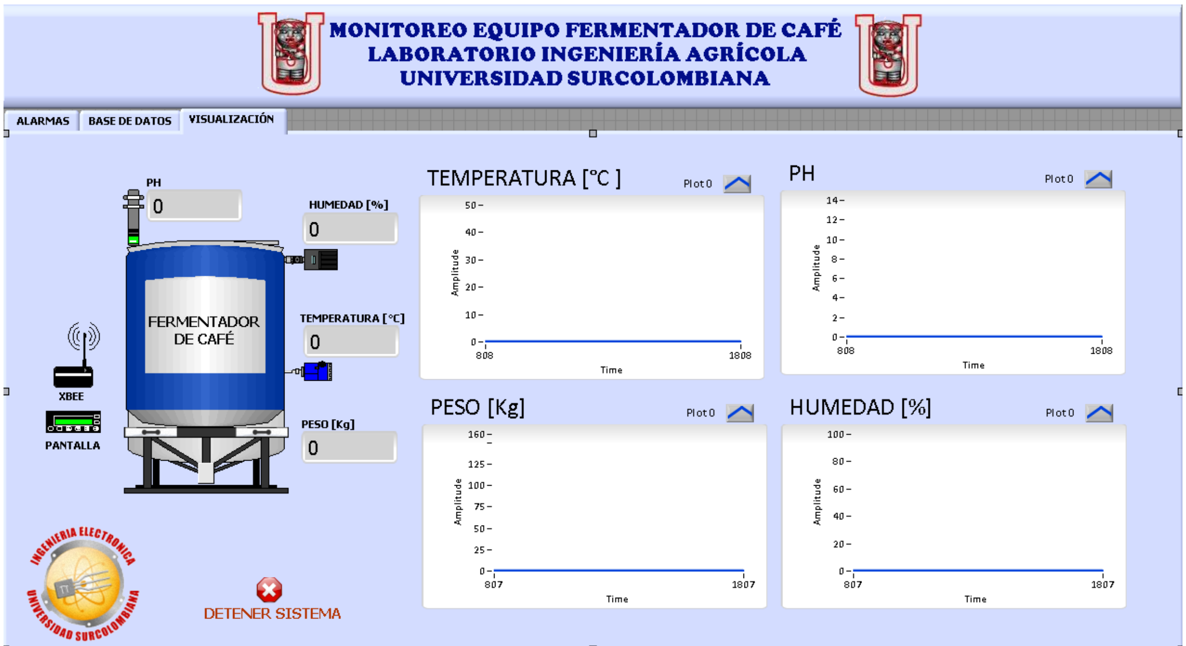
3.6.2 Ventana de Base de Datos Esta se observa en la figura 56, en el panel izquierdo de la ventana se ingresan los datos para crear los usuarios en la base de datos, en el panel derecho se observan dos pestañas una de ellas sirve para buscar, eliminar registros anteriores o el registro del proceso actual. El proceso de búsqueda se realiza por el nombre del usuario y por el número del lote de café que se tiene en fermentación figura 56. La pestaña dos tiene la opción de generar un reporte que se exporta a una hoja de excel. Este se utiliza para un análisis y se pueden graficar los datos para su respectiva interpretación figura 57.

Figura 56 Frontal Base de Datos y Buscar Registros

Figura 57 Frontal Base de Datos y Generar Reporte

3.6.3 Ventana Visualización. Esta ventana es donde se proyecta en tiempo real la evolución de las variables en una ilustración del proceso que muestra el valor que cada sensor está leyendo, y se grafica cada valor por separado Figura 58.

Figura 58 Frontal de Visualización

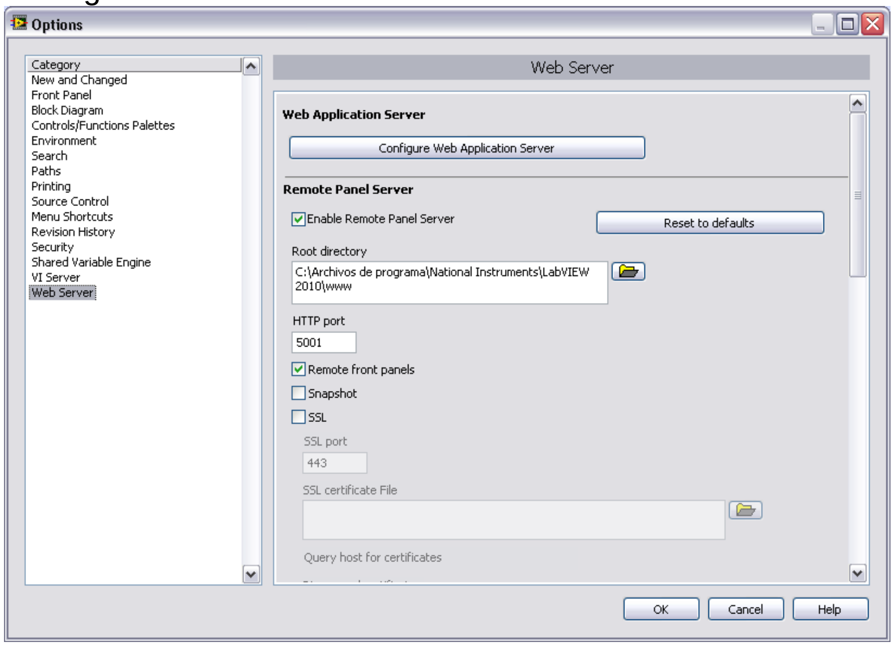


3.6.4 Monitoreo desde Internet. El monitoreo remoto desde otra computadora a través de internet es una de las herramientas que nos proporciona Labview y que nos permite mantener un seguimiento completo de todo el proceso así no se esté en las instalaciones del fermentador.

Labview ya cuenta con un servidor web que hace posible subir instrumentos virtuales a la red, dando una URL al sistema con la IP de la computadora.

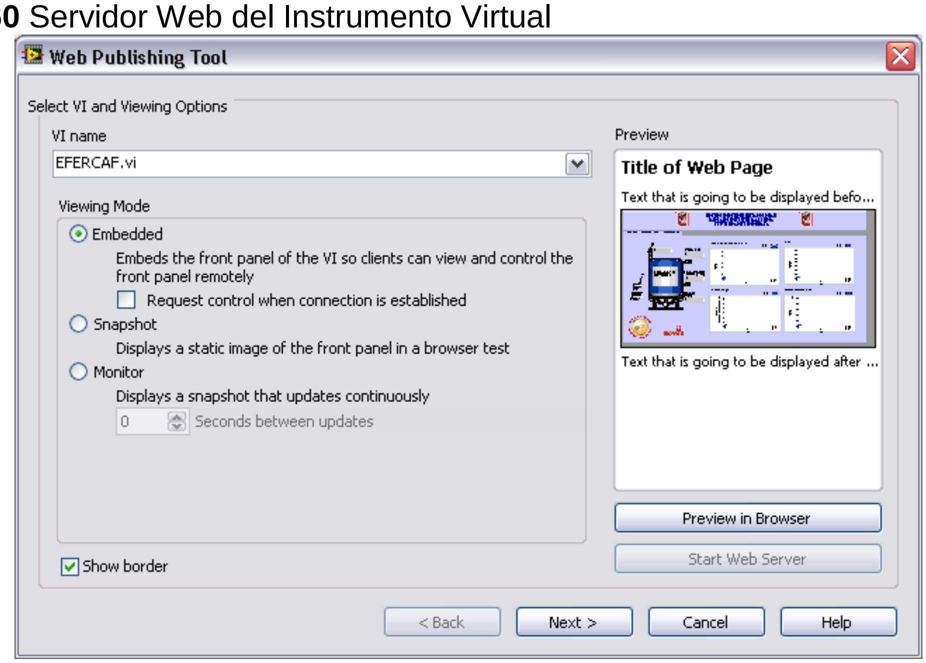
El puerto que se usó fue el 5001 debido a que no tiene un servicio asignado. Para seleccionar el puerto 5001 en Labview se escogió en la barra de menú la opción *Tools* y posteriormente la casilla de *Options*. Apareció una ventana como la que se observa en la figura 59. Y ahí se seleccionó la opción W*eb Server Configurations,* en esa ventana se configuró el puerto http que se usó para tener acceso al sistema.

Figura 59 Configuración Web Server Labview



Para conocer la dirección URL por la cual se tuvo acceso al sistema se habilitó el servidor web de Labview. Primero, se ingresó al servidor web del instrumento virtual en el que se estaba trabajando, desde la pantalla principal de Labview. Para ello, se seleccionó en la barra de menús la opción *Tools* y se seleccionó *Web Publishing Tool,* posteriormente se abrió una ventana como se muestra en la figura 60.

Figura 60 Servidor Web del Instrumento Virtual



Se siguen las instrucciones y al final el programa nos proporciona la URL en nuestro caso es http://5.166.136.6:5001/EFERCAF.html y al ingresar se debe utilizar Internet Explorer y se tiene el panel mostrado en la figura 61.

Figura 61 Panel Frontal Remoto Internet

3.7 SISTEMA DE COMUNICACIÓN

El sistema cuenta con un sistema de comunicación inalámbrico Zigbee bajo el estándar IEEE 802.15.4
Entre las principales características de este tipo de dispositivos se encuentran:

- Voltaje de alimentación de 3.3 voltios.
- Alcance de 1000 metros en línea libre de visión y 500 metros en interiores.
- Frecuencia de transmisión de 2.4GHz en la banda industrial, científica y médica.
- Poseen mayor potencia a la salida y capacidad para formar redes más grandes.

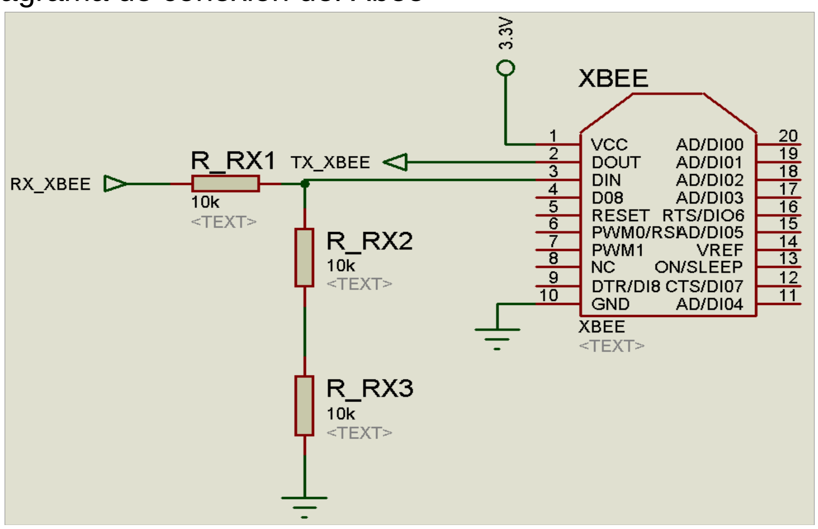
Para más información ver (Anexo G. Xbee)

En la Figura 62 se muestra el dispositivo escogido. Y en la Figura 63 se observa el diagrama de conexión correspondiente para este modelo.

Figura 62 Xbee Pro S1

Fuente: http://2r-he.blogspot.com/2009/07/xbee-pro-low-cost-wireless-sensor.html

Figura 63 Diagrama de conexión del Xbee



Fuente: (Losada, T. et al., 2012).

En circuito de la Figura 63 las resistencias R_RX1, R_RX2 y R_RX3 conforman un divisor de voltaje que tiene una entrada de 5 voltios provenientes de microcontrolador cuando está en modo de transmisión y en la salida tiene un voltaje de 3.3 voltios, el cual es el nivel de voltaje con el que operan las entradas del dispositivo. Este divisor está dado por la ecuación 15.

Ecuación 15. $$V_o = \frac{(R\_RX2 + R\_RX3) * V_i}{(R\_RX2 + R\_RX3 + R\_RX1)}$$

Donde V_o es el voltaje en la salida del divisor, es decir la entrada del dispositivo y V_i es el voltaje que sale del microcontrolador, es decir en el circuito RX_XBEE (Losada, T. et al., 2012).

4. CONCLUSIONES

- Se instaló un completo lote de sensores que permiten el monitoreo de temperatura, peso, PH y humedad del proceso, la sensorica utilizada es de bajo costo con un muy buen desempeño, haciendo al sistema accesible a pequeños y grandes productores de café

- La incorporación de tecnología inalámbrica Zigbee, permite hacer el equipo versátil en cuanto a movilidad, el computador no tiene que estar expuesto a sustancias que lo pueden dañar causando pérdidas de información y dinero, se puede monitorear el fermentador desde la comodidad del hogar, debido a que los sitios de beneficio se ubican alejados de la vivienda.

- El software desarrollado permite un completo manejo de los datos en cuanto a visualización y almacenamiento, es de fácil manejo y la interfaz programada en Labview tiene un aspecto novedoso, agradable, fresco. Con monitoreo remoto desde la web, lo que hace al sistema totalmente independiente del sitio donde se encuentra el equipo fermentador, solo basta una conexión a internet para saber el estado real del proceso.

- Se diseñó en Solid Edge ST3 la plataforma de pesaje, que permite el seguimiento másico del grano de café en fermentación. Es una estructura robusta construida en metal de alta calidad, con una capacidad de 125Kg

- Una de las variables más importantes en el beneficio húmedo del café es el grado de PH, para este fin se diseño e implemento un medidor de PH el cual utiliza un electrodo PE-11 el cual determina la concentración de iones de hidrógeno [H^+] en el medio a medir. El peachímetro diseñado funciona en un rango de 0-14. Con él monitoreo del PH se puede determinar el punto exacto de terminación de la fermentación, evitando sobrefermento que decline la calidad organoléptica del café

- Se implementó un display LCD con un menú de visualización en el sitio del equipo de fermentación, permitiendo una rápida lectura del estado de las variables, humedad peso, temperatura y PH. Sin necesidad de tener el computador cerca o encendido. Con lo cual se pueden tomar decisiones rápidas sobre el curso que debe tener el fermentado.

- La base de datos se desarrolló en MYSQL de distribución libre, con ella se permite llevar un completo registro y control de los usuarios del equipo de fermentació, tiene la función de generar reporte a excel para un análisis más detallado y preciso de los datos

5. RECOMENDACIONES

- Utilizar software libre para evitar la compra de licencias por los ejecutables de programas como Labview, minimizando costos de implementación.

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ANEXOS

ANEXO A. HOJA DE DATOS CELDA DE CARGA SP06-AL MV

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO B. AMPLIFICADOR DE INSTRUMENTACIÓN INA-128

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO C. HOJA DE DATOS SENSOR DE TEMPERATURA LM-35

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO D. HOJA DE DATOS SENSOR DE HUMEDAD HIH-4000

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO E. HOJA DE DATOS AMPLIFICADOR LF-444

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO F. CÓDIGO DEL PROGRAMA DE MONITOREO LABVIEW

Este anexo se encuentra en el CD que acompaña este libro.

ANEXO G. HOJA DE DATOS MODULO XBEE PRO

Este anexo se encuentra en el CD que acompaña este libro.

Diseño e Implementación de Sistema de Monitoreo para Equipo Fermentador de Café.

Design and Implementation of Measure System for a Fermenter of Coffee.

José Duban Henao Cuellar[1], Agustín Soto Otalora[2], Junior Francisco Quijano Mosos[3], Manuel Fernando Ovalle Cerquera[4]

Resumen

El proyecto consiste en el diseño e implementación de un sistema de monitoreo de un fermentador de café, se instaló un lote de sensores que permiten obtener en tiempo real las condiciones en que se encuentra el grano de café en fermentación en cuanto a temperatura, humedad, pH y peso. Con estos datos se tiene suficiente información para determinar cuándo el proceso está terminado y pasar al lavado del café. El equipo implementado, cuenta con un tanque de fermentación ubicado sobre una plataforma de pesaje que posee cuatro celdas de carga que monitorean el comportamiento másico del grano.

Se desarrolló una interfaz en Labview 2010, la cual cuenta con la visualización y la evolución de las variables medidas, así como la gestión de la base de datos creada en MYSQL, con opciones de crear, deshacer y exportar a excel la información de los registros para su posterior análisis. Se incorporó el monitoreo remoto en internet donde se tendrá le interfaz con toda la información y el estado del proceso. El dispositivo se equipó con tecnología Zigbee para comunicarse con el computador, este instrumento trabaja bajo el estándar IEEE 802.15.4 de redes inalámbricas de área personal, permite que el fermentador sea portátil en un rango de 1000 metros con línea de vista y 500 metros en interiores.

Palabras clave: Labview; MYSQL; monitoreo; fermentador; café

Abstract

The project is about designing and implementing of a monitoring system for a coffee fermenter. This machine has got a batch of sensors that allow getting real-time temperature, humidity, pH and weight conditions during fermentation process. These data are enough information to determine the ending process in order to start the washing coffee process. The team implemented, has a fermentation tank located on a platform that has four weighing load cells that monitor the behavior of the grain mass.

The interface was developed in Labview 2010, which shows the evolution of the measured variables, also, a database created in MySQL, which has the options to create and export to excel the record information for analysis. This work has remote monitoring internet where users can access to all the information and status of the process. The device is equipped with Zigbee technology to communicate with the computer, this instrument works on the

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IEEE 802.15.4 standard for wireless personal area networks, allows the fermenter being portable in a range of 1000 meters with a line of view and 500 meters indoor.

Keywords: Labview; MYSQL; monitoring; fermenter; coffee

1. Introducción

Tradicionalmente el café ha sido el producto de mayor exportación en Colombia y la base de su economía nacional. En este contexto el departamento del Huila como región caficultora se ratificó como el primer productor de café en el país, con un 16.01% de la producción nacional. Sin embargo una de las principales dificultades que enfrenta el gremio es que solo el 56% de los caficultores cuentan con asistencia técnica (Diario del Huila., 2011), ésta es una de las grandes premisas para el desarrollo del proyecto de monitoreo de fermentación de café.

El proceso de fermentado es una de la etapas más delicadas en el beneficio del café, este procedimiento es la licuefacción del mucilago por medio de enzimas y bacterias, que hacen que a medida que la descomposición avanza el PH disminuye, la temperatura en la pila de fermentación aumenta y el grano pierde peso (Berthaut, J. et al., 1985). Cuando no se realiza un seguimiento a estas variables puede ocurrir una sobre fermentación dando como resultado cafés de baja calidad con sabores como: vinagre, guayaba, rancio, piña madura, condiciones que devalúan el precio del grano.

El equipo desarrollado contribuirá al conocimiento detallado del proceso de fermentación y a tomar una mejor decisión del momento en que se debe llevar el grano al lavado para obtener cafés de alta calidad y de cualidades que se pueden manipular ya que podemos hacer que el café se fermente más o menos de una forma controlada buscando que tanto incide de una manera cuantitativa la fermentación en el procesado del café.

Este fermentador fortalecerá la investigación de grupos que buscan siempre mejorar la calidad en los granos, para así obtener mayores ingresos y ser competitivos en mercados nacionales e internacionales.

2. Metodología

2.1 Diseño estructural. En el proyecto, la primera fase correspondió al diseño de la plataforma base sobre la cual se colocara el tanque de fermentación. Se modeló con el software Solid Edge ST3 de la empresa Siemens, el programa permite realizar diseños de estructuras 3D y proporciona las pruebas de esfuerzo a los que son sometidos los materiales de construcción de la plataforma para saber si soportarán el peso con el cual trabaja. En ella se ubicaron cuatro celdas de carga (una en cada esquina) permitiendo que el peso se distribuya de manera uniforme y perpendicular a la superficie de contacto.

La plataforma se construyó en acero estructural en tubería cuadrada de 1” y calibre 1/8” formando una canasta, para dar estabilidad a movimientos horizontales que afectan y pueden ocasionar fracturas en las celdas de carga y medidas reales del peso del grano en fermentación. Su imagen final es como se muestra en la figura 1.

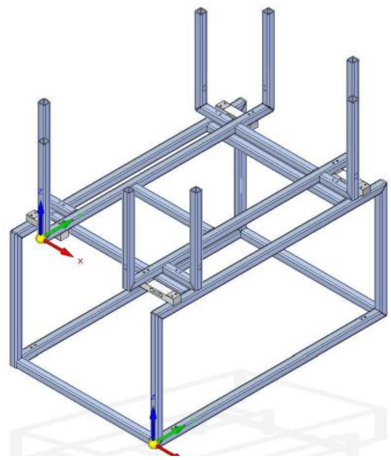

Fig. 1. Plataforma de pesaje, prototipo final. Solid Edge ST3

2.2 Descripción del Hardware. El sistema consta de tres tarjetas electrónicas: dos tarjetas para el acondicionamiento de la señal de peso y pH respectivamente, y una tarjeta central que contiene los sensores de humedad, temperatura y un microcontrolador quien realiza la adquisición de las señales, recibe órdenes del operador, muestra en pantalla el estado de las variables en tiempo real y trasmite información a una estación remota. En la figura 2. Se ve el diagrama en bloques.

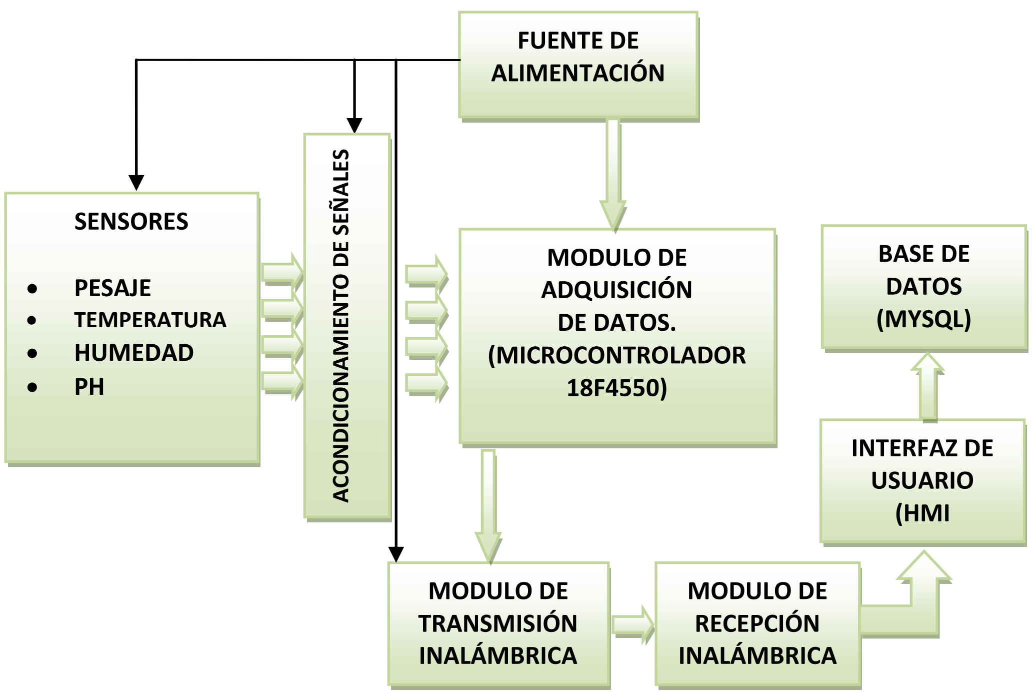

Fig. 2. Diagrama de bloques del sistema

2.2.1 Sensores y acondicionamiento de señal. Los sensores involucrados son cuatros sensores de peso (celdas de cargas), un sensor de temperatura, un sensor de humedad HIH 4000-002, un sensor de pH.

El sensor de temperatura corresponde a la serie LM35 (figura 3), es un circuito integrado de precisión, cuya salida de tensión es linealmente proporcional a la temperatura en grados Celsius. Su salida en grados centígrados le da una ventaja a la hora del tratamiento de su señal, ya que esta unidad es la preferida en las diferentes aplicaciones. Este sensor tiene una salida con una precisión calibrada de 1º Centígrado y un rango que abarca desde -55º a +150ºC. La salida lineal equivale a 10mV/ºC (Góngora, M.A.et al, 2010).

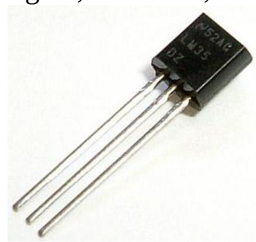

Fig. 3. Sensor LM35

El sensor de humedad HIH 4000-002 (Figura 4), da una señal de voltaje que varía con los cambios de humedad relativa en el ambiente. Por recomendación del fabricante cuenta con un amplificador operacional en configuracion seguidor para realizar el respectivo acople de impedancias y su señal es enviada al microcontrolador en donde por medio de la ecuación característica dada por el fabricante se adquiere el dato exacto de la variable. Fue seleccionado por su alto grado de exactitud, salida en voltaje lineal, rápida respuesta en el tiempo, voltaje de alimentación entre 4 y 5.8 voltios DC y un rango de operación de humedad relativa entre 0 y 100% dentro de un rango de temperatura de -40°C a 85°C (Losada Tovar, O.M. et al, 2012), el cual se ajusta a el rango de operación en temperatura del proyecto.

Fig. 4. Sensor de humedad relativa HIH 4000-002

Para el diseño de la tarjeta de pesaje se utilizaron cuatro celdas de carga (Figura 5). Cada una con una capacidad nominal de 40Kg. para un total de 160Kg como peso máximo que puede soportar la plataforma. Este modelo tiene una salida a plena escala es 1.8 mV/V, en donde V es el voltaje DC de alimentación de 0-12 VDC. Para esta aplicación se establece 12 VDC. Se tiene entonces que para cada sensor, la salida máxima (40Kg) es de 21.6mV de acuerdo con la ecuación 1 característica de la celda de carga:

$$V_{salida} = V_{cc} * Sensibilidad \qquad (1)$$

$$V_{salida} = 12V * \left(\frac{1.8mV}{V}\right)$$

$$V_{salida} = 21.6\ mV$$

Fig. 5. Celda de carga mono-bloque SP06-AL MV

Los circuitos que se encargan de amplificar las señales de milivoltios provenientes de las celdas de carga y de convertir la señal flotante proveniente del puente de cada sensor, en señales referenciadas a tierra para las etapas siguientes, son los amplificadores de instrumentación (A.I.) y para cada celda de carga son idénticos, ver figura 6.

El INA128 es un amplificador de instrumentación de alto rendimiento que requiere de un solo resistor externo para conseguir una ganancia de 1 a 1000. La selección de la ganancia está dada por la ecuación 2.

$$R_G = \frac{50K\Omega}{G-1} \qquad (2)$$

Se deben tener en cuenta cada sensor llega a un circuito sumador que entregara una señal ponderada no mayor a 5V hacia el conversor análogo-digital luego de ser filtrada.

Entonces, la ganancia de cada A.I. está limitada para un voltaje de salida máximo de 1.25V de tal manera que la suma de las cuatro sea igual a 5V cuando las cuatro celdas de carga entreguen una señal máxima.

Así, los valores de G y RG, están dados por las ecuaciones 3 y 4, respectivamente.

$$G = \frac{1.25V}{21.6mV} = 57{,}87 \quad (3) \qquad R_{G1} = \frac{50K\Omega}{57.87 - 1} \approx 879{,}2\Omega \quad (4)$$

Posteriormente se implementó un circuito encargado de sumar (figura 7) ponderadamente las cuatro señales provenientes de los amplificadores de instrumentación conectados a cada sensor. De esta manera se obtiene una única señal que representa el peso total.

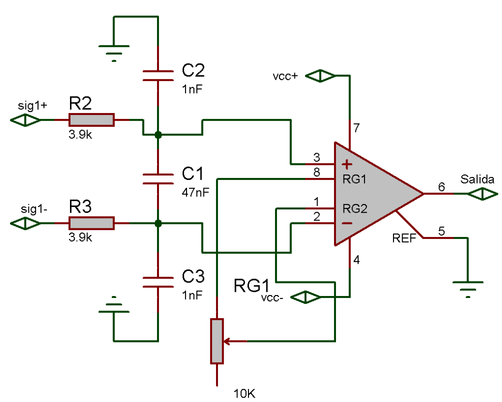

Fig. 6. Circuito de amplificación con el INA128

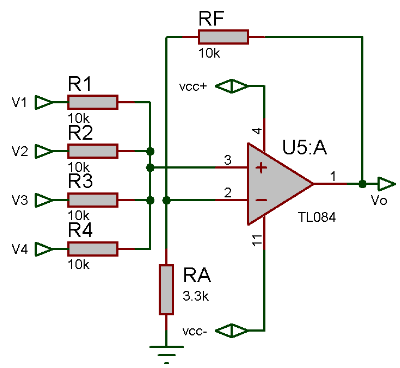

Fig. 7. Circuito sumador con amplificador TL084

La señal de salida del circuito sumador puede tener algún nivel de ruido proveniente de las mismas celdas de carga que pudieran ser amplificados y sumados, niveles de ruido debido a interferencias en cualquier parte del circuito acondicionador, por estas razones, es importante implementar una etapa que filtre al máximo la señal de interés antes de llegar al conversor análogo digital asegurando una correcta medida del peso. Es un filtro pasa-bajo de cuatro polos (figura 8) con una frecuencia de corte de 1.59 Hz, suficiente para filtrar la señal DC proveniente de las celdas de carga, para el diseño del filtro se tiene la ecuación 5.

$$f_{c1} = \frac{1}{2\pi R_6 * \sqrt{C_1 * C_2}} = \frac{1}{2\pi(1M\Omega) * \sqrt{0.1\mu F * 0.1\mu F}} = 1.59Hz \qquad (5)$$

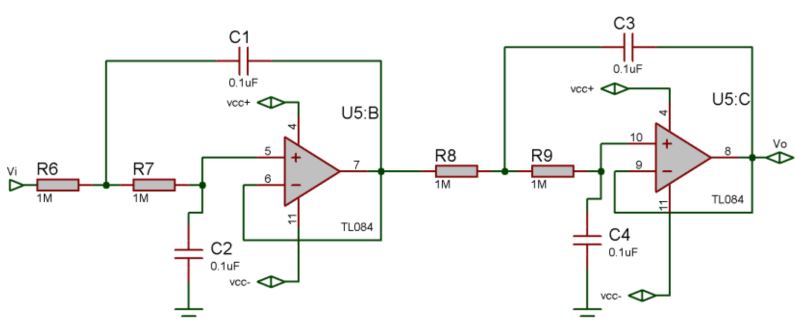

Fig. 8. Filtro pasa-bajo usando amplificador TL084

El circuito final implementado con las cuatro celdas de carga, el sumador y el filtro se puede apreciar en la figura 9.

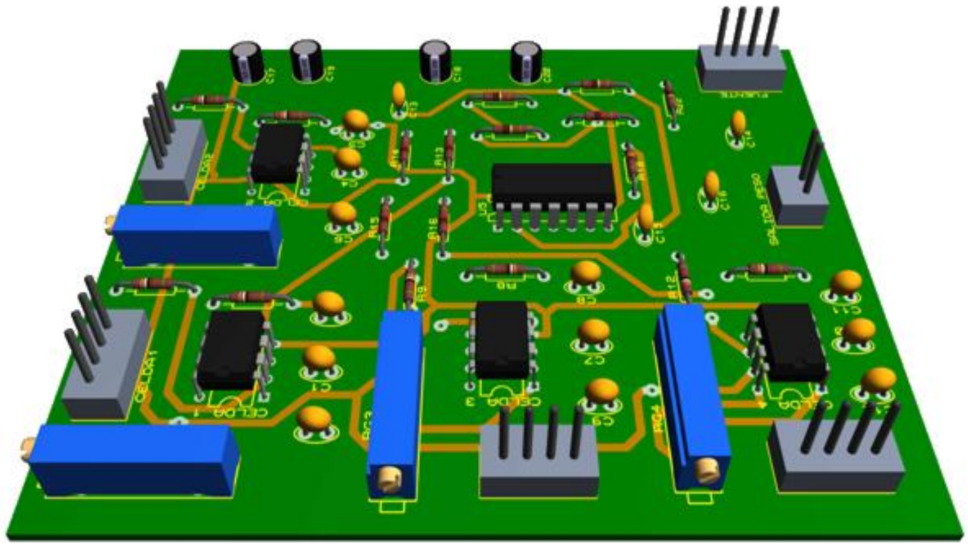

Fig. 9. Tarjeta electrónica de pesaje.

El electrodo de pH que se utilizó fue el PE-11 LUTRON (figura 10), el cual detecta los cambios de potencial (voltaje) causados por la diferencia de acidez en el agua. Por otra parte, estos electrodos son un excelente método para la medida del pH debido a su linealidad, precisión, inmunidad al color o turbidez de la muestra, bajo costo y rápida respuesta.

Fig. 10. Electrodo de pH

Este electrodo establece la relación de 59.1 mV por unidad de pH (a 25°C) (Mendoza Livia, W.R., 2011) en la figura 11 se muestra la curva de un electrodo de pH.

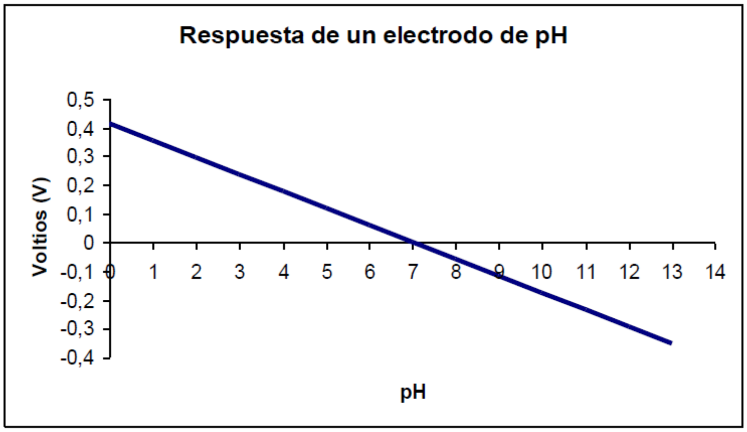

Fig. 11. Respuesta electrodo. pH vs Voltaje (V)

Para obtener esta señal en el rango de 0 a 5 voltios requerido por el conversor análogo digital, se utilizaron amplificadores operacionales los cuales implementaron la ecuación 6.

$$V_{0ut} = 6,5 * (0.380 - V_{Sensor}) \quad (6)$$

Los electrodos de vidrio tienen una impedancia muy alta de aproximadamente 50 MΩ hasta 500 MΩ por esto se hace necesario un amplificador como el LF444 que tiene una impedancia de entrada muy alta 10^{12} Ω suficiente para realizar un buen acople con el electrodo de pH. El circuito completo del acondicionamiento del electrodo de pH se presenta en la figura 12.

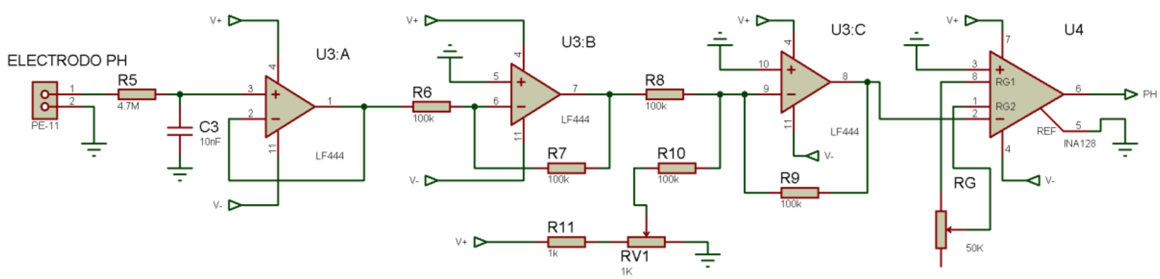

Fig. 12 Circuito de acondicionamiento electrodo pH

2.2.2 Módulo de adquisición e interfaz de usuario. Este módulo está compuesto de una pantalla LCD y por un potenciómetro, los cuales son manejados por un microcontrolador 18F4550, por medio del cual se adquieren las variables medidas y se muestran en pantalla todos los datos de interés para el usuario.

2.2.3 Sistema de comunicaciones. La comunicación de la incubadora con la estación de monitoreo se realizó usando el protocolo de comunicaciones inalámbrico ZigBee, escogido por su bajo consumo, facilidad de integración, transmisión de bajo flujo de datos y velocidad de transmisión hasta de 250 Kbps (Valverde Rebaza, J.C., 2007). Se usó el dispositivo Xbee (figura 13), el cual es compatible con el estándar de comunicaciones IEEE 802.15.4 o ZigBee.

Fig. 13. Xbee

2.3 Software de monitoreo. El sistema cuenta con un programa de monitoreo (Figura 14), desarrollado en Labview el cual es un software de programación gráfica que permite crear aplicaciones muy amigables al usuario y de un fácil manejo. Permite mantener un constante conocimiento de manera remota del estado de los diferentes sensores, almacenando la información en una base de datos en MYSQL y permitiendo acceder a ellos a través de un servidor en internet.

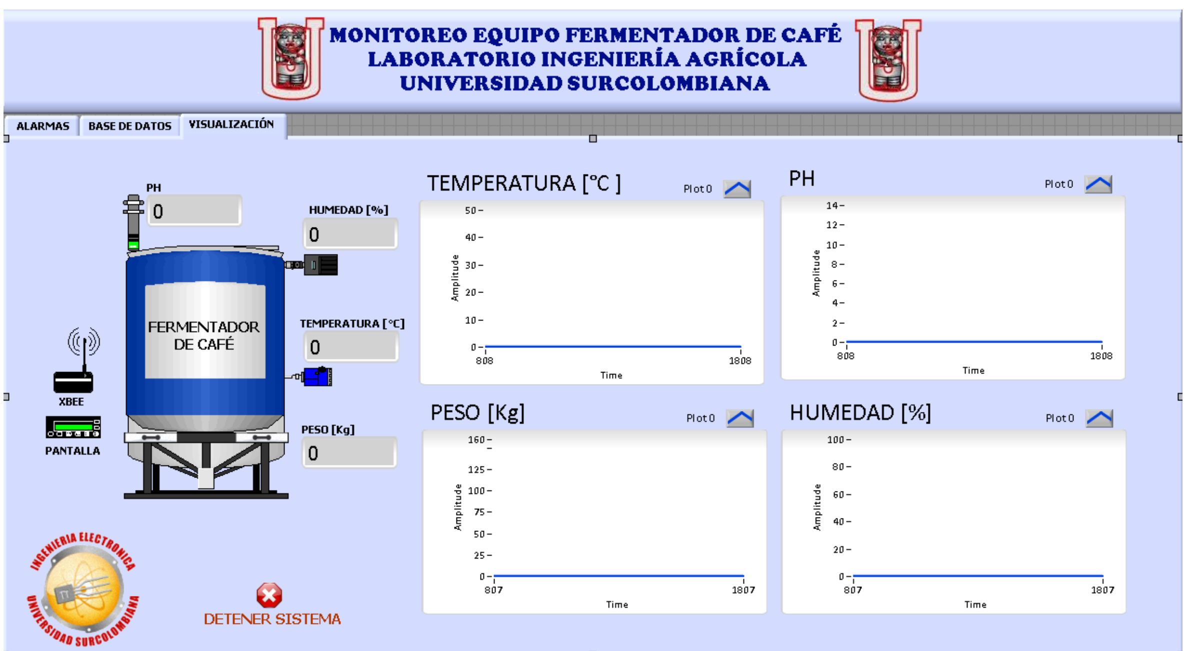

Fig. 1 Panel Frontal Software Monitoreo

3. Resultados

La implementación del diseño propuesto dio como resultado el equipo fermentador mostrado en la figura 15, la cual cuenta con todos los módulos para un completo monitoreo de humedad, peso, pH y temperatura.

Fig. 15. Equipo fermentador final

Finalmente, luego de realizar la integración de todos los sistemas y subsistemas a nivel electrónico, se concluye con una tarjeta de adquisición (figura 16 y figura 17), con la cual el fermentador lleva a cabo todas las acciones de monitoreo del proceso.

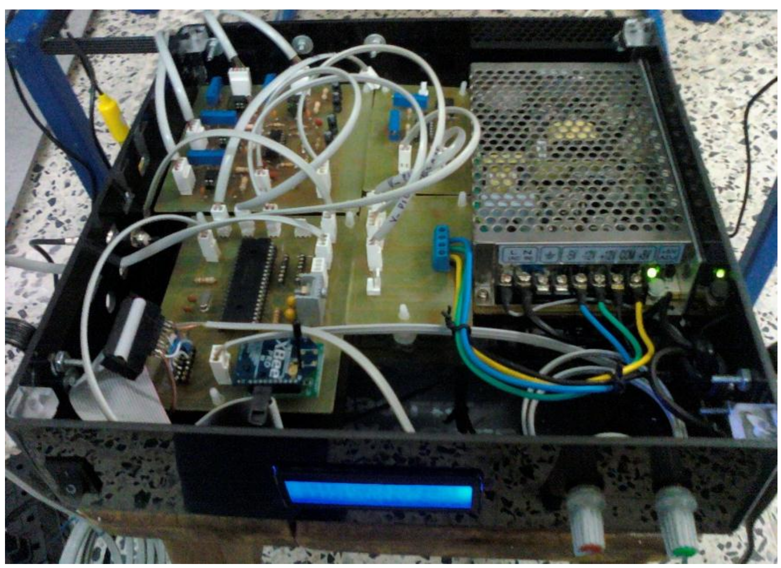

Fig. 16. Tarjeta Electrónica de Adquisición

Fig. 17. Panel Frontal de visualización

4. Conclusiones

- La incorporación de tecnología inalámbrica Zigbee, permite hacer el equipo versátil en cuanto a movilidad, el computador no tiene que estar expuesto a sustancias que lo pueden dañar y causar pérdidas de información y dinero, se puede monitorear el fermentador desde la comodidad del hogar, debido a que los sitios de beneficio se ubican alejados de la vivienda.

- El software desarrollado permite un completo manejo de los datos en cuanto a visualización y almacenamiento, es de fácil manejo y la interfaz programada en Labview tiene un aspecto novedoso, agradable, fresco. Con monitoreo remoto desde la web, lo que hace al sistema totalmente independiente del sitio donde se encuentra el equipo fermentador, solo basta una conexión a internet para saber el estado real del proceso.

- Se diseñó en Solid Edge ST3 la plataforma de pesaje, que permite el seguimiento másico del grano de café en fermentación. Es una estructura robusta construida en metal de alta calidad, con una capacidad de 125Kg

- Una de las variables más importantes en el beneficio húmedo del café es el grado de pH, para este fin se diseñó e implementó un medidor de pH el cual utiliza un electrodo PE-11 el cual determina la concentración de iones de hidrógeno $[H^+]$ en el medio a medir. El peachímetro diseñado funciona en un rango de 0-14. Con el monitoreo del pH se puede determinar el punto exacto de terminación de la fermentación, evitando sobre-fermento que decline la calidad organoléptica del café

- Se implementó una display LCD con un menú de visualización en el sitio del equipo de fermentación, permitiendo una rápida lectura del estado de las variables, humedad peso, temperatura y pH. Sin necesidad de tener el computador cerca o encendido. Con lo cual se pueden tomar decisiones rápidas sobre el curso que debe tener el fermentado.

- La base de datos se desarrolló en MYSQL de distribución libre, con ella se permite llevar un completo registro y control de los usuarios del equipo de fermentación y tiene la función de generar reporte a excel para un análisis más detallado y preciso de los datos

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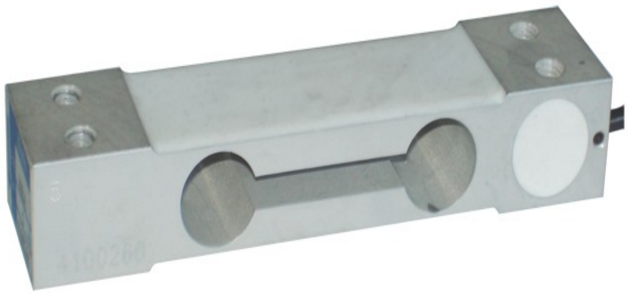
Data Sheet

Ver. 1 (2011/04)

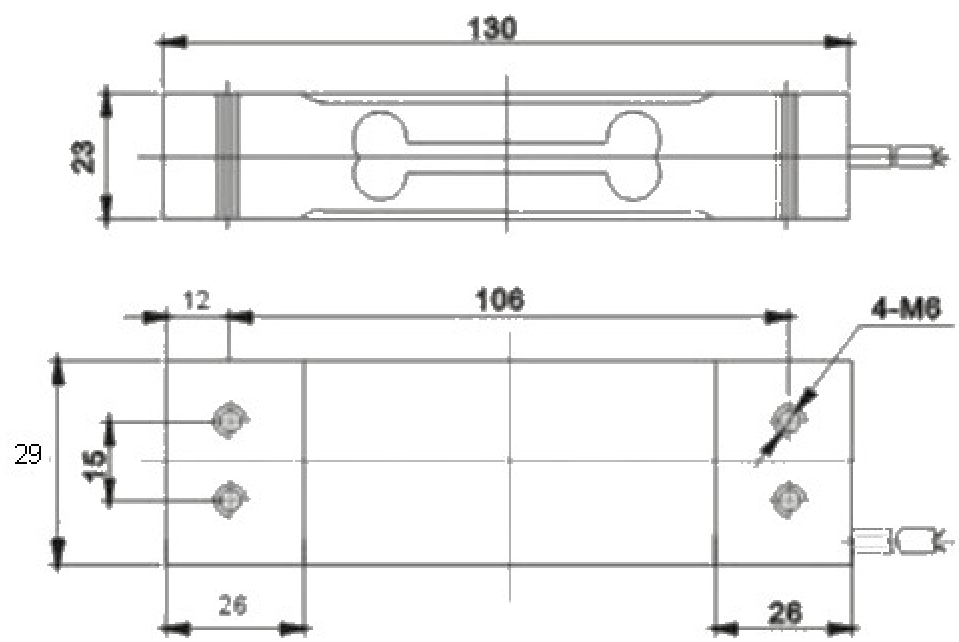


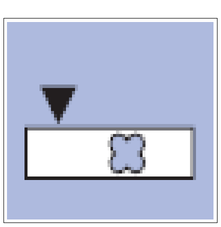
SP06-AL MV

Load Cell Single Point
for Platform Scale
30 X 30 cm

Dimensions

Dimensions in mm





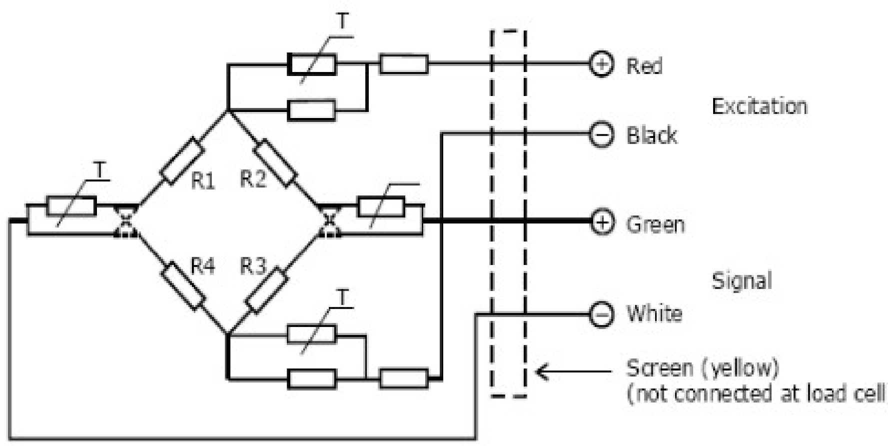
LEXUS
ELECTRONIC SCALES

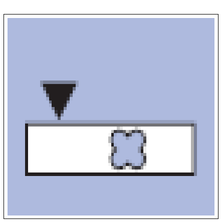
Specification

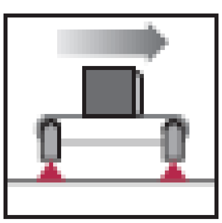
Item / Parameter	C3	Unit
Capacities	3, 6, 12, 20, 30 Y 40	kg
Sensitivity	1.8 ± 0.002	mV/V
Total Error	0.03	±% of rated output
Repeatability, Nonlinearity, Hysteresis	0.03	±% of rated output
Creep (30 min)	0.03	±% of rated output
Temperature Effect On Output	0.02./10	±% of rated output/ºC
Temperature Effect On Zero	0.02./10	±% of rated output/ºC
Temperature Compensated	-30 +70	ºC
Zero Balance	1.0	±% of rated output
Input Impedance	400±10	Ohms
Output Impedance	352 ±2	Ohms
Insulation Impedance	≥5000	Mega – Ohms
Recommended Excitation	10~12	VDC
Maximum Excitation	15	VDC
Safe Overload	150	%
Ultimate Overload	200	%
Construction	Aluminium	
Protection Class	IP65	
Cable	Φ5mm x 1m	
Platform Size	300×300mm	

Circuit Diagram

Note:
Do not change length of 4 core cables, or else it will effect sensitivity of load cell.



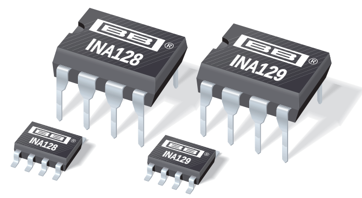




LEXUS
ELECTRONIC SCALES

Nota : Caracteristicas sujetas a cambio sin previo aviso

BURR - BROWN®



INA128
INA129

Precision, Low Power
INSTRUMENTATION AMPLIFIERS

FEATURES

- LOW OFFSET VOLTAGE: 50μV max
- LOW DRIFT: 0.5μV/°C max
- LOW INPUT BIAS CURRENT: 5nA max
- HIGH CMR: 120dB min
- INPUTS PROTECTED TO ±40V
- WIDE SUPPLY RANGE: ±2.25 to ±18V
- LOW QUIESCENT CURRENT: 700μA
- 8-PIN PLASTIC DIP, SO-8

APPLICATIONS

- BRIDGE AMPLIFIER
- THERMOCOUPLE AMPLIFIER
- RTD SENSOR AMPLIFIER
- MEDICAL INSTRUMENTATION
- DATA ACQUISITION

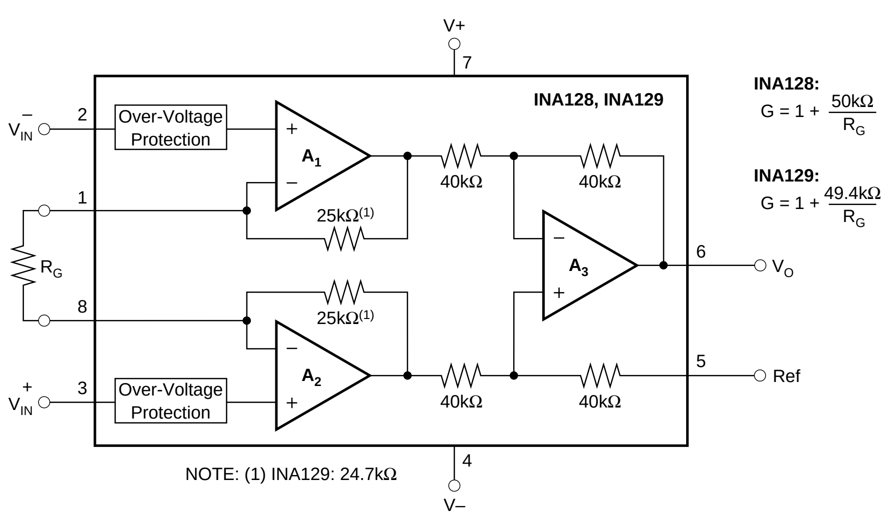
DESCRIPTION

The INA128 and INA129 are low power, general purpose instrumentation amplifiers offering excellent accuracy. Their versatile 3-op amp design and small size make them ideal for a wide range of applications. Current-feedback input circuitry provides wide bandwidth even at high gain (200kHz at G = 100).

A single external resistor sets any gain from 1 to 10,000. INA128 provides an industry standard gain equation; INA129's gain equation is compatible with the AD620.

The INA128/INA129 is laser trimmed for very low offset voltage (50μV), drift (0.5μV/°C) and high common-mode rejection (120dB at G ≥ 100). It operates with power supplies as low as ±2.25V, and quiescent current is only 700μA—ideal for battery operated systems. Internal input protection can withstand up to ±40V without damage.

The INA128/INA129 is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the –40°C to +85°C temperature range. The INA128 is also available in dual configuration, the INA2128.



NOTE: (1) INA129: 24.7kΩ

International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

 PDS-1296C Printed in U.S.A. October, 1996

SPECIFICATIONS

At T_A = +25°C, V_S = ±15V, R_L = 10kΩ, unless otherwise noted.

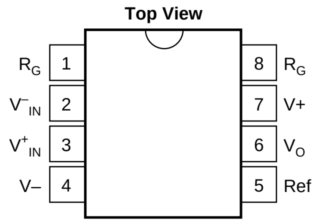
PARAMETER	CONDITIONS	INA128P, U INA129P, U			INA128PA, UA INA129PA, UA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
INPUT								
Offset Voltage, RTI								
Initial	T_A = +25°C		±10 ±100/G	±50 ±500/G		±25 ±100/G	±125 ±1000/G	µV
vs Temperature	$T_A = T_{MIN}$ to T_{MAX}		±0.2 ± 2/G	±0.5 ± 20/G		±0.2 ± 5/G	±1 ± 20/G	µV/°C
vs Power Supply	V_S = ±2.25V to ±18V		±0.2 ±20/G	±1 ±100/G		*	±2 ±200/G	µV/V
Long-Term Stability			±0.1 ±3/G			*		µV/mo
Impedance, Differential			10^{10} ∥ 2			*		Ω ∥ pF
Common-Mode			10^{11} ∥ 9			*		Ω ∥ pF
Common-Mode Voltage Range(1)	V_O = 0V	(V+) – 2	(V+) – 1.4		*	*		V
		(V–) + 2	(V–) + 1.7		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM} = ±13V, ΔR_S = 1kΩ							
	G=1	80	86		73	*		dB
	G=10	100	106		93	*		dB
	G=100	120	125		110	*		dB
	G=1000	120	130		110	*		dB
BIAS CURRENT			±2	±5		*	±10	nA
vs Temperature			±30			*		pA/°C
Offset Current			±1	±5		*	±10	nA
vs Temperature			±30			*		pA/°C
NOISE VOLTAGE, RTI	G = 1000, R_S = 0Ω							
f = 10Hz			10			*		nV/√Hz
f = 100Hz			8			*		nV/√Hz
f = 1kHz			8			*		nV/√Hz
f_B = 0.1Hz to 10Hz			0.2			*		µVp-p
Noise Current								
f=10Hz			0.9			*		pA/√Hz
f=1kHz			0.3			*		pA/√Hz
f_B = 0.1Hz to 10Hz			30			*		pAp-p
GAIN								
Gain Equation, INA128			1 + (50kΩ/R_G)			*		V/V
INA129			1 + (49.4kΩ/R_G)			*		V/V
Range of Gain		1		10000	*		*	V/V
Gain Error	G=1		±0.01	±0.024		*	±0.1	%
	G=10		±0.02	±0.4		*	±0.5	%
	G=100		±0.05	±0.5		*	±0.7	%
	G=1000		±0.5	±1		*	±2	%
Gain vs Temperature(2)	G=1		±1	±10		*	*	ppm/°C
50kΩ (or 49.4kΩ) Resistance(2, 3)			±25	±100		*	*	ppm/°C
Nonlinearity	V_O = ±13.6V, G=1		±0.0001	±0.001		*	±0.002	% of FSR
	G=10		±0.0003	±0.002		*	±0.004	% of FSR
	G=100		±0.0005	±0.002		*	±0.004	% of FSR
	G=1000		±0.001	(Note 4)		*	*	% of FSR
OUTPUT								
Voltage: Positive	R_L = 10kΩ	(V+) – 1.4	(V+) – 0.9		*	*		V
Negative	R_L = 10kΩ	(V–) + 1.4	(V–) + 0.8		*	*		V
Load Capacitance Stability			1000			*		pF
Short-Circuit Current			+6/–15			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G=1		1.3			*		MHz
	G=10		700			*		kHz
	G=100		200			*		kHz
	G=1000		20			*		kHz
Slew Rate	V_O = ±10V, G=10		4			*		V/µs
Settling Time, 0.01%	G=1		7			*		µs
	G=10		7			*		µs
	G=100		9			*		µs
	G=1000		80			*		µs
Overload Recovery	50% Overdrive		4			*		µs
POWER SUPPLY								
Voltage Range		±2.25	±15	±18	*	*	*	V
Current, Total	V_{IN} = 0V		±700	±750		*	*	µA
TEMPERATURE RANGE								
Specification		–40		85	*		*	°C
Operating		–40		125	*		*	°C
θ_{JA} 8-Pin Dip			80			*		°C/W
SO-8 SOIC			150			*		°C/W

* Specification same as INA128P, U or INA129P, U.

NOTE: (1) Input common-mode range varies with output voltage—see typical curves. (2) Guaranteed by wafer test. (3) Temperature coefficient of the 50kΩ (or 49.4kΩ) term in the gain equation. (4) Nonlinearity measurements in G = 1000 are dominated by noise. Typical nonlinearity is ±0.001%.

PIN CONFIGURATION

8-Pin DIP and SO-8



ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Analog Input Voltage Range	±40V
Output Short-Circuit (to ground)	Continuous
Operating Temperature	–40°C to +125°C
Storage Temperature	–40°C to +125°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C

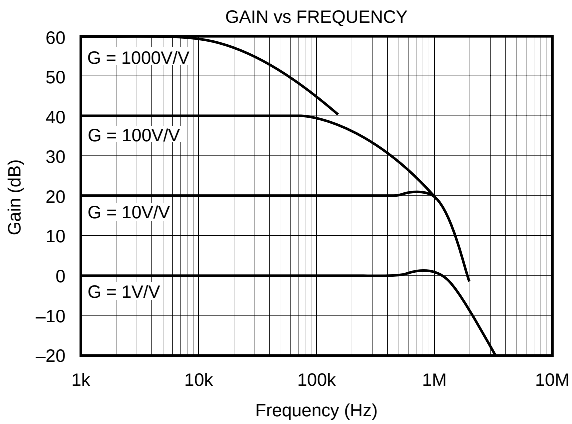
ORDERING INFORMATION

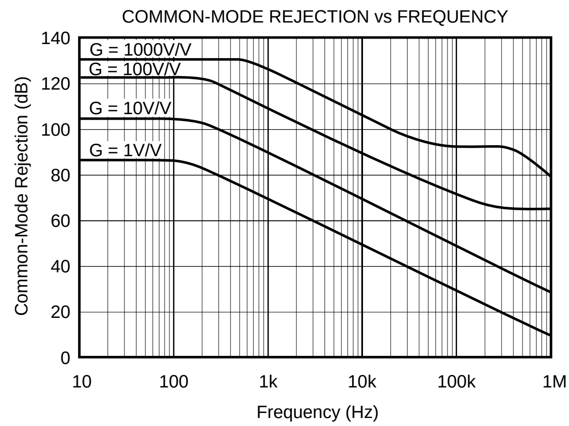
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)	TEMPERATURE RANGE
INA128PA	8-Pin Plastic DIP	006	–40°C to +85°C
INA128P	8-Pin Plastic DIP	006	–40°C to +85°C
INA128UA	SO-8 Surface-Mount	182	–40°C to +85°C
INA128U	SO-8 Surface-Mount	182	–40°C to +85°C
INA129PA	8-Pin Plastic DIP	006	–40°C to +85°C
INA129P	8-Pin Plastic DIP	006	–40°C to +85°C
INA129UA	SO-8 Surface-Mount	182	–40°C to +85°C
INA129U	SO-8 Surface-Mount	182	–40°C to +85°C

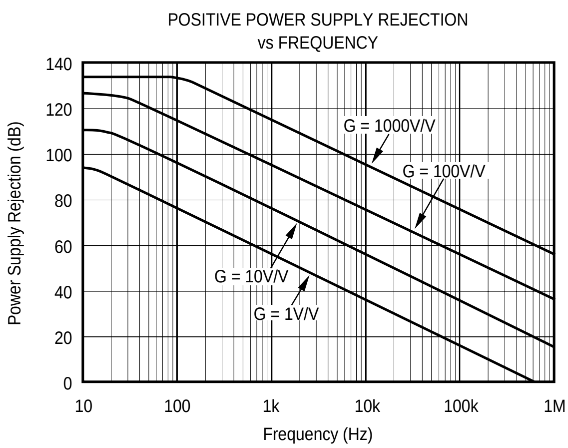
NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

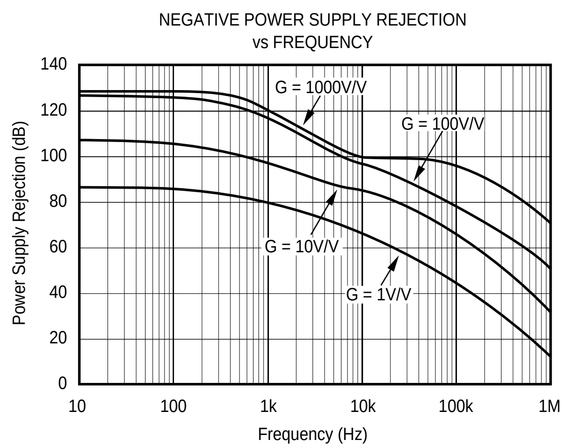
TYPICAL PERFORMANCE CURVES

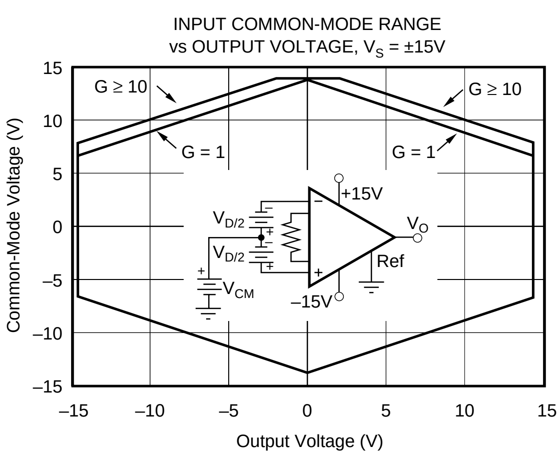
At T_A = +25°C, V_S = ±15V, unless otherwise noted.

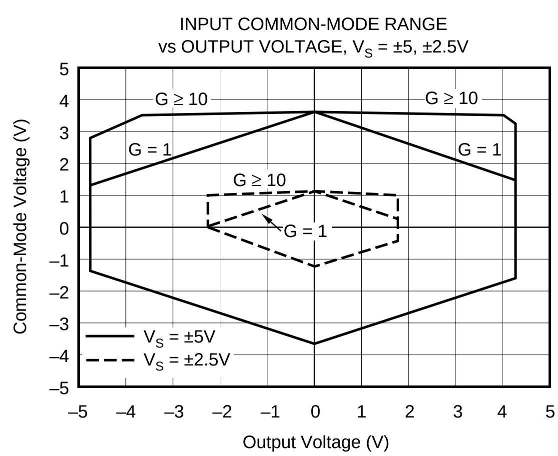






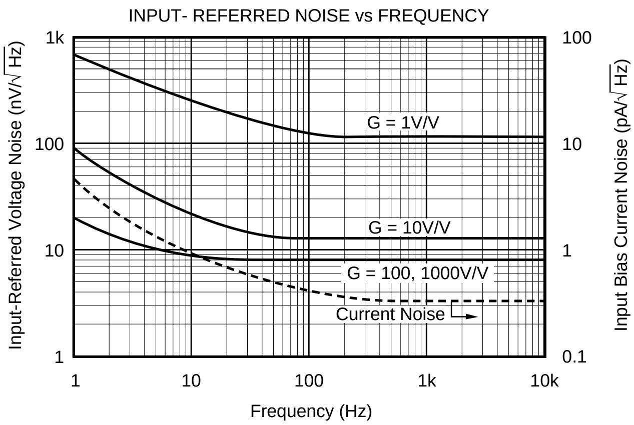


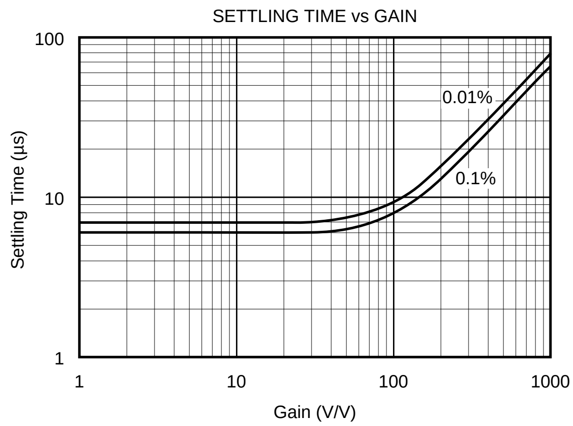


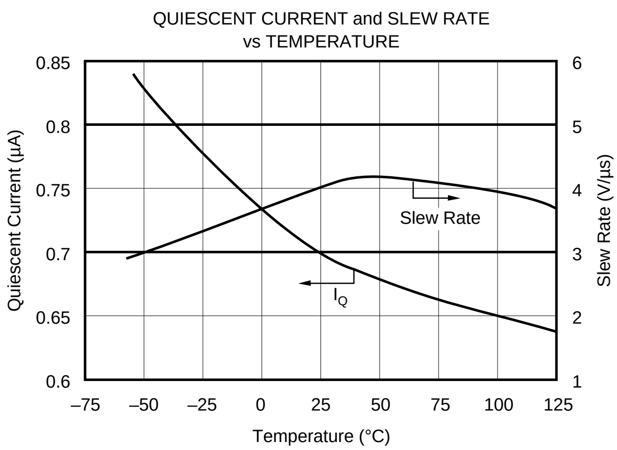


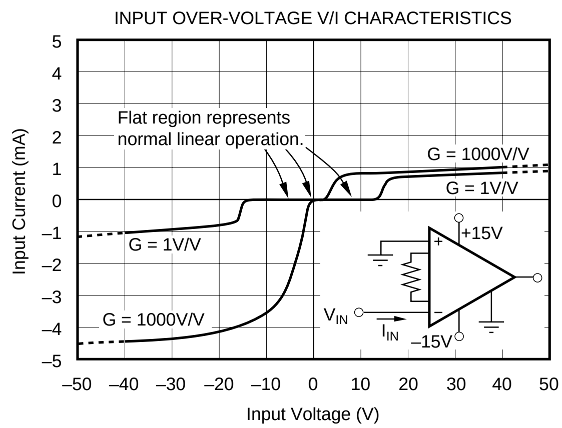
TYPICAL PERFORMANCE CURVES (CONT)

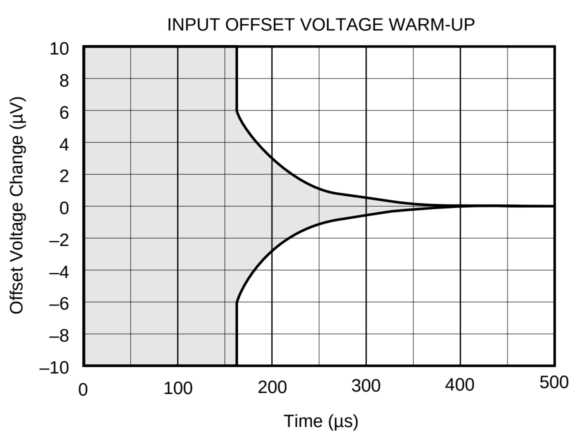
At T_A = +25°C, V_S = ±15V, unless otherwise noted.

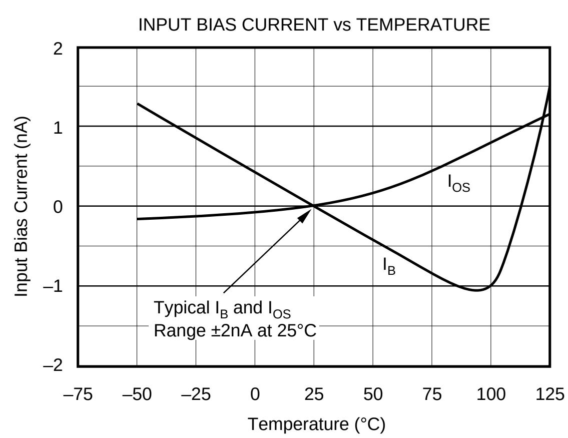






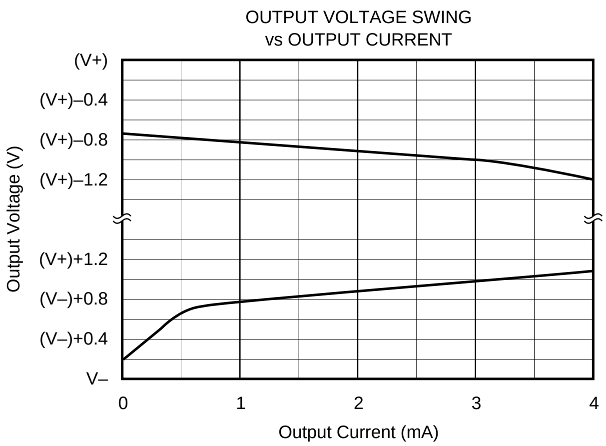


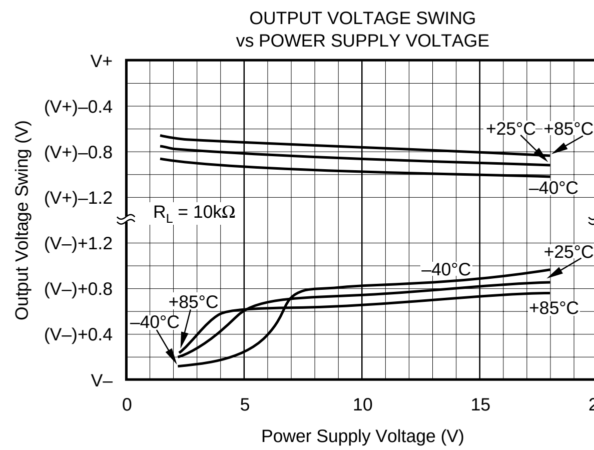


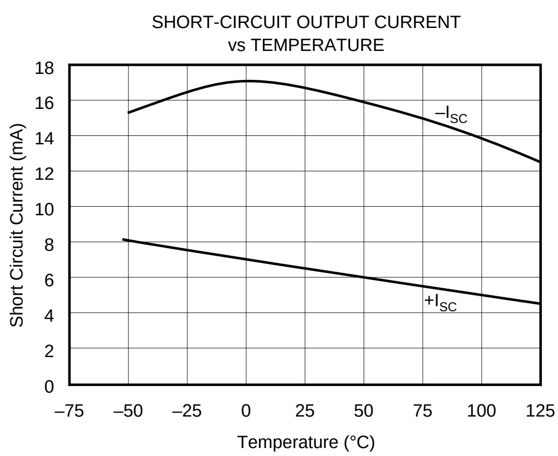


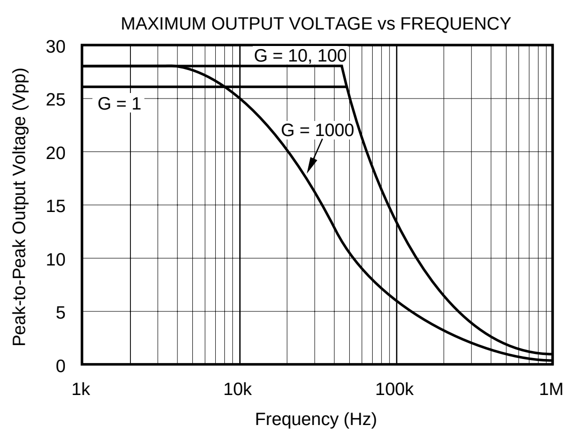
TYPICAL PERFORMANCE CURVES (CONT)

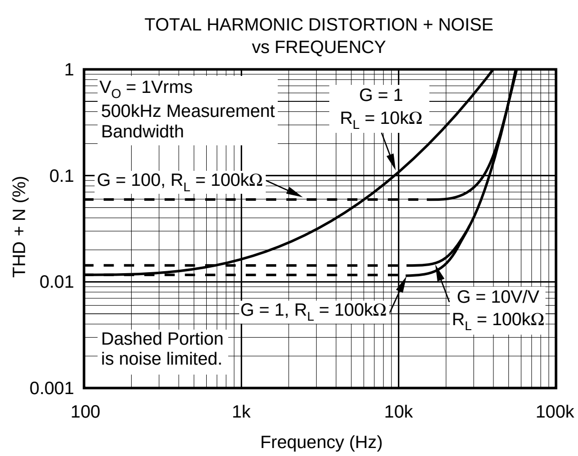
At T_A = +25°C, V_S = ±15V, unless otherwise noted.











TYPICAL PERFORMANCE CURVES (CONT)

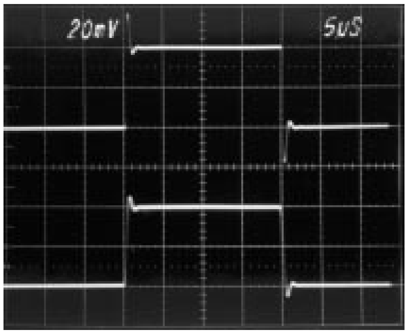
At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

SMALL-SIGNAL
(G = 1, 10)

G = 1

20mV/div

G = 10



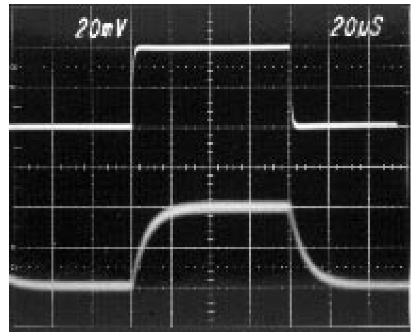
5µs/div

SMALL-SIGNAL
(G = 100, 1000)

G = 100

20mV/div

G = 1000



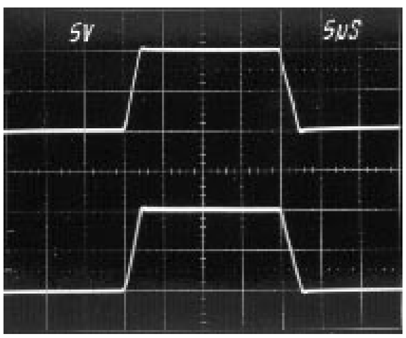
20µs/div

LARGE-SIGNAL
(G = 1, 10)

G = 1

5V/div

G = 10



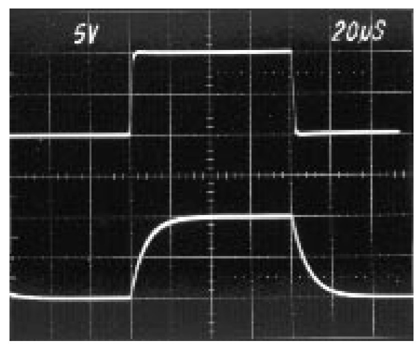
5µs/div

LARGE-SIGNAL
(G = 100, 1000)

G = 100

5V/div

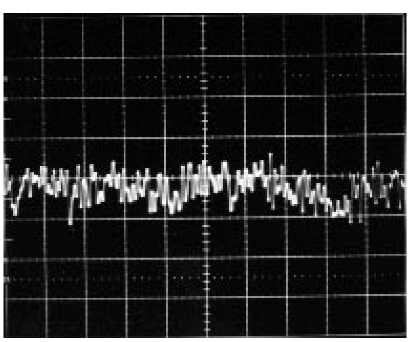
G = 1000



20µs/div

VOLTAGE NOISE 0.1 to 10Hz
INPUT-REFERRED, G ≥ 100

0.1µV/div



1s/div

APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA128/INA129. 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 must be a low-impedance connection to assure good common-mode rejection. A resistance of 8Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain is set by connecting a single external resistor, R_G, connected between pins 1 and 8:

INA128:
$$G = 1 + \frac{50k\Omega}{R_G} \quad (1)$$

INA129:
$$G = 1 + \frac{49.4k\Omega}{R_G} \quad (2)$$

Commonly used gains and resistor values are shown in Figure 1.

The 50kΩ term in Equation 1 (49.4kΩ in Equation 2) comes from the sum of the two internal feedback resistors of A_1 and A_2. These on-chip metal film resistors are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these internal resistors are included in the gain accuracy and drift specifications of the INA128/INA129.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G's contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

DYNAMIC PERFORMANCE

The typical performance curve "Gain vs Frequency" shows that, despite its low quiescent current, the INA128/INA129 achieves wide bandwidth, even at high gain. This is due to the current-feedback topology of the input stage circuitry. Settling time also remains excellent at high gain.

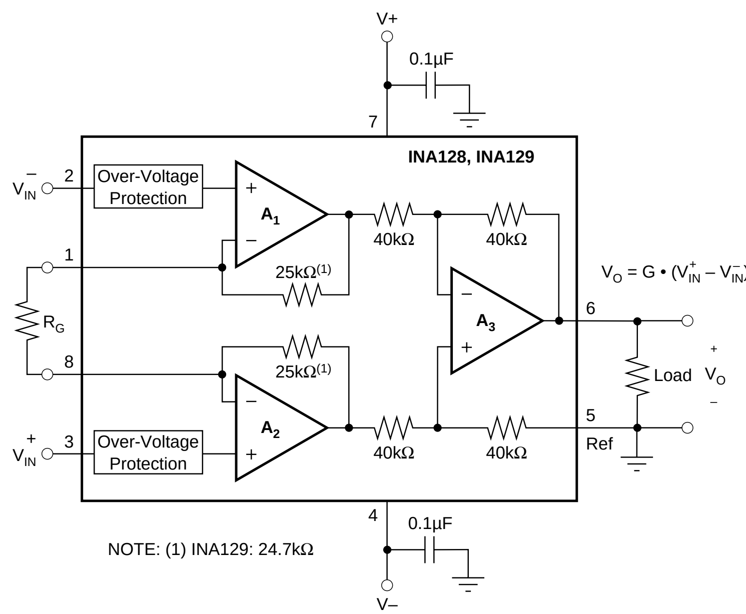
NOISE PERFORMANCE

The INA128/INA129 provides very low noise in most applications. Low frequency noise is approximately 0.2µVp-p measured from 0.1 to 10Hz (G ≥ 100). This provides dramatically improved noise when compared to state-of-the-art chopper-stabilized amplifiers.

INA128: $G = 1 + \frac{50k\Omega}{R_G}$ **INA129:** $G = 1 + \frac{49.4k\Omega}{R_G}$

DESIRED GAIN (V/V)	INA128		INA129	
	R_G (Ω)	NEAREST 1% R_G (Ω)	R_G (Ω)	NEAREST 1% R_G (Ω)
1	NC	NC	NC	NC
2	50.00k	49.9k	49.4k	49.9k
5	12.50k	12.4k	12.35k	12.4k
10	5.556k	5.62k	5489	5.49k
20	2.632k	2.61k	2600	2.61k
50	1.02k	1.02k	1008	1k
100	505.1	511	499	499
200	251.3	249	248	249
500	100.2	100	99	100
1000	50.05	49.9	49.5	49.9
2000	25.01	24.9	24.7	24.9
5000	10.00	10	9.88	9.76
10000	5.001	4.99	4.94	4.87

NC: No Connection.



Also drawn in simplified form:

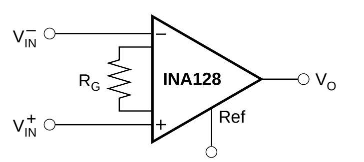


FIGURE 1. Basic Connections.

OFFSET TRIMMING

The INA128/INA129 is laser trimmed for low offset voltage and offset voltage drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed with the output. The op amp buffer provides low impedance at the Ref terminal to preserve good common-mode rejection.

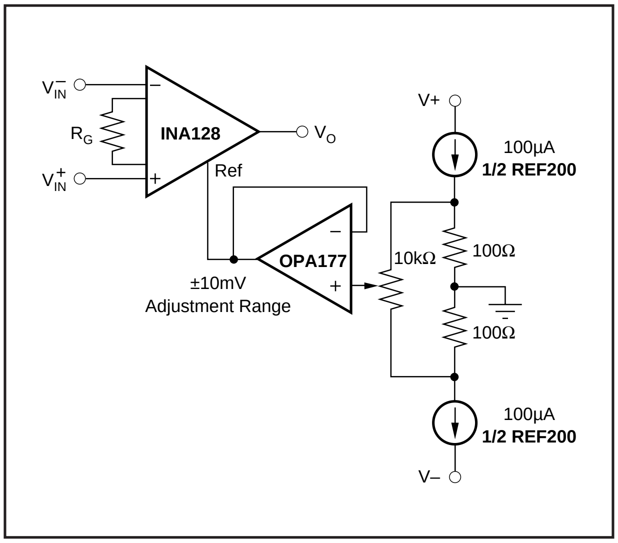


FIGURE 2. Optional Trimming of Output Offset Voltage.

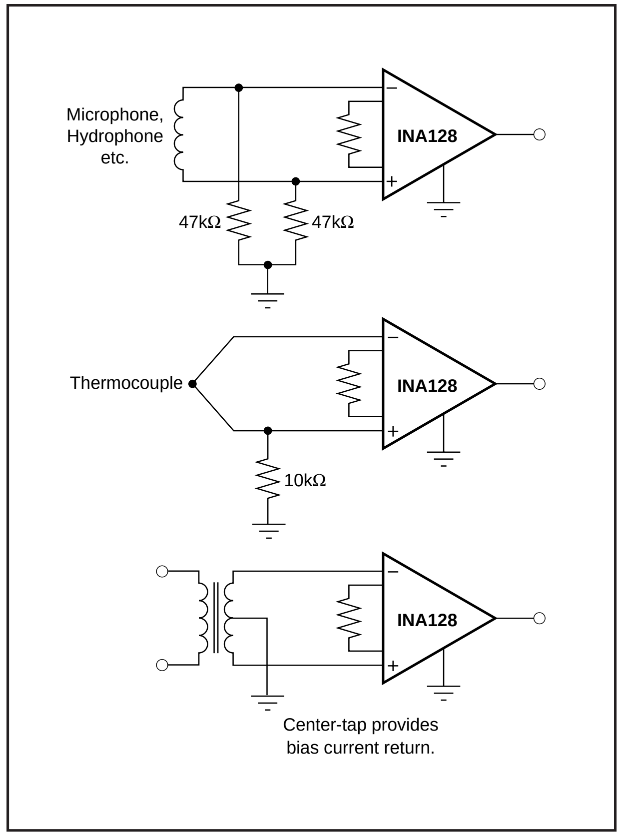


FIGURE 3. Providing an Input Common-Mode Current Path.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA128/INA129 is extremely high—approximately $10^{10}\Omega$. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately ±2nA. 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 3 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 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

INPUT COMMON-MODE RANGE

The linear input voltage range of the input circuitry of the INA128/INA129 is from approximately 1.4V below the positive supply voltage to 1.7V above the negative supply. As a differential input voltage causes the output voltage increase, however, the linear input range will be limited by the output voltage swing of amplifiers A_1 and A_2. So the linear common-mode input range is related to the output voltage of the complete amplifier. This behavior also depends on supply voltage—see performance curves "Input Common-Mode Range vs Output Voltage".

Input-overload can produce an output voltage that appears normal. For example, if an input overload condition drives both input amplifiers to their positive output swing limit, the difference voltage measured by the output amplifier will be near zero. The output of A_3 will be near 0V even though both inputs are overloaded.

LOW VOLTAGE OPERATION

The INA128/INA129 can be operated on power supplies as low as ±2.25V. Performance remains excellent with power supplies ranging from ±2.25V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to assure that the input voltages remain within their linear range. Voltage swing requirements of internal nodes limit the input common-mode range with low power supply voltage. Typical performance curves, "Input Common-Mode Range vs Output Voltage" show the range of linear operation for ±15V, ±5V, and ±2.5V supplies.

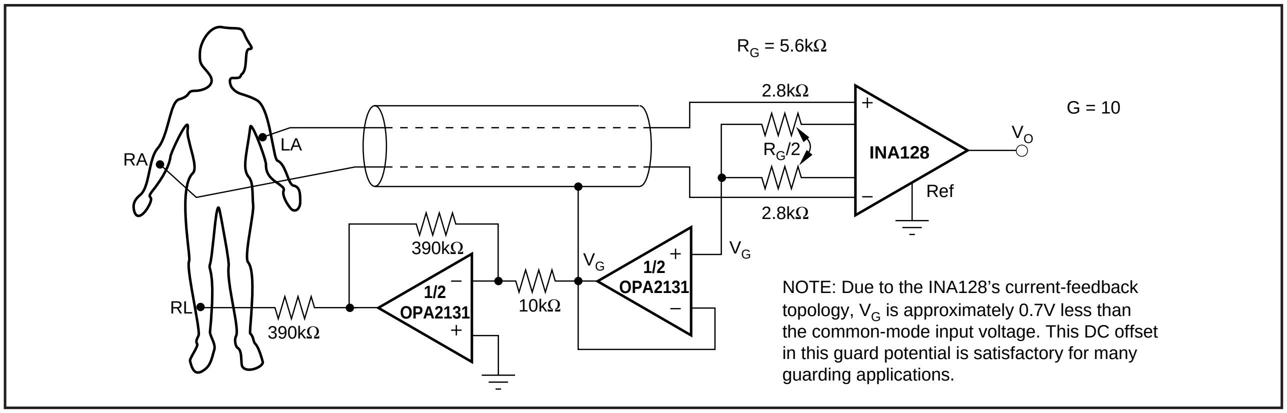


FIGURE 4. ECG Amplifier With Right-Leg Drive.

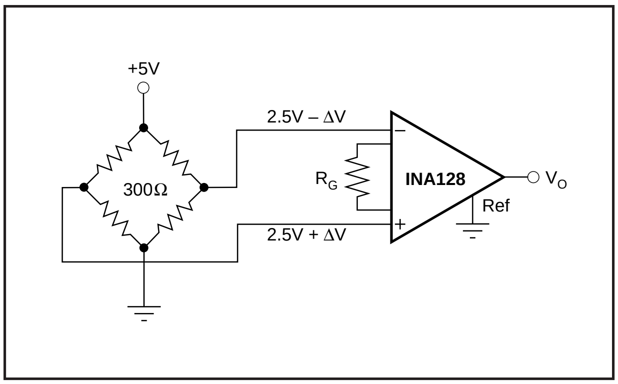


FIGURE 5. Bridge Amplifier.

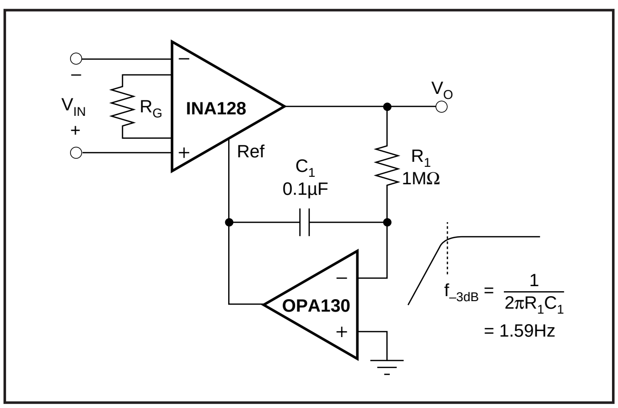
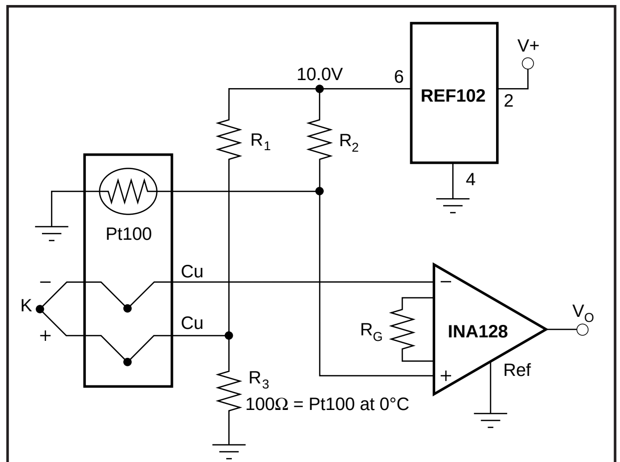
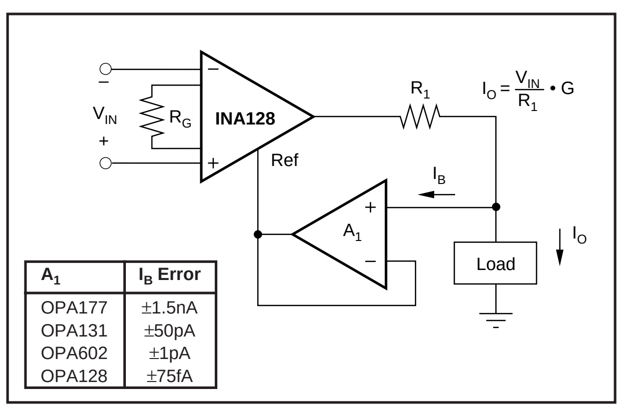


FIGURE 6. AC-Coupled Instrumentation Amplifier.



ISA TYPE	MATERIAL	SEEBECK COEFFICIENT (µV/°C)	R_1, R_2
E	+ Chromel – Constantan	58.5	66.5kΩ
J	+ Iron – Constantan	50.2	76.8kΩ
K	+ Chromel – Alumel	39.4	97.6kΩ
T	+ Copper – Constantan	38.0	102kΩ

FIGURE 7. Thermocouple Amplifier With RTD Cold-Junction Compensation.



A_1	I_B Error
OPA177	±1.5nA
OPA131	±50pA
OPA602	±1pA
OPA128	±75fA

FIGURE 8. Differential Voltage to Current Converter.

LM35

LM35 Precision Centigrade Temperature Sensors

Literature Number: SNIS159B

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

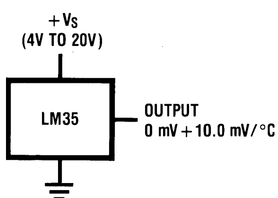
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

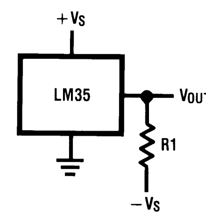
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



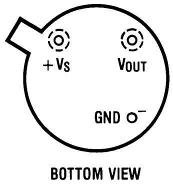
DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

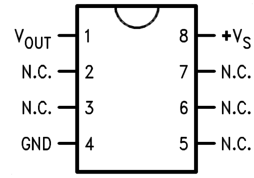


DS005516-1

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

SO-8
Small Outline Molded Package

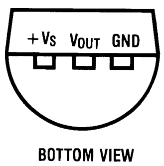


DS005516-21

N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

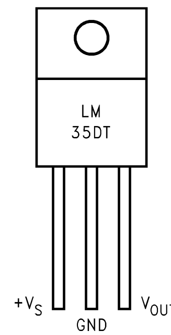
TO-92
Plastic Package



DS005516-2

Order Number LM35CZ,
LM35CAZ or LM35DZ
See NS Package Number Z03A

TO-220
Plastic Package*



DS005516-24

*Tab is connected to the negative pin (GND).
Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60˚C to +180˚C
TO-92 Package,	−60˚C to +150˚C
SO-8 Package,	−65˚C to +150˚C
TO-220 Package,	−65˚C to +150˚C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300˚C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260˚C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55˚C to +150˚C
LM35C, LM35CA	−40˚C to +110˚C
LM35D	0˚C to +100˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25˚C	±0.2	±0.5		±0.2	±0.5		˚C
	T_A=−10˚C	±0.3			±0.3		±1.0	˚C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		˚C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	˚C
Nonlinearity (Note 8)	$T_{MIN}≤T_A≤T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	˚C
Sensor Gain (Average Slope)	$T_{MIN}≤T_A≤T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/˚C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}≤T_A≤T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.05		±0.01	±0.05		mV/V
	4V≤V_S≤30V	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25˚C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	4V≤V_S≤30V, +25˚C	0.2	1.0		0.2	1.0		µA
	4V≤V_S≤30V	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		˚C
	T_A=−10˚C	±0.5			±0.5		±1.5	˚C
	$T_A=T_{MAX}$	±0.8	±1.5		±0.8		±1.5	˚C
	$T_A=T_{MIN}$	±0.8		±1.5	±0.8		±2.0	˚C
Accuracy, LM35D (Note 7)	T_A=+25˚C				±0.6	±1.5		˚C
	$T_A=T_{MAX}$				±0.9		±2.0	˚C
	$T_A=T_{MIN}$				±0.9		±2.0	˚C
Nonlinearity (Note 8)	$T_{MIN}\leq T_A\leq T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	˚C
Sensor Gain (Average Slope)	$T_{MIN}\leq T_A\leq T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/˚C
Load Regulation (Note 3) $0\leq I_L\leq 1$ mA	T_A=+25˚C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN}\leq T_A\leq T_{MAX}$	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V\leq V_S\leq 30V$	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	80		56	80		µA
	V_S=+5V	**105**		**158**	**91**		**138**	µA
	V_S=+30V, +25˚C	56.2	82		56.2	82		µA
	V_S=+30V	**105.5**		**161**	**91.5**		**141**	µA
Change of Quiescent Current (Note 3)	$4V\leq V_S\leq 30V$, +25˚C	0.2	2.0		0.2	2.0		µA
	$4V\leq V_S\leq 30V$	**0.5**		**3.0**	**0.5**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Note 1: Unless otherwise noted, these specifications apply: $-55˚C\leq T_J\leq +150˚C$ for the LM35 and LM35A; $-40˚\leq T_J\leq +110˚C$ for the LM35C and LM35CA; and $0˚\leq T_J\leq +100˚C$ for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2˚C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/˚C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in ˚C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

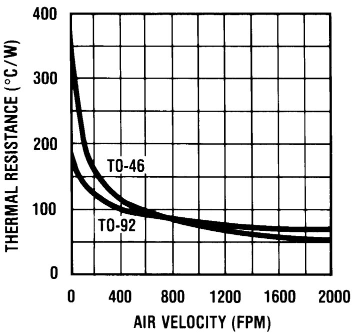
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

Thermal Resistance Junction to Air



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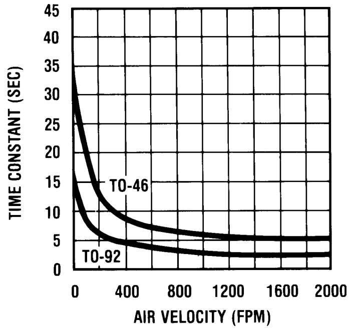
Thermal Time Constant



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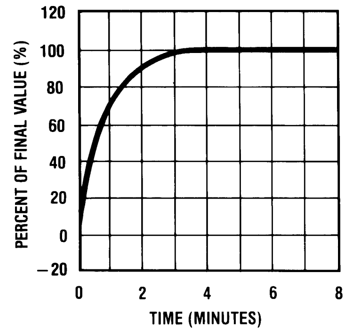
Thermal Response in Still Air



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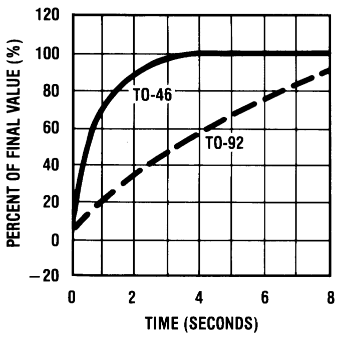
Thermal Response in Stirred Oil Bath



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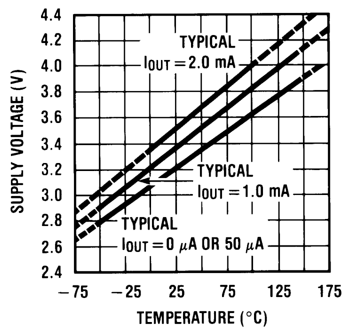
Minimum Supply Voltage vs. Temperature



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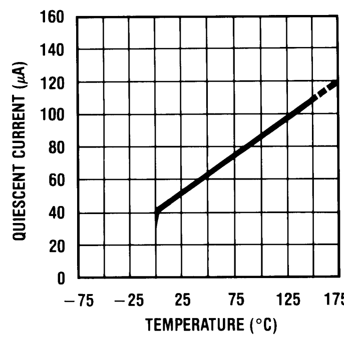
Quiescent Current vs. Temperature (In Circuit of ***Figure 1*****.)**



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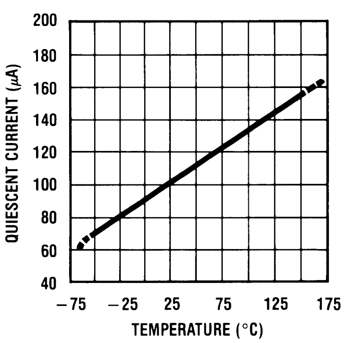
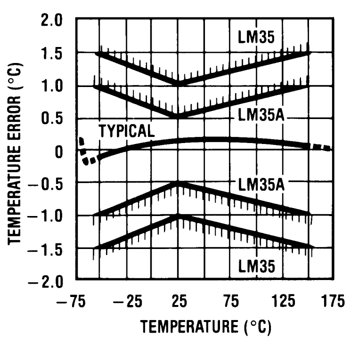
Quiescent Current vs. Temperature (In Circuit of ***Figure 2*****.)**



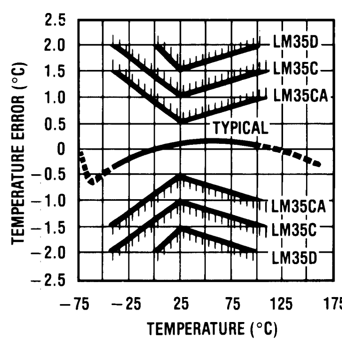
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

Accuracy vs. Temperature (Guaranteed)



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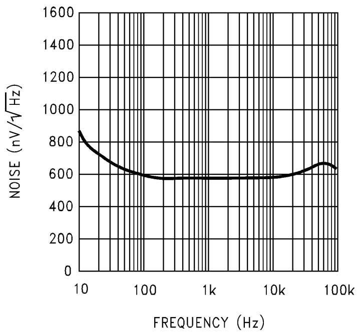
Typical Performance Characteristics (Continued)

Noise Voltage



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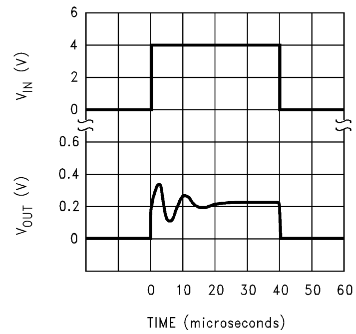
Start-Up Response



DS005516-35

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01˚C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

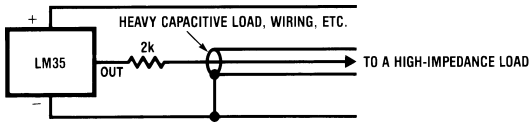
These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	TO-46, no heat sink	TO-46*, small heat fin	TO-92, no heat sink	TO-92**, small heat fin	SO-8 no heat sink	SO-8** small heat fin	TO-220 no heat sink
Still air	400˚C/W	100˚C/W	180˚C/W	140˚C/W	220˚C/W	110˚C/W	90˚C/W
Moving air	100˚C/W	40˚C/W	90˚C/W	70˚C/W	105˚C/W	90˚C/W	26˚C/W
Still oil	100˚C/W	40˚C/W	90˚C/W	70˚C/W			
Stirred oil	50˚C/W	30˚C/W	45˚C/W	40˚C/W			
(Clamped to metal, Infinite heat sink)		(24˚C/W)				(55˚C/W)	

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications



DS005516-19

FIGURE 3. LM35 with Decoupling from Capacitive Load

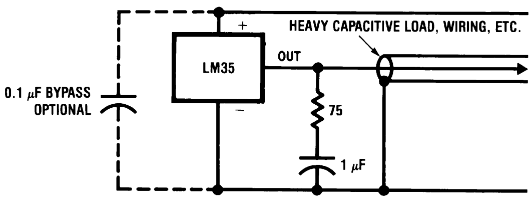


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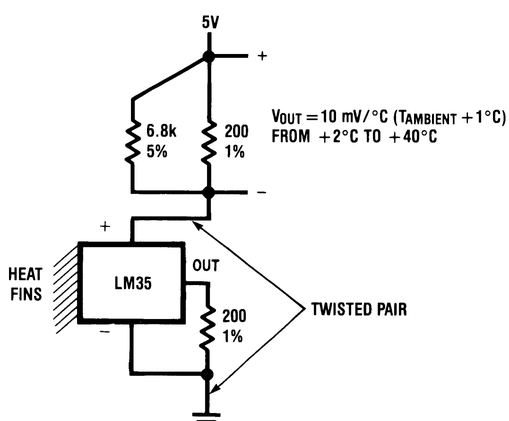
FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

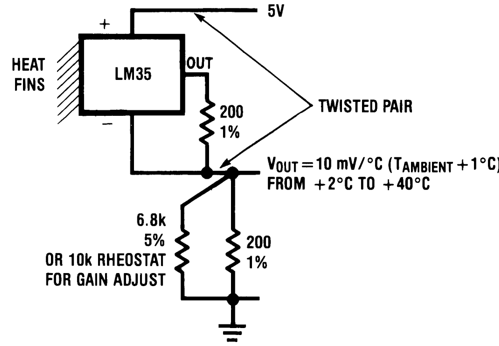
Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see *Figure 4*.

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5*, *Figure 6* or *Figure 8* it is relatively immune to wiring capacitance because the capacitance forms a bypass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 µF from output to ground are often useful. These are shown in *Figure 13*, *Figure 14*, and *Figure 16*.



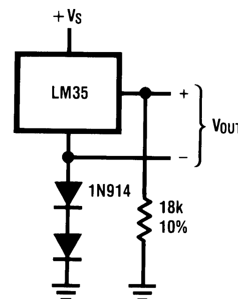
DS005516-5

FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)



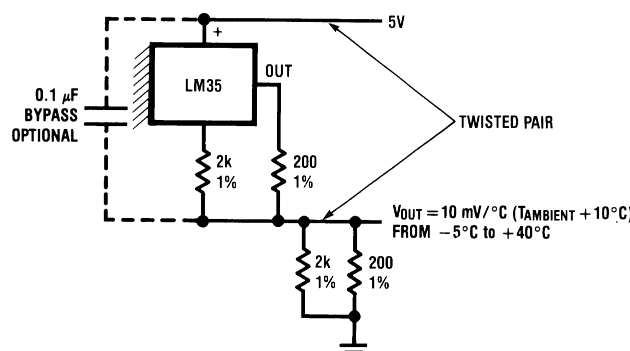
DS005516-6

FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



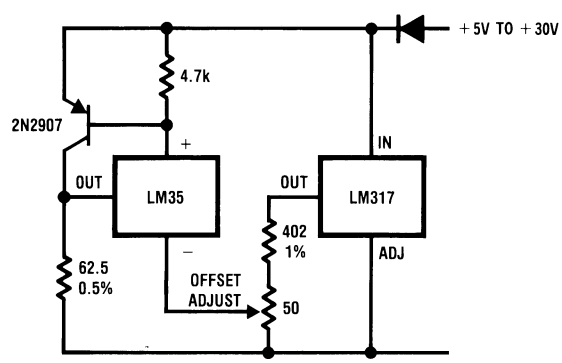
DS005516-7

FIGURE 7. Temperature Sensor, Single Supply, −55˚ to +150˚C



DS005516-8

FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



DS005516-9

FIGURE 9. 4-To-20 mA Current Source (0˚C to +100˚C)

Typical Applications (Continued)

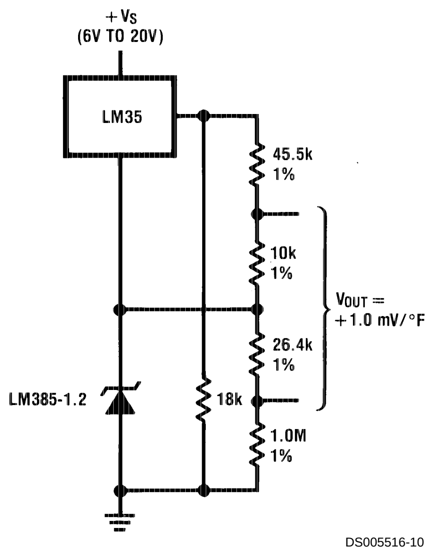


FIGURE 10. Fahrenheit Thermometer

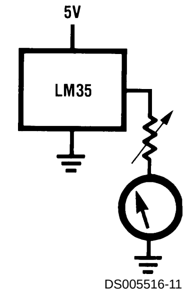


FIGURE 11. Centigrade Thermometer (Analog Meter)

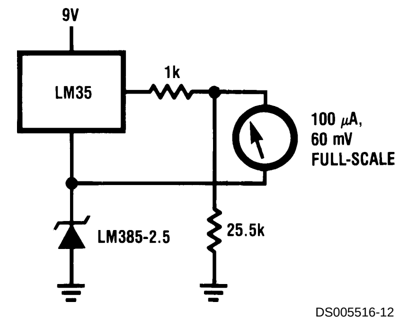


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50˚ to 80˚ Fahrenheit, for Example Shown)

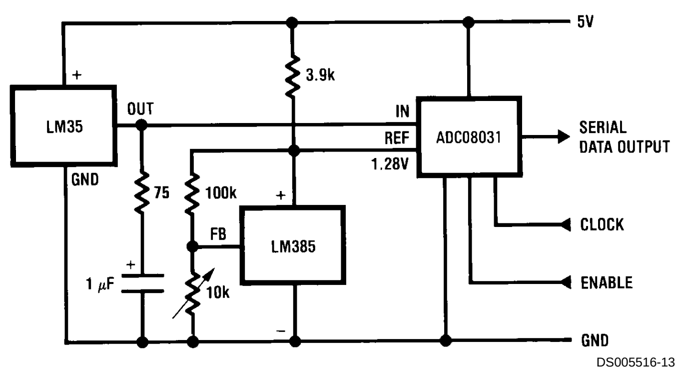


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128˚C Full Scale)

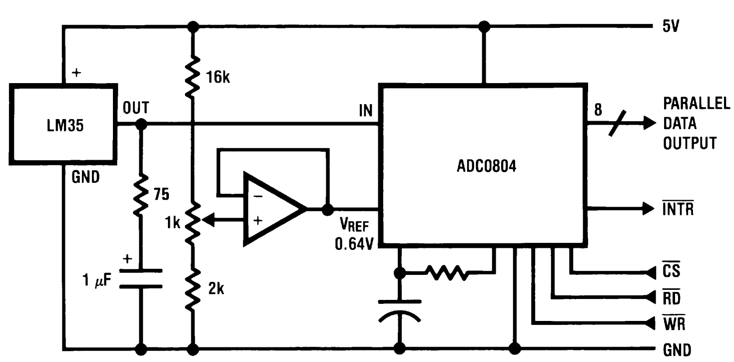
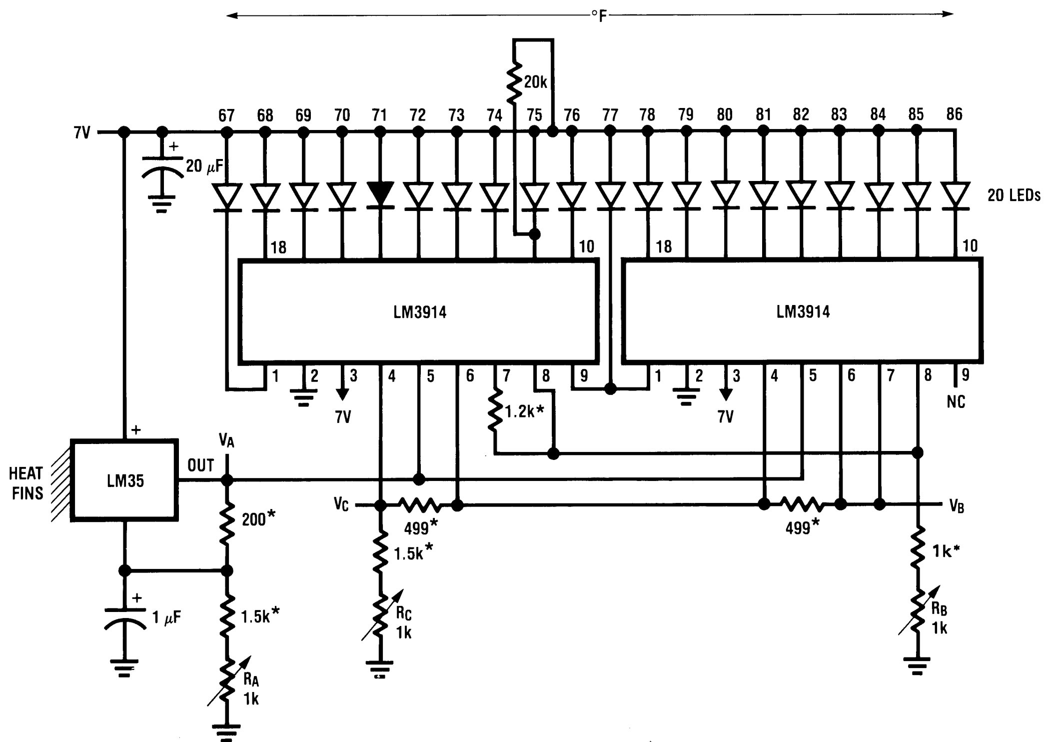


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to μP Interface) (128˚C Full Scale)

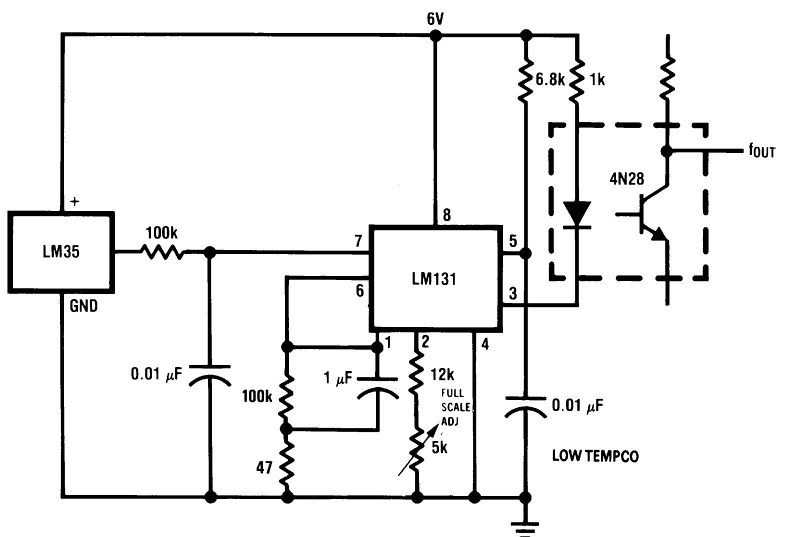
Typical Applications (Continued)



DS005516-16

*=1% or 2% film resistor
Trim R_B for V_B=3.075V
Trim R_C for V_C=1.955V
Trim R_A for V_A=0.075V + 100mV/˚C x $T_{ambient}$
Example, V_A=2.275V at 22˚C

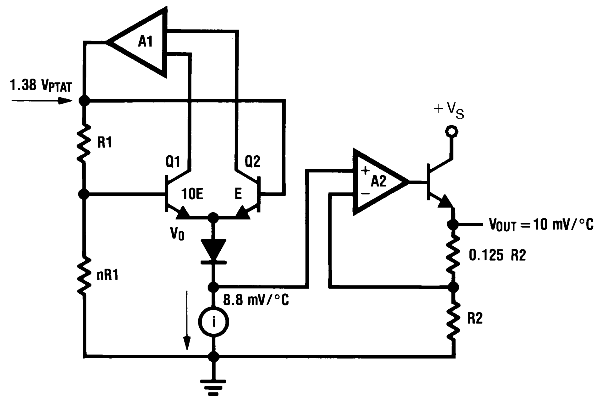
FIGURE 15. Bar-Graph Temperature Display (Dot Mode)



DS005516-15

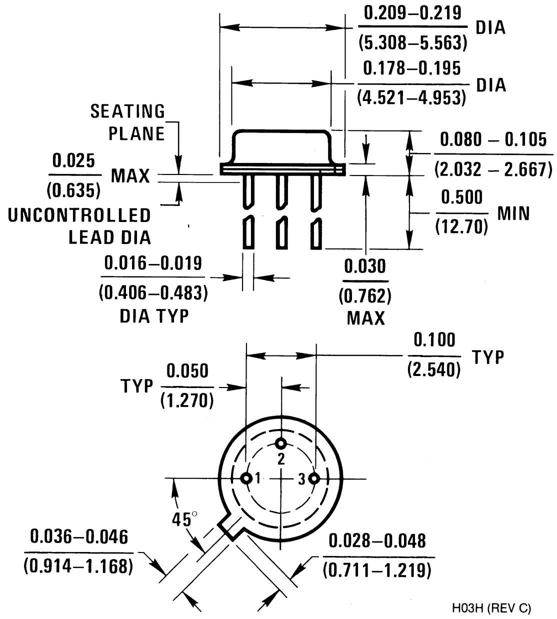
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2˚C to +150˚C; 20 Hz to 1500 Hz)

Block Diagram

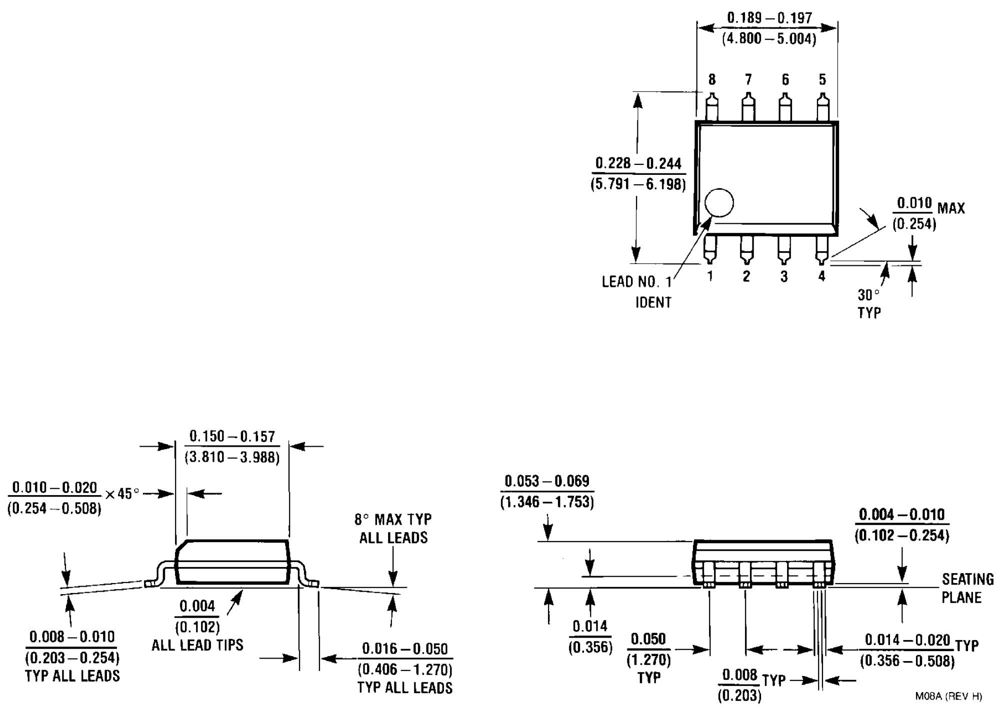


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

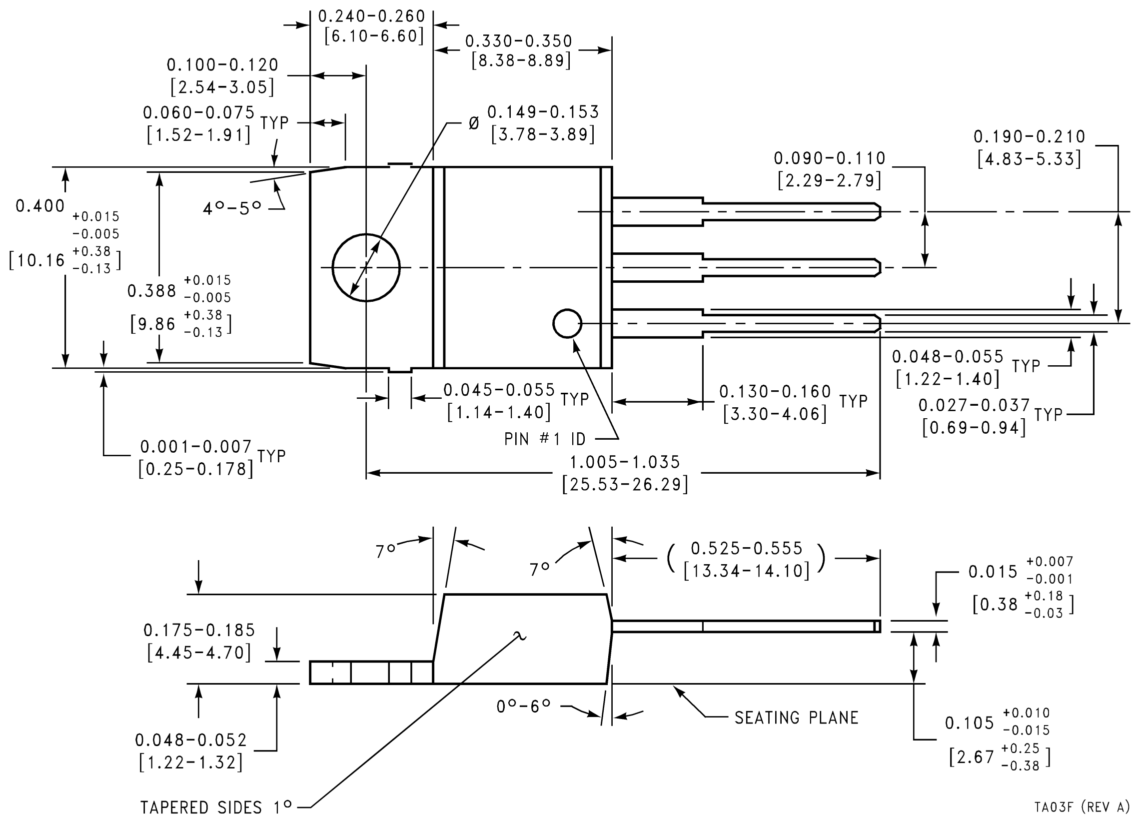


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



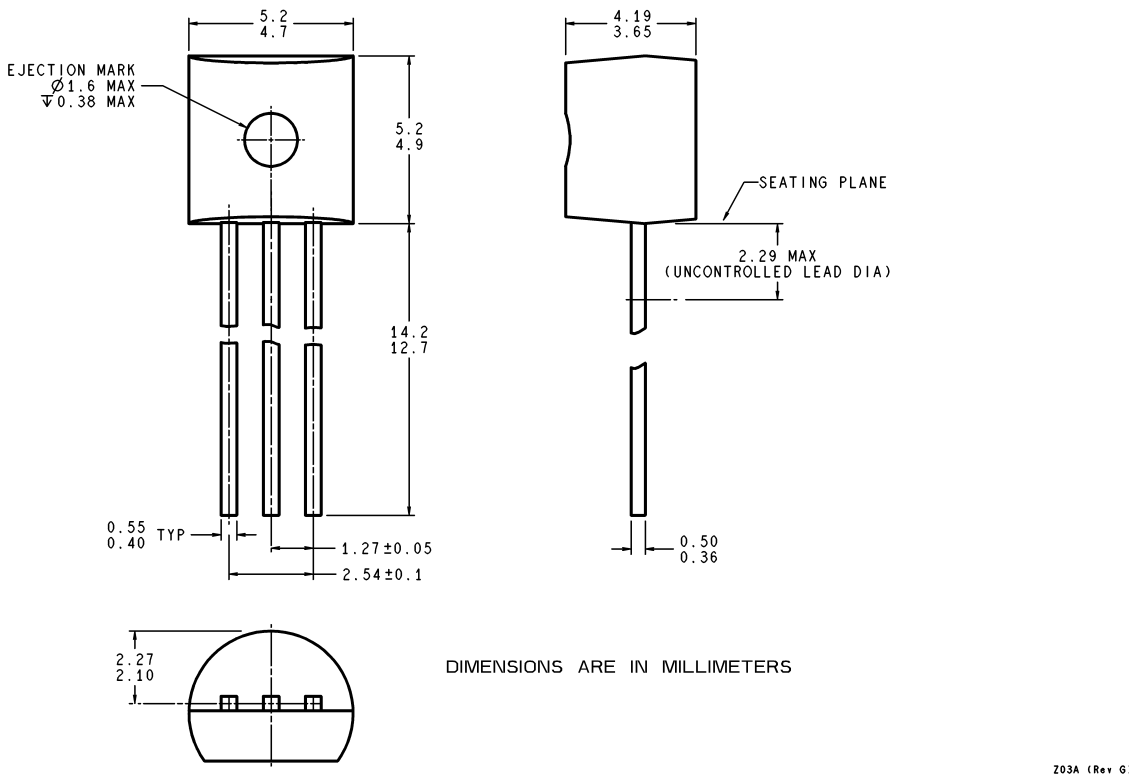
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

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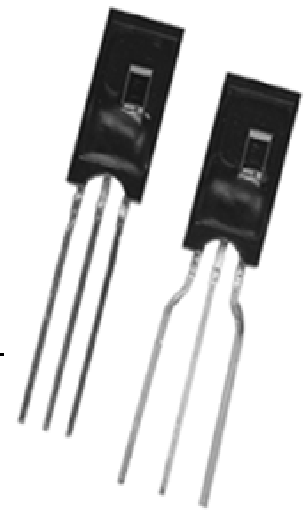


HIH-4000 Series

Humidity Sensors

The HIH-4000 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users. Direct input to a controller or other device is made possible by this sensor's linear voltage output. With a typical current draw of only 200 µA, the HIH-4000 Series is often ideally suited for low drain, battery operated systems. Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4000 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SIP (Single In-line Package). Available in two lead spacing configurations, the RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element's multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals.

FEATURES

- Molded thermoset plastic housing
- Linear voltage output vs %RH
- Laser trimmed interchangeability
- Low power design
- High accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

TYPICAL APPLICATIONS

- Refrigeration equipment
- HVAC equipment
- Medical equipment
- Drying
- Metrology
- Battery-powered systems
- OEM assemblies

HIH-4000 Series

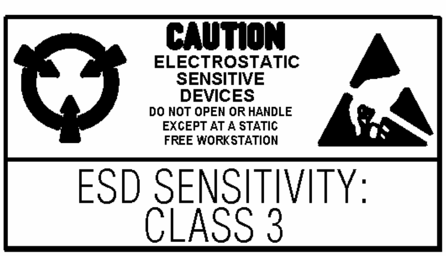
TABLE 1. PERFORMANCE SPECIFICATIONS (At 5 Vdc supply and 25 ºC [77 ºF] unless otherwise noted.)
(%RH performance specifications include test system measurement errors (±0.5 % typical.)

Parameter	Minimum	Typical	Maximum	Unit
Interchangeability (best fit straight line)	–	–	–	–
0 % to 60 %	-5	–	5	%RH
60 % to 100 %	-8	–	8	%RH
Interchangeability (2nd order curve)	–	±3.5	–	%RH
Accuracy[1] (best fit straight line)	–	±3.5	–	%RH
Accuracy (2nd order curve)	–	±2.5	–	%RH
Hysterisis	–	3	–	%RH
Repeatability	–	±0.5	–	%RH
Settling time	–	–	70	ms
Response time (1/e in slow moving air)	–	15	–	s
Stability[2] (@ 50 %RH)	–	±1.2 (per year)	–	%RH
Stability[3] (@ 50 %RH)	–	±0.5 (per year)	–	%RH
Voltage supply	4	–	5.8	Vdc
Current supply	–	–	500	µA
Voltage output (1^{st} order fit)	$V_{out}=V_{supply}(0.0062(\text{sensor RH})+0.16)$			
Voltage output (2nd order curve fit)	$V_{out}=0.00003(\text{sensor RH})^2+0.0281(\text{sensor RH})+0.820$, typical @ 25 ºC			
Temperature compensation	$V_{out}=(0.0305+0.000044T-0.0000011T^2)(\text{Sensor RH})+(0.9237-0.0041T+0.000040T^2)$, T=Temperature in ºC			
Operating temperature	-40[-40]	See Figure 1.	85[185]	ºC[ºF]
Operating humidity	0	See Figure 2.	100	%RH
Storage temperature	-40[-40]	–	125[257]	ºC[ºF]
Storage humidity	See Figure 2.			%RH

Notes:
1. For HIH-4000-003 and -004 only.
2. Specification includes testing outside of recommended operating zone.
3. Specification includes testing for recommended operating zone only.

NOTICE
- Do not expose sensor to condensing environments. Exposure to condensing environments will cause sensor output to indicate 0 %RH.
- Sensor is light sensitive. For best performance, shield sensor from bright light.
- Sensor is static sensitive. Sensor connection protected to 15 kV maximum.
- Sensor output is ratiometric to supply voltage.

Failure to comply with these instructions could result in death or serious injury.



FACTORY CALIBRATION DATA

HIH-4000 Sensors may be ordered with a calibration and data printout (Table 2). See order guide on back page.

TABLE 2. EXAMPLE DATA PRINTOUT

Model	**HIH-4000-001**
Channel	92
Wafer	030996M
MRP	337313
Calculated values at 5 V V_{out} @ 0 %RH V_{out} @ 75.3 %RH	 0.958 V 3.268 V
Linear output for 2 %RH accuracy @ 25 °C Zero offset Slope RH	 0.958 V 30.680 mV/%RH (V_{out}-zero offset)/slope (V_{out}-0.958)/0.0307
Ratiometric response for 0 % to 100 %RH V_{out}	 V_{supply} (0.1915 to 0.8130)

FIGURE 1. RECOMMENDED OPERATING CONDITIONS

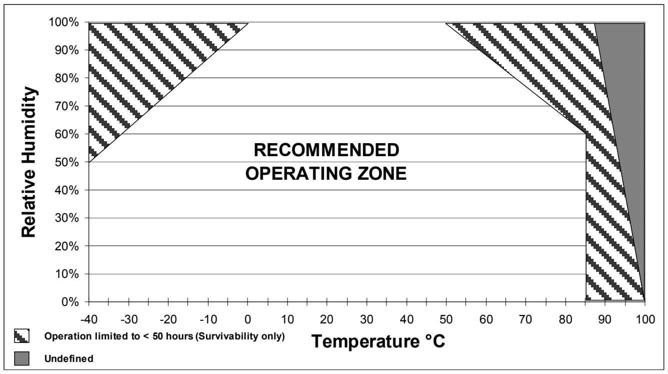


FIGURE 2. STORAGE ENVIRONMENT

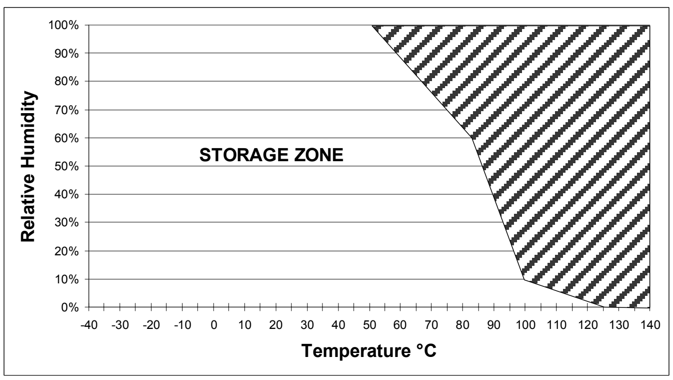


FIGURE 3. MOUNTING DIMENSIONS for reference only mm/[in]

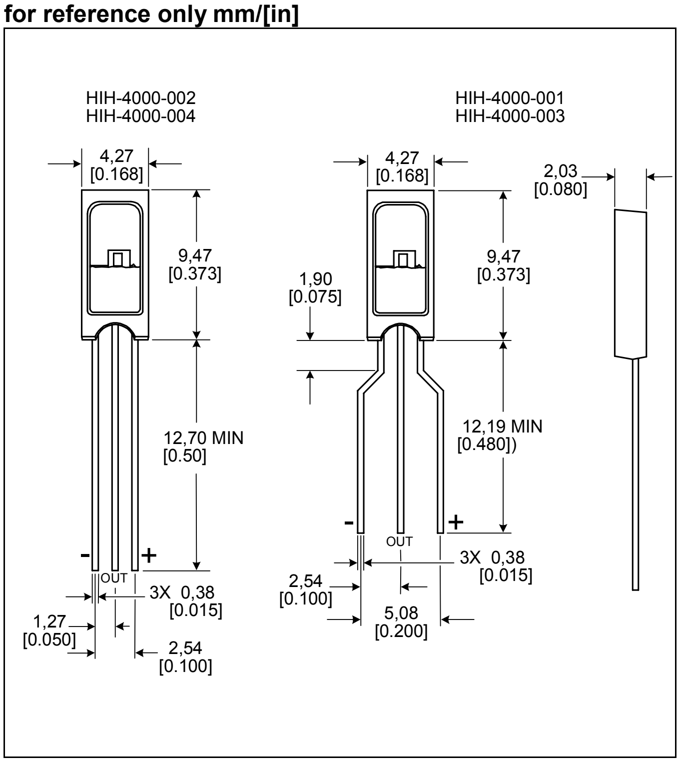


FIGURE 4. TYPICAL BEST FIT STRAIGHT LINE

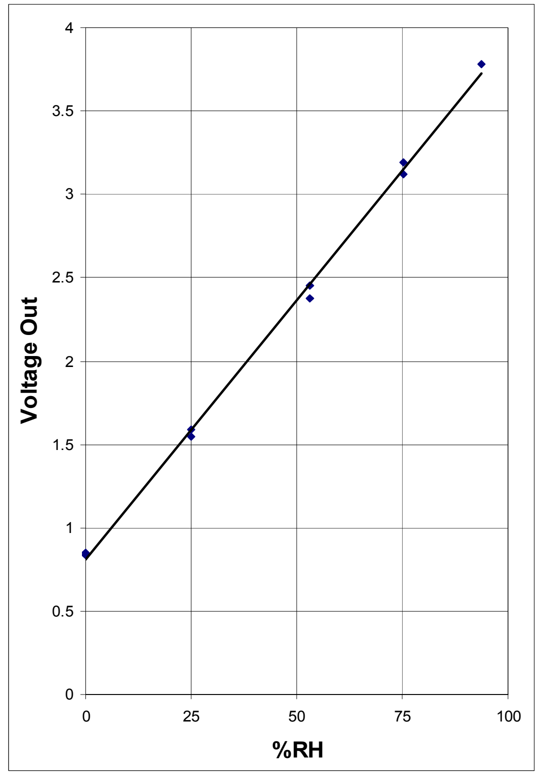
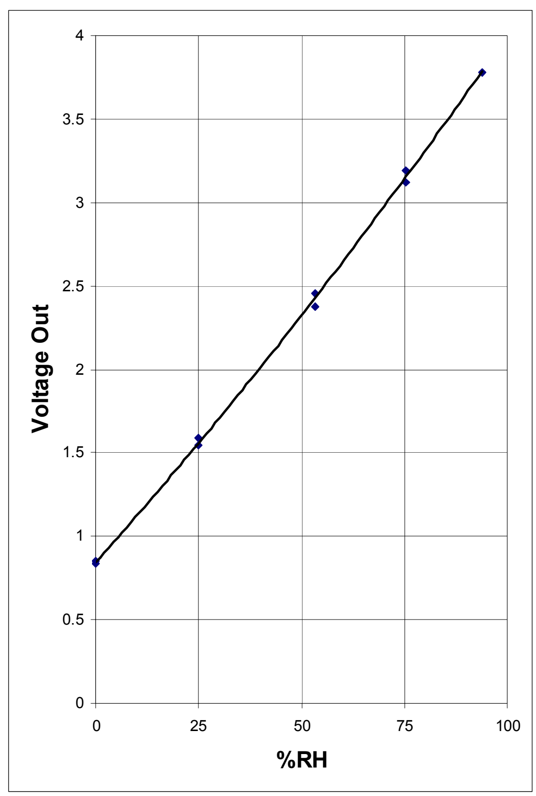


FIGURE 5. TYPICAL 2nd ORDER CURVE FIT



ORDER GUIDE

Catalog Listing	Description
HIH-4000-001	Integrated circuitry humidity sensor, 0.100 in lead pitch SIP
HIH-4000-002	Integrated circuitry humidity sensor, 0.050 in lead pitch SIP
HIH-4000-003	Integrated circuitry humidity sensor, 0.100 in lead pitch SIP with calibration and data printout
HIH-4000-004	Integrated circuitry humidity sensor, 0.050 in lead pitch SIP with calibration and data printout

⚠ WARNING

MISUSE OF DOCUMENTATION

- The information presented in this product sheet is for reference only. Do not use this document as a product installation guide.
- Complete installation, operation, and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

⚠ WARNING

PERSONAL INJURY

DO NOT USE these products as safety or emergency stop devices or in any other application where failure of the product could result in personal injury.

Failure to comply with these instructions could result in death or serious injury.

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August 2000

LF444
Quad Low Power JFET Input Operational Amplifier

General Description

The LF444 quad low power operational amplifier provides many of the same AC characteristics as the industry standard LM148 while greatly improving the DC characteristics of the LM148. The amplifier has the same bandwidth, slew rate, and gain (10 kΩ load) as the LM148 and only draws one fourth the supply current of the LM148. In addition the well matched high voltage JFET input devices of the LF444 reduce the input bias and offset currents by a factor of 10,000 over the LM148. The LF444 also has a very low equivalent input noise voltage for a low power amplifier.

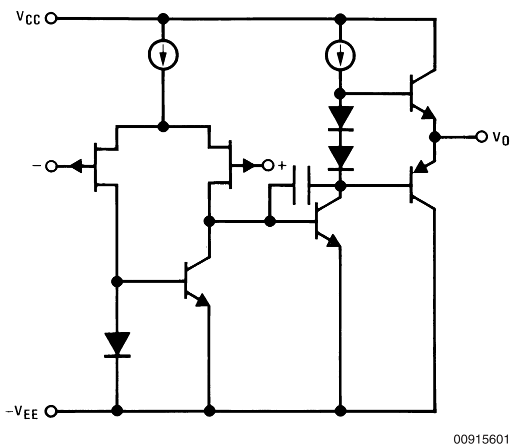
The LF444 is pin compatible with the LM148 allowing an immediate 4 times reduction in power drain in many applications. The LF444 should be used wherever low power dissipation and good electrical characteristics are the major considerations.

Features

- ¼ supply current of a LM148: 200 µA/Amplifier (max)
- Low input bias current: 50 pA (max)
- High gain bandwidth: 1 MHz
- High slew rate: 1 V/µs
- Low noise voltage for low power $35\ nV/\sqrt{Hz}$
- Low input noise current $0.01\ pA/\sqrt{Hz}$
- High input impedance: $10^{12}\Omega$
- High gain: 50k (min)

Simplified Schematic

1/4 Quad



Ordering Information

LF444XYZ

X indicates electrical grade

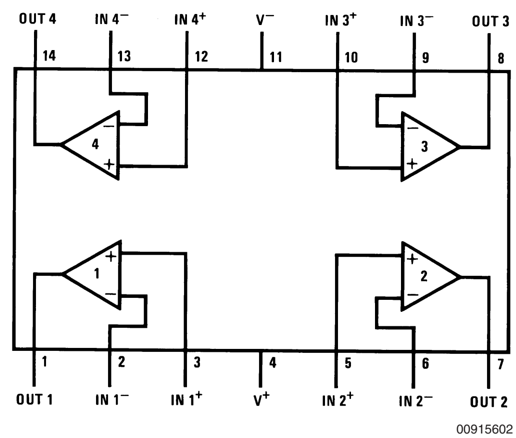
Y indicates temperature range

"M" for military, "C" for commercial

Z indicates package type "D", "M" or "N"

Connection Diagram

Dual-In-Line Package



Top View
Order Number LF444CM, LF444CMX, LF444ACN, LF 444CN or LF444MD/883
See NS Package Number D14E, M14A or N14A

Absolute Maximum Ratings (Note 11)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

	LF444A	LF444
Supply Voltage	±22V	±18V
Differential Input Voltage	±38V	±30V
Input Voltage Range (Note 1)	±19V	±15V
Output Short Circuit Duration (Note 2)	Continuous	Continuous

	D Package	N, M Packages
Power Dissipation (Notes 3, 9)	900 mW	670 mW
T_j max	150˚C	115˚C
θ_{jA} (Typical)	100˚C/W	85˚C/W

	LF444A/LF444
Operating Temperature Range	(Note 4)
Storage Temperature Range	$-65˚C \leq T_A \leq 150˚C$
ESD Tolerance (Note 10)	Rating to be determined
Soldering Information	
Dual-In-Line Packages	
(Soldering, 10 sec.)	260˚C
Small Outline Package	
Vapor Phase (60 sec.)	215˚C
Infrared (15 sec.)	220˚C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

DC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions		LF444A Min	LF444A Typ	LF444A Max	LF444 Min	LF444 Typ	LF444 Max	Units
V_{OS}	Input Offset Voltage	R_S = 10k, T_A = 25˚C			2	5		3	10	mV
		$0˚C \leq T_A \leq +70˚C$				6.5			12	mV
		$-55˚C \leq T_A \leq +125˚C$				8				mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S = 10 kΩ			10			10		μV/˚C
I_{OS}	Input Offset Current	V_S = ±15V (Notes 5, 6)	T_j = 25˚C		5	25		5	50	pA
			T_j = 70˚C			1.5			1.5	nA
			T_j = 125˚C			10				nA
I_B	Input Bias Current	V_S = ±15V (Notes 5, 6)	T_j = 25˚C		10	50		10	100	pA
			T_j = 70˚C			3			3	nA
			T_j = 125˚C			20				nA
R_{IN}	Input Resistance	T_j = 25˚C			10^{12}			10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	V_S = ±15V, V_O = ±10V, R_L = 10 kΩ, T_A = 25˚C		50	100		25	100		V/mV
		Over Temperature		25			15			V/mV
V_O	Output Voltage Swing	V_S = ±15V, R_L = 10 kΩ		±12	±13		±12	±13		V
V_{CM}	Input Common-Mode Voltage Range			±16	+18		±11	+14		V
					−17			−12		V
CMRR	Common-Mode Rejection Ratio	$R_S \leq 10$ kΩ		80	100		70	95		dB
PSRR	Supply Voltage Rejection Ratio	(Note 7)		80	100		70	90		dB
I_S	Supply Current				0.6	0.8		0.6	1.0	mA

AC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions	LF444A			LF444			Units
			Min	Typ	Max	Min	Typ	Max	
	Amplifier-to-Amplifier Coupling			–120			–120		dB
SR	Slew Rate	$V_S = \pm 15V$, $T_A = 25^\circ C$		1			1		V/μs
GBW	Gain-Bandwidth Product	$V_S = \pm 15V$, $T_A = 25^\circ C$		1			1		MHz
e_n	Equivalent Input Noise Voltage	$T_A = 25^\circ C$, $R_S = 100\Omega$, f = 1 kHz		35			35		$nV/\sqrt{Hz}$
i_n	Equivalent Input Noise Current	$T_A = 25^\circ C$, f = 1 kHz		0.01			0.01		$pA/\sqrt{Hz}$

Note 1: Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

Note 2: Any of the amplifier outputs can be shorted to ground indefinitely, however, more than one should not be simultaneously shorted as the maximum junction temperature will be exceeded.

Note 3: For operating at elevated temperature, these devices must be derated based on a thermal resistance of θ_{jA}.

Note 4: The LF444A is available in both the commercial temperature range $0^\circ C \leq T_A \leq 70^\circ C$ and the military temperature range $-55^\circ C \leq T_A \leq 125^\circ C$. The LF444 is available in the commercial temperature range only. The temperature range is designated by the position just before the package type in the device number. A "C" indicates the commercial temperature range and an "M" indicates the military temperature range. The military temperature range is available in "D" package only.

Note 5: Unless otherwise specified the specifications apply over the full temperature range and for $V_S = \pm 20V$ for the LF444A and for $V_S = \pm 15V$ for the LF444. V_{OS}, I_B, and I_{OS} are measured at $V_{CM} = 0$.

Note 6: The input bias currents are junction leakage currents which approximately double for every 10˚C increase in the junction temperature, T_j. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P_D. $T_j = T_A + \theta_{jA} P_D$ where θ_{jA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

Note 7: Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice from ±15V to ±5V for the LF444 and from ±20V to ±5V for the LF444A.

Note 8: Refer to RETS444X for LF444MD military specifications.

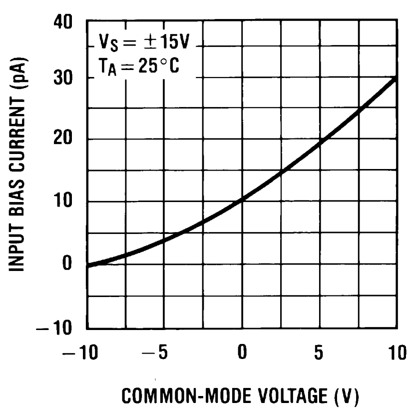
Note 9: Max. Power Dissipation is defined by the package characteristics. Operating the part near the Max. Power Dissipation may cause the part to operate outside guaranteed limits.

Note 10: Human body model, 1.5 kΩ in series with 100 pF.

Note 11: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. Electrical Characteristics state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

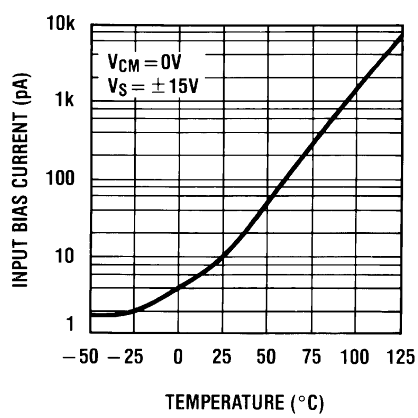
Typical Performance Characteristics

Input Bias Current



00915612

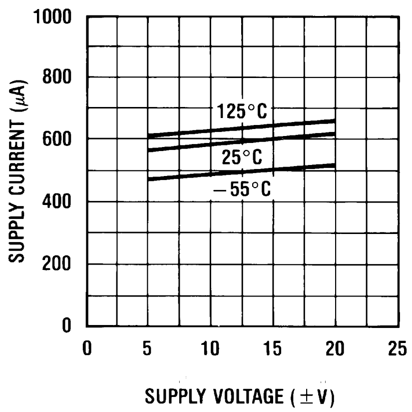
Input Bias Current



00915613

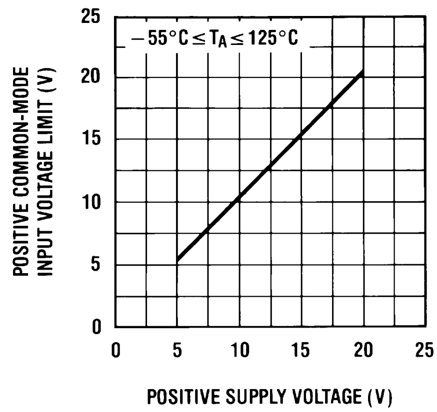
Typical Performance Characteristics (Continued)

Supply Current



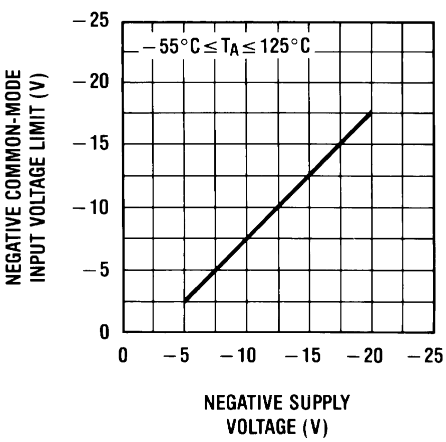
00915614

Positive Common-Mode Input Voltage Limit



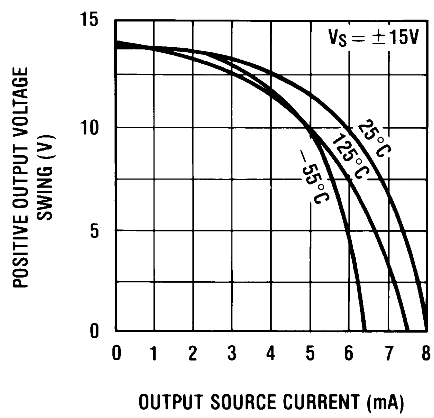
00915615

Negative Common-Mode Input Voltage Limit



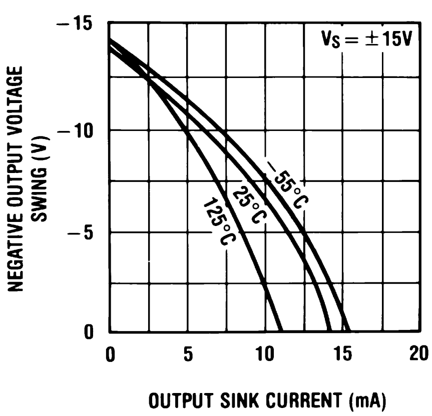
00915616

Positive Current Limit



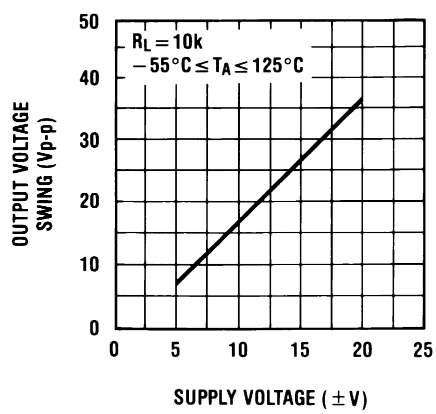
00915617

Negative Current Limit



00915618

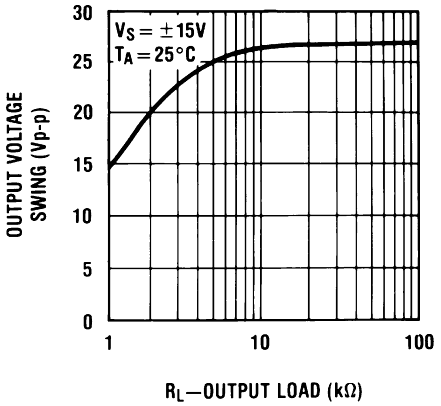
Output Voltage Swing



00915619

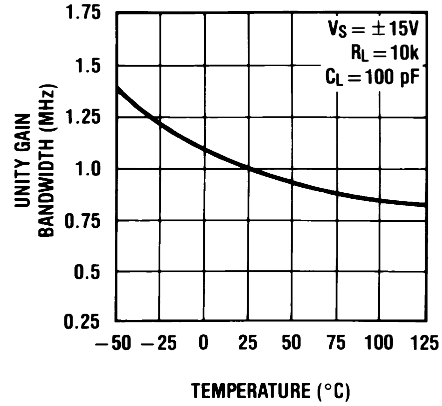
Typical Performance Characteristics (Continued)

Output Voltage Swing



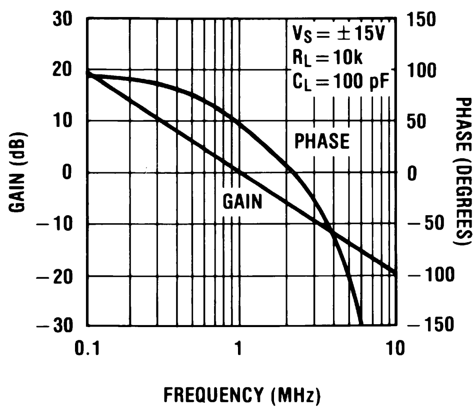
00915620

Gain Bandwidth



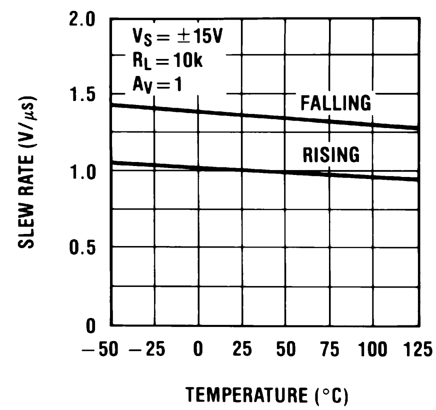
00915621

Bode Plot



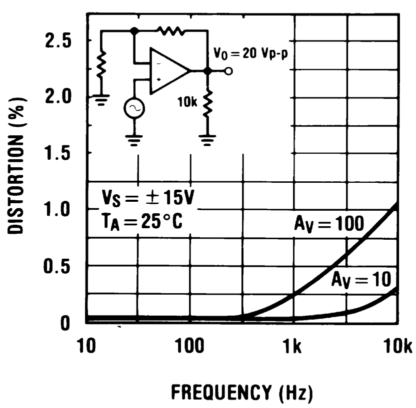
00915622

Slew Rate



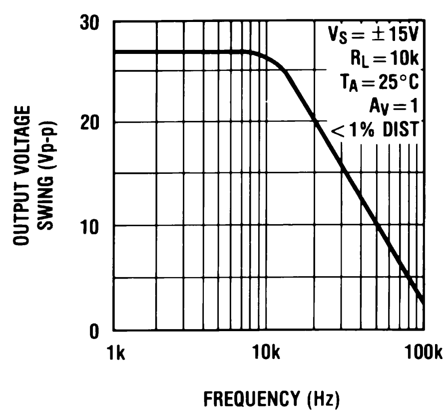
00915623

Distortion vs Frequency



00915624

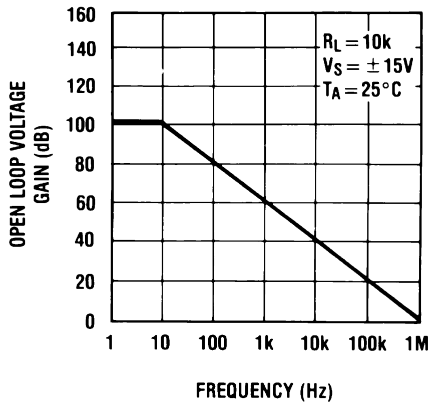
Undistorted Output Voltage Swing



00915625

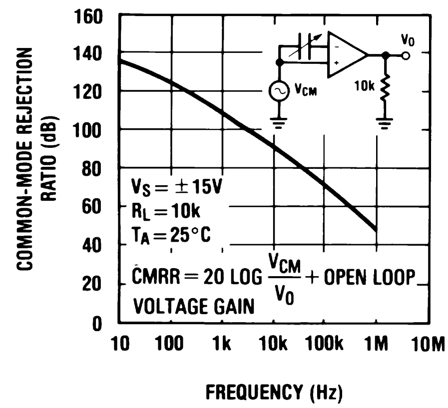
Typical Performance Characteristics (Continued)

Open Loop Frequency Response



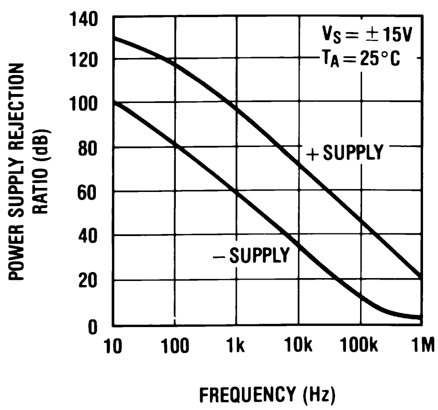
00915626

Common-Mode Rejection Ratio



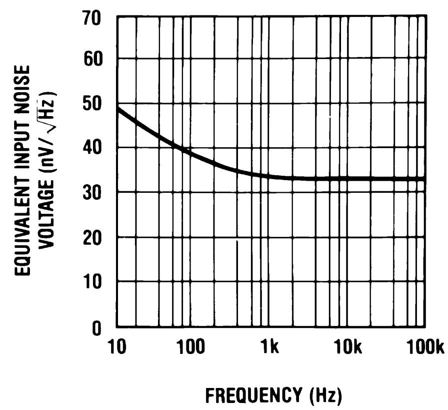
00915627

Power Supply Rejection Ratio



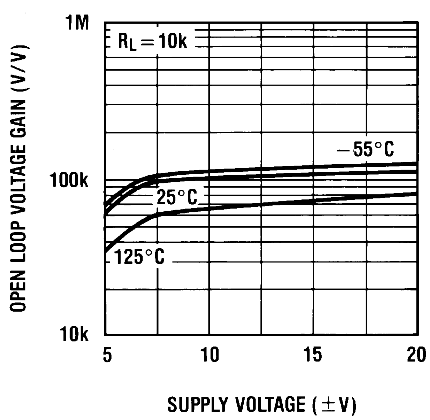
00915628

Equivalent Input Noise Voltage



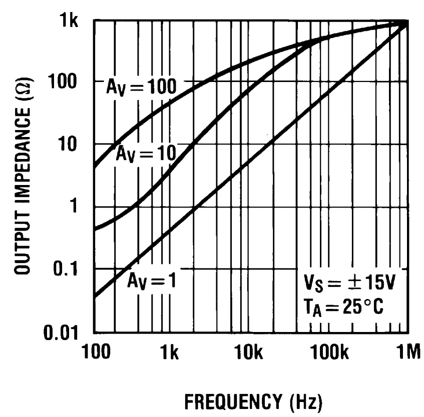
00915629

Open Loop Voltage Gain



00915630

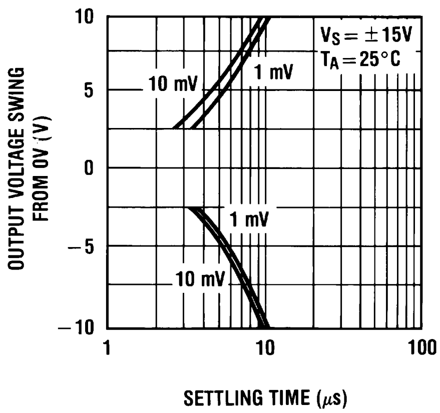
Output Impedance



00915631

Typical Performance Characteristics (Continued)

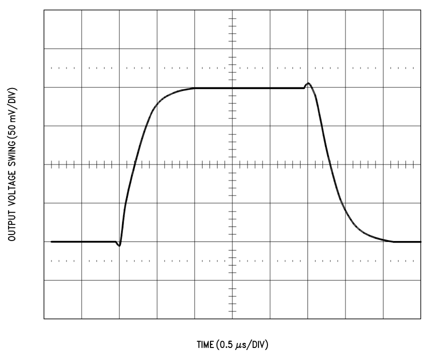
Inverter Settling Time



00915632

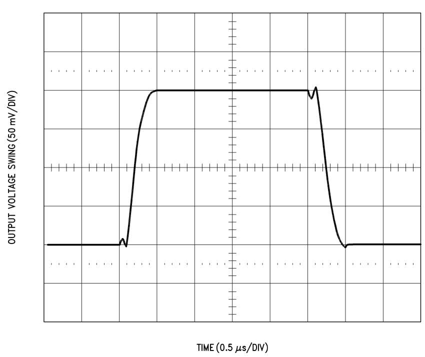
Pulse Response R_L = 10 kΩ, C_L = 10 pF

Small Signal Inverting



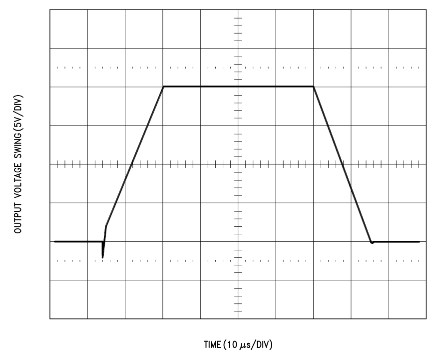
00915606

Small Signal Non-Inverting



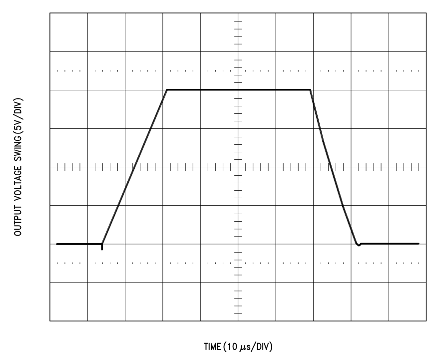
00915607

Large Signal Inverting



00915608

Large Signal Non-Inverting



00915609

Application Hints

This device is a quad low power op amp with JFET input devices (BI-FET™). These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore, large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

Application Hints (Continued)

Exceeding the negative common-mode limit on either input will force the output to a high state, potentially causing a reversal of phase to the output. Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output; however, if both inputs exceed the limit, the output of the amplifier will be forced to a high state.

The amplifiers will operate with a common-mode input voltage equal to the positive supply; however, the gain bandwidth and slew rate may be decreased in this condition. When the negative common-mode voltage swings to within 3V of the negative supply, an increase in input offset voltage may occur.

Each amplifier is individually biased to allow normal circuit operation with power supplies of ±3.0V. Supply voltages less than these may degrade the common-mode rejection and restrict the output voltage swing.

The amplifiers will drive a 10 kΩ load resistance to ±10V over the full temperature range. If the amplifier is forced to drive heavier load currents, however, an increase in input offset voltage may occur on the negative voltage swing and finally reach an active current limit on both positive and negative swings.

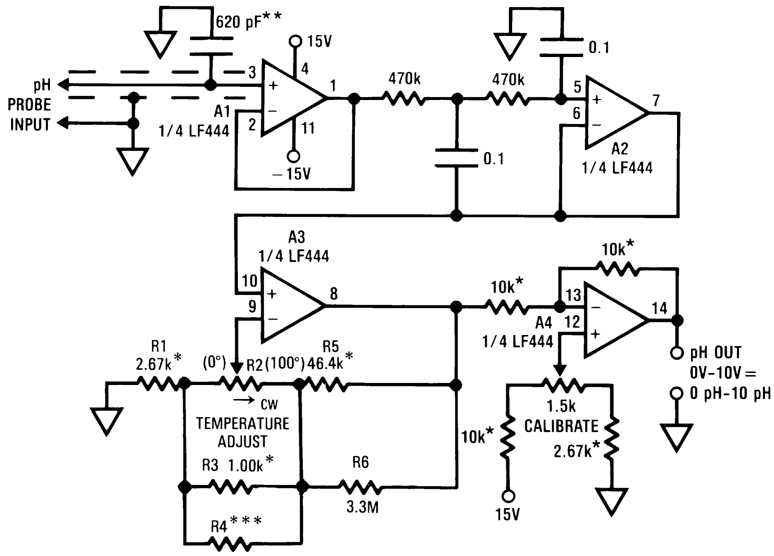
Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize “pick-up” and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately 6 times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

Typical Application

pH Probe Amplifier/Temperature Compensator



00915610

***For R2 = 50k, R4 = 330k ±1%

For R2 = 100k, R4 = 75k ±1%

For R2 = 200k, R4 = 56k ±1%

**Polystyrene

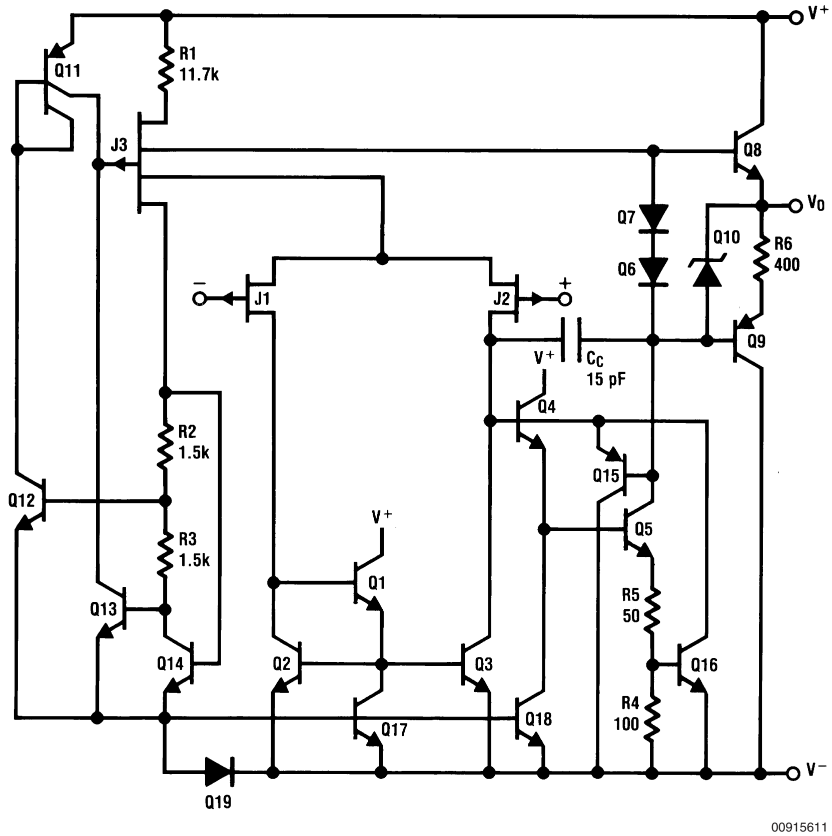
*Film resistor type RN60C

To calibrate, insert probe in pH =7 solution. Set the “TEMPERATURE ADJUST” pot, R2, to correspond to the solution temperature: full clockwise for 0˚C, and proportionately for intermediate temperatures, using a turns-counting dial. Then set “CALIBRATE” pot so output reads 7V.

Typical probe = Ingold Electrodes #465-35

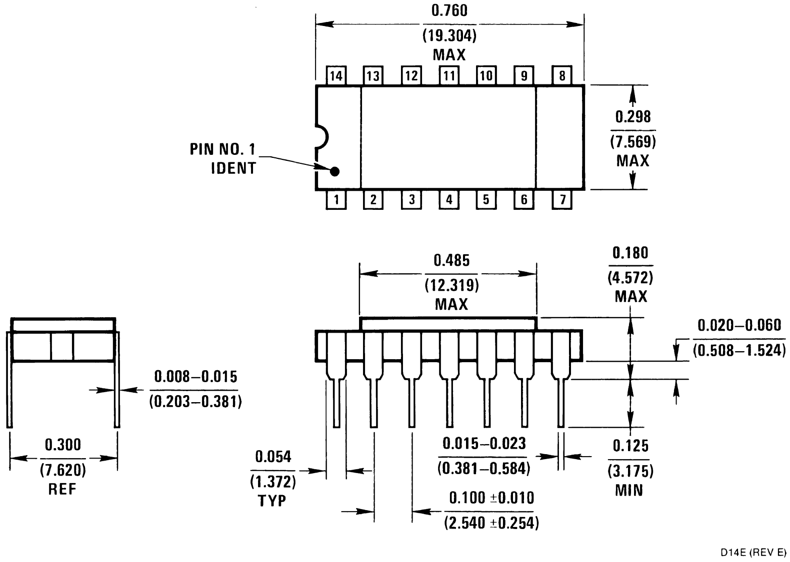
Detailed Schematic

1/4 Quad

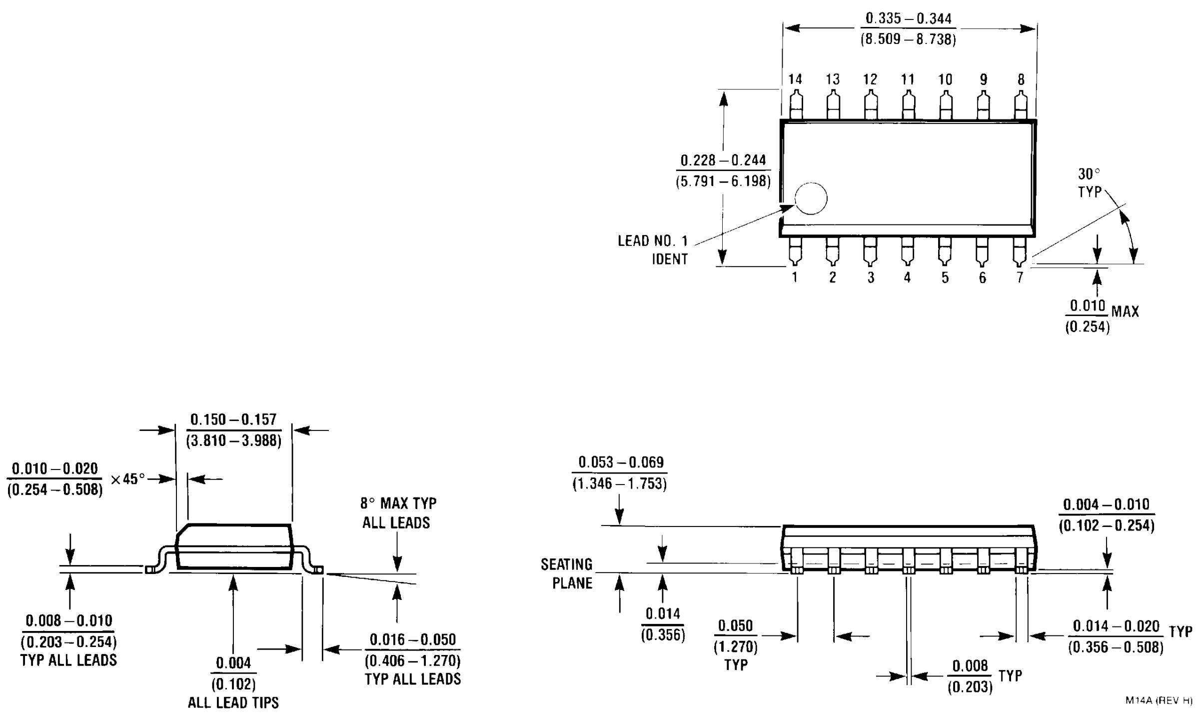


Physical Dimensions inches (millimeters)

unless otherwise noted

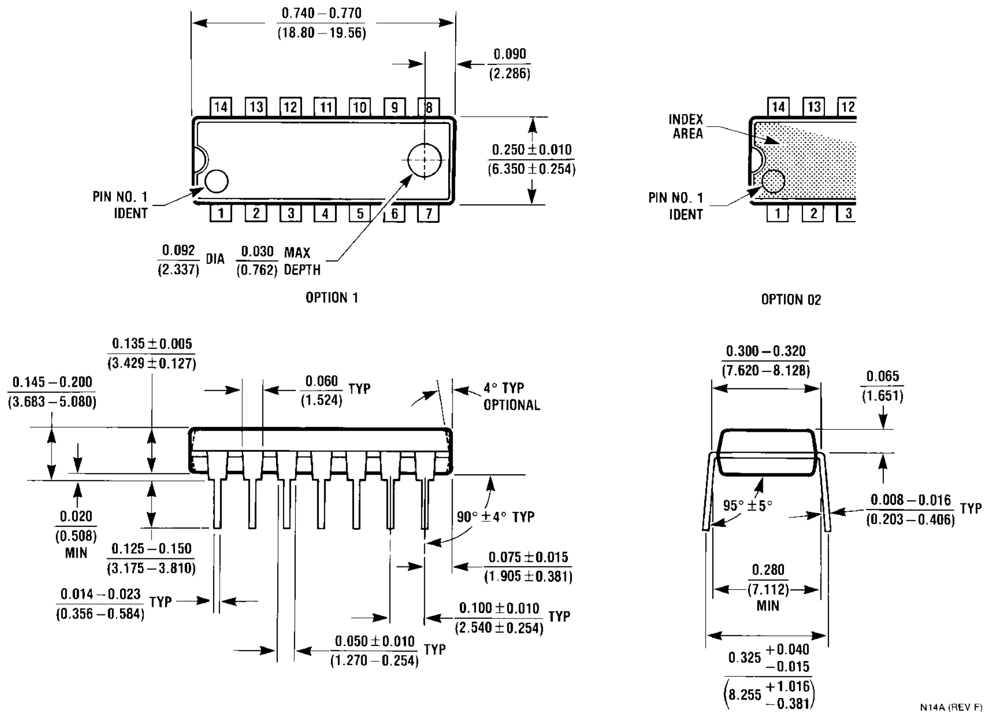


Order Number LF444MD/883
See NS Package Number D14E



Order Number LF444CM or LF444CMX
See NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Order Number LF444ACN or LF444CN
See NS Package Number N14A

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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XBee®/XBee-PRO® RF Modules

XBee®/XBee-PRO® RF Modules

RF Module Operation

RF Module Configuration

Appendices

Product Manual v1.xEx - 802.15.4 Protocol

For RF Module Part Numbers: XB24-A...-001, XBP24-A...-001

IEEE® 802.15.4 RF Modules by Digi International

Digi International Inc.
11001 Bren Road East
Minnetonka, MN 55343
877 912-3444 or 952 912-3444
http://www.digi.com

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2009.09.23

Technical Support:	Phone:	(866) 765-9885 toll-free U.S.A. & Canada (801) 765-9885 Worldwide 8:00 am - 5:00 pm [U.S. Mountain Time]
	Live Chat:	www.digi.com
	Online Support:	http://www.digi.com/support/eservice/login.jsp
	Email:	rf-experts@digi.com

Contents

1. XBee®/XBee-PRO® RF Modules

The XBee and XBee-PRO RF Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices.

The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.

Key Features

Long Range Data Integrity

XBee

- Indoor/Urban: up to 100’ (30 m)
- Outdoor line-of-sight: up to 300’ (90 m)
- Transmit Power: 1 mW (0 dBm)
- Receiver Sensitivity: -92 dBm

XBee-PRO

- Indoor/Urban: up to 300’ (90 m), 200' (60 m) for International variant
- Outdoor line-of-sight: up to 1 mile (1600 m), 2500' (750 m) for International variant
- Transmit Power: 63mW (18dBm), 10mW (10dBm) for International variant
- Receiver Sensitivity: -100 dBm

RF Data Rate: 250,000 bps

Advanced Networking & Security

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

Each direct sequence channels has over 65,000 unique network addresses available

Source/Destination Addressing

Unicast & Broadcast Communications

Point-to-point, point-to-multipoint and peer-to-peer topologies supported

Low Power

XBee

- TX Peak Current: 45 mA (@3.3 V)
- RX Current: 50 mA (@3.3 V)
- Power-down Current: < 10 µA

XBee-PRO

- TX Peak Current: 250mA (150mA for international variant)
- TX Peak Current (RPSMA module only): 340mA (180mA for international varian
- RX Current: 55 mA (@3.3 V)
- Power-down Current: < 10 µA

ADC and I/O line support

Analog-to-digital conversion, Digital I/O

I/O Line Passing

Easy-to-Use

No configuration necessary for out-of box RF communications

Free X-CTU Software
(Testing and configuration software)

AT and API Command Modes for configuring module parameters

Extensive command set

Small form factor

Worldwide Acceptance

FCC Approval (USA) Refer to Appendix A [p64] for FCC Requirements.
Systems that contain XBee®/XBee-PRO® RF Modules inherit Digi Certifications.

ISM (Industrial, Scientific & Medical) **2.4 GHz frequency band**

Manufactured under **ISO 9001:2000** registered standards

XBee®/XBee-PRO® RF Modules are optimized for use in the United States, Canada, Australia, Japan, and Europe. Contact Digi for complete list of government agency approvals.

Specifications

Table 1-01. Specifications of the XBee®/XBee-PRO® RF Modules

Specification	XBee	XBee-PRO
Performance		
Indoor/Urban Range	Up to 100 ft (30 m)	Up to 300 ft. (90 m), up to 200 ft (60 m) International variant
Outdoor RF line-of-sight Range	Up to 300 ft (90 m)	Up to 1 mile (1600 m), up to 2500 ft (750 m) international variant
Transmit Power Output (software selectable)	1mW (0 dBm)	63mW (18dBm)* 10mW (10 dBm) for International variant
RF Data Rate	250,000 bps	250,000 bps
Serial Interface Data Rate (software selectable)	1200 bps - 250 kbps (non-standard baud rates also supported)	1200 bps - 250 kbps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)	250mA (@3.3 V) (150mA for international variant) RPSMA module only: 340mA (@3.3 V) (180mA for international variant)
Idle / Receive Current (typical)	50mA (@ 3.3 V)	55mA (@ 3.3 V)
Power-down Current	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960" x 1.297" (2.438cm x 3.294cm)
Operating Temperature	-40 to 85º C (industrial)	-40 to 85º C (industrial)
Antenna Options	Integrated Whip, Chip or U.FL Connector, RPSMA Connector	Integrated Whip, Chip or U.FL Connector, RPSMA Connector
Networking & Security		
Supported Network Topologies	Point-to-point, Point-to-multipoint & Peer-to-peer	
Number of Channels (software selectable)	16 Direct Sequence Channels	12 Direct Sequence Channels
Addressing Options	PAN ID, Channel and Addresses	PAN ID, Channel and Addresses
Agency Approvals		
United States (FCC Part 15.247)	OUR-XBEE	OUR-XBEEPRO
Industry Canada (IC)	4214A XBEE	4214A XBEEPRO
Europe (CE)	ETSI	ETSI (Max. 10 dBm transmit power output)*
Japan	R201WW07215214	R201WW08215111 (Max. 10 dBm transmit power output)*
Austraila	C-Tick	C-Tick

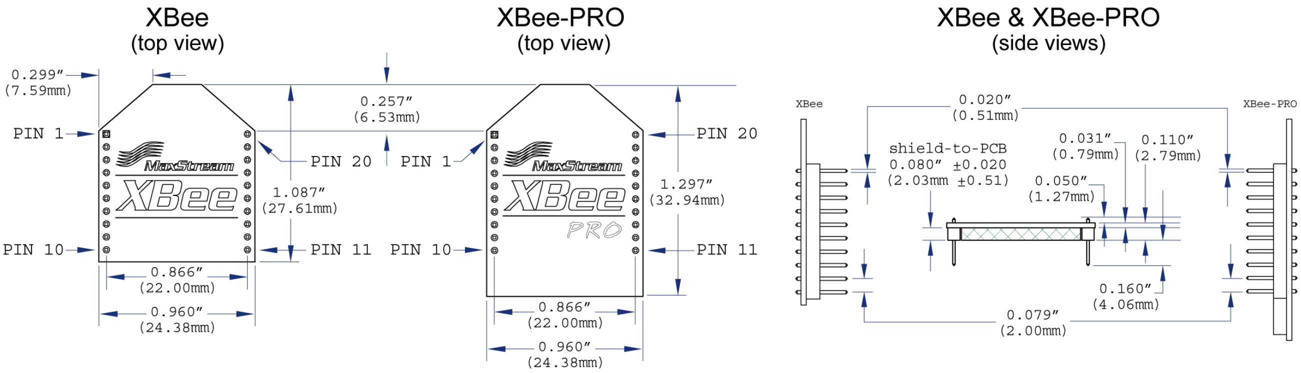
* See Appendix A for region-specific certification requirements.

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the Whip and Dipole antenna options when transmitting outdoors.For more information, refer to the "XBee Antennas" Knowledgebase Article located on Digi's Support Web site

Mechanical Drawings

Figure 1-01. Mechanical drawings of the XBee®/XBee-PRO® RF Modules (antenna options not shown)

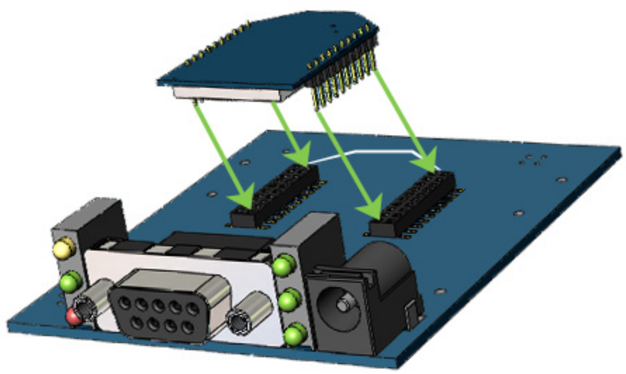
The XBee and XBee-PRO RF Modules are pin-for-pin compatible.



Mounting Considerations

The XBee®/XBee-PRO® RF Module was designed to mount into a receptacle (socket) and therefore does not require any soldering when mounting it to a board. The XBee Development Kits contain RS-232 and USB interface boards which use two 20-pin receptacles to receive modules.

Figure 1-02. XBee Module Mounting to an RS-232 Interface Board.



The receptacles used on Digi development boards are manufactured by Century Interconnect. Several other manufacturers provide comparable mounting solutions; however, Digi currently uses the following receptacles:

- Through-hole single-row receptacles -
  Samtec P/N: MMS-110-01-L-SV (or equivalent)
- Surface-mount double-row receptacles -
  Century Interconnect P/N: CPRMSL20-D-0-1 (or equivalent)
- Surface-mount single-row receptacles -
  Samtec P/N: SMM-110-02-SM-S

Digi also recommends printing an outline of the module on the board to indicate the orientation the module should be mounted.

Pin Signals

Figure 1-03. XBee®/XBee-PRO® RF Module Pin Numbers

(top sides shown - shields on bottom)

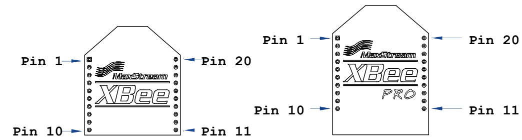


Table 1-02. Pin Assignments for the XBee and XBee-PRO Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **CONFIG**	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	**RESET**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	**CTS** / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **SLEEP**	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	**RTS** / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

* Function is not supported at the time of this release

Design Notes:

- Minimum connections: VCC, GND, DOUT & DIN
- Minimum connections for updating firmware: VCC, GND, DIN, DOUT, RTS & DTR
- Signal Direction is specified with respect to the module
- Module includes a 50k Ω pull-up resistor attached to **RESET**
- Several of the input pull-ups can be configured using the PR command
- Unused pins should be left disconnected

Electrical Characteristics

Table 1-03. DC Characteristics (VCC = 2.8 - 3.4 VDC)

Symbol	Characteristic	Condition	Min	Typical		Max	Unit
V_{IL}	Input Low Voltage	All Digital Inputs	-	-		0.35 * VCC	V
V_{IH}	Input High Voltage	All Digital Inputs	0.7 * VCC	-		-	V
V_{OL}	Output Low Voltage	I_{OL} = 2 mA, VCC >= 2.7 V	-	-		0.5	V
V_{OH}	Output High Voltage	I_{OH} = -2 mA, VCC >= 2.7 V	VCC - 0.5	-		-	V
II_{IN}	Input Leakage Current	V_{IN} = VCC or GND, all inputs, per pin	-	0.025		1	µA
II_{OZ}	High Impedance Leakage Current	V_{IN} = VCC or GND, all I/O High-Z, per pin	-	0.025		1	µA
TX	Transmit Current	VCC = 3.3 V	-	45 (XBee)	215, 140 (PRO, Int)	-	mA
RX	Receive Current	VCC = 3.3 V	-	50 (XBee)	55 (PRO)	-	mA
PWR-DWN	Power-down Current	SM parameter = 1	-	< 10		-	µA

Table 1-04. ADC Characteristics (Operating)

Symbol	Characteristic	Condition	Min	Typical	Max	Unit
V_{REFH}	VREF - Analog-to-Digital converter reference range		2.08	-	V_{DDAD}*	V
I_{REF}	VREF - Reference Supply Current	Enabled	-	200	-	µA
		Disabled or Sleep Mode	-	< 0.01	0.02	µA
V_{INDC}	Analog Input Voltage[1]		V_{SSAD} - 0.3	-	V_{DDAD} + 0.3	V

1. Maximum electrical operating range, not valid conversion range.

* V_{DDAD} is connected to VCC.

Table 1-05. ADC Timing/Performance Characteristics[1]

Symbol	Characteristic	Condition	Min	Typical	Max	Unit
R_{AS}	Source Impedance at Input[2]		-	-	10	kΩ
V_{AIN}	Analog Input Voltage[3]		V_{REFL}		V_{REFH}	V
RES	Ideal Resolution (1 LSB)[4]	2.08V ≤ V_{DDAD} ≤ 3.6V	2.031	-	3.516	mV
DNL	Differential Non-linearity[5]		-	±0.5	±1.0	LSB
INL	Integral Non-linearity[6]		-	±0.5	±1.0	LSB
E_{ZS}	Zero-scale Error[7]		-	±0.4	±1.0	LSB
F_{FS}	Full-scale Error[8]		-	±0.4	±1.0	LSB
E_{IL}	Input Leakage Error[9]		-	±0.05	±5.0	LSB
E_{TU}	Total Unadjusted Error[10]		-	±1.1	±2.5	LSB

1. All ACCURACY numbers are based on processor and system being in WAIT state (very little activity and no IO switching) and that adequate low-pass filtering is present on analog input pins (filter with 0.01 μF to 0.1 μF capacitor between analog input and VREFL). Failure to observe these guidelines may result in system or microcontroller noise causing accuracy errors which will vary based on board layout and the type and magnitude of the activity.
Data transmission and reception during data conversion may cause some degradation of these specifications, depending on the number and timing of packets. It is advisable to test the ADCs in your installation if best accuracy is required.
2. R_{AS} is the real portion of the impedance of the network driving the analog input pin. Values greater than this amount may not fully charge the input circuitry of the ATD resulting in accuracy error.
3. Analog input must be between V_{REFL} and V_{REFH} for valid conversion. Values greater than V_{REFH} will convert to $3FF.
4. The resolution is the ideal step size or 1LSB = $(V_{REFH}–V_{REFL})/1024$
5. Differential non-linearity is the difference between the current code width and the ideal code width (1LSB). The current code width is the difference in the transition voltages to and from the current code.
6. Integral non-linearity is the difference between the transition voltage to the current code and the adjusted ideal transition voltage for the current code. The adjusted ideal transition voltage is $(\text{Current Code}–1/2)*(1/((V_{REFH}+E_{FS})–(V_{REFL}+E_{ZS})))$.
7. Zero-scale error is the difference between the transition to the first valid code and the ideal transition to that code. The Ideal transition voltage to a given code is $(\text{Code}–1/2)*(1/(V_{REFH}–V_{REFL}))$.
8. Full-scale error is the difference between the transition to the last valid code and the ideal transition to that code. The ideal transition voltage to a given code is $(\text{Code}–1/2)*(1/(V_{REFH}–V_{REFL}))$.
9. Input leakage error is error due to input leakage across the real portion of the impedance of the network driving the analog pin. Reducing the impedance of the network reduces this error.

10. Total unadjusted error is the difference between the transition voltage to the current code and the ideal straight-line transfer function. This measure of error includes inherent quantization error (1/2LSB) and circuit error (differential, integral, zero-scale, and full-scale) error. The specified value of E_{TU} assumes zero E_{IL} (no leakage or zero real source impedance).

2. RF Module Operation

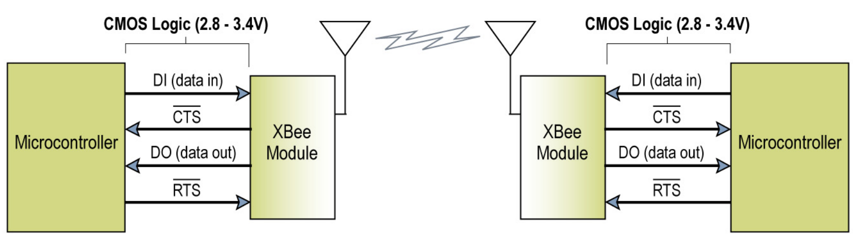
Serial Communications

The XBee®/XBee-PRO® RF Modules interface to a host device through a logic-level asynchronous serial port. Through its serial port, the module can communicate with any logic and voltage compatible UART; or through a level translator to any serial device (For example: Through a Digi proprietary RS-232 or USB interface board).

UART Data Flow

Devices that have a UART interface can connect directly to the pins of the RF module as shown in the figure below.

Figure 2-01. System Data Flow Diagram in a UART-interfaced environment
(Low-asserted signals distinguished with horizontal line over signal name.)

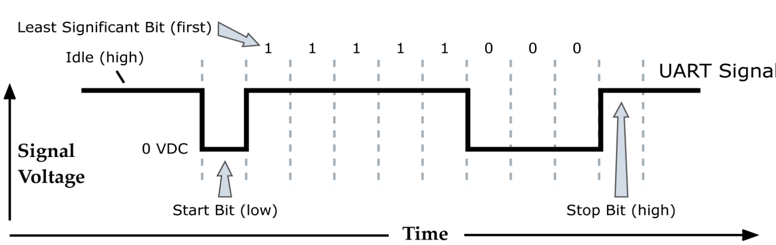


Serial Data

Data enters the module UART through the DI pin (pin 3) as an asynchronous serial signal. The signal should idle high when no data is being transmitted.

Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high). The following figure illustrates the serial bit pattern of data passing through the module.

Figure 2-02. UART data packet 0x1F (decimal number "31") as transmitted through the RF module
Example Data Format is 8-N-1 (bits - parity - # of stop bits)



Serial communications depend on the two UARTs (the microcontroller's and the RF module's) to be configured with compatible settings (baud rate, parity, start bits, stop bits, data bits).

The UART baud rate and parity settings on the XBee module can be configured with the BD and SB commands, respectively. See the command table in Chapter 3 for details.

Transparent Operation

By default, XBee®/XBee-PRO® RF Modules operate in Transparent Mode. When operating in this mode, the modules act as a serial line replacement - all UART data received through the DI pin is queued up for RF transmission. When RF data is received, the data is sent out the DO pin.

Serial-to-RF Packetization

Data is buffered in the DI buffer until one of the following causes the data to be packetized and transmitted:

1. No serial characters are received for the amount of time determined by the RO (Packetization Timeout) parameter. If RO = 0, packetization begins when a character is received.
2. The maximum number of characters that will fit in an RF packet (100) is received.
3. The Command Mode Sequence (GT + CC + GT) is received. Any character buffered in the DI buffer before the sequence is transmitted.

If the module cannot immediately transmit (for instance, if it is already receiving RF data), the serial data is stored in the DI Buffer. The data is packetized and sent at any RO timeout or when 100 bytes (maximum packet size) are received.

If the DI buffer becomes full, hardware or software flow control must be implemented in order to prevent overflow (loss of data between the host and module).

API Operation

API (Application Programming Interface) Operation is an alternative to the default Transparent Operation. The frame-based API extends the level to which a host application can interact with the networking capabilities of the module.

When in API mode, all data entering and leaving the module is contained in frames that define operations or events within the module.

Transmit Data Frames (received through the DI pin (pin 3)) include:

- RF Transmit Data Frame
- Command Frame (equivalent to AT commands)

Receive Data Frames (sent out the DO pin (pin 2)) include:

- RF-received data frame
- Command response
- Event notifications such as reset, associate, disassociate, etc.

The API provides alternative means of configuring modules and routing data at the host application layer. A host application can send data frames to the module that contain address and payload information instead of using command mode to modify addresses. The module will send data frames to the application containing status packets; as well as source, RSSI and payload information from received data packets.

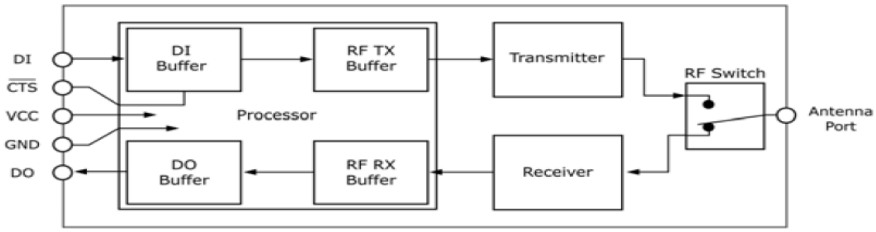
The API operation option facilitates many operations such as the examples cited below:

-> Transmitting data to multiple destinations without entering Command Mode
-> Receive success/failure status of each transmitted RF packet
-> Identify the source address of each received packet

To implement API operations, refer to API sections [p57].

Flow Control

Figure 2-03. Internal Data Flow Diagram



DI (Data In) Buffer

When serial data enters the RF module through the DI pin (pin 3), the data is stored in the DI Buffer until it can be processed.

Hardware Flow Control ($\overline{\text{CTS}}$). When the DI buffer is 17 bytes away from being full; by default, the module de-asserts $\overline{\text{CTS}}$ (high) to signal to the host device to stop sending data [refer to D7 (DIO7 Configuration) parameter]. $\overline{\text{CTS}}$ is re-asserted after the DI Buffer has 34 bytes of memory available.

How to eliminate the need for flow control:

1. Send messages that are smaller than the DI buffer size (202 bytes).
2. Interface at a lower baud rate [BD (Interface Data Rate) parameter] than the throughput data rate.

Case in which the DI Buffer may become full and possibly overflow:

If the module is receiving a continuous stream of RF data, any serial data that arrives on the DI pin is placed in the DI Buffer. The data in the DI buffer will be transmitted over-the-air when the module is no longer receiving RF data in the network.

Refer to the RO (Packetization Timeout), BD (Interface Data Rate) and D7 (DIO7 Configuration) command descriptions for more information.

DO (Data Out) Buffer

When RF data is received, the data enters the DO buffer and is sent out the serial port to a host device. Once the DO Buffer reaches capacity, any additional incoming RF data is lost.

Hardware Flow Control ($\overline{\text{RTS}}$). If $\overline{\text{RTS}}$ is enabled for flow control (D6 (DIO6 Configuration) Parameter = 1), data will not be sent out the DO Buffer as long as $\overline{\text{RTS}}$ (pin 16) is de-asserted.

Two cases in which the DO Buffer may become full and possibly overflow:

1. If the RF data rate is set higher than the interface data rate of the module, the module will receive data from the transmitting module faster than it can send the data to the host.
2. If the host does not allow the module to transmit data out from the DO buffer because of being held off by hardware or software flow control.

Refer to the D6 (DIO6 Configuration) command description for more information.

ADC and Digital I/O Line Support

The XBee®/XBee-PRO® RF Modules support ADC (Analog-to-digital conversion) and digital I/O line passing. The following pins support multiple functions:

Table 2-01. Pin functions and their associated pin numbers and commands
AD = Analog-to-Digital Converter, DIO = Digital Input/Output
Pin functions not applicable to this section are denoted within (parenthesis).

Pin Function	Pin#	AT Command
AD0 / DIO0	20	D0
AD1 / DIO1	19	D1
AD2 / DIO2	18	D2
AD3 / DIO3 / (COORD_SEL)	17	D3
AD4 / DIO4	11	D4
AD5 / DIO5 / (ASSOCIATE)	15	D5
DIO6 / (RTS)	16	D6
DIO7 / (CTS)	12	D7
DI8 / (DTR) / (Sleep_RQ)	9	D8

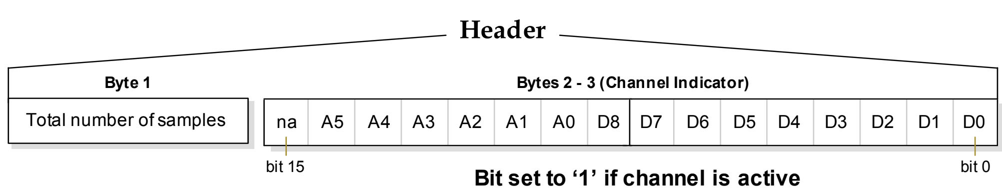
To enable ADC and DIO pin functions:

For ADC Support:	Set ATDn = 2
For Digital Input support:	Set ATDn = 3
For Digital Output Low support:	Set ATDn = 4
For Digital Output High support:	Set ATDn = 5

I/O Data Format

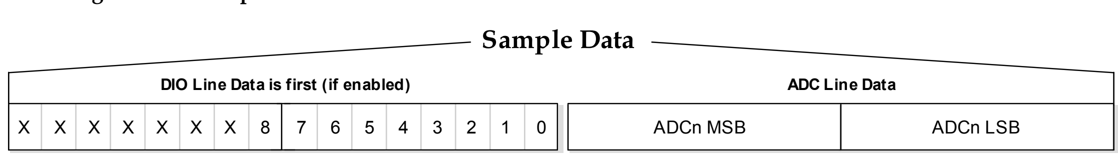
I/O data begins with a header. The first byte of the header defines the number of samples forthcoming. The last 2 bytes of the header (Channel Indicator) define which inputs are active. Each bit represents either a DIO line or ADC channel.

Figure 2-04. Header



Sample data follows the header and the channel indicator frame is used to determine how to read the sample data. If any of the DIO lines are enabled, the first 2 bytes are the DIO sample. The ADC data follows. ADC channel data is represented as an unsigned 10-bit value right-justified on a 16- bit boundary.

Figure 2-05. Sample Data



API Support

I/O data is sent out the UART using an API frame. All other data can be sent and received using Transparent Operation [refer to p11] or API framing if API mode is enabled (AP > 0).

API Operations support two RX (Receive) frame identifiers for I/O data (set 16-bit address to 0xFFFE and the module will do 64-bit addressing):

- 0x82 for RX (Receive) Packet: 64-bit address I/O
- 0x83 for RX (Receive) Packet: 16-bit address I/O

The API command header is the same as shown in the "RX (Receive) Packet: 64-bit Address" and "RX (Receive) Packet: 64-bit Address" API types [refer to p63]. RX data follows the format described in the I/O Data Format section [p13].

Applicable Commands: AP (API Enable)

Sleep Support

Automatic wakeup sampling can be suppressed by setting SO bit 1.When an RF module wakes, it will always do a sample based on any active ADC or DIO lines. This allows sampling based on the sleep cycle whether it be Cyclic Sleep (SM parameter = 4 or 5) or Pin Sleep (SM = 1 or 2). To gather more samples when awake, set the IR (Sample Rate) parameter.

For Cyclic Sleep modes: If the IR parameter is set, the module will stay awake until the IT (Samples before TX) parameter is met. The module will stay awake for ST (Time before Sleep) time.

Applicable Commands: IR (Sample Rate), IT (Samples before TX), SM (Sleep Mode), IC (DIO Change Detect), SO (Sleep Options)

DIO Pin Change Detect

When "DIO Change Detect" is enabled (using the IC command), DIO lines 0-7 are monitored. When a change is detected on a DIO line, the following will occur:

1. An RF packet is sent with the updated DIO pin levels. This packet will not contain any ADC samples.
2. Any queued samples are transmitted before the change detect data. This may result in receiving a packet with less than IT (Samples before TX) samples.

Note: Change detect will not affect Pin Sleep wake-up. The D8 pin (DTR/Sleep_RQ/DI8) is the only line that will wake a module from Pin Sleep. If not all samples are collected, the module will still enter Sleep Mode after a change detect packet is sent.

Applicable Commands: IC (DIO Change Detect), IT (Samples before TX)

NOTE: Change detect is only supported when the Dx (DIOx Configuration) parameter equals 3,4 or 5.

Sample Rate (Interval)

The Sample Rate (Interval) feature allows enabled ADC and DIO pins to be read periodically on modules that are not configured to operate in Sleep Mode. When one of the Sleep Modes is enabled and the IR (Sample Rate) parameter is set, the module will stay awake until IT (Samples before TX) samples have been collected.

Once a particular pin is enabled, the appropriate sample rate must be chosen. The maximum sample rate that can be achieved while using one A/D line is 1 sample/ms or 1 KHz (Note that the modem will not be able to keep up with transmission when IR & IT are equal to "1" and that configuring the modem to sample at rates greater than once every 20ms is not recommended).

Applicable Commands: IR (Sample Rate), IT (Samples before TX), SM (Sleep Mode)

I/O Line Passing

Virtual wires can be set up between XBee®/XBee-PRO® Modules. When an RF data packet is received that contains I/O data, the receiving module can be setup to update any enabled outputs (PWM and DIO) based on the data it receives.

Note that I/O lines are mapped in pairs. For example: AD0 can only update PWM0 and DI5 can only update DO5. The default setup is for outputs not to be updated, which results in the I/O data being sent out the UART (refer to the IU (Enable I/O Output) command). To enable the outputs to be updated, the IA (I/O Input Address) parameter must be setup with the address of the module that has the appropriate inputs enabled. This effectively binds the outputs to a particular module's input. This does not affect the ability of the module to receive I/O line data from other modules - only its ability to update enabled outputs. The IA parameter can also be setup to accept I/O data for output changes from any module by setting the IA parameter to 0xFFFF.

When outputs are changed from their non-active state, the module can be setup to return the output level to it non-active state. The timers are set using the Tn (Dn Output Timer) and PT (PWM Output Timeout) commands. The timers are reset every time a valid I/O packet (passed IA check) is received. The IC (Change Detect) and IR (Sample Rate) parameters can be setup to keep the output set to their active output if the system needs more time than the timers can handle.

Note: DI8 cannot be used for I/O line passing.

Applicable Commands: IA (I/O Input Address), Tn (Dn Output Timeout), P0 (PWM0 Configuration), P1 (PWM1 Configuration), M0 (PWM0 Output Level), M1 (PWM1 Output Level), PT (PWM Output Timeout), RP (RSSSI PWM Timer)

Configuration Example

As an example for a simple A/D link, a pair of RF modules could be set as follows:

Remote Configuration	Base Configuration
DL = 0x1234	DL = 0x5678
MY = 0x5678	MY = 0x1234
D0 = 2	P0 = 2
D1 = 2	P1 = 2
IR = 0x14	IU = 1
IT = 5	IA = 0x5678 (or 0xFFFF)

These settings configure the remote module to sample AD0 and AD1 once each every 20 ms. It then buffers 5 samples each before sending them back to the base module. The base should then receive a 32-Byte transmission (20 Bytes data and 12 Bytes framing) every 100 ms.

XBee®/XBee-PRO® Networks

The following terms will be used to explicate the network operations:

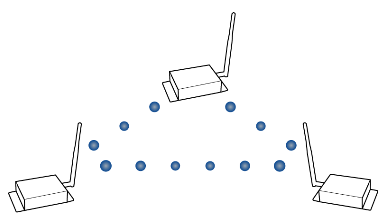
Table 2-02. Terms and definitions

Term	Definition
PAN	Personal Area Network - A data communication network that includes one or more End Devices and optionally a Coordinator.
Coordinator	A Full-function device (FFD) that provides network synchronization by polling nodes [NonBeacon (w/ Coordinator) networks only]
End Device	*When in the same network as a Coordinator* - RF modules that rely on a Coordinator for synchronization and can be put into states of sleep for low-power applications.
Association	The establishment of membership between End Devices and a Coordinator. Association is only applicable in NonBeacon (w/Coordinator) networks.

Peer-to-Peer

By default, XBee®/XBee-PRO RF Modules are configured to operate within a Peer-to-Peer network topology and therefore are not dependent upon Master/Slave relationships. NonBeacon systems operate within a Peer-to-Peer network topology and therefore are not dependent upon Master/Slave relationships. This means that modules remain synchronized without use of master/server configurations and each module in the network shares both roles of master and slave. Digi's peer-to-peer architecture features fast synchronization times and fast cold start times. This default configuration accommodates a wide range of RF data applications.

Figure 2-06. Peer-to-Peer Architecture



A peer-to-peer network can be established by configuring each module to operate as an End Device (CE = 0), disabling End Device Association on all modules (A1 = 0) and setting ID and CH parameters to be identical across the network.

NonBeacon (w/ Coordinator)

A device is configured as a Coordinator by setting the CE (Coordinator Enable) parameter to "1". Coordinator power-up is governed by the A2 (Coordinator Association) parameter.

In a Coordinator system, the Coordinator can be configured to use direct or indirect transmissions. If the SP (Cyclic Sleep Period) parameter is set to "0", the Coordinator will send data immediately. Otherwise, the SP parameter determines the length of time the Coordinator will retain the data before discarding it. Generally, SP (Cyclic Sleep Period) and ST (Time before Sleep) parameters should be set to match the SP and ST settings of the End Devices.

Association

Association is the establishment of membership between End Devices and a Coordinator. The establishment of membership is useful in scenarios that require a central unit (Coordinator) to relay messages to or gather data from several remote units (End Devices), assign channels or assign PAN IDs.

An RF data network that consists of one Coordinator and one or more End Devices forms a PAN (Personal Area Network). Each device in a PAN has a PAN Identifier [ID (PAN ID) parameter]. PAN IDs must be unique to prevent miscommunication between PANs. The Coordinator PAN ID is set using the ID (PAN ID) and A2 (Coordinator Association) commands.

An End Device can associate to a Coordinator without knowing the address, PAN ID or channel of the Coordinator. The A1 (End Device Association) parameter bit fields determine the flexibility of an End Device during association. The A1 parameter can be used for an End Device to dynamically set its destination address, PAN ID and/or channel.

For example: If the PAN ID of a Coordinator is known, but the operating channel is not; the A1 command on the End Device should be set to enable the 'Auto_Associate' and 'Reassign_Channel' bits. Additionally, the ID parameter should be set to match the PAN ID of the associated Coordinator.

Coordinator / End Device Setup and Operation

To configure a module to operate as a Coordinator, set the CE (Coordinator Enable) parameter to '1'. Set the CE parameter of End Devices to '0' (default). Coordinator and End Devices should contain matching firmware versions.

NonBeacon (w/ Coordinator) Systems

The Coordinator can be configured to use direct or indirect transmissions. If the SP (Cyclic Sleep Period) parameter is set to '0', the Coordinator will send data immediately. Otherwise, the SP parameter determines the length of time the Coordinator will retain the data before discarding it. Generally, SP (Cyclic Sleep Period) and ST (Time before Sleep) parameters should be set to match the SP and ST settings of the End Devices.

Coordinator Start-up

Coordinator power-up is governed by the A2 (Coordinator Association) command. On power-up, the Coordinator undergoes the following sequence of events:

1. Check A2 parameter- Reassign_PANID Flag

Set (bit 0 = 1) - The Coordinator issues an Active Scan. The Active Scan selects one channel and transmits a request to the broadcast address (0xFFFF) and broadcast PAN ID (0xFFFF). It then listens on that channel for beacons from any Coordinator operating on that channel. The listen time on each channel is determined by the SD (Scan Duration) parameter value.

Once the time expires on that channel, the Active Scan selects another channel and again transmits the BeaconRequest as before. This process continues until all channels have been scanned, or until 5 PANs have been discovered. When the Active Scan is complete, the results include a list of PAN IDs and Channels that are being used by other PANs. This list is used to assign an unique PAN ID to the new Coordinator. The ID parameter will be retained if it is not found in the Active Scan results. Otherwise, the ID (PAN ID) parameter setting will be updated to a PAN ID that was not detected.

Not Set (bit 0 = 0) - The Coordinator retains its ID setting. No Active Scan is performed.

2. Check A2 parameter - Reassign_Channel Flag (bit 1)

Set (bit 1 = 1) - The Coordinator issues an Energy Scan. The Energy Scan selects one channel and scans for energy on that channel. The duration of the scan is specified by the SD (Scan Duration) parameter. Once the scan is completed on a channel, the Energy Scan selects the next channel and begins a new scan on that channel. This process continues until all channels have been scanned.

When the Energy Scan is complete, the results include the maximal energy values detected on each channel. This list is used to determine a channel where the least energy was detected. If an Active Scan was performed (Reassign_PANID Flag set), the channels used by the detected PANs are eliminated as possible channels. Thus, the results of the Energy Scan and the Active Scan (if performed) are used to find the best channel (channel with the least energy that is not used by any detected PAN). Once the best channel has been selected, the CH (Channel) parameter value is updated to that channel.

Not Set (bit 1 = 0) - The Coordinator retains its CH setting. An Energy Scan is not performed.

3. Start Coordinator

The Coordinator starts on the specified channel (CH parameter) and PAN ID (ID parameter). Note, these may be selected in steps 1 and/or 2 above. The Coordinator will only allow End Devices to associate to it if the A2 parameter "AllowAssociation" flag is set. Once the Coordinator has successfully started, the Associate LED will blink 1 time per second. (The LED is solid if the Coordinator has not started.)

4. Coordinator Modifications

Once a Coordinator has started:
Modifying the A2 (Reassign_Channel or Reassign_PANID bits), ID, CH or MY parameters will cause the Coordinator's MAC to reset (The Coordinator RF module (including volatile RAM) is not reset). Changing the A2 AllowAssociation bit will not reset the Coordinator's MAC. In a non-beaconing system, End Devices that associated to the Coordinator prior to a MAC reset will have knowledge of the new settings on the Coordinator. Thus, if the Coordinator were to change its ID, CH or MY settings, the End Devices would no longer be able to communicate with the non-beacon Coordinator. Once a Coordinator has started, the ID, CH, MY or A2 (Reassign_Channel or Reassign_PANID bits) should not be changed.

End Device Start-up

End Device power-up is governed by the A1 (End Device Association) command. On power-up, the End Device undergoes the following sequence of events:

1. Check A1 parameter - AutoAssociate Bit

Set (bit 2 = 1) - End Device will attempt to associate to a Coordinator. (refer to steps 2-3).

Not Set (bit 2 = 0) - End Device will not attempt to associate to a Coordinator. The End Device will operate as specified by its ID, CH and MY parameters. Association is considered complete and the Associate LED will blink quickly (5 times per second). When the AutoAssociate bit is not set, the remaining steps (2-3) do not apply.

2. Discover Coordinator (if Auto-Associate Bit Set)

The End Device issues an Active Scan. The Active Scan selects one channel and transmits a BeaconRequest command to the broadcast address (0xFFFF) and broadcast PAN ID (0xFFFF). It then listens on that channel for beacons from any Coordinator operating on that channel. The listen time on each channel is determined by the SD parameter.

Once the time expires on that channel, the Active Scan selects another channel and again transmits the BeaconRequest command as before. This process continues until all channels have been scanned, or until 5 PANs have been discovered. When the Active Scan is complete, the results include a list of PAN IDs and Channels that are being used by detected PANs.

The End Device selects a Coordinator to associate with according to the A1 parameter "Reassign_PANID" and "Reassign_Channel" flags:

Reassign_PANID Bit Set (bit 0 = 1)- End Device can associate with a PAN with any ID value.

Reassign_PANID Bit Not Set (bit 0 = 0) - End Device will only associate with a PAN whose ID setting matches the ID setting of the End Device.

Reassign_Channel Bit Set (bit 1 = 1) - End Device can associate with a PAN with any CH value.

Reassign_Channel Bit Not Set (bit 1 = 0)- End Device will only associate with a PAN whose CH setting matches the CH setting of the End Device.

After applying these filters to the discovered Coordinators, if multiple candidate PANs exist, the End Device will select the PAN whose transmission link quality is the strongest. If no valid Coordinator is found, the End Device will either go to sleep (as dictated by its SM (Sleep Mode) parameter) or retry Association.

Note - An End Device will also disqualify Coordinators if they are not allowing association (A2 - AllowAssociation bit); or, if the Coordinator is not using the same NonBeacon scheme as the End Device. (They must both be programmed with NonBeacon code.)

3. Associate to Valid Coordinator

Once a valid Coordinator is found (step 2), the End Device sends an AssociationRequest message to the Coordinator. It then waits for an AssociationConfirmation to be sent from the Coordinator. Once the Confirmation is received, the End Device is Associated and the Associate LED will blink rapidly (2 times per second). The LED is solid if the End Device has not associated.

4. End Device Changes once an End Device has associated

Changing A1, ID or CH parameters will cause the End Device to disassociate and restart the Association procedure.

If the End Device fails to associate, the AI command can give some indication of the failure.

XBee®/XBee-PRO® Addressing

Every RF data packet sent over-the-air contains a Source Address and Destination Address field in its header. The RF module conforms to the 802.15.4 specification and supports both short 16-bit addresses and long 64-bit addresses. A unique 64-bit IEEE source address is assigned at the factory and can be read with the SL (Serial Number Low) and SH (Serial Number High) commands. Short addressing must be configured manually. A module will use its unique 64-bit address as its Source Address if its MY (16-bit Source Address) value is “0xFFFF” or “0xFFFE”.

To send a packet to a specific module using 64-bit addressing: Set the Destination Address (DL + DH) of the sender to match the Source Address (SL + SH) of the intended destination module.

To send a packet to a specific module using 16-bit addressing: Set DL (Destination Address Low) parameter to equal the MY parameter of the intended destination module and set the DH (Destination Address High) parameter to '0'.

Unicast Mode

By default, the RF module operates in Unicast Mode. Unicast Mode is the only mode that supports retries. While in this mode, receiving modules send an ACK (acknowledgement) of RF packet reception to the transmitter. If the transmitting module does not receive the ACK, it will re-send the packet up to three times or until the ACK is received.

Short 16-bit addresses. The module can be configured to use short 16-bit addresses as the Source Address by setting (MY < 0xFFFE). Setting the DH parameter (DH = 0) will configure the Destination Address to be a short 16-bit address (if DL < 0xFFFE). For two modules to communicate using short addressing, the Destination Address of the transmitter module must match the MY parameter of the receiver.

The following table shows a sample network configuration that would enable Unicast Mode communications using short 16-bit addresses.

Table 2-03. Sample Unicast Network Configuration (using 16-bit addressing)

Parameter	RF Module 1	RF Module 2
MY (Source Address)	0x01	0x02
DH (Destination Address High)	0	0
DL (Destination Address Low)	0x02	0x01

Long 64-bit addresses. The RF module’s serial number (SL parameter concatenated to the SH parameter) can be used as a 64-bit source address when the MY (16-bit Source Address) parameter is disabled. When the MY parameter is disabled (MY = 0xFFFF or 0xFFFE), the module’s source address is set to the 64-bit IEEE address stored in the SH and SL parameters.

When an End Device associates to a Coordinator, its MY parameter is set to 0xFFFE to enable 64-bit addressing. The 64-bit address of the module is stored as SH and SL parameters. To send a packet to a specific module, the Destination Address (DL + DH) on the sender must match the Source Address (SL + SH) of the desired receiver.

Broadcast Mode

Any RF module within range will accept a packet that contains a broadcast address. When configured to operate in Broadcast Mode, receiving modules do not send ACKs (Acknowledgements) and transmitting modules do not automatically re-send packets as is the case in Unicast Mode.

To send a broadcast packet to all modules regardless of 16-bit or 64-bit addressing, set the destination addresses of all the modules as shown below.

Sample Network Configuration (All modules in the network):

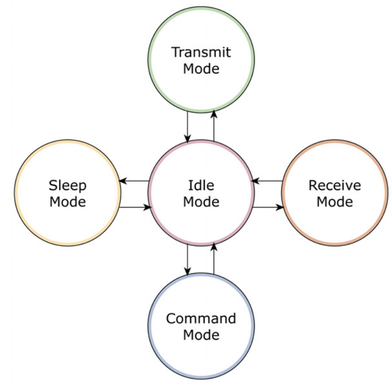
- DL (Destination Low Address) = 0x0000FFFF
- DH (Destination High Address) = 0x00000000 (default value)

NOTE: When programming the module, parameters are entered in hexadecimal notation (without the “0x” prefix). Leading zeros may be omitted.

Modes of Operation

XBee®/XBee-PRO® RF Modules operate in five modes.

Figure 2-07. Modes of Operation



Idle Mode

When not receiving or transmitting data, the RF module is in Idle Mode. The module shifts into the other modes of operation under the following conditions:

- Transmit Mode (Serial data is received in the DI Buffer)
- Receive Mode (Valid RF data is received through the antenna)
- Sleep Mode (Sleep Mode condition is met)
- Command Mode (Command Mode Sequence is issued)

Transmit/Receive Modes

RF Data Packets

Each transmitted data packet contains a Source Address and Destination Address field. The Source Address matches the address of the transmitting module as specified by the MY (Source Address) parameter (if MY >= 0xFFFE), the SH (Serial Number High) parameter or the SL (Serial Number Low) parameter. The <Destination Address> field is created from the DH (Destination Address High) and DL (Destination Address Low) parameter values. The Source Address and/or Destination Address fields will either contain a 16-bit short or long 64-bit long address.

The RF data packet structure follows the 802.15.4 specification.

[Refer to the XBee/XBee-PRO Addressing section for more information]

Direct and Indirect Transmission

There are two methods to transmit data:

- Direct Transmission - data is transmitted immediately to the Destination Address
- Indirect Transmission - A packet is retained for a period of time and is only transmitted after the destination module (Source Address = Destination Address) requests the data.

Indirect Transmissions can only occur on a Coordinator. Thus, if all nodes in a network are End Devices, only Direct Transmissions will occur. Indirect Transmissions are useful to ensure packet delivery to a sleeping node. The Coordinator currently is able to retain up to 2 indirect messages.

Direct Transmission

A Coordinator can be configured to use only Direct Transmission by setting the SP (Cyclic Sleep Period) parameter to "0". Also, a Coordinator using indirect transmissions will revert to direct transmission if it knows the destination module is awake.

To enable this behavior, the ST (Time before Sleep) value of the Coordinator must be set to match the ST value of the End Device. Once the End Device either transmits data to the Coordinator or polls the Coordinator for data, the Coordinator will use direct transmission for all subsequent data transmissions to that module address until ST time occurs with no activity (at which point it will revert to using indirect transmissions for that module address). "No activity" means no transmission or reception of messages with a specific address. Global messages will not reset the ST timer.

Indirect Transmission

To configure Indirect Transmissions in a PAN (Personal Area Network), the SP (Cyclic Sleep Period) parameter value on the Coordinator must be set to match the longest sleep value of any End Device. The sleep period value on the Coordinator determines how long (time or number of beacons) the Coordinator will retain an indirect message before discarding it.

An End Device must poll the Coordinator once it wakes from Sleep to determine if the Coordinator has an indirect message for it. For Cyclic Sleep Modes, this is done automatically every time the module wakes (after SP time). For Pin Sleep Modes, the A1 (End Device Association) parameter value must be set to enable Coordinator polling on pin wake-up. Alternatively, an End Device can use the FP (Force Poll) command to poll the Coordinator as needed.

CCA (Clear Channel Assessment)

Prior to transmitting a packet, a CCA (Clear Channel Assessment) is performed on the channel to determine if the channel is available for transmission. The detected energy on the channel is compared with the CA (Clear Channel Assessment) parameter value. If the detected energy exceeds the CA parameter value, the packet is not transmitted.

Also, a delay is inserted before a transmission takes place. This delay is settable using the RN (Backoff Exponent) parameter. If RN is set to “0”, then there is no delay before the first CCA is performed. The RN parameter value is the equivalent of the “minBE” parameter in the 802.15.4 specification. The transmit sequence follows the 802.15.4 specification.

By default, the MM (MAC Mode) parameter = 0. On a CCA failure, the module will attempt to re-send the packet up to two additional times.

When in Unicast packets with RR (Retries) = 0, the module will execute two CCA retries. Broadcast packets always get two CCA retries.

Acknowledgement

If the transmission is not a broadcast message, the module will expect to receive an acknowledgement from the destination node. If an acknowledgement is not received, the packet will be resent up to 3 more times. If the acknowledgement is not received after all transmissions, an ACK failure is recorded.

Sleep Mode

Sleep Modes enable the RF module to enter states of low-power consumption when not in use. In order to enter Sleep Mode, one of the following conditions must be met (in addition to the module having a non-zero SM parameter value):

- Sleep_RQ (pin 9) is asserted and the module is in a pin sleep mode (SM = 1, 2, or 5)
- The module is idle (no data transmission or reception) for the amount of time defined by the ST (Time before Sleep) parameter. [NOTE: ST is only active when SM = 4-5.]

Table 2-04. Sleep Mode Configurations

Sleep Mode Setting	Transition into Sleep Mode	Transition out of Sleep Mode (wake)	Characteristics	Related Commands	Power Consumption
Pin Hibernate (SM = 1)	Assert (high) Sleep_RQ (pin 9)	De-assert (low) Sleep_RQ	Pin/Host-controlled / NonBeacon systems only / Lowest Power	(SM)	< 10 µA (@3.0 VCC)
Pin Doze (SM = 2)	Assert (high) Sleep_RQ (pin 9)	De-assert (low) Sleep_RQ	Pin/Host-controlled / NonBeacon systems only / Fastest wake-up	(SM)	< 50 µA
Cyclic Sleep (SM = 4)	Automatic transition to Sleep Mode as defined by the SM (Sleep Mode) and ST (Time before Sleep) parameters.	Transition occurs after the cyclic sleep time interval elapses. The time interval is defined by the SP (Cyclic Sleep Period) parameter.	RF module wakes in pre-determined time intervals to detect if RF data is present / When SM = 5	(SM), SP, ST	< 50 µA when sleeping
Cyclic Sleep (SM = 5)	Automatic transition to Sleep Mode as defined by the SM (Sleep Mode) and ST (Time before Sleep) parameters or or on a falling edge transition of the SLEEP_RQ pin.	Transition occurs after the cyclic sleep time interval elapses. The time interval is defined by the SP (Cyclic Sleep Period) parameter.	RF module wakes in pre-determined time intervals to detect if RF data is present. Module also wakes on a falling edge of SLEEP_RQ	(SM), SP, ST	< 50 µA when sleeping

The SM command is central to setting Sleep Mode configurations. By default, Sleep Modes are disabled (SM = 0) and the module remains in Idle/Receive Mode. When in this state, the module is constantly ready to respond to serial or RF activity.

Pin/Host-controlled Sleep Modes

The transient current when waking from pin sleep (SM = 1 or 2) does not exceed the idle current of the module. The current ramps up exponentially to its idle current.

Pin Hibernate (SM = 1)

- Pin/Host-controlled
- Typical power-down current: < 10 µA (@3.0 VCC)
- Wake-up time: 13.2 msec

Pin Hibernate Mode minimizes quiescent power (power consumed when in a state of rest or inactivity). This mode is voltage level-activated; when Sleep_RQ (pin 9) is asserted, the module will finish any transmit, receive or association activities, enter Idle Mode, and then enter a state of sleep. The module will not respond to either serial or RF activity while in pin sleep.

To wake a sleeping module operating in Pin Hibernate Mode, de-assert Sleep_RQ (pin 9). The module will wake when Sleep_RQ is de-asserted and is ready to transmit or receive when the CTS line is low. When waking the module, the pin must be de-asserted at least two 'byte times' after CTS goes low. This assures that there is time for the data to enter the DI buffer.

Pin Doze (SM = 2)

- Pin/Host-controlled
- Typical power-down current: < 50 µA
- Wake-up time: 2 msec

Pin Doze Mode functions as does Pin Hibernate Mode; however, Pin Doze features faster wake-up time and higher power consumption.

To wake a sleeping module operating in Pin Doze Mode, de-assert Sleep_RQ (pin 9). The module will wake when Sleep_RQ is de-asserted and is ready to transmit or receive when the CTS line is low. When waking the module, the pin must be de-asserted at least two 'byte times' after CTS goes low. This assures that there is time for the data to enter the DI buffer.

Cyclic Sleep Modes

Cyclic Sleep Remote (SM = 4)

- Typical Power-down Current: < 50 μA (when asleep)
- Wake-up time: 2 msec

The Cyclic Sleep Modes allow modules to periodically check for RF data. When the SM parameter is set to '4', the module is configured to sleep, then wakes once a cycle to check for data from a module configured as a Cyclic Sleep Coordinator (SM = 0, CE = 1). The Cyclic Sleep Remote sends a poll request to the coordinator at a specific interval set by the SP (Cyclic Sleep Period) parameter. The coordinator will transmit any queued data addressed to that specific remote upon receiving the poll request.

If no data is queued for the remote, the coordinator will not transmit and the remote will return to sleep for another cycle. If queued data is transmitted back to the remote, it will stay awake to allow for back and forth communication until the ST (Time before Sleep) timer expires.

Also note that $\overline{\text{CTS}}$ will go low each time the remote wakes, allowing for communication initiated by the remote host if desired.

Cyclic Sleep Remote with Pin Wake-up (SM = 5)

Use this mode to wake a sleeping remote module through either the RF interface or by the de-assertion of Sleep_RQ for event-driven communications. The cyclic sleep mode works as described above (Cyclic Sleep Remote) with the addition of a pin-controlled wake-up at the remote module. The Sleep_RQ pin is edge-triggered, not level-triggered. The module will wake when a low is detected then set $\overline{\text{CTS}}$ low as soon as it is ready to transmit or receive.

Any activity will reset the ST (Time before Sleep) timer so the module will go back to sleep only after there is no activity for the duration of the timer. Once the module wakes (pin-controlled), further pin activity is ignored. The module transitions back into sleep according to the ST time regardless of the state of the pin.

[Cyclic Sleep Coordinator (SM = 6)]

- Typical current = Receive current
- Always awake

NOTE: The SM=6 parameter value exists solely for backwards compatibility with firmware version 1.x60. If backwards compatibility with the older firmware version is not required, always use the CE (Coordinator Enable) command to configure a module as a Coordinator.

This mode configures a module to wake cyclic sleeping remotes through RF interfacing. The Coordinator will accept a message addressed to a specific remote 16 or 64-bit address and hold it in a buffer until the remote wakes and sends a poll request. Messages not sent directly (buffered and requested) are called "Indirect messages". The Coordinator only queues one indirect message at a time. The Coordinator will hold the indirect message for a period 2.5 times the sleeping period indicated by the SP (Cyclic Sleep Period) parameter. The Coordinator's SP parameter should be set to match the value used by the remotes.

Command Mode

To modify or read RF Module parameters, the module must first enter into Command Mode - a state in which incoming characters are interpreted as commands. Two Command Mode options are supported: AT Command Mode [refer to section below] and API Command Mode [p57].

AT Command Mode

To Enter AT Command Mode:

Send the 3-character command sequence "+++" and observe guard times before and after the command characters. [Refer to the "Default AT Command Mode Sequence" below.]

Default AT Command Mode Sequence (for transition to Command Mode):

- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]
- Input three plus characters ("+++") within one second [CC (Command Sequence Character) parameter = 0x2B.]
- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]

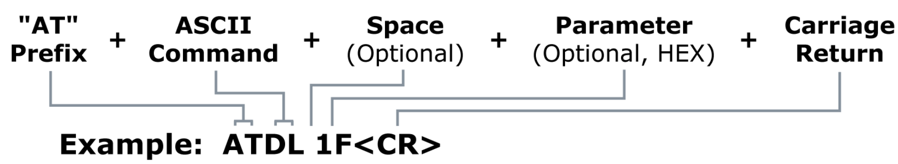
All of the parameter values in the sequence can be modified to reflect user preferences.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the "PC Settings" tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (9600 bps).

To Send AT Commands:

Send AT commands and parameters using the syntax shown below.

Figure 2-08. Syntax for sending AT Commands



To read a parameter value stored in the RF module's register, omit the parameter field.

The preceding example would change the RF module Destination Address (Low) to "0x1F". To store the new value to non-volatile (long term) memory, subsequently send the WR (Write) command.

For modified parameter values to persist in the module's registry after a reset, changes must be saved to non-volatile memory using the WR (Write) Command. Otherwise, parameters are restored to previously saved values after the module is reset.

System Response. When a command is sent to the module, the module will parse and execute the command. Upon successful execution of a command, the module returns an "OK" message. If execution of a command results in an error, the module returns an "ERROR" message.

To Exit AT Command Mode:

1. Send the ATCN (Exit Command Mode) command (followed by a carriage return).
   [OR]
2. If no valid AT Commands are received within the time specified by CT (Command Mode Timeout) Command, the RF module automatically returns to Idle Mode.

For an example of programming the RF module using AT Commands and descriptions of each configurable parameter, refer to the RF Module Configuration chapter [p26].

3. RF Module Configuration

Programming the RF Module

Refer to the Command Mode section [p25] for more information about entering Command Mode, sending AT commands and exiting Command Mode. For information regarding module programming using API Mode, refer to the API Operation sections [p57].

Programming Examples

Setup

The programming examples in this section require the installation of Digi's X-CTU Software and a serial connection to a PC. (Digi stocks RS-232 and USB boards to facilitate interfacing with a PC.)

1. Install Digi's X-CTU Software to a PC by double-clicking the "setup_X-CTU.exe" file. (The file is located on the Digi CD and www.digi.com/xctu.)
2. Mount the RF module to an interface board, then connect the module assembly to a PC.
3. Launch the X-CTU Software and select the 'PC Settings' tab. Verify the baud and parity settings of the Com Port match those of the RF module.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the 'PC Settings' tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (which corresponds to 9600 bps).

Sample Configuration: Modify RF Module Destination Address

Example: Utilize the X-CTU "Terminal" tab to change the RF module's DL (Destination Address Low) parameter and save the new address to non-volatile memory.

After establishing a serial connection between the RF module and a PC [refer to the 'Setup' section above], select the "Terminal" tab of the X-CTU Software and enter the following command lines ('CR' stands for carriage return):

Method 1 (One line per command)

Send AT Command	**System Response**
+++	OK <CR> (Enter into Command Mode)
ATDL <Enter>	{current value} <CR> (Read Destination Address Low)
ATDL1A0D <Enter>	OK <CR> (Modify Destination Address Low)
ATWR <Enter>	OK <CR> (Write to non-volatile memory)
ATCN <Enter>	OK <CR> (Exit Command Mode)

Method 2 (Multiple commands on one line)

Send AT Command	**System Response**
+++	OK <CR> (Enter into Command Mode)
ATDL <Enter>	{current value} <CR> (Read Destination Address Low)
ATDL1A0D,WR,CN <Enter>	OK<CR> OK<CR> OK<CR>

Sample Configuration: Restore RF Module Defaults

Example: Utilize the X-CTU "Modem Configuration" tab to restore default parameter values.

After establishing a connection between the module and a PC [refer to the 'Setup' section above], select the "Modem Configuration" tab of the X-CTU Software.

1. Select the 'Read' button.
2. Select the 'Restore' button.

Remote Configuration Commands

The API firmware has provisions to send configuration commands to remote devices using the Remote Command Request API frame (see API Operation). This API frame can be used to send commands to a remote module to read or set command parameters.

The API firmware has provisions to send configuration commands (set or read) to a remote module using the Remote Command Request API frame (see API Operations). Remote commands can be issued to read or set command parameters on a remote device.

Sending a Remote Command

To send a remote command, the Remote Command Request frame should be populated with values for the 64 bit and 16 bit addresses. If 64 bit addressing is desired then the 16 bit address field should be filled with 0xFFFE. If any value other than 0xFFFE is used in the 16 bit address field then the 64 bit address field will be ignored and 16 bit addressing will be used. If a command response is desired, the Frame ID should be set to a non-zero value.

Applying Changes on Remote

When remote commands are used to change command parameter settings on a remote device, parameter changes do not take effect until the changes are applied. For example, changing the BD parameter will not change the actual serial interface rate on the remote until the changes are applied. Changes can be applied using remote commands in one of three ways:

Set the apply changes option bit in the API frame

Issue an AC command to the remote device

Issue a WR + FR command to the remote device to save changes and reset the device.

Remote Command Responses

If the remote device receives a remote command request transmission, and the API frame ID is non-zero, the remote will send a remote command response transmission back to the device that sent the remote command. When a remote command response transmission is received, a device sends a remote command response API frame out its UART. The remote command response indicates the status of the command (success, or reason for failure), and in the case of a command query, it will include the register value.

The device that sends a remote command will not receive a remote command response frame if:

The destination device could not be reached

The frame ID in the remote command request is set to 0.

Command Reference Tables

XBee®/XBee-PRO® RF Modules expect numerical values in hexadecimal. Hexadecimal values are designated by a “0x” prefix. Decimal equivalents are designated by a “d” suffix. Commands are contained within the following command categories (listed in the order that their tables appear):

- Special
- Networking & Security
- RF Interfacing
- Sleep (Low Power)
- Serial Interfacing
- I/O Settings
- Diagnostics
- AT Command Options

All modules within a PAN should operate using the same firmware version.

Special

Table 3-01. XBee-PRO Commands - Special

AT Command	Command Category	Name and Description	Parameter Range	Default
WR	Special	**Write**. Write parameter values to non-volatile memory so that parameter modifications persist through subsequent power-up or reset. Note: Once WR is issued, no additional characters should be sent to the module until after the response "OK\r" is received.	-	-
RE	Special	**Restore Defaults**. Restore module parameters to factory defaults.	-	-
FR (v1.x80*)	Special	**Software Reset**. Responds immediately with an OK then performs a hard reset ~100ms later.	-	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Networking & Security

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
CH	Networking {Addressing}	**Channel**. Set/Read the channel number used for transmitting and receiving data between RF modules (uses 802.15.4 protocol channel numbers).	0x0B - 0x1A (XBee) 0x0C - 0x17 (XBee-PRO)	0x0C (12d)
ID	Networking {Addressing}	**PAN ID**. Set/Read the PAN (Personal Area Network) ID. Use 0xFFFF to broadcast messages to all PANs.	0 - 0xFFFF	0x3332 (13106d)
DH	Networking {Addressing}	**Destination Address High**. Set/Read the upper 32 bits of the 64-bit destination address. When combined with DL, it defines the destination address used for transmission. To transmit using a 16-bit address, set DH parameter to zero and DL less than 0xFFFF. 0x000000000000FFFF is the broadcast address for the PAN.	0 - 0xFFFFFFFF	0
DL	Networking {Addressing}	**Destination Address Low**. Set/Read the lower 32 bits of the 64-bit destination address. When combined with DH, DL defines the destination address used for transmission. To transmit using a 16-bit address, set DH parameter to zero and DL less than 0xFFFF. 0x000000000000FFFF is the broadcast address for the PAN.	0 - 0xFFFFFFFF	0
MY	Networking {Addressing}	**16-bit Source Address.** Set/Read the RF module 16-bit source address. Set MY = 0xFFFF to disable reception of packets with 16-bit addresses. 64-bit source address (serial number) and broadcast address (0x000000000000FFFF) is always enabled.	0 - 0xFFFF	0
SH	Networking {Addressing}	**Serial Number High**. Read high 32 bits of the RF module's unique IEEE 64-bit address. 64-bit source address is always enabled.	0 - 0xFFFFFFFF [read-only]	Factory-set
SL	Networking {Addressing}	**Serial Number Low**. Read low 32 bits of the RF module's unique IEEE 64-bit address. 64-bit source address is always enabled.	0 - 0xFFFFFFFF [read-only]	Factory-set
RR (v1.xA0*)	Networking {Addressing}	**XBee Retries**. Set/Read the maximum number of retries the module will execute in addition to the 3 retries provided by the 802.15.4 MAC. For each XBee retry, the 802.15.4 MAC can execute up to 3 retries.	0 - 6	0
RN	Networking {Addressing}	**Random Delay Slots.** Set/Read the minimum value of the back-off exponent in the CSMA-CA algorithm that is used for collision avoidance. If RN = 0, collision avoidance is disabled during the first iteration of the algorithm (802.15.4 - macMinBE).	0 - 3 [exponent]	0
MM (v1.x80*)	Networking {Addressing}	**MAC Mode.** MAC Mode. Set/Read MAC Mode value. MAC Mode enables/disables the use of a Digi header in the 802.15.4 RF packet. When Modes 0 or 3 are enabled (MM=0,3), duplicate packet detection is enabled as well as certain AT commands. Please see the detailed MM description on page 47 for additional information.	0 - 3 0 = Digi Mode 1 = 802.15.4 (no ACKs) 2 = 802.15.4 (with ACKs) 3 = Digi Mode (no ACKs)	0
NI (v1.x80*)	Networking {Identification}	**Node Identifier.** Stores a string identifier. The register only accepts printable ASCII data. A string can not start with a space. Carriage return ends command. Command will automatically end when maximum bytes for the string have been entered. This string is returned as part of the ND (Node Discover) command. This identifier is also used with the DN (Destination Node) command.	20-character ASCII string	-
ND (v1.x80*)	Networking {Identification}	**Node Discover.** Discovers and reports all RF modules found. The following information is reported for each module discovered (the example cites use of Transparent operation (AT command format) - refer to the long ND command description regarding differences between Transparent and API operation). MY<CR> SH<CR> SL<CR> DB<CR> NI<CR><CR> The amount of time the module allows for responses is determined by the NT parameter. In Transparent operation, command completion is designated by a <CR> (carriage return). ND also accepts a Node Identifier as a parameter. In this case, only a module matching the supplied identifier will respond. If ND self-response is enabled (NO=1) the module initiating the node discover will also output a response for itself.	optional 20-character NI value	
NT (v1.xA0*)	Networking {Identification}	**Node Discover Time.** Set/Read the amount of time a node will wait for responses from other nodes when using the ND (Node Discover) command.	0x01 - 0xFC [x 100 ms]	0x19

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
NO (v1xC5)	Networking {Identification}	**Node Discover Options**. Enables node discover self-response on the module.	0-1	0
DN (v1.x80*)	Networking {Identification}	**Destination Node.** Resolves an NI (Node Identifier) string to a physical address. The following events occur upon successful command execution: 1. DL and DH are set to the address of the module with the matching Node Identifier. 2. "OK" is returned. 3. RF module automatically exits AT Command Mode If there is no response from a module within 200 msec or a parameter is not specified (left blank), the command is terminated and an "ERROR" message is returned.	20-character ASCII string	-
CE (v1.x80*)	Networking {Association}	**Coordinator Enable**. Set/Read the coordinator setting.	0 - 1 0 = End Device 1 = Coordinator	0
SC (v1.x80*)	Networking {Association}	**Scan Channels**. Set/Read list of channels to scan for all Active and Energy Scans as a bitfield. This affects scans initiated in command mode (AS, ED) and during End Device Association and Coordinator startup: bit 0 - 0x0B bit 4 - 0x0F bit 8 - 0x13 bit12 - 0x17 bit 1 - 0x0C bit 5 - 0x10 bit 9 - 0x14 bit13 - 0x18 bit 2 - 0x0D bit 6 - 0x11 bit 10 - 0x15 bit14 - 0x19 bit 3 - 0x0E bit 7 - 0x12 bit 11 - 0x16 bit 15 - 0x1A	0 - 0xFFFF [bitfield] (bits 0, 14, 15 not allowed on the XBee-PRO)	0x1FFE (all XBee-PRO Channels)
SD (v1.x80*)	Networking {Association}	**Scan Duration**. Set/Read the scan duration exponent. ***End Device*** - Duration of Active Scan during Association. ***Coordinator*** - If 'ReassignPANID' option is set on Coordinator [refer to A2 parameter], SD determines the length of time the Coordinator will scan channels to locate existing PANs. If 'ReassignChannel' option is set, SD determines how long the Coordinator will perform an Energy Scan to determine which channel it will operate on. 'Scan Time' is measured as (# of channels to scan] * (2 ^ SD) * 15.36ms). The number of channels to scan is set by the SC command. The XBee can scan up to 16 channels (SC = 0xFFFF). The XBee PRO can scan up to 13 channels (SC = 0x3FFE). Example: The values below show results for a 13 channel scan: If SD = 0, time = 0.18 sec SD = 8, time = 47.19 sec SD = 2, time = 0.74 sec SD = 10, time = 3.15 min SD = 4, time = 2.95 sec SD = 12, time = 12.58 min SD = 6, time = 11.80 sec SD = 14, time = 50.33 min	0-0x0F [exponent]	4
A1 (v1.x80*)	Networking {Association}	**End Device Association**. Set/Read End Device association options. bit 0 - ReassignPanID 0 - Will only associate with Coordinator operating on PAN ID that matches module ID 1 - May associate with Coordinator operating on any PAN ID bit 1 - ReassignChannel 0 - Will only associate with Coordinator operating on matching CH Channel setting 1 - May associate with Coordinator operating on any Channel bit 2 - AutoAssociate 0 - Device will not attempt Association 1 - Device attempts Association until success Note: This bit is used only for Non-Beacon systems. End Devices in Beacon-enabled system must always associate to a Coordinator bit 3 - PollCoordOnPinWake 0 - Pin Wake will not poll the Coordinator for indirect (pending) data 1 - Pin Wake will send Poll Request to Coordinator to extract any pending data bits 4 - 7 are reserved	0 - 0x0F [bitfield]	0
A2 (v1.x80*)	Networking {Association}	**Coordinator Association**. Set/Read Coordinator association options. bit 0 - ReassignPanID 0 - Coordinator will not perform Active Scan to locate available PAN ID. It will operate on ID (PAN ID). 1 - Coordinator will perform Active Scan to determine an available ID (PAN ID). If a PAN ID conflict is found, the ID parameter will change. bit 1 - ReassignChannel - 0 - Coordinator will not perform Energy Scan to determine free channel. It will operate on the channel determined by the CH parameter. 1 - Coordinator will perform Energy Scan to find a free channel, then operate on that channel. bit 2 - AllowAssociation - 0 - Coordinator will not allow any devices to associate to it. 1 - Coordinator will allow devices to associate to it. bits 3 - 7 are reserved	0 - 7 [bitfield]	0

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
AI (v1.x80*)	Networking {Association}	**Association Indication**. Read errors with the last association request: 0x00 - Successful Completion - Coordinator successfully started or End Device association complete 0x01 - Active Scan Timeout 0x02 - Active Scan found no PANs 0x03 - Active Scan found PAN, but the CoordinatorAllowAssociation bit is not set 0x04 - Active Scan found PAN, but Coordinator and End Device are not configured to support beacons 0x05 - Active Scan found PAN, but the Coordinator ID parameter does not match the ID parameter of the End Device 0x06 - Active Scan found PAN, but the Coordinator CH parameter does not match the CH parameter of the End Device 0x07 - Energy Scan Timeout 0x08 - Coordinator start request failed 0x09 - Coordinator could not start due to invalid parameter 0x0A - Coordinator Realignment is in progress 0x0B - Association Request not sent 0x0C - Association Request timed out - no reply was received 0x0D - Association Request had an Invalid Parameter 0x0E - Association Request Channel Access Failure. Request was not transmitted - CCA failure 0x0F - Remote Coordinator did not send an ACK after Association Request was sent 0x10 - Remote Coordinator did not reply to the Association Request, but an ACK was received after sending the request 0x11 - [reserved] 0x12 - Sync-Loss - Lost synchronization with a Beaconing Coordinator 0x13 - Disassociated - No longer associated to Coordinator 0xFF - RF Module is attempting to associate	0 - 0x13 [read-only]	-
DA (v1.x80*)	Networking {Association}	**Force Disassociation**. End Device will immediately disassociate from a Coordinator (if associated) and reattempt to associate.	-	-
FP (v1.x80*)	Networking {Association}	**Force Poll**. Request indirect messages being held by a coordinator.	-	-
AS (v1.x80*)	Networking {Association}	**Active Scan**. Send Beacon Request to Broadcast Address (0xFFFF) and Broadcast PAN (0xFFFF) on every channel. The parameter determines the time the radio will listen for Beacons on each channel. A PanDescriptor is created and returned for every Beacon received from the scan. Each PanDescriptor contains the following information: CoordAddress (SH, SL)<CR> CoordPanID (ID)<CR> CoordAddrMode <CR> 0x02 = 16-bit Short Address 0x03 = 64-bit Long Address Channel (CH parameter) <CR> SecurityUse<CR> ACLEntry<CR> SecurityFailure<CR> SuperFrameSpec<CR> (2 bytes): bit 15 - Association Permitted (MSB) bit 14 - PAN Coordinator bit 13 - Reserved bit 12 - Battery Life Extension bits 8-11 - Final CAP Slot bits 4-7 - Superframe Order bits 0-3 - Beacon Order GtsPermit<CR> RSSI<CR> (RSSI is returned as -dBm) TimeStamp<CR> (3 bytes) <CR> A carriage return <CR> is sent at the end of the AS command. The Active Scan is capable of returning up to 5 PanDescriptors in a scan. The actual scan time on each channel is measured as Time = [(2 ^SD PARAM) * 15.36] ms. Note the total scan time is this time multiplied by the number of channels to be scanned (16 for the XBee and 13 for the XBee-PRO). Also refer to SD command description.	0 - 6	-
ED (v1.x80*)	Networking {Association}	**Energy Scan**. Send an Energy Detect Scan. This parameter determines the length of scan on each channel. The maximal energy on each channel is returned & each value is followed by a carriage return. An additional carriage return is sent at the end of the command. The values returned represent the detected energy level in units of -dBm. The actual scan time on each channel is measured as Time = [(2 ^ED) * 15.36] ms. Note the total scan time is this time multiplied by the number of channels to be scanned (refer to SD parameter).	0 - 6	-
EE (v1.xA0*)	Networking {Security}	**AES Encryption Enable**. Disable/Enable 128-bit AES encryption support. Use in conjunction with the KY command.	0 - 1	0 (disabled)
KY (v1.xA0*)	Networking {Security}	**AES Encryption Key**. Set the 128-bit AES (Advanced Encryption Standard) key for encrypting/decrypting data. The KY register cannot be read.	0 - (any 16-Byte value)	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

RF Interfacing

Table 3-03. XBee/XBee-PRO Commands - RF Interfacing

AT Command	Command Category	Name and Description	Parameter Range	Default
PL	RF Interfacing	**Power Level**. Select/Read the power level at which the RF module transmits conducted power.	0 - 4 (XBee / XBee-PRO) 0 = -10 / 10 dBm 1 = -6 / 12 dBm 2 = -4 / 14 dBm 3 = -2 / 16 dBm 4 = 0 / 18 dBm XBee-PRO International variant: PL=4: 10 dBm PL=3: 8 dBm PL=2: 2 dBm PL=1: -3 dBm PL=0: -3 dBm	4
CA (v1.x80*)	RF Interfacing	**CCA Threshold**. Set/read the CCA (Clear Channel Assessment) threshold. Prior to transmitting a packet, a CCA is performed to detect energy on the channel. If the detected energy is above the CCA Threshold, the module will not transmit the packet.	0x24 - 0x50 [-dBm]	0x2C (-44d dBm)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Sleep (Low Power)

Table 3-04. XBee®/XBee-PRO® Commands - Sleep (Low Power)

AT Command	Command Category	Name and Description	Parameter Range	Default
SM	Sleep (Low Power)	**Sleep Mode**. Set/Read Sleep Mode configurations.	0 - 5 0 = No Sleep 1 = Pin Hibernate 2 = Pin Doze 3 = Reserved 4 = Cyclic sleep remote 5 = Cyclic sleep remote w/ pin wake-up 6 = [Sleep Coordinator] for backwards compatibility w/ v1.x6 only; otherwise, use CE command.	0
SO	Sleep (Low Power)	Sleep Options Set/Read the sleep mode options. Bit 0 - Poll wakeup disable 0 - Normal operations. A module configured for cyclic sleep will poll for data on waking. 1 - Disable wakeup poll. A module configured for cyclic sleep will not poll for data on waking. Bit 1 - ADC/DIO wakeup sampling disable. 0 - Normal operations. A module configured in a sleep mode with ADC/DIO sampling enabled will automatically perform a sampling on wakeup. 1 - Suppress sample on wakeup. A module configured in a sleep mode with ADC/DIO sampling enabled will not automatically sample on wakeup.	0-4	0
ST	Sleep (Low Power)	**Time before Sleep.** <NonBeacon firmware> Set/Read time period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode. ST parameter is only valid with Cyclic Sleep settings (SM = 4 - 5). Coordinator and End Device ST values must be equal. Also note, the GT parameter value must always be less than the ST value. (If GT > ST, the configuration will render the module unable to enter into command mode.) If the ST parameter is modified, also modify the GT parameter accordingly.	1 - 0xFFFF [x 1 ms]	0x1388 (5000d)
SP	Sleep (Low Power)	**Cyclic Sleep Period.** <NonBeacon firmware> Set/Read sleep period for cyclic sleeping remotes. Coordinator and End Device SP values should always be equal. To send Direct Messages, set SP = 0. *End Device* - SP determines the sleep period for cyclic sleeping remotes. Maximum sleep period is 268 seconds (0x68B0). *Coordinator* - If non-zero, SP determines the time to hold an indirect message before discarding it. A Coordinator will discard indirect messages after a period of (2.5 * SP).	0 - 0x68B0 [x 10 ms]	0
DP (1.x80*)	Sleep (Low Power)	**Disassociated Cyclic Sleep Period.** <NonBeacon firmware> *End Device* - Set/Read time period of sleep for cyclic sleeping remotes that are configured for Association but are not associated to a Coordinator. (i.e. If a device is configured to associate, configured as a Cyclic Sleep remote, but does not find a Coordinator, it will sleep for DP time before reattempting association.) Maximum sleep period is 268 seconds (0x68B0). DP should be > 0 for NonBeacon systems.	1 - 0x68B0 [x 10 ms]	0x3E8 (1000d)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Serial Interfacing

Table 3-05. XBee-PRO Commands - Serial Interfacing

AT Command	Command Category	Name and Description	Parameter Range	Default
BD	Serial Interfacing	**Interface Data Rate**. Set/Read the serial interface data rate for communications between the RF module serial port and host. Request non-standard baud rates with values above 0x80 using a terminal window. Read the BD register to find actual baud rate achieved.	0 - 7 (standard baud rates) 0 = 1200 bps 1 = 2400 2 = 4800 3 = 9600 4 = 19200 5 = 38400 6 = 57600 7 = 115200 0x80 - 0x3D090 (non-standard baud rates up to 250 Kbps)	3
RO	Serial Interfacing	**Packetization Timeout**. Set/Read number of character times of inter-character delay required before transmission. Set to zero to transmit characters as they arrive instead of buffering them into one RF packet.	0 - 0xFF [x character times]	3
AP (v1.x80*)	Serial Interfacing	**API Enable**. Disable/Enable API Mode.	0 - 2 0 =Disabled 1 = API enabled 2 = API enabled (w/escaped control characters)	0
NB	Serial Interfacing	**Parity.** Set/Read parity settings.	0 - 4 0 = 8-bit no parity 1 = 8-bit even 2 = 8-bit odd 3 = 8-bit mark 4 = 8-bit space	0
PR (v1.x80*)	Serial Interfacing	**Pull-up Resistor Enable**. Set/Read bitfield to configure internal pull-up resistor status for I/O lines Bitfield Map: bit 0 - AD4/DIO4 (pin11) bit 1 - AD3 / DIO3 (pin17) bit 2 - AD2/DIO2 (pin18) bit 3 - AD1/DIO1 (pin19) bit 4 - AD0 / DIO0 (pin20) bit 5 - RTS / AD6 / DIO6 (pin16) bit 6 - DTR / SLEEP_RQ / DI8 (pin9) bit 7 - DIN/CONFIG (pin3) Bit set to “1” specifies pull-up enabled; “0” specifies no pull-up	0 - 0xFF	0xFF

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

I/O Settings

Table 3-06. XBee-PRO Commands - I/O Settings (sub-category designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
D8	I/O Settings	**DI8 Configuration**. Select/Read options for the DI8 line (pin 9) of the RF module.	0 - 1 0 = Disabled 3 = DI (1,2,4 & 5 n/a)	0
D7 (v1.x80*)	I/O Settings	**DIO7 Configuration**. Select/Read settings for the DIO7 line (pin 12) of the RF module. Options include CTS flow control and I/O line settings.	0 - 1 0 = Disabled 1 = CTS Flow Control 2 = (n/a) 3 = DI 4 = DO low 5 = DO high 6 = RS485 Tx Enable Low 7 = RS485 Tx Enable High	1
D6 (v1.x80*)	I/O Settings	**DIO6 Configuration**. Select/Read settings for the DIO6 line (pin 16) of the RF module. Options include RTS flow control and I/O line settings.	0 - 1 0 = Disabled 1 = RTS flow control 2 = (n/a) 3 = DI 4 = DO low 5 = DO high	0

Table 3-06. XBee-PRO Commands - I/O Settings (sub-category designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
D5 (v1.x80*)	I/O Settings	**DIO5 Configuration**. Configure settings for the DIO5 line (pin 15) of the RF module. Options include Associated LED indicator (blinks when associated) and I/O line settings.	0 - 1 0 = Disabled 1 = Associated indicator 2 = ADC 3 = DI 4 = DO low 5 = DO high	1
D0 - D4 (v1.xA0*)	I/O Settings	**(DIO4 -DIO4) Configuration**. Select/Read settings for the following lines: AD0/DIO0 (pin 20), AD1/DIO1 (pin 19), AD2/DIO2 (pin 18), AD3/DIO3 (pin 17), AD4/DIO4 (pin 11). Options include: Analog-to-digital converter, Digital Input and Digital Output.	0 - 1 0 = Disabled 1 = (n/a) 2 = ADC 3 = DI 4 = DO low 5 = DO high	0
IU (v1.xA0*)	I/O Settings	**I/O Output Enable.** Disables/Enables I/O data received to be sent out UART. The data is sent using an API frame regardless of the current AP parameter value.	0 - 1 0 = Disabled 1 = Enabled	1
IT (v1.xA0*)	I/O Settings	**Samples before TX.** Set/Read the number of samples to collect before transmitting data. Maximum number of samples is dependent upon the number of enabled inputs.	1 - 0xFF	1
IS (v1.xA0*)	I/O Settings	**Force Sample.** Force a read of all enabled inputs (DI or ADC). Data is returned through the UART. If no inputs are defined (DI or ADC), this command will return error.	8-bit bitmap (each bit represents the level of an I/O line setup as an output)	-
IO (v1.xA0*)	I/O Settings	**Digital Output Level.** Set digital output level to allow DIO lines that are setup as outputs to be changed through Command Mode.	-	-
IC (v1.xA0*)	I/O Settings	**DIO Change Detect.** Set/Read bitfield values for change detect monitoring. Each bit enables monitoring of DIO0 - DIO7 for changes. If detected, data is transmitted with DIO data only. Any samples queued waiting for transmission will be sent first.	0 - 0xFF [bitfield]	0 (disabled)
IR (v1.xA0*)	I/O Settings	**Sample Rate.** Set/Read sample rate. When set, this parameter causes the module to sample all enabled inputs at a specified interval.	0 - 0xFFFF [x 1 msec]	0
IA (v1.xA0*)	I/O Settings {I/O Line Passing}	**I/O Input Address**. Set/Read addresses of module to which outputs are bound. Setting all bytes to 0xFF will not allow any received I/O packet to change outputs. Setting address to 0xFFFF will allow any received I/O packet to change outputs.	0 - 0xFFFFFFFFFFFFFFFF	0xFFFFFFFF FFFFFFFF
T0 - T7 (v1.xA0*)	I/O Settings {I/O Line Passing}	**(D0 - D7) Output Timeout.** Set/Read Output timeout values for lines that correspond with the D0 - D7 parameters. When output is set (due to I/O line passing) to a non-default level, a timer is started which when expired will set the output to it default level. The timer is reset when a valid I/O packet is received.	0 - 0xFF [x 100 ms]	0xFF
P0	I/O Settings {I/O Line Passing}	**PWM0 Configuration**. Select/Read function for PWM0 pin.	0 - 2 0 = Disabled 1 = RSSI 2 = PWM Output	1
P1 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM1 Configuration**. Select/Read function for PWM1 pin.	0 - 2 0 = Disabled 1 = RSSI 2 = PWM Output	0
M0 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM0 Output Level**. Set/Read the PWM0 output level.	0 - 0x03FF	-
M1 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM1 Output Level**. Set/Read the PWM1 output level.	0 - 0x03FF	-
PT (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM Output Timeout.** Set/Read output timeout value for both PWM outputs. When PWM is set to a non-zero value: Due to I/O line passing, a time is started which when expired will set the PWM output to zero. The timer is reset when a valid I/O packet is received.]	0 - 0xFF [x 100 ms]	0xFF
RP	I/O Settings {I/O Line Passing}	**RSSI PWM Timer.** Set/Read PWM timer register. Set the duration of PWM (pulse width modulation) signal output on the RSSI pin. The signal duty cycle is updated with each received packet and is shut off when the timer expires.]	0 - 0xFF [x 100 ms]	0x28 (40d)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Diagnostics

Table 3-07. XBee®/XBee-PRO® Commands - Diagnostics

AT Command	Command Category	Name and Description	Parameter Range	Default
VR	Diagnostics	**Firmware Version**. Read firmware version of the RF module.	0 - 0xFFFF [read-only]	Factory-set
VL (v1.x80*)	Diagnostics	**Firmware Version - Verbose**. Read detailed version information (including application build date, MAC, PHY and bootloader versions). The VL command has been deprecated in version 10C9. It is not supported in firmware versions after 10C8	-	-

Table 3-07. XBee®/XBee-PRO® Commands - Diagnostics

AT Command	Command Category	Name and Description	Parameter Range	Default
HV (v1.x80*)	Diagnostics	**Hardware Version**. Read hardware version of the RF module.	0 - 0xFFFF [read-only]	Factory-set
DB	Diagnostics	**Received Signal Strength**. Read signal level [in dB] of last good packet received (RSSI). Absolute value is reported. (For example: 0x58 = -88 dBm) Reported value is accurate between -40 dBm and RX sensitivity.	0x17-0x5C (XBee) 0x24-0x64 (XBee-PRO) [read-only]	-
EC (v1.x80*)	Diagnostics	**CCA Failures.** Reset/Read count of CCA (Clear Channel Assessment) failures. This parameter value increments when the module does not transmit a packet because it detected energy above the CCA threshold level set with CA command. This count saturates at its maximum value. Set count to “0” to reset count.	0 - 0xFFFF	-
EA (v1.x80*)	Diagnostics	**ACK Failures**. Reset/Read count of acknowledgment failures. This parameter value increments when the module expires its transmission retries without receiving an ACK on a packet transmission. This count saturates at its maximum value. Set the parameter to “0” to reset count.	0 - 0xFFFF	-
ED (v1.x80*)	Diagnostics	**Energy Scan**. Send ‘Energy Detect Scan’. ED parameter determines the length of scan on each channel. The maximal energy on each channel is returned and each value is followed by a carriage return. Values returned represent detected energy levels in units of -dBm. Actual scan time on each channel is measured as Time = [(2 ^ SD) * 15.36] ms. Total scan time is this time multiplied by the number of channels to be scanned.	0 - 6	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

AT Command Options

Table 3-08. XBee®/XBee-PRO® Commands - AT Command Options

AT Command	Command Category	Name and Description	Parameter Range	Default
CT	AT Command Mode Options	**Command Mode Timeout.** Set/Read the period of inactivity (no valid commands received) after which the RF module automatically exits AT Command Mode and returns to Idle Mode.	2 - 0xFFFF [x 100 ms]	0x64 (100d)
CN	AT Command Mode Options	**Exit Command Mode**. Explicitly exit the module from AT Command Mode.	--	--
AC (v1.xA0*)	AT Command Mode Options	**Apply Changes**. Explicitly apply changes to queued parameter value(s) and re-initialize module.	--	--
GT	AT Command Mode Options	**Guard Times**. Set required period of silence before and after the Command Sequence Characters of the AT Command Mode Sequence (GT+ CC + GT). The period of silence is used to prevent inadvertent entrance into AT Command Mode.	2 - 0x0CE4 [x 1 ms]	0x3E8 (1000d)
CC	AT Command Mode Options	**Command Sequence Character**. Set/Read the ASCII character value to be used between Guard Times of the AT Command Mode Sequence (GT+CC+GT). The AT Command Mode Sequence enters the RF module into AT Command Mode.	0 - 0xFF	0x2B ('+' ASCII)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Command Descriptions

Command descriptions in this section are listed alphabetically. Command categories are designated within "< >" symbols that follow each command title. XBee®/XBee-PRO® RF Modules expect parameter values in hexadecimal (designated by the "0x" prefix).

All modules operating within the same network should contain the same firmware version.

A1 (End Device Association) Command

<Networking {Association}> The A1 command is used to set and read association options for an End Device.

Use the table below to determine End Device behavior in relation to the A1 parameter.

AT Command: ATA1

Parameter Range: 0 – 0x0F [bitfield]

Default Parameter Value: 0

Related Commands: ID (PAN ID), NI (Node Identifier), CH (Channel), CE (Coordinator Enable), A2 (Coordinator Association)

Minimum Firmware Version Required: v1.x80

Bit number	End Device Association Option
0 - ReassignPanID	0 - Will only associate with Coordinator operating on PAN ID that matches Node Identifier
	1 - May associate with Coordinator operating on any PAN ID
1 - ReassignChannel	0 - Will only associate with Coordinator operating on Channel that matches CH setting
	1 - May associate with Coordinator operating on any Channel
2 - AutoAssociate	0 - Device will not attempt Association
	1 - Device attempts Association until success Note: This bit is used only for Non-Beacon systems. End Devices in a Beaconing system must always associate to a Coordinator
3 - PollCoordOnPinWake	0 - Pin Wake will not poll the Coordinator for pending (indirect) Data
	1 - Pin Wake will send Poll Request to Coordinator to extract any pending data
4 - 7	[reserved]

A2 (Coordinator Association) Command

<Networking {Association}> The A2 command is used to set and read association options of the Coordinator.

Use the table below to determine Coordinator behavior in relation to the A2 parameter.

AT Command: ATA2

Parameter Range: 0 – 7 [bitfield]

Default Parameter Value: 0

Related Commands: ID (PAN ID), NI (Node Identifier), CH (Channel), CE (Coordinator Enable), A1 (End Device Association), AS Active Scan), ED (Energy Scan)

Minimum Firmware Version Required: v1.x80

Bit number	End Device Association Option
0 - ReassignPanID	0 - Coordinator will not perform Active Scan to locate available PAN ID. It will operate on ID (PAN ID).
	1 - Coordinator will perform Active Scan to determine an available ID (PAN ID). If a PAN ID conflict is found, the ID parameter will change.
1 - ReassignChannel	0 - Coordinator will not perform Energy Scan to determine free channel. It will operate on the channel determined by the CH parameter.
	1 - Coordinator will perform Energy Scan to find a free channel, then operate on that channel.
2 - AllowAssociate	0 - Coordinator will not allow any devices to associate to it.
	1 - Coordinator will allow devices to associate to it.
3 - 7	[reserved]

The binary equivalent of the default value (0x06) is 00000110. 'Bit 0' is the last digit of the sequence.

AC (Apply Changes) Command

AT Command: ATAC	
Minimum Firmware Version Required: v1.xA0	

<AT Command Mode Options> The AC command is used to explicitly apply changes to module parameter values. 'Applying changes' means that the module is re-initialized based on changes made to its parameter values. Once changes are applied, the module immediately operates according to the new parameter values.

This behavior is in contrast to issuing the WR (Write) command. The WR command saves parameter values to non-volatile memory, but the module still operates according to previously saved values until the module is re-booted or the CN (Exit AT Command Mode) command is issued.

Refer to the "AT Command - Queue Parameter Value" API type for more information.

AI (Association Indication) Command

AT Command: ATAI

Parameter Range: 0 - 0x13 [read-only]

Related Commands: AS (Active Scan), ID (PAN ID), CH (Channel), ED (Energy Scan), A1 (End Device Association), A2 (Coordinator Association), CE (Coordinator Enable)

Minimum Firmware Version Required: v1.x80

<Networking {Association}> The AI command is used to indicate occurrences of errors during the last association request.

Use the table below to determine meaning of the returned values.

Returned Value (Hex)	Association Indication
0x00	Successful Completion - Coordinator successfully started or End Device association complete
0x01	Active Scan Timeout
0x02	Active Scan found no PANs
0x03	Active Scan found PAN, but the Coordinator Allow Association bit is not set
0x04	Active Scan found PAN, but Coordinator and End Device are not configured to support beacons
0x05	Active Scan found PAN, but Coordinator ID (PAN ID) value does not match the ID of the End Device
0x06	Active Scan found PAN, but Coordinator CH (Channel) value does not match the CH of the End Device
0x07	Energy Scan Timeout
0x08	Coordinator start request failed
0x09	Coordinator could not start due to Invalid Parameter
0x0A	Coordinator Realignment is in progress
0x0B	Association Request not sent
0x0C	Association Request timed out - no reply was received
0x0D	Association Request had an Invalid Parameter
0x0E	Association Request Channel Access Failure - Request was not transmitted - CCA failure
0x0F	Remote Coordinator did not send an ACK after Association Request was sent
0x10	Remote Coordinator did not reply to the Association Request, but an ACK was received after sending the request
0x11	[reserved]
0x12	Sync-Loss - Lost synchronization with a Beaconing Coordinator
0x13	Disassociated - No longer associated to Coordinator
0xFF	RF Module is attempting to associate

AP (API Enable) Command

<Serial Interfacing> The AP command is used to enable the RF module to operate using a frame-based API instead of using the default Transparent (UART) mode.

AT Command: ATAP

Parameter Range:0 – 2

Parameter	Configuration
0	Disabled (Transparent operation)
1	API enabled
2	API enabled (with escaped characters)

Default Parameter Value:0

Minimum Firmware Version Required: v1.x80

Refer to the API Operation section when API operation is enabled (AP = 1 or 2).

AS (Active Scan) Command

<Network {Association}> The AS command is used to send a Beacon Request to a Broadcast (0xFFFF) and Broadcast PAN (0xFFFF) on every channel. The parameter determines the amount of time the RF module will listen for Beacons on each channel. A 'PanDescriptor' is created and returned for every Beacon received from the scan. Each PanDescriptor contains the following information:

AT Command: ATAS

Parameter Range: 0 – 6

Related Command: SD (Scan Duration), DL (Destination Low Address), DH (Destination High Address), ID (PAN ID), CH (Channel)

Minimum Firmware Version Required: v1.x80

CoordAddress (SH + SL parameters)<CR> (NOTE: If MY on the coordinator is set less than 0xFFFF, the MY value is displayed)
CoordPanID (ID parameter)<CR>
CoordAddrMode <CR>
  0x02 = 16-bit Short Address
  0x03 = 64-bit Long Address
Channel (CH parameter) <CR>
SecurityUse<CR>
ACLEntry<CR>
SecurityFailure<CR>
SuperFrameSpec<CR> (2 bytes):
  bit 15 - Association Permitted (MSB)
  bit 14 - PAN Coordinator
  bit 13 - Reserved
  bit 12 - Battery Life Extension
  bits 8-11 - Final CAP Slot
  bits 4-7 - Superframe Order
  bits 0-3 - Beacon Order
GtsPermit<CR>
RSSI<CR> (- RSSI is returned as -dBm)
TimeStamp<CR> (3 bytes)
<CR> (A carriage return <CR> is sent at the end of the AS command.

The Active Scan is capable of returning up to 5 PanDescriptors in a scan. The actual scan time on each channel is measured as Time = [(2 ^ (SD Parameter)) * 15.36] ms. Total scan time is this time multiplied by the number of channels to be scanned (16 for the XBee, 12 for the XBee-PRO).

NOTE: Refer the scan table in the SD description to determine scan times. If using API Mode, no <CR>'s are returned in the response. Refer to the API Mode Operation section.

BD (Interface Data Rate) Command

<Serial Interfacing> The BD command is used to set and read the serial interface data rate used between the RF module and host. This parameter determines the rate at which serial data is sent to the module from the host. Modified interface data rates do not take effect until the CN (Exit AT Command Mode) command is issued and the system returns the 'OK' response.

When parameters 0-7 are sent to the module, the respective interface data rates are used (as shown in the table on the right).

The RF data rate is not affected by the BD parameter. If the interface data rate is set higher than the RF data rate, a flow control configuration may need to be implemented.

AT Command: ATBD

Parameter Range:0 – 7 (standard rates)
0x80-0x3D090 (non-standard rates up to 250 Kbps)

Parameter	Configuration (bps)
0	1200
1	2400
2	4800
3	9600
4	19200
5	38400
6	57600
7	115200

Default Parameter Value:3

Non-standard Interface Data Rates:
Any value above 0x07 will be interpreted as an actual baud rate. When a value above 0x07 is sent, the closest interface data rate represented by the number is stored in the BD register. For example, a rate of 19200 bps can be set by sending the following command line "ATBD4B00". NOTE: When using Digi's X-CTU Software, non-standard interface data rates can only be set and read using the X-CTU 'Terminal' tab. Non-standard rates are not accessible through the 'Modem Configuration' tab.

When the BD command is sent with a non-standard interface data rate, the UART will adjust to accommodate the requested interface rate. In most cases, the clock resolution will cause the stored BD parameter to vary from the parameter that was sent (refer to the table below). Reading the BD command (send "ATBD" command without an associated parameter value) will return the value actually stored in the module's BD register.

Parameters Sent Versus Parameters Stored

BD Parameter Sent (HEX)	Interface Data Rate (bps)	BD Parameter Stored (HEX)
0	1200	0
4	19,200	4
7	115,200*	7
12C	300	12B
1C200	115,200	1B207

* The 115,200 baud rate setting is actually at 111,111 baud (-3.5% target UART speed).

CA (CCA Threshold) Command

<RF Interfacing> CA command is used to set and read CCA (Clear Channel Assessment) thresholds.

Prior to transmitting a packet, a CCA is performed to detect energy on the transmit channel. If the detected energy is above the CCA Threshold, the RF module will not transmit the packet.

AT Command: ATCA

Parameter Range: 0 – 0x50 [-dBm]

Default Parameter Value: 0x2C (-44 decimal dBm)

Minimum Firmware Version Required: v1.x80

CC (Command Sequence Character) Command

<AT Command Mode Options> The CC command is used to set and read the ASCII character used between guard times of the AT Command Mode Sequence (GT + CC + GT). This sequence enters the RF module into AT Command Mode so that data entering the module from the host is recognized as commands instead of payload.

AT Command: ATCC
Parameter Range: 0 – 0xFF
Default Parameter Value: 0x2B (ASCII "+")
Related Command: GT (Guard Times)

The AT Command Sequence is explained further in the AT Command Mode section.

CE (Coordinator Enable) Command

<Networking {Association} The CE command is used to set and read the behavior (End Device vs. Coordinator) of the RF module.

AT Command: ATCE

Parameter Range:0 – 1

Parameter	Configuration
0	End Device
1	Coordinator

Default Parameter Value:0

Minimum Firmware Version Required: v1.x80

CH (Channel) Command

<Networking {Addressing}> The CH command is used to set/read the operating channel on which RF connections are made between RF modules. The channel is one of three addressing options available to the module. The other options are the PAN ID (ID command) and destination addresses (DL & DH commands).

AT Command: ATCH
Parameter Range: 0x0B – 0x1A (XBee) 0x0C – 0x17 (XBee-PRO)
Default Parameter Value: 0x0C (12 decimal)
Related Commands: ID (PAN ID), DL (Destination Address Low, DH (Destination Address High)

In order for modules to communicate with each other, the modules must share the same channel number. Different channels can be used to prevent modules in one network from listening to transmissions of another. Adjacent channel rejection is 23 dB.

The module uses channel numbers of the 802.15.4 standard.

Center Frequency = 2.405 + (CH - 11d) * 5 MHz (d = decimal)

Refer to the XBee/XBee-PRO Addressing section for more information.

CN (Exit Command Mode) Command

<AT Command Mode Options> The CN command is used to explicitly exit the RF module from AT Command Mode.

AT Command: ATCN

CT (Command Mode Timeout) Command

<AT Command Mode Options> The CT command is used to set and read the amount of inactive time that elapses before the RF module automatically exits from AT Command Mode and returns to Idle Mode.

Use the CN (Exit Command Mode) command to exit AT Command Mode manually.

AT Command: ATCT
Parameter Range:2 – 0xFFFF [x 100 milliseconds]
Default Parameter Value: 0x64 (100 decimal (which equals 10 decimal seconds))
Number of bytes returned: 2
Related Command: CN (Exit Command Mode)

D0 - D4 (DIOn Configuration) Commands

<I/O Settings> The D0, D1, D2, D3 and D4 commands are used to select/read the behavior of their respective AD/DIO lines (pins 20, 19, 18, 17 and 11 respectively).

Options include:

- Analog-to-digital converter
- Digital input
- Digital output

AT Commands: ATD0, ATD1, ATD2, ATD3, ATD4

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	n/a
2	ADC
3	DI
4	DO low
5	DO high

Default Parameter Value:0

Minimum Firmware Version Required: 1.x.A0

D5 (DIO5 Configuration) Command

<I/O Settings> The D5 command is used to select/read the behavior of the DIO5 line (pin 15).

Options include:

- Associated Indicator (LED blinks when the module is associated)
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD5

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	Associated Indicator
2	ADC
3	DI
4	DO low
5	DO high

Default Parameter Value:1

Parameters 2-5 supported as of firmware version 1.xA0

D6 (DIO6 Configuration) Command

<I/O Settings> The D6 command is used to select/read the behavior of the DIO6 line (pin 16). Options include:

- RTS flow control
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD6

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	RTS Flow Control
2	n/a
3	DI
4	DO low
5	DO high

Default Parameter Value:0

Parameters 3-5 supported as of firmware version 1.xA0

D7 (DIO7 Configuration) Command

<I/O Settings> The D7 command is used to select/read the behavior of the DIO7 line (pin 12). Options include:

- CTS flow control
- Analog-to-digital converter
- Digital input
- Digital output
- RS485 TX Enable (this output is 3V CMOS level, and is useful in a 3V CMOS to RS485 conversion circuit)

AT Command: ATD7

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	CTS Flow Control
2	n/a
3	DI
4	DO low
5	DO high
6	RS485 TX Enable Low
7	RS485 TX Enable High

Default Parameter Value:1

Parameters 3-7 supported as of firmware version 1.x.A0

D8 (DI8 Configuration) Command

<I/O Settings> The D8 command is used to select/read the behavior of the DI8 line (pin 9). This command enables configuring the pin to function as a digital input. This line is also used with Pin Sleep.

AT Command: ATD8

Parameter Range:0 – 5
(1, 2, 4 & 5 n/a)

Parameter	Configuration
0	Disabled
3	DI

Default Parameter Value:0

Minimum Firmware Version Required: 1.xA0

DA (Force Disassociation) Command

<(Special)> The DA command is used to immediately disassociate an End Device from a Coordinator and reattempt to associate.

AT Command: ATDA

Minimum Firmware Version Required: v1.x80

DB (Received Signal Strength) Command

<Diagnostics> DB parameter is used to read the received signal strength (in dBm) of the last RF packet received. Reported values are accurate between -40 dBm and the RF module's receiver sensitivity.

AT Command: ATDB

Parameter Range [read-only]:
0x17-0x5C (XBee), 0x24-0x64 (XBee-PRO)

Absolute values are reported. For example: 0x58 = -88 dBm (decimal). If no packets have been received (since last reset, power cycle or sleep event), "0" will be reported.

DH (Destination Address High) Command

<Networking {Addressing}> The DH command is used to set and read the upper 32 bits of the RF module's 64-bit destination address. When combined with the DL (Destination Address Low) parameter, it defines the destination address used for transmission.

An module will only communicate with other modules having the same channel (CH parameter), PAN ID (ID parameter) and destination address (DH + DL parameters).

AT Command: ATDH

Parameter Range: 0 – 0xFFFFFFFF

Default Parameter Value: 0

Related Commands: DL (Destination Address Low), CH (Channel), ID (PAN VID), MY (Source Address)

To transmit using a 16-bit address, set the DH parameter to zero and the DL parameter less than 0xFFFF. 0x000000000000FFFF (DL concatenated to DH) is the broadcast address for the PAN.

Refer to the XBee/XBee-PRO Addressing section for more information.

DL (Destination Address Low) Command

AT Command: ATDL
Parameter Range: 0 - 0xFFFFFFFF
Default Parameter Value: 0
Related Commands: DH (Destination Address High), CH (Channel), ID (PAN VID), MY (Source Address)

<Networking {Addressing}> The DL command is used to set and read the lower 32 bits of the RF module's 64-bit destination address. When combined with the DH (Destination Address High) parameter, it defines the destination address used for transmission.

A module will only communicate with other modules having the same channel (CH parameter), PAN ID (ID parameter) and destination address (DH + DL parameters).

To transmit using a 16-bit address, set the DH parameter to zero and the DL parameter less than 0xFFFF. 0x000000000000FFFF (DL concatenated to DH) is the broadcast address for the PAN.

Refer to the XBee/XBee-PRO Addressing section for more information.

DN (Destination Node) Command

AT Command: ATDN
Parameter Range: 20-character ASCII String
Minimum Firmware Version Required: v1.x80

<Networking {Identification}> The DN command is used to resolve a NI (Node Identifier) string to a physical address. The following events occur upon successful command execution:

1. DL and DH are set to the address of the module with the matching NI (Node Identifier).
2. 'OK' is returned.
3. RF module automatically exits AT Command Mode.

If there is no response from a modem within 200 msec or a parameter is not specified (left blank), the command is terminated and an 'ERROR' message is returned.

DP (Disassociation Cyclic Sleep Period) Command

AT Command: ATDP
Parameter Range: 1 – 0x68B0 [x 10 milliseconds]
Default Parameter Value:0x3E8 (1000 decimal)
Related Commands: SM (Sleep Mode), SP (Cyclic Sleep Period), ST (Time before Sleep)
Minimum Firmware Version Required: v1.x80

<Sleep Mode (Low Power)>

NonBeacon Firmware

End Device - The DP command is used to set and read the time period of sleep for cyclic sleeping remotes that are configured for Association but are not associated to a Coordinator. (i.e. If a device is configured to associate, configured as a Cyclic Sleep remote, but does not find a Coordinator; it will sleep for DP time before reattempting association.) Maximum sleep period is 268 seconds (0x68B0). DP should be > 0 for NonBeacon systems.

EA (ACK Failures) Command

AT Command: ATEA
Parameter Range:0 – 0xFFFF
Minimum Firmware Version Required: v1.x80

<Diagnostics> The EA command is used to reset and read the count of ACK (acknowledgement) failures. This parameter value increments when the module expires its transmission retries without receiving an ACK on a packet transmission. This count saturates at its maximum value.

Set the parameter to "0" to reset count.

EC (CCA Failures) Command

<Diagnostics> The EC command is used to read and reset the count of CCA (Clear Channel Assessment) failures. This parameter value increments when the RF module does not transmit a packet due to the detection of energy that is above the CCA threshold level (set with CA command). This count saturates at its maximum value.

Set the EC parameter to "0" to reset count.

AT Command: ATEC
Parameter Range:0 – 0xFFFF
Related Command: CA (CCA Threshold)
Minimum Firmware Version Required: v1.x80

ED (Energy Scan) Command

<Networking {Association}> The ED command is used to send an "Energy Detect Scan". This parameter determines the length of scan on each channel. The maximal energy on each channel is returned and each value is followed by a carriage return. An additional carriage return is sent at the end of the command.

AT Command: ATED
Parameter Range:0 – 6
Related Command: SD (Scan Duration), SC (Scan Channel)
Minimum Firmware Version Required: v1.x80

The values returned represent the detected energy level in units of -dBm. The actual scan time on each channel is measured as Time = [(2 ^ ED PARAM) * 15.36] ms.

Note: Total scan time is this time multiplied by the number of channels to be scanned. Also refer to the SD (Scan Duration) table. Use the SC (Scan Channel) command to choose which channels to scan.

EE (AES Encryption Enable) Command

<Networking {Security}> The EE command is used to set/read the parameter that disables/enables 128-bit AES encryption.

The XBee®/XBee-PRO® firmware uses the 802.15.4 Default Security protocol and uses AES encryption with a 128-bit key. AES encryption dictates that all modules in the network use the same key and the maximum RF packet size is 95 Bytes.

AT Command: ATEE	
Parameter Range:0 – 1	
Parameter	Configuration
0	Disabled
1	Enabled
Default Parameter Value:0	
Related Commands: KY (Encryption Key), AP (API Enable), MM (MAC Mode)	
Minimum Firmware Version Required: v1.xA0	

When encryption is enabled, the module will always use its 64-bit long address as the source address for RF packets. This does not affect how the MY (Source Address), DH (Destination Address High) and DL (Destination Address Low) parameters work

If MM (MAC Mode) > 0 and AP (API Enable) parameter > 0:
With encryption enabled and a 16-bit short address set, receiving modules will only be able to issue RX (Receive) 64-bit indicators. This is not an issue when MM = 0.

If a module with a non-matching key detects RF data, but has an incorrect key: When encryption is enabled, non-encrypted RF packets received will be rejected and will not be sent out the UART.

Transparent Operation --> All RF packets are sent encrypted if the key is set.

API Operation --> Receive frames use an option bit to indicate that the packet was encrypted.

FP (Force Poll) Command

<Networking (Association)> The FP command is used to request indirect messages being held by a Coordinator.

AT Command: ATFP
Minimum Firmware Version Required: v1.x80

FR (Software Reset) Command

<Special> The FR command is used to force a software reset on the RF module. The reset simulates powering off and then on again the module.

AT Command: ATFR
Minimum Firmware Version Required: v1.x80

GT (Guard Times) Command

<AT Command Mode Options> GT Command is used to set the DI (data in from host) time-of-silence that surrounds the AT command sequence character (CC Command) of the AT Command Mode sequence (GT + CC + GT).

The DI time-of-silence is used to prevent inadvertent entrance into AT Command Mode.

Refer to the Command Mode section for more information regarding the AT Command Mode Sequence.

AT Command: ATGT
Parameter Range:2 – 0x0CE4 [x 1 millisecond]
Default Parameter Value:0x3E8 (1000 decimal)
Related Command: CC (Command Sequence Character)

HV (Hardware Version) Command

<Diagnostics> The HV command is used to read the hardware version of the RF module.

AT Command: ATHV
Parameter Range:0 – 0xFFFF [Read-only]
Minimum Firmware Version Required: v1.x80

IA (I/O Input Address) Command

<I/O Settings {I/O Line Passing}> The IA command is used to bind a module output to a specific address. Outputs will only change if received from this address. The IA command can be used to set/read both 16 and 64-bit addresses.

Setting all bytes to 0xFF will not allow the reception of any I/O packet to change outputs. Setting the IA address to 0xFFFF will cause the module to accept all I/O packets.

AT Command: ATIA
Parameter Range:0 – 0xFFFFFFFFFFFFFFFF
Default Parameter Value:0xFFFFFFFFFFFFFFFF (will not allow any received I/O packet to change outputs)
Minimum Firmware Version Required: v1.xA0

IC (DIO Change Detect) Command

<I/O Settings> Set/Read bitfield values for change detect monitoring. Each bit enables monitoring of DIO0 - DIO7 for changes.

If detected, data is transmitted with DIO data only. Any samples queued waiting for transmission will be sent first.

AT Command: ATIC
Parameter Range:0 – 0xFF [bitfield]
Default Parameter Value:0 (disabled)
Minimum Firmware Version Required: 1.xA0

Refer to the “ADC and Digital I/O Line Support” sections of the “RF Module Operations” chapter for more information.

ID (Pan ID) Command

<Networking {Addressing}> The ID command is used to set and read the PAN (Personal Area Network) ID of the RF module. Only modules with matching PAN IDs can communicate with each other. Unique PAN IDs enable control of which RF packets are received by a module.

AT Command: ATID
Parameter Range: 0 – 0xFFFF
Default Parameter Value:0x3332 (13106 decimal)

Setting the ID parameter to 0xFFFF indicates a global transmission for all PANs. It does not indicate a global receive.

IO (Digital Output Level) Command

<I/O Settings> The IO command is used to set digital output levels. This allows DIO lines setup as outputs to be changed through Command Mode.

AT Command: ATIO
Parameter Range: 8-bit bitmap (where each bit represents the level of an I/O line that is setup as an output.)
Minimum Firmware Version Required: v1.xA0

IR (Sample Rate) Command

<I/O Settings> The IR command is used to set/ read the sample rate. When set, the module will sample all enabled DIO/ADC lines at a specified interval. This command allows periodic reads of the ADC and DIO lines in a non-Sleep Mode setup. A sample rate which requires transmissions at a rate greater than once every 20ms is not recommended.

AT Command: ATIR
Parameter Range: 0 - 0xFFFF [x 1 msec] (cannot guarantee 1 ms timing when IT=1)
Default Parameter Value:0
Related Command: IT (Samples before TX)
Minimum Firmware Version Required: v1.xA0

Example: When IR = 0x14, the sample rate is 20 ms (or 50 Hz).

IS (Force Sample) Command

<I/O Settings> The IS command is used to force a read of all enabled DIO/ADC lines. The data is returned through the UART.

When operating in Transparent Mode (AP=0), the data is retuned in the following format:

AT Command: ATIS
Parameter Range: 1 - 0xFF
Default Parameter Value:1
Minimum Firmware Version Required: v1.xA0

All bytes are converted to ASCII:
- number of samples<CR>
- channel mask<CR>
- DIO data<CR> (If DIO lines are enabled<CR>
- ADC channel Data<cr> <-This will repeat for every enabled ADC channel<CR>
- <CR> (end of data noted by extra <CR>)

When operating in API mode (AP > 0), the command will immediately return an 'OK' response. The data will follow in the normal API format for DIO data.

IT (Samples before TX) Command

<I/O Settings> The IT command is used to set/ read the number of DIO and ADC samples to collect before transmitting data.

One ADC sample is considered complete when all enabled ADC channels have been read. The module can buffer up to 93 Bytes of sample data.

AT Command: ATIT
Parameter Range: 1 - 0xFF
Default Parameter Value:1
Minimum Firmware Version Required: v1.xA0

Since the module uses a 10-bit A/D converter, each sample uses two Bytes. This leads to a maximum buffer size of 46 samples or IT=0x2E.

When Sleep Modes are enabled and IR (Sample Rate) is set, the module will remain awake until IT samples have been collected.

IU (I/O Output Enable) Command

<I/O Settings> The IU command is used to disable/enable I/O UART output. When enabled (IU = 1), received I/O line data packets are sent out the UART. The data is sent using an API frame regardless of the current AP parameter value.

AT Command: ATIU

Parameter Range:0 – 1

Parameter	Configuration
0	Disabled – Received I/O line data packets will be NOT sent out UART.
1	Enabled – Received I/O line data will be sent out UART

Default Parameter Value:1

Minimum Firmware Version Required: 1.xA0

KY (AES Encryption Key) Command

<Networking {Security}> The KY command is used to set the 128-bit AES (Advanced Encryption Standard) key for encrypting/decrypting data. Once set, the key cannot be read out of the module by any means.

AT Command: ATKY

Parameter Range:0 – (any 16-Byte value)

Default Parameter Value:0

Related Command: EE (Encryption Enable)

Minimum Firmware Version Required: v1.xA0

The entire payload of the packet is encrypted using the key and the CRC is computed across the ciphertext. When encryption is enabled, each packet carries an additional 16 Bytes to convey the random CBC Initialization Vector (IV) to the receiver(s). The KY value may be “0” or any 128-bit value. Any other value, including entering KY by itself with no parameters, is invalid. All ATKY entries (valid or not) are received with a returned 'OK'.

A module with the wrong key (or no key) will receive encrypted data, but the data driven out the serial port will be meaningless. A module with a key and encryption enabled will receive data sent from a module without a key and the correct unencrypted data output will be sent out the serial port. Because CBC mode is utilized, repetitive data appears differently in different transmissions due to the randomly-generated IV.

When queried, the system will return an ‘OK’ message and the value of the key will not be returned.

M0 (PWM0 Output Level) Command

<I/O Settings> The M0 command is used to set/read the output level of the PWM0 line (pin 6).

Before setting the line as an output:
1. Enable PWM0 output (P0 = 2)
2. Apply settings (use CN or AC)

The PWM period is 64 µsec and there are 0x03FF (1023 decimal) steps within this period. When M0 = 0 (0% PWM), 0x01FF (50% PWM), 0x03FF (100% PWM), etc.

AT Command: ATM0

Parameter Range:0 – 0x03FF [steps]

Default Parameter Value:0

Related Commands: P0 (PWM0 Enable), AC (Apply Changes), CN (Exit Command Mode)

Minimum Firmware Version Required: v1.xA0

M1 (PWM1 Output Level) Command

<I/O Settings> The M1 command is used to set/read the output level of the PWM1 line (pin 7).

Before setting the line as an output:
1. Enable PWM1 output (P1 = 2)
2. Apply settings (use CN or AC)

AT Command: ATM1

Parameter Range:0 – 0x03FF

Default Parameter Value:0

Related Commands: P1 (PWM1 Enable), AC (Apply Changes), CN (Exit Command Mode)

Minimum Firmware Version Required: v1.xA0

MM (MAC Mode) Command

<Networking {Addressing}> The MM command is used to set and read the MAC Mode value. The MM command disables/enables the use of a Digi header contained in the 802.15.4 RF packet. By default (MM = 0), Digi Mode is enabled and the module adds an extra header to the data portion of the 802.15.4 packet. This enables the following features:

- ND and DN command support
- Duplicate packet detection when using ACKs
- "RR command
- "DIO/AIO sampling support

The MM command allows users to turn off the use of the extra header. Modes 1 and 2 are strict 802.15.4 modes. If the Digi header is disabled, ND and DN parameters are also disabled.

Note: When MM=0 or 3, application and CCA failure retries are not supported.

AT Command: ATMM

Parameter Range:0 – 3

Parameter	Configuration
0	Digi Mode (802.15.4 + Digi header)
1	802.15.4 (no ACKs)
2	802.15.4 (with ACKs)
3	Digi Mode (no ACKs)

Default Parameter Value:0

Related Commands: ND (Node Discover), DN (Destination Node)

Minimum Firmware Version Required: v1.x80

MY (16-bit Source Address) Command

<Networking {Addressing}> The MY command is used to set and read the 16-bit source address of the RF module.

By setting MY to 0xFFFF, the reception of RF packets having a 16-bit address is disabled. The 64-bit address is the module's serial number and is always enabled.

AT Command: ATMY

Parameter Range: 0 – 0xFFFF

Default Parameter Value: 0

Related Commands: DH (Destination Address High), DL (Destination Address Low), CH (Channel), ID (PAN ID)

NB (Parity) Command

<Serial Interfacing> The NB command is used to select/read the parity settings of the RF module for UART communications.

Note: the module does not actually calculate and check the parity; it only interfaces with devices at the configured parity and stop bit settings.

AT Command: ATNB

Parameter Range: 0 – 4

Parameter	Configuration
0	8-bit no parity
1	8-bit even
2	8-bit odd
3	8-bit mark
4	8-bit space

Default Parameter Value: 0

Number of bytes returned: 1

ND (Node Discover) Command

AT Command: ATND	
Range: optional 20-character NI value	
Related Commands: CH (Channel), ID (Pan ID), MY (Source Address), SH (Serial Number High), SL (Serial Number Low), NI (Node Identifier), NT (Node Discover Time)	
Minimum Firmware Version Required: v1.x80	

<Networking {Identification}> The ND command is used to discover and report all modules on its current operating channel (CH parameter) and PAN ID (ID parameter). ND also accepts an NI (Node Identifier) value as a parameter. In this case, only a module matching the supplied identifier will respond.

ND uses a 64-bit long address when sending and responding to an ND request. The ND command causes a module to transmit a globally addressed ND command packet. The amount of time allowed for responses is determined by the NT (Node Discover Time) parameter.

In AT Command mode, command completion is designated by a carriage return (0x0D). Since two carriage returns end a command response, the application will receive three carriage returns at the end of the command. If no responses are received, the application should only receive one carriage return. When in API mode, the application should receive a frame (with no data) and status (set to 'OK') at the end of the command. When the ND command packet is received, the remote sets up a random time delay (up to 2.2 sec) before replying as follows:

Node Discover Response (AT command mode format - Transparent operation):
MY (Source Address) value<CR>
SH (Serial Number High) value<CR>
SL (Serial Number Low) value<CR>
DB (Received Signal Strength) value<CR>
NI (Node Identifier) value<CR>
<CR> (This is part of the response and not the end of command indicator.)

Node Discover Response (API format - data is binary (except for NI)):
2 bytes for MY (Source Address) value
4 bytes for SH (Serial Number High) value
4 bytes for SL (Serial Number Low) value
1 byte for DB (Received Signal Strength) value
NULL-terminated string for NI (Node Identifier) value (max 20 bytes w/out NULL terminator)

NI (Node Identifier) Command

AT Command: ATNI	
Parameter Range: 20-character ASCII string	
Related Commands: ND (Node Discover), DN (Destination Node)	
Minimum Firmware Version Required: v1.x80	

<Networking {Identification}> The NI command is used to set and read a string for identifying a particular node.

Rules:

- Register only accepts printable ASCII data.
- A string can not start with a space.
- A carriage return ends command
- Command will automatically end when maximum bytes for the string have been entered.

This string is returned as part of the ND (Node Discover) command. This identifier is also used with the DN (Destination Node) command.

NO (Node Discover Options) Command

AT Command: ATNO	
Parameter Range: "0-1	
Related Commands: ND (Node Discover), DN (Destination Node)	
Minimum Firmware Version Required: v1.xC5	

<Networking {Identification}> The NO command is used to suppress/include a self-response to Node Discover commands. When NO=1 a module doing a Node Discover will include a response entry for itself.

NT (Node Discover Time) Command

<Networking {Identification}> The NT command is used to set the amount of time a base node will wait for responses from other nodes when using the ND (Node Discover) command. The NT value is transmitted with the ND command.

Remote nodes will set up a random hold-off time based on this time. The remotes will adjust this time down by 250 ms to give each node the ability to respond before the base ends the command. Once the ND command has ended, any response received on the base will be discarded.

AT Command: ATNT
Parameter Range: 0x01 - 0xFC [x 100 msec]
Default: 0x19 (2.5 decimal seconds)
Related Commands: ND (Node Discover)
Minimum Firmware Version Required: 1.xA0

P0 (PWM0 Configuration) Command

<I/O Setting {I/O Line Passing}> The P0 command is used to select/read the function for PWM0 (Pulse Width Modulation output 0). This command enables the option of translating incoming data to a PWM so that the output can be translated back into analog form.

With the IA (I/O Input Address) parameter correctly set, AD0 values can automatically be passed to PWM0.

AT Command: ATP0
The second character in the command is the number zero ("0"), not the letter "O".

Parameter Range: 0 - 2

Parameter	Configuration
0	Disabled
1	RSSI
2	PWM0 Output

Default Parameter Value: 1

P1 (PWM1 Configuration) Command

<I/O Setting {I/O Line Passing}> The P1 command is used to select/read the function for PWM1 (Pulse Width Modulation output 1). This command enables the option of translating incoming data to a PWM so that the output can be translated back into analog form.

With the IA (I/O Input Address) parameter correctly set, AD1 values can automatically be passed to PWM1.

AT Command: ATP1

Parameter Range: 0 - 2

Parameter	Configuration
0	Disabled
1	RSSI
2	PWM1 Output

Default Parameter Value: 0

Minimum Firmware Version Required: v1.xA0

PL (Power Level) Command

<RF Interfacing> The PL command is used to select and read the power level at which the RF module transmits conducted power.

When operating in Europe, XBee-PRO 802.15.4 modules must operate at or below a transmit power output level of 10dBm. Customers have 2 choices for transmitting at or below 10dBm:

- Order the standard XBee-PRO module and change the PL command to "0" (10dBm),
- Order the International variant of the XBee-PRO module, which has a maximum transmit output power of 10dBm.

AT Command: ATPL

Parameter Range: 0 - 4

Parameter	XBee	XBee-PRO	XBee-PRO International variant
0	-10 dBm	10 dBm	PL=4: 10 dBm
1	-6 dBm	12 dBm	PL=3: 8 dBm
2	-4 dBm	14 dBm	PL=2: 2 dBm
3	-2 dBm	16 dBm	PL=1: -3 dBm
4	0 dBm	18 dBm	PL=0: -3 dBm

Default Parameter Value: 4

PR (Pull-up Resistor) Command

<Serial Interfacing> The PR command is used to set and read the bit field that is used to configure internal the pull-up resistor status for I/O lines. "1" specifies the pull-up resistor is enabled. "0" specifies no pull up.

AT Command: ATPR
Parameter Range: 0 – 0xFF
Default Parameter Value: 0xFF (all pull-up resistors are enabled)
Minimum Firmware Version Required: v1.x80

bit 0 - AD4/DIO4 (pin 11)
bit 1 - AD3/DIO3 (pin 17)
bit 2 - AD2/DIO2 (pin 18)
bit 3 - AD1/DIO1 (pin 19)
bit 4 - AD0/DIO0 (pin 20)
bit 5 - AD6/DIO6 (pin 16)
bit 6 - DI8 (pin 9)
bit 7 - DIN/CONFIG (pin 3)

For example: Sending the command "ATPR 6F" will turn bits 0, 1, 2, 3, 5 and 6 ON; and bits 4 & 7 will be turned OFF. (The binary equivalent of "0x6F" is "01101111". Note that 'bit 0' is the last digit in the bitfield.

PT (PWM Output Timeout) Command

<I/O Settings {I/O Line Passing}> The PT command is used to set/read the output timeout value for both PWM outputs.

When PWM is set to a non-zero value: Due to I/O line passing, a time is started which when expired will set the PWM output to zero. The timer is reset when a valid I/O packet is received.

AT Command: ATPT
Parameter Range: 0 – 0xFF [x 100 msec]
Default Parameter Value: 0xFF
Minimum Firmware Version Required: 1.xA0

RE (Restore Defaults) Command

<(Special)> The RE command is used to restore all configurable parameters to their factory default settings. The RE command does not write restored values to non-volatile (persistent) memory. Issue the WR (Write) command subsequent to issuing the RE command to save restored parameter values to non-volatile memory.

AT Command: ATRE

RN (Random Delay Slots) Command

<Networking & Security> The RN command is used to set and read the minimum value of the back-off exponent in the CSMA-CA algorithm. The CSMA-CA algorithm was engineered for collision avoidance (random delays are inserted to prevent data loss caused by data collisions).

AT Command: ATRN
Parameter Range: 0 – 3 [exponent]
Default Parameter Value: 0

If RN = 0, collision avoidance is disabled during the first iteration of the algorithm (802.15.4 - macMinBE).

CSMA-CA stands for "Carrier Sense Multiple Access - Collision Avoidance". Unlike CSMA-CD (reacts to network transmissions after collisions have been detected), CSMA-CA acts to prevent data collisions before they occur. As soon as a module receives a packet that is to be transmitted, it checks if the channel is clear (no other module is transmitting). If the channel is clear, the packet is sent over-the-air. If the channel is not clear, the module waits for a randomly selected period of time, then checks again to see if the channel is clear. After a time, the process ends and the data is lost.

RO (Packetization Timeout) Command

AT Command: ATRO
Parameter Range:0 – 0xFF [x character times]
Default Parameter Value: 3

<Serial Interfacing> RO command is used to set and read the number of character times of inter-character delay required before transmission.

RF transmission commences when data is detected in the DI (data in from host) buffer and RO character times of silence are detected on the UART receive lines (after receiving at least 1 byte).

RF transmission will also commence after 100 Bytes (maximum packet size) are received in the DI buffer.

Set the RO parameter to '0' to transmit characters as they arrive instead of buffering them into one RF packet.

RP (RSSI PWM Timer) Command

AT Command: ATRP
Parameter Range:0 – 0xFF [x 100 msec]
Default Parameter Value: 0x28 (40 decimal)

<I/O Settings {I/O Line Passing}> The RP command is used to enable PWM (Pulse Width Modulation) output on the RF module. The output is calibrated to show the level a received RF signal is above the sensitivity level of the module. The PWM pulses vary from 24 to 100%. Zero percent means PWM output is inactive. One to 24% percent means the received RF signal is at or below the published sensitivity level of the module. The following table shows levels above sensitivity and PWM values.

The total period of the PWM output is 64 µs. Because there are 445 steps in the PWM output, the minimum step size is 144 ns.

PWM Percentages

dB above Sensitivity	PWM percentage (high period / total period)
10	41%
20	58%
30	75%

A non-zero value defines the time that the PWM output will be active with the RSSI value of the last received RF packet. After the set time when no RF packets are received, the PWM output will be set low (0 percent PWM) until another RF packet is received. The PWM output will also be set low at power-up until the first RF packet is received. A parameter value of 0xFF permanently enables the PWM output and it will always reflect the value of the last received RF packet.

RR (XBee Retries) Command

AT Command: ATRR
Parameter Range: 0 – 6
Default: 0
Minimum Firmware Version Required: 1.xA0

<Networking {Addressing}> The RR command is used set/read the maximum number of retries the module will execute in addition to the 3 retries provided by the 802.15.4 MAC. For each XBee retry, the 802.15.4 MAC can execute up to 3 retries.

This values does not need to be set on all modules for retries to work. If retries are enabled, the transmitting module will set a bit in the Digi RF Packet header which requests the receiving module to send an ACK (acknowledgement). If the transmitting module does not receive an ACK within 200 msec, it will re-send the packet within a random period up to 48 msec. Each XBee retry can potentially result in the MAC sending the packet 4 times (1 try plus 3 retries). Note that retries are not attempted for packets that are purged when transmitting with a Cyclic Sleep Coordinator.

SC (Scan Channels) Command

<Networking {Association}> The SC command is used to set and read the list of channels to scan for all Active and Energy Scans as a bit field.

This affects scans initiated in command mode [AS (Active Scan) and ED (Energy Scan) commands] and during End Device Association and Coordinator startup.

AT Command: ATSC
Parameter Range: 1-0xFFFF [Bitfield] (bits 0, 14, 15 are not allowed when using the XBee-PRO)
Default Parameter Value: 0x1FFE (all XBee-PRO channels)
Related Commands: ED (Energy Scan), SD (Scan Duration)
Minimum Firmware Version Required: v1.x80

bit 0 - 0x0B	bit 4 - 0x0F	bit 8 - 0x13	bit 12 - 0x17
bit 1 - 0x0C	bit 5 - 0x10	bit 9 - 0x14	bit 13 - 0x18
bit 2 - 0x0D	bit 6 - 0x11	bit 10 - 0x15	bit 14 - 0x19
bit 3 - 0x0E	bit 7 - 0x12	bit 11 - 0x16	bit 15 - 0x1A

SD (Scan Duration) Command

<Networking {Association}> The SD command is used to set and read the exponent value that determines the duration (in time) of a scan.

End Device (Duration of Active Scan during Association) - In a Beacon system, set SD = BE of the Coordinator. SD must be set at least to the highest BE parameter of any Beaconing Coordinator with which an End Device or Coordinator wish to discover.

AT Command: ATSD
Parameter Range: 0 – 0x0F
Default Parameter Value: 4
Related Commands: ED (Energy Scan), SC (Scan Channel)
Minimum Firmware Version Required: v1.x80

Coordinator - If the 'ReassignPANID' option is set on the Coordinator [refer to A2 parameter], the SD parameter determines the length of time the Coordinator will scan channels to locate existing PANs. If the 'ReassignChannel' option is set, SD determines how long the Coordinator will perform an Energy Scan to determine which channel it will operate on.

Scan Time is measured as ((# of Channels to Scan) * (2 ^ SD) * 15.36ms). The number of channels to scan is set by the SC command. The XBee RF Module can scan up to 16 channels (SC = 0xFFFF). The XBee PRO RF Module can scan up to 12 channels (SC = 0x1FFE).

Examples: Values below show results for a 12-channel scan

If SD = 0, time = 0.18 sec	SD = 8, time = 47.19 sec
SD = 2, time = 0.74 sec	SD = 10, time = 3.15 min
SD = 4, time = 2.95 sec	SD = 12, time = 12.58 min
SD = 6, time = 11.80 sec	SD = 14, time = 50.33 min

SH (Serial Number High) Command

<Diagnostics> The SH command is used to read the high 32 bits of the RF module's unique IEEE 64-bit address.

The module serial number is set at the factory and is read-only.

AT Command: ATSH
Parameter Range: 0 – 0xFFFFFFFF [read-only]
Related Commands: SL (Serial Number Low), MY (Source Address)

SL (Serial Number Low) Command

<Diagnostics> The SL command is used to read the low 32 bits of the RF module's unique IEEE 64-bit address.

The module serial number is set at the factory and is read-only.

AT Command: ATSL
Parameter Range: 0 – 0xFFFFFFFF [read-only]
Related Commands: SH (Serial Number High), MY (Source Address)

SM (Sleep Mode) Command

<Sleep Mode (Low Power)> The SM command is used to set and read Sleep Mode settings. By default, Sleep Modes are disabled (SM = 0) and the RF module remains in Idle/Receive Mode. When in this state, the module is constantly ready to respond to either serial or RF activity.

* The Sleep Coordinator option (SM=6) only exists for backwards compatibility with firmware version 1.x06 only. In all other cases, use the CE command to enable a Coordinator.

AT Command: ATSM

Parameter Range: 0 - 6

Parameter	Configuration
0	Disabled
1	Pin Hibernate
2	Pin Doze
3	(reserved)
4	Cyclic Sleep Remote
5	Cyclic Sleep Remote (with Pin Wake-up)
6	Sleep Coordinator*

Default Parameter Value: 0

SO (Sleep Mode Command)

Sleep (Low Power) Sleep Options Set/Read the sleep mode options.

Bit 0 - Poll wakeup disable

- 0 - Normal operations. A module configured for cyclic sleep will poll for data on waking.
- 1 - Disable wakeup poll. A module configured for cyclic sleep will not poll for data on waking.

Bit 1 - ADC/DIO wakeup sampling disable.

- 0 - Normal operations. A module configured in a sleep mode with ADC/DIO sampling enabled will automatically perform a sampling on wakeup.
- 1 - Suppress sample on wakeup. A module configured in a sleep mode with ADC/DIO sampling enabled will not automatically sample on wakeup.

AT Command: ATSO

Parameter Range:	0-4
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep), DP (Disassociation Cyclic Sleep Period, BE (Beacon Order)	

SP (Cyclic Sleep Period) Command

<Sleep Mode (Low Power)> The SP command is used to set and read the duration of time in which a remote RF module sleeps. After the cyclic sleep period is over, the module wakes and checks for data. If data is not present, the module goes back to sleep. The maximum sleep period is 268 seconds (SP = 0x68B0).

The SP parameter is only valid if the module is configured to operate in Cyclic Sleep (SM = 4-6). Coordinator and End Device SP values should always be equal.

To send Direct Messages, set SP = 0.

AT Command: ATSP

Parameter Range:	NonBeacon Firmware: 0-0x68B0 [x 10 milliseconds]
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep), DP (Disassociation Cyclic Sleep Period, BE (Beacon Order)	

NonBeacon Firmware

End Device - SP determines the sleep period for cyclic sleeping remotes. Maximum sleep period is 268 seconds (0x68B0).

Coordinator - If non-zero, SP determines the time to hold an indirect message before discarding it. A Coordinator will discard indirect messages after a period of (2.5 * SP).

ST (Time before Sleep) Command

<Sleep Mode (Low Power)> The ST command is used to set and read the period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode.

NonBeacon Firmware

Set/Read time period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode. ST parameter is only valid with Cyclic Sleep settings (SM = 4 - 5).

Coordinator and End Device ST values must be equal.

AT Command: ATST	
Parameter Range:	NonBeacon Firmware: 1 – 0xFFFF [x 1 millisecond]
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep)	

T0 - T7 ((D0-D7) Output Timeout) Command

AT Commands: ATT0 – ATT7	
Parameter Range:0 – 0xFF [x 100 msec]	
Default Parameter Value:0xFF	
Minimum Firmware Version Required: v1.xA0	

<I/O Settings {I/O Line Passing}> The T0, T1, T2, T3, T4, T5, T6 and T7 commands are used to set/read output timeout values for the lines that correspond with the D0 - D7 parameters. When output is set (due to I/O line passing) to a non-default level, a timer is started which when expired, will set the output to its default level. The timer is reset when a valid I/O packet is received. The Tn parameter defines the permissible amount of time to stay in a non-default (active) state. If Tn = 0, Output Timeout is disabled (output levels are held indefinitely).

VL (Firmware Version - Verbose)

AT Command: ATVL
Parameter Range:0 – 0xFF [x 100 milliseconds]
Default Parameter Value: 0x28 (40 decimal)
Minimum Firmware Version Required: v1.x80 – v1.xC8

<Diagnostics> The VL command is used to read detailed version information about the RF module. The information includes:
application build date; MAC, PHY and bootloader versions; and build dates. This command was removed from firmware 1xC9 and later versions.

VR (Firmware Version) Command

AT Command: ATVR
Parameter Range: 0 – 0xFFFF [read only]

<Diagnostics> The VR command is used to read which firmware version is stored in the module.

XBee version numbers will have four significant digits. The reported number will show three or four numbers and is stated in hexadecimal notation. A version can be reported as "ABC" or "ABCD". Digits ABC are the main release number and D is the revision number from the main release. "D" is not required and if it is not present, a zero is assumed for D. "B" is a variant designator. The following variants exist:

- "0" = Non-Beacon Enabled 802.15.4 Code
- "1" = Beacon Enabled 802.15.4 Code

WR (Write) Command

AT Command: ATWR

<(Special)> The WR command is used to write configurable parameters to the RF module's non-volatile memory. Parameter values remain in the module's memory until overwritten by subsequent use of the WR Command.

If changes are made without writing them to non-volatile memory, the module reverts back to previously saved parameters the next time the module is powered-on.

NOTE: Once the WR command is sent to the module, no additional characters should be sent until after the “OK/r” response is received.

API Operation

By default, XBee®/XBee-PRO® RF Modules act as a serial line replacement (Transparent Operation) - all UART data received through the DI pin is queued up for RF transmission. When the module receives an RF packet, the data is sent out the DO pin with no additional information.

Inherent to Transparent Operation are the following behaviors:

- If module parameter registers are to be set or queried, a special operation is required for transitioning the module into Command Mode.
- In point-to-multipoint systems, the application must send extra information so that the receiving module(s) can distinguish between data coming from different remotes.

As an alternative to the default Transparent Operation, API (Application Programming Interface) Operations are available. API operation requires that communication with the module be done through a structured interface (data is communicated in frames in a defined order). The API specifies how commands, command responses and module status messages are sent and received from the module using a UART Data Frame.

API Frame Specifications

Two API modes are supported and both can be enabled using the AP (API Enable) command. Use the following AP parameter values to configure the module to operate in a particular mode:

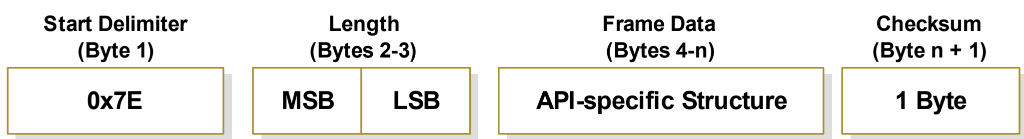
- AP = 0 (default): Transparent Operation (UART Serial line replacement)
  API modes are disabled.
- AP = 1: API Operation
- AP = 2: API Operation (with escaped characters)

Any data received prior to the start delimiter is silently discarded. If the frame is not received correctly or if the checksum fails, the data is silently discarded.

API Operation (AP parameter = 1)

When this API mode is enabled (AP = 1), the UART data frame structure is defined as follows:

Figure 3-01. UART Data Frame Structure:

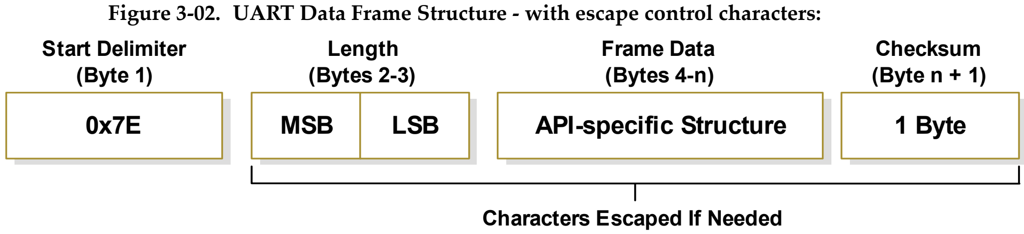


MSB = Most Significant Byte, LSB = Least Significant Byte

API Operation - with Escape Characters (AP parameter = 2)

When this API mode is enabled (AP = 2), the UART data frame structure is defined as follows:

Figure 3-02. UART Data Frame Structure - with escape control characters:



MSB = Most Significant Byte, LSB = Least Significant Byte

Escape characters. When sending or receiving a UART data frame, specific data values must be escaped (flagged) so they do not interfere with the UART or UART data frame operation. To escape an interfering data byte, insert 0x7D and follow it with the byte to be escaped XOR'd with 0x20.

Data bytes that need to be escaped:

- 0x7E – Frame Delimiter
- 0x7D – Escape
- 0x11 – XON
- 0x13 – XOFF

Example - Raw UART Data Frame (before escaping interfering bytes):
0x7E 0x00 0x02 0x23 0x11 0xCB

0x11 needs to be escaped which results in the following frame:
0x7E 0x00 0x02 0x23 0x7D 0x31 0xCB

Note: In the above example, the length of the raw data (excluding the checksum) is 0x0002 and the checksum of the non-escaped data (excluding frame delimiter and length) is calculated as: 0xFF - (0x23 + 0x11) = (0xFF - 0x34) = 0xCB.

Checksum

To test data integrity, a checksum is calculated and verified on non-escaped data.

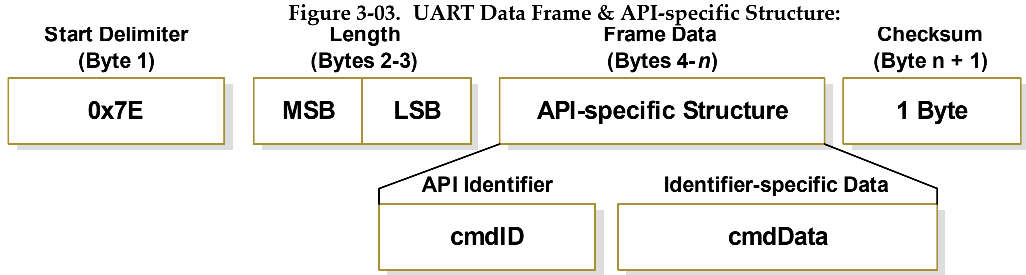
To calculate: Not including frame delimiters and length, add all bytes keeping only the lowest 8 bits of the result and subtract from 0xFF.

To verify: Add all bytes (include checksum, but not the delimiter and length). If the checksum is correct, the sum will equal 0xFF.

API Types

Frame data of the UART data frame forms an API-specific structure as follows:

Figure 3-03. UART Data Frame & API-specific Structure:

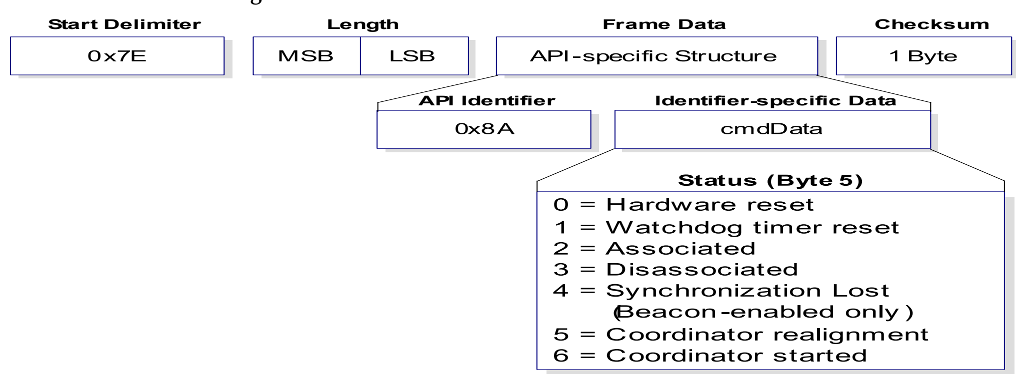


The cmdID frame (API-identifier) indicates which API messages will be contained in the cmdData frame (Identifier-specific data). Refer to the sections that follow for more information regarding the supported API types. Note that multi-byte values are sent big endian.

Modem Status

API Identifier: 0x8A
RF module status messages are sent from the module in response to specific conditions.

Figure 3-04. Modem Status Frames



AT Command

API Identifier Value: 0x08

The "AT Command" API type allows for module parameters to be queried or set. When using this command ID, new parameter values are applied immediately. This includes any register set with the "AT Command - Queue Parameter Value" (0x09) API type.

Figure 3-05. AT Command Frames

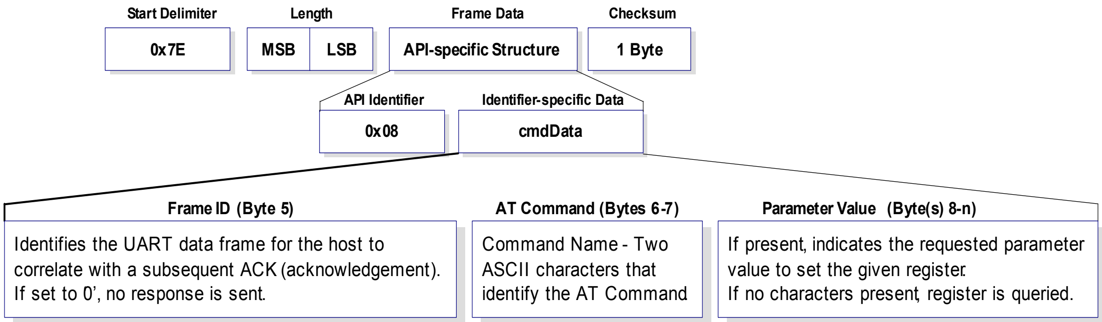


Figure 3-06. Example: API frames when reading the DL parameter value of the module.

Byte 1	Bytes 2-3		Byte 4	Byte 5	Bytes 6-7		Byte 8
0x7E	0x00	0x04	0x08	0x52 (R)	0x44 (D)	0x4C (L)	0x15
Start Delimiter	Length*		API Identifier	Frame ID**	AT Command		Checksum

** Length [Bytes] = API Identifier + Frame ID + AT Command*

*** "R" value was arbitrarily selected.*

Figure 3-07. Example: API frames when modifying the DL parameter value of the module.

Byte 1	Bytes 2-3		Byte 4	Byte 5	Bytes 6-7		Bytes 8-11	Byte 12
0x7E	0x00	0x08	0x08	0x4D (M)	0x44 (D)	0x4C (L)	0x00000FFF	0x0C
Start Delimiter	Length*		API Identifier	Frame ID**	AT Command		Parameter Value	Checksum

** Length [Bytes] = API Identifier + Frame ID + AT Command + Parameter Value*

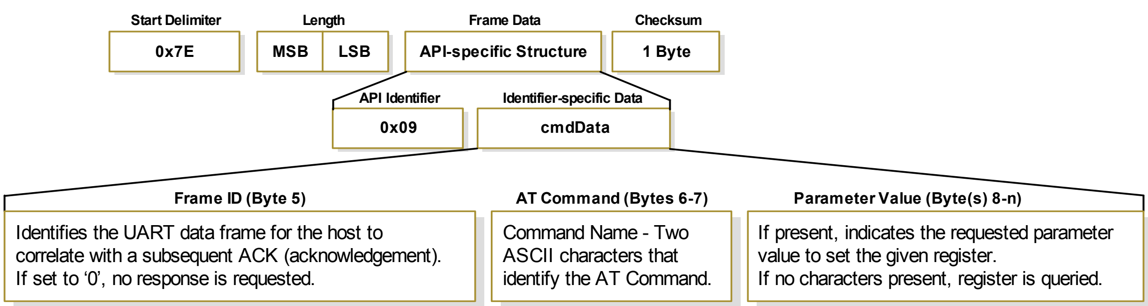
*** "M" value was arbitrarily selected.*

AT Command - Queue Parameter Value

API Identifier Value: 0x09

This API type allows module parameters to be queried or set. In contrast to the "AT Command" API type, new parameter values are queued and not applied until either the "AT Command" (0x08) API type or the AC (Apply Changes) command is issued. Register queries (reading parameter values) are returned immediately.

Figure 3-08. AT Command Frames
(Note that frames are identical to the "AT Command" API type except for the API identifier.)



AT Command Response

API Identifier Value: 0x88

Response to previous command.

In response to an AT Command message, the module will send an AT Command Response message. Some commands will send back multiple frames (for example, the ND (Node Discover) and AS (Active Scan) commands). These commands will end by sending a frame with a status of ATCMD_OK and no cmdData.

Figure 3-09. AT Command Response Frames.

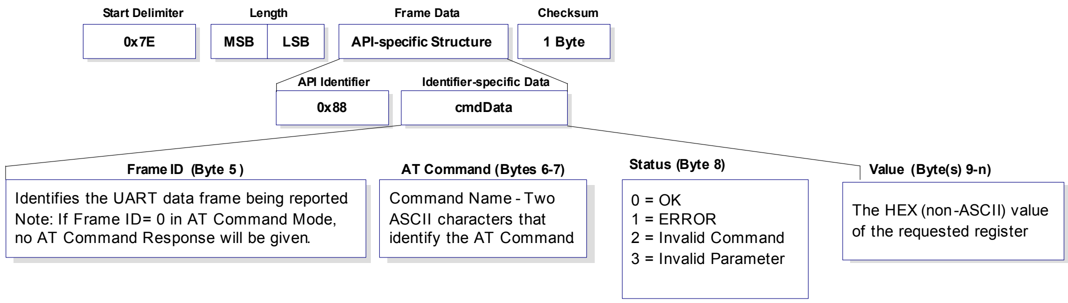
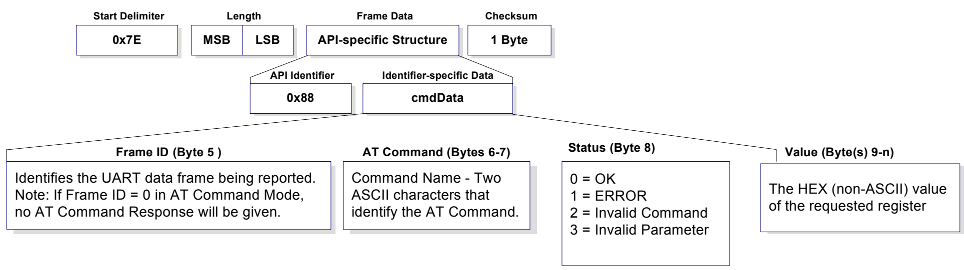


Figure 3-10. AT Command Response Frames.

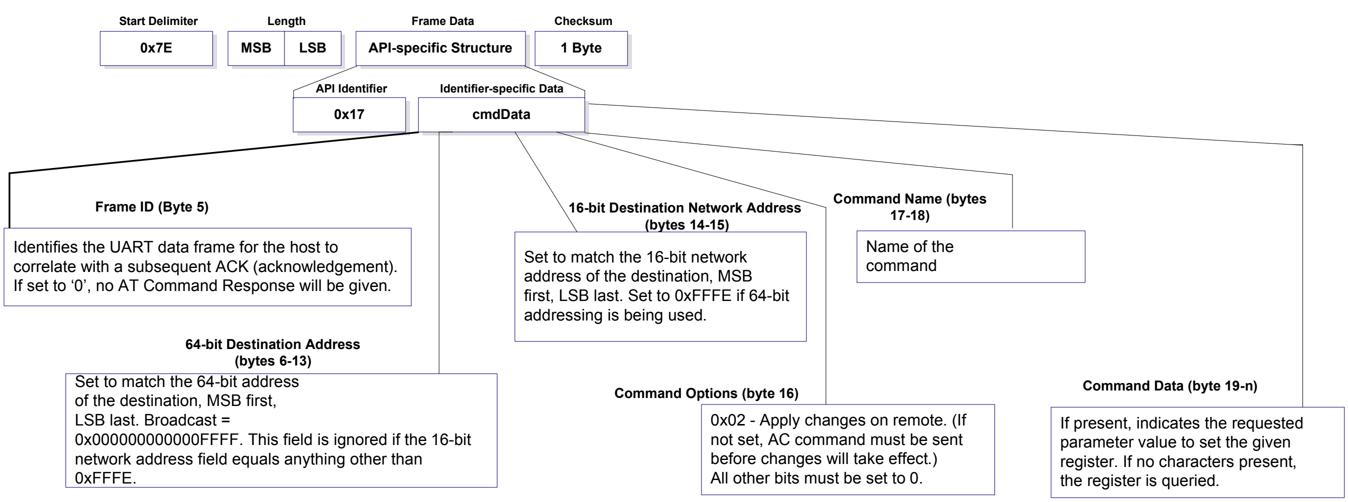


Remote AT Command Request

API Identifier Value: 0x17

Allows for module parameter registers on a remote device to be queried or set

Figure 3-11. Remote AT Command Request

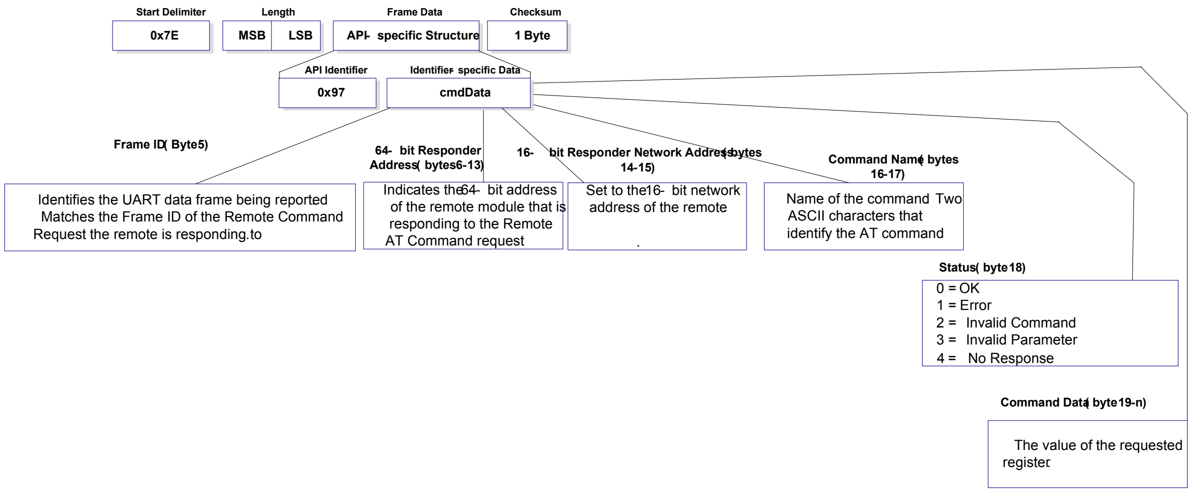


Remote Command Response

API Identifier Value: 0x97

If a module receives a remote command response RF data frame in response to a Remote AT Command Request, the module will send a Remote AT Command Response message out the UART. Some commands may send back multiple frames--for example, Node Discover (ND) command.

Figure 3-12. Remote AT Command Response.

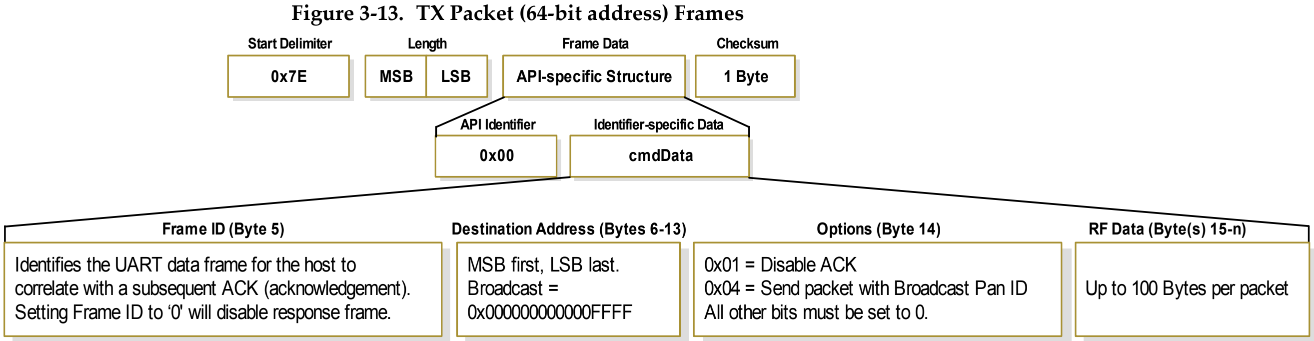


TX (Transmit) Request: 64-bit address

API Identifier Value: 0x00

A TX Request message will cause the module to send RF Data as an RF Packet.

Figure 3-13. TX Packet (64-bit address) Frames

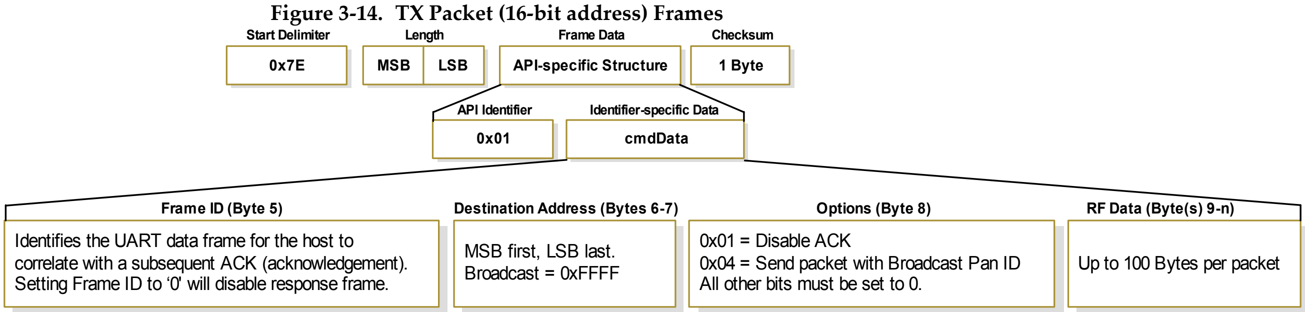


TX (Transmit) Request: 16-bit address

API Identifier Value: 0x01

A TX Request message will cause the module to send RF Data as an RF Packet.

Figure 3-14. TX Packet (16-bit address) Frames

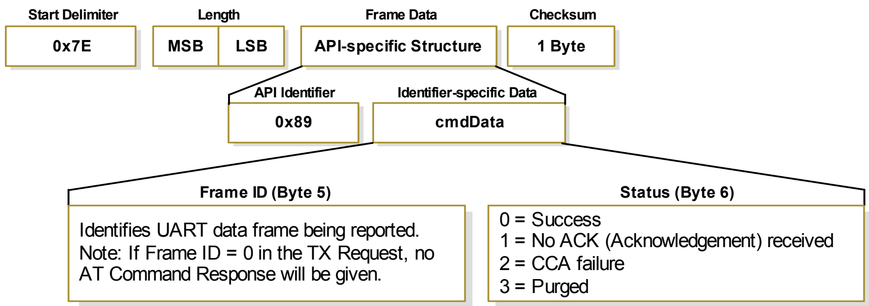


TX (Transmit) Status

API Identifier Value: 0x89

When a TX Request is completed, the module sends a TX Status message. This message will indicate if the packet was transmitted successfully or if there was a failure.

Figure 3-15. TX Status Frames



NOTES:

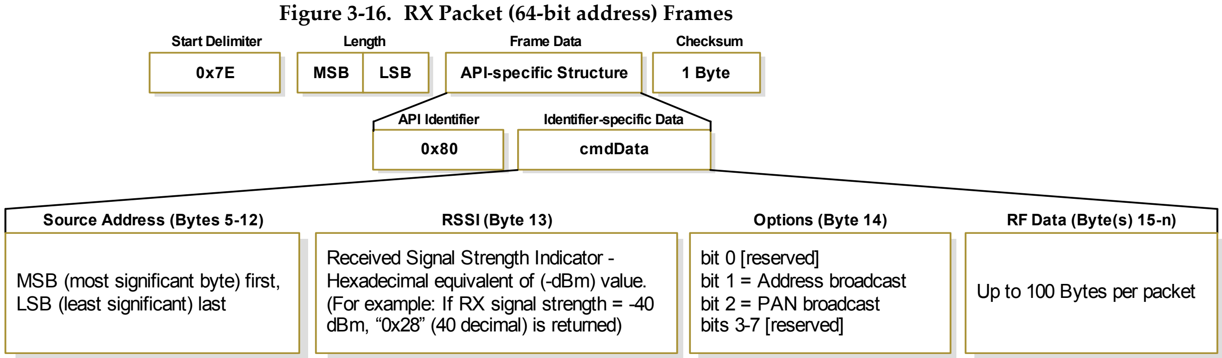
- "STATUS = 1" occurs when all retries are expired and no ACK is received.
- If transmitter broadcasts (destination address = 0x000000000000FFFF), only "STATUS = 0 or 2" will be returned.
- "STATUS = 3" occurs when Coordinator times out of an indirect transmission. Timeout is defined as (2.5 x SP (Cyclic Sleep Period) parameter value).

RX (Receive) Packet: 64-bit Address

API Identifier Value: 0x80

When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-16. RX Packet (64-bit address) Frames

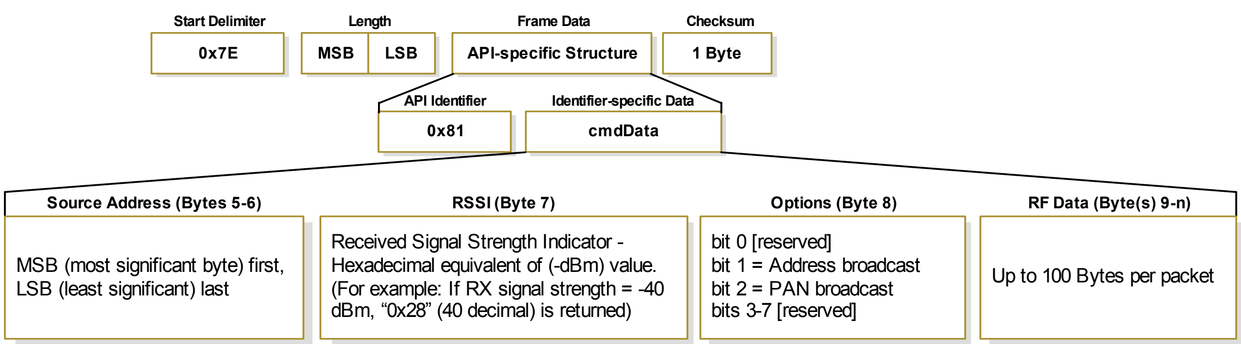


RX (Receive) Packet: 16-bit Address

API Identifier Value: 0x81

When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-17. RX Packet (16-bit address) Frames



Appendix A: Agency Certifications

United States (FCC)

XBee®/XBee-PRO® RF Modules comply with Part 15 of the FCC rules and regulations. Compliance with the labeling requirements, FCC notices and antenna usage guidelines is required.

To fulfill FCC Certification requirements, the OEM must comply with the following regulations:

1. The system integrator must ensure that the text on the external label provided with this device is placed on the outside of the final product [Figure A-01].
2. XBee®/XBee-PRO® RF Modules may only be used with antennas that have been tested and approved for use with this module [refer to the antenna tables in this section].

OEM Labeling Requirements

WARNING: The Original Equipment Manufacturer (OEM) must ensure that FCC labeling requirements are met. This includes a clearly visible label on the outside of the final product enclosure that displays the contents shown in the figure below.

Figure 4-01. Required FCC Label for OEM products containing the XBee®/XBee-PRO® RF Module

Contains FCC ID: OUR-XBEE/OUR-XBEEPRO**

The enclosed device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (*i.*) this device may not cause harmful interference and (*ii.*) this device must accept any interference received, including interference that may cause undesired operation.

* The FCC ID for the XBee is “OUR-XBEE”. The FCC ID for the XBee-PRO is “OUR-XBEEPRO”.

FCC Notices

IMPORTANT: The XBee®/XBee-PRO® RF Module has been certified by the FCC for use with other products without any further certification (as per FCC section 2.1091). Modifications not expressly approved by Digi could void the user's authority to operate the equipment.

IMPORTANT: OEMs must test final product to comply with unintentional radiators (FCC section 15.107 & 15.109) before declaring compliance of their final product to Part 15 of the FCC Rules.

IMPORTANT: The RF module has been certified for remote and base radio applications. If the module will be used for portable applications, the device must undergo SAR testing.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation.

If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures: Re-orient or relocate the receiving antenna, Increase the separation between the equipment and receiver, Connect equipment and receiver to outlets on different circuits, or Consult the dealer or an experienced radio/TV technician for help.

FCC-Approved Antennas (2.4 GHz)

XBee/XBee-PRO RF Modules can be installed using antennas and cables constructed with standard connectors (Type-N, SMA, TNC, etc.) if the installation is performed professionally and according to FCC guidelines. For installations not performed by a professional, non-standard connectors (RPSMA, RPTNC, etc) must be used.

The modules are FCC-approved for fixed base station and mobile applications on channels 0x0B - 0x1A (XBee) and 0x0C - 0x17 (XBee-PRO). If the antenna is mounted at least 20cm (8 in.) from nearby persons, the application is considered a mobile application. Antennas not listed in the table must be tested to comply with FCC Section 15.203 (Unique Antenna Connectors) and Section 15.247 (Emissions).

XBee RF Modules (1 mW): XBee Modules have been tested and approved for use with all of the antennas listed in the tables below (Cable-loss IS NOT required).

XBee-PRO RF Modules (60 mW): XBee-PRO Modules have been tested and approved for use with the antennas listed in the tables below (Cable-loss IS required when using antennas listed in the second table.

The antennas in the tables below have been approved for use with this module. Digi does not carry all of these antenna variants. Contact Digi Sales for available antennas.

Antennas approved for use with the XBee®/XBee-PRO® RF Modules (Cable-loss is not required.)

Part Number	Type (Description)	Gain	Application*	Min. Separation
A24-HASM-450	Dipole (Half-wave articulated RPSMA - 4.5”)	2.1 dBi	Fixed/Mobile	20 cm
A24-HABSM	Dipole (Articulated RPSMA)	2.1 dBi	Fixed	20 cm
A24-HABUF-P5I	Dipole (Half-wave articulated bulkhead mount U.FL. w/ 5” pigtail)	2.1 dBi	Fixed	20 cm
A24-HASM-525	Dipole (Half-wave articulated RPSMA - 5.25")	2.1 dBi	Fixed/Mobile	20 cm
A24-QI	Monopole (Integrated whip)	1.5 dBi	Fixed	20 cm

Antennas approved for use with the XBee RF Modules (Cable-loss is required)

Part Number	Type (Description)	Gain	Application*	Min. Separation	Required Cable-loss
Omni-Directional Class Antennas					
A24-Y6NF	Yagi (6-element)	8.8 dBi	Fixed	2 m	1.7 dB
A24-Y7NF	Yagi (7-element)	9.0 dBi	Fixed	2 m	1.9 dB
A24-Y9NF	Yagi (9-element)	10.0 dBi	Fixed	2 m	2.9 dB
A24-Y10NF	Yagi (10-element)	11.0 dBi	Fixed	2 m	3.9 dB
A24-Y12NF	Yagi (12-element)	12.0 dBi	Fixed	2 m	4.9 dB
A24-Y13NF	Yagi (13-element)	12.0 dBi	Fixed	2 m	4.9 dB
A24-Y15NF	Yagi (15-element)	12.5 dBi	Fixed	2 m	5.4 dB
A24-Y16NF	Yagi (16-element)	13.5 dBi	Fixed	2 m	6.4 dB
A24-Y16RM	Yagi (16-element, RPSMA connector)	13.5 dBi	Fixed	2 m	6.4 dB
A24-Y18NF	Yagi (18-element)	15.0 dBi	Fixed	2 m	7.9 dB
Omni-Directional Class Antennas					
A24-C1	Surface Mount	-1.5 dBi	Fixed/Mobile	20 cm	-
A24-F2NF	Omni-directional (Fiberglass base station)	2.1 dBi	Fixed/Mobile	20 cm	
A24-F3NF	Omni-directional (Fiberglass base station)	3.0 dBi	Fixed/Mobile	20 cm	
A24-F5NF	Omni-directional (Fiberglass base station)	5.0 dBi	Fixed/Mobile	20 cm	
A24-F8NF	Omni-directional (Fiberglass base station)	8.0 dBi	Fixed	2 m	
A24-F9NF	Omni-directional (Fiberglass base station)	9.5 dBi	Fixed	2 m	0.2 dB
A24-F10NF	Omni-directional (Fiberglass base station)	10.0 dBi	Fixed	2 m	0.7 dB
A24-F12NF	Omni-directional (Fiberglass base station)	12.0 dBi	Fixed	2 m	2.7 dB
A24-F15NF	Omni-directional (Fiberglass base station)	15.0 dBi	Fixed	2 m	5.7 dB
A24-W7NF	Omni-directional (Base station)	7.2 dBi	Fixed	2 m	
A24-M7NF	Omni-directional (Mag-mount base station)	7.2 dBi	Fixed	2 m	
Panel Class Antennas					
A24-P8SF	Flat Panel	8.5 dBi	Fixed	2 m	1.5 dB
A24-P8NF	Flat Panel	8.5 dBi	Fixed	2 m	1.5 dB
A24-P13NF	Flat Panel	13.0 dBi	Fixed	2 m	6 dB
A24-P14NF	Flat Panel	14.0 dBi	Fixed	2 m	7 dB
A24-P15NF	Flat Panel	15.0 dBi	Fixed	2 m	8 dB
A24-P16NF	Flat Panel	16.0 dBi	Fixed	2 m	9 dB

Antennas approved for use with the XBee®/XBee-PRO® RF Modules (Cable-loss is required)

Part Number	Type (Description)	Gain	Application*	Min. Separation	Required Cable-loss
A24-C1	Surface Mount	-1.5 dBi	Fixed/Mobile	20 cm	-
A24-Y4NF	Yagi (4-element)	6.0 dBi	Fixed	2 m	8.1 dB
A24-Y6NF	Yagi (6-element)	8.8 dBi	Fixed	2 m	10.9 dB
A24-Y7NF	Yagi (7-element)	9.0 dBi	Fixed	2 m	11.1 dB
A24-Y9NF	Yagi (9-element)	10.0 dBi	Fixed	2 m	12.1 dB
A24-Y10NF	Yagi (10-element)	11.0 dBi	Fixed	2 m	13.1 dB
A24-Y12NF	Yagi (12-element)	12.0 dBi	Fixed	2 m	14.1 dB
A24-Y13NF	Yagi (13-element)	12.0 dBi	Fixed	2 m	14.1 dB
A24-Y15NF	Yagi (15-element)	12.5 dBi	Fixed	2 m	14.6 dB
A24-Y16NF	Yagi (16-element)	13.5 dBi	Fixed	2 m	15.6 dB
A24-Y16RM	Yagi (16-element, RPSMA connector)	13.5 dBi	Fixed	2 m	15.6 dB
A24-Y18NF	Yagi (18-element)	15.0 dBi	Fixed	2 m	17.1 dB
A24-F2NF	Omni-directional (Fiberglass base station)	2.1 dBi	Fixed/Mobile	20 cm	4.2 dB
A24-F3NF	Omni-directional (Fiberglass base station)	3.0 dBi	Fixed/Mobile	20 cm	5.1 dB
A24-F5NF	Omni-directional (Fiberglass base station)	5.0 dBi	Fixed/Mobile	20 cm	7.1 dB
A24-F8NF	Omni-directional (Fiberglass base station)	8.0 dBi	Fixed	2 m	10.1 dB
A24-F9NF	Omni-directional (Fiberglass base station)	9.5 dBi	Fixed	2 m	11.6 dB
A24-F10NF	Omni-directional (Fiberglass base station)	10.0 dBi	Fixed	2 m	12.1 dB
A24-F12NF	Omni-directional (Fiberglass base station)	12.0 dBi	Fixed	2 m	14.1 dB
A24-F15NF	Omni-directional (Fiberglass base station)	15.0 dBi	Fixed	2 m	17.1 dB
A24-W7NF	Omni-directional (Base station)	7.2 dBi	Fixed	2 m	9.3 dB
A24-M7NF	Omni-directional (Mag-mount base station)	7.2 dBi	Fixed	2 m	9.3 dB
A24-P8SF	Flat Panel	8.5 dBi	Fixed	2 m	8.6 dB
A24-P8NF	Flat Panel	8.5 dBi	Fixed	2 m	8.6 dB
A24-P13NF	Flat Panel	13.0 dBi	Fixed	2 m	13.1 dB
A24-P14NF	Flat Panel	14.0 dBi	Fixed	2 m	14.1 dB
A24-P15NF	Flat Panel	15.0 dBi	Fixed	2 m	15.1 dB
A24-P16NF	Flat Panel	16.0 dBi	Fixed	2 m	16.1 dB
A24-P19NF	Flat Panel	19.0 dBi	Fixed	2 m	19.1 dB

*** If using the RF module in a portable application** (For example - If the module is used in a handheld device and the antenna is less than 20cm from the human body when the device is operation): The integrator is responsible for passing additional SAR (Specific Absorption Rate) testing based on FCC rules 2.1091 and FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields, OET Bulletin and Supplement C. The testing results will be submitted to the FCC for approval prior to selling the integrated unit. The required SAR testing measures emissions from the module and how they affect the person.

RF Exposure

WARNING: To satisfy FCC RF exposure requirements for mobile transmitting devices, a separation distance of 20 cm or more should be maintained between the antenna of this device and persons during device operation. To ensure compliance, operations at closer than this distance is not recommended. The antenna used for this transmitter must not be co-located in conjunction with any other antenna or transmitter.

The preceding statement must be included as a CAUTION statement in OEM product manuals in order to alert users of FCC RF Exposure compliance.

Europe (ETSI)

The XBee RF Modules have been certified for use in several European countries. For a complete list, refer to www.digi.com

If the XBee RF Modules are incorporated into a product, the manufacturer must ensure compliance of the final product to the European harmonized EMC and low-voltage/safety standards. A Declaration of Conformity must be issued for each of these standards and kept on file as described in Annex II of the R&TTE Directive.

Furthermore, the manufacturer must maintain a copy of the XBee user manual documentation and ensure the final product does not exceed the specified power ratings, antenna specifications, and/or installation requirements as specified in the user manual. If any of these specifications are exceeded in the final product, a submission must be made to a notified body for compliance testing to all required standards.

OEM Labeling Requirements

The 'CE' marking must be affixed to a visible location on the OEM product.

CE Labeling Requirements

The CE mark shall consist of the initials "CE" taking the following form:

- If the CE marking is reduced or enlarged, the proportions given in the above graduated drawing must be respected.
- The CE marking must have a height of at least 5mm except where this is not possible on account of the nature of the apparatus.
- The CE marking must be affixed visibly, legibly, and indelibly.

Restrictions

Power Output: When operating in Europe, XBee-PRO 802.15.4 modules must operate at or below a transmit power output level of 10dBm. Customers have two choices for transmitting at or below 10dBm:

a. Order the standard XBee-PRO module and change the PL command to 0 (10dBm)

b. Order the International variant of the XBee-PRO module, which has a maximum transmit output power of 10dBm (@ PL=4).

Additionally, European regulations stipulate an EIRP power maximum of 12.86 dBm (19 mW) for the XBee-PRO and 12.11 dBm for the XBee when integrating antennas.

France: Outdoor use limited to 10 mW EIRP within the band 2454-2483.5 MHz.

Norway: Norway prohibits operation near Ny-Alesund in Svalbard. More information can be found at the Norway Posts and Telecommunications site (www.npt.no).

Declarations of Conformity

Digi has issued Declarations of Conformity for the XBee RF Modules concerning emissions, EMC and safety. Files can be obtained by contacting Digi Support.

Important Note:

Digi does not list the entire set of standards that must be met for each country. Digi customers assume full responsibility for learning and meeting the required guidelines for each country in their distribution market. For more information relating to European compliance of an OEM product incorporating the XBee RF Module, contact Digi, or refer to the following web sites:

CEPT ERC 70-03E - Technical Requirements, European restrictions and general requirements: Available at www.ero.dk/.

R&TTE Directive - Equipment requirements, placement on market: Available at www.ero.dk/.

Approved Antennas

When integrating high-gain antennas, European regulations stipulate EIRP power maximums. Use the following guidelines to determine which antennas to design into an application.

XBee-PRO RF Module

The following antenna types have been tested and approved for use with the XBee Module:

Antenna Type: Yagi
RF module was tested and approved with 15 dBi antenna gain with 1 dB cable-loss (EIRP Maximum of 14 dBm). Any Yagi type antenna with 14 dBi gain or less can be used with no cable-loss.

Antenna Type: Omni-directional
RF module was tested and approved with 15 dBi antenna gain with 1 dB cable-loss (EIRP Maxi-

mum of 14 dBm). Any Omni-directional type antenna with 14 dBi gain or less can be used with no cable-loss.

Antenna Type: Flat Panel
RF module was tested and approved with 19 dBi antenna gain with 4.8 dB cable-loss (EIRP Maximum of 14.2 dBm). Any Flat Panel type antenna with 14.2 dBi gain or less can be used with no cable-loss.

XBee-PRO RF Module (@ 10 dBm Transmit Power, PL parameter value must equal 0, or use International variant)

The following antennas have been tested and approved for use with the embedded XBee-PRO RF Module:

- Dipole (2.1 dBi, Omni-directional, Articulated RPSMA, Digi part number A24-HABSM)
- Chip Antenna (-1.5 dBi)
- Attached Monopole Whip (1.5 dBi)

The RF modem encasement was designed to accommodate the RPSMA antenna option.

Canada (IC)

Labeling Requirements

Labeling requirements for Industry Canada are similar to those of the FCC. A clearly visible label on the outside of the final product enclosure must display the following text:

Contains Model XBee Radio, IC: 4214A-XBEE
Contains Model XBee-PRO Radio, IC: 4214A-XBEEPRO

The integrator is responsible for its product to comply with IC ICES-003 & FCC Part 15, Sub. B - Unintentional Radiators. ICES-003 is the same as FCC Part 15 Sub. B and Industry Canada accepts FCC test report or CISPR 22 test report for compliance with ICES-003.

Japan

In order to gain approval for use in Japan, the XBee RF module or the International variant of the XBee-PRO RF module (which has 10 dBm transmit output power) must be used.

Labeling Requirements

A clearly visible label on the outside of the final product enclosure must display the following text:

ID: 005NYCA0378

Appendix B. Additional Information

1-Year Warranty

XBee®/XBee-PRO® RF Modules from Digi Intenational, Inc. (the "Product") are warranted against defects in materials and workmanship under normal use, for a period of 1-year from the date of purchase. In the event of a product failure due to materials or workmanship, Digi will repair or replace the defective product. For warranty service, return the defective product to Digi, shipping prepaid, for prompt repair or replacement.

The foregoing sets forth the full extent of Digi's warranties regarding the Product. Repair or replacement at Digi's option is the exclusive remedy. THIS WARRANTY IS GIVEN IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, AND DIGI SPECIFICALLY DISCLAIMS ALL WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. IN NO EVENT SHALL DIGI, ITS SUPPLIERS OR LICENSORS BE LIABLE FOR DAMAGES IN EXCESS OF THE PURCHASE PRICE OF THE PRODUCT, FOR ANY LOSS OF USE, LOSS OF TIME, INCONVENIENCE, COMMERCIAL LOSS, LOST PROFITS OR SAVINGS, OR OTHER INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PRODUCT, TO THE FULL EXTENT SUCH MAY BE DISCLAIMED BY LAW. SOME STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES. THEREFORE, THE FOREGOING EXCLUSIONS MAY NOT APPLY IN ALL CASES. This warranty provides specific legal rights. Other rights which vary from state to state may also apply.