

Universidad de Costa Rica

Laboratorio V

STM32 Arduino: GPIO, Giroscopio, comunicaciones,
TinyML

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1. Resumen

2. Nota Teórica

2.1. Arduino Nano Sense 33 BLE Sense

El Arduino Nano 33 BLE Sense se presenta como un módulo de tamaño reducido que alberga el módulo NINA 8306, fundamentado en Nordic nRF52480. Internamente, integra un Cortex M4F, un chip criptográfico para el almacenamiento seguro de certificados y claves precompartidas, así como una unidad de medición inercial (IMU) de 9 ejes. Su concepción está orientada hacia el ámbito maker, mejoras y aplicaciones en el Internet de las cosas (IoT).

Una característica sobresaliente de esta placa es su módulo NINA B306, el cual emplea el núcleo ARM Cortex-M4 de 32 bits. Este microcontrolador ofrece un rendimiento eficaz y una eficiencia energética destacada, siendo capaz de operar a una frecuencia de reloj de hasta 64 MHz. Incluye una memoria flash de 1 MB y 256 KB de memoria RAM, otorgando un amplio espacio para el código del programa y los datos requeridos por las aplicaciones [1].

Otra característica importante es la variedad de periféricos integrados que facilitan una conectividad y funcionalidad versátiles. Entre estos periféricos se encuentran un acelerómetro de 6 ejes y un sensor de temperatura. Asimismo, dispone de un sensor de humedad, presión y luminosidad, lo que la convierte en una elección adecuada para proyectos que demandan monitoreo ambiental. Adicionalmente, la placa cuenta con conectividad Bluetooth de baja energía (BLE), posibilitando la comunicación inalámbrica con otros dispositivos y aplicaciones [1].

Proporciona una interfaz USB destinada a la programación y la comunicación con la computadora personal. Asimismo, dispone de pines tanto digitales como analógicos, junto con interfaces de comunicación como UART, SPI e I2C, simplificando la conexión con distintos dispositivos y periféricos [1].

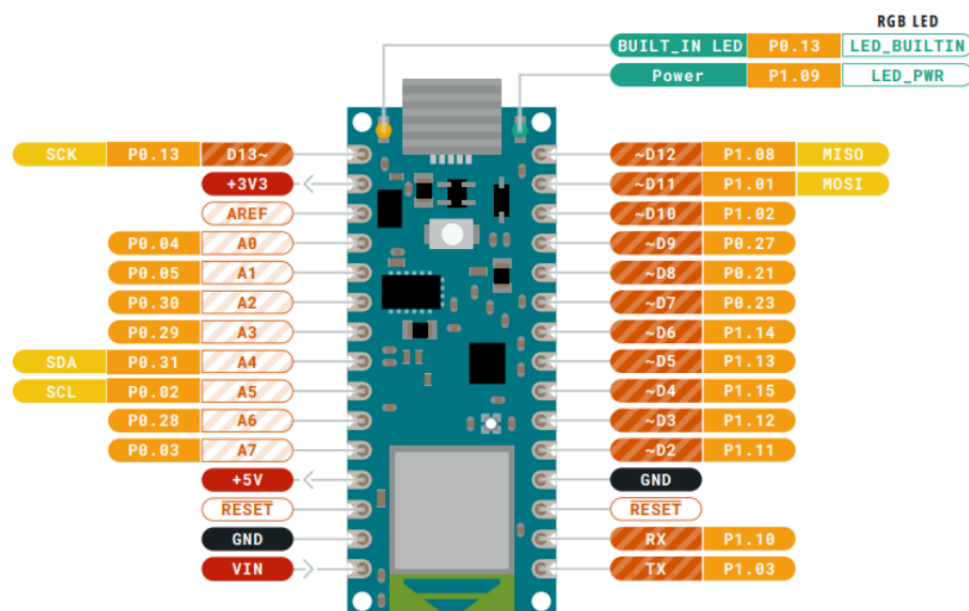


Figura 1: Diagrama de pines de Arduino Nano Sense 33 BLE Sense. [1]

Las características eléctricas generales se enlistan a continuación:

- **Alimentación:** La placa puede recibir energía a través del puerto USB o mediante una fuente externa, siempre respetando su tensión de operación de 3.3 V. Sin embargo, dado que VUSB suministra VIN a través de un diodo Schottky y un regulador DC-DC cuya tensión de entrada mínima especificada es de 4.5 V, la tensión de alimentación mínima desde USB debe aumentarse a un voltaje en el rango entre 4.8 V y 4.96 V, dependiendo de la corriente consumida.
- **Temperatura de Operación:** El rango de temperatura de operación se sitúa entre -40° C y 85° C [1].

2.2. Microcontrolador nRF52480

El nRF52480, un robusto integrante de la familia nRF52 de Nordic Semiconductor, se erige como un microcontrolador de alto calibre. Fundamentado en el núcleo ARM Cortex-M4, despliega un rendimiento excepcional y una eficiencia energética destacada. Con una frecuencia de reloj que alcanza los 64 MHz y una memoria flash de 1 MB, este dispositivo tiene la capacidad de realizar tareas complejas y almacenar de manera significativa código de programa [2].

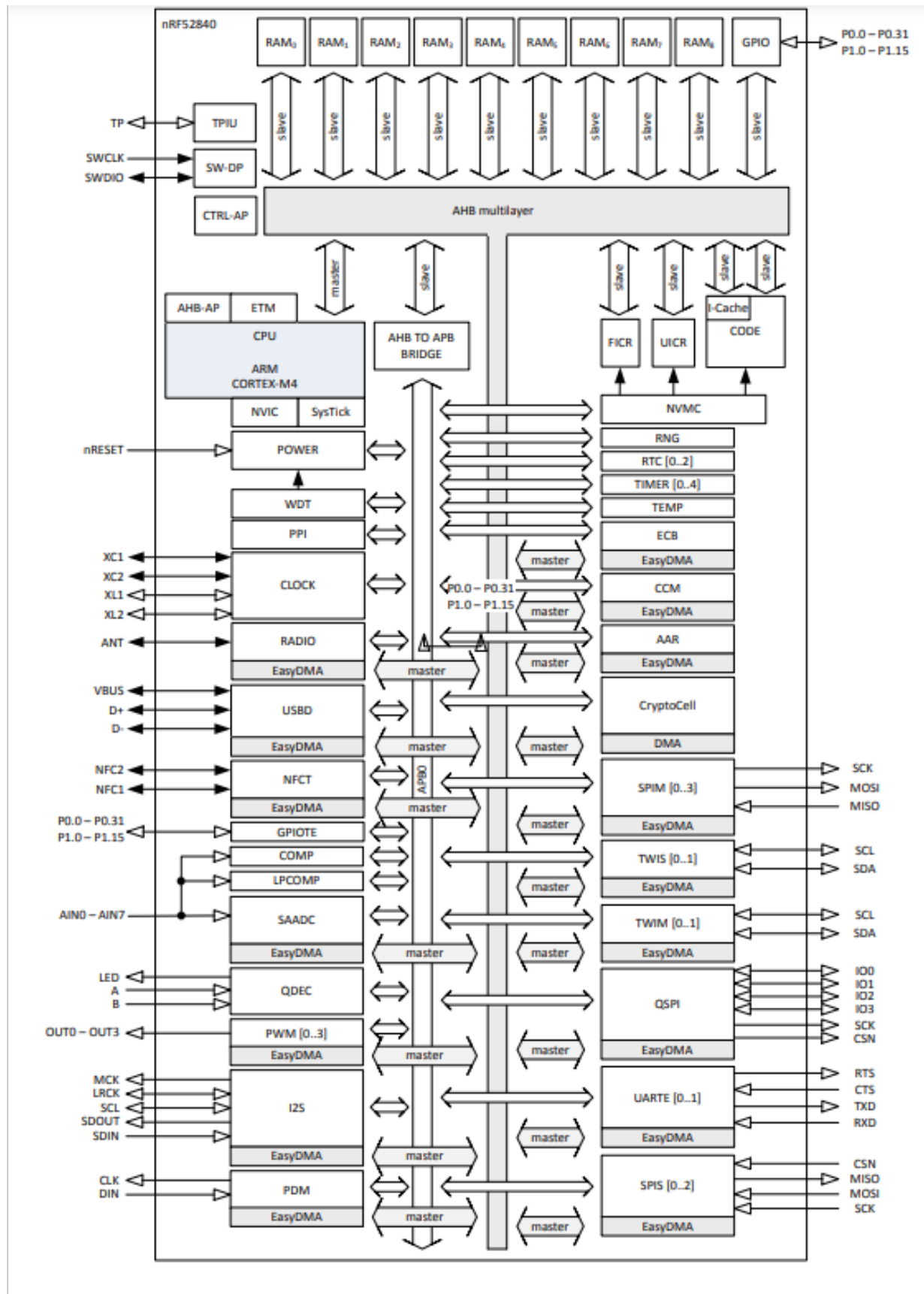


Figura 2: Diagrama de Bloques del Microcontrolador nRF5480. [2]

El nRF52840 presenta una extensa variedad de periféricos integrados, lo que lo posiciona como una opción idónea para aplicaciones en el Internet de las cosas (IoT) y conectividad inalámbrica. Con su respaldo para Bluetooth de baja energía (BLE) y protocolos de comunicación como UART, SPI e I2C, este microcontrolador ofrece una conectividad versátil y se integra fácilmente con otros dispositivos. Además, incorpora un potente transceptor de radio multibanda que posibilita la comunicación en frecuencias de 2.4 GHz y es compatible con diversos estándares inalámbricos. Esta versatilidad lo convierte en una elección destacada para aplicaciones que involucren redes de sensores y dispositivos conectados [2].

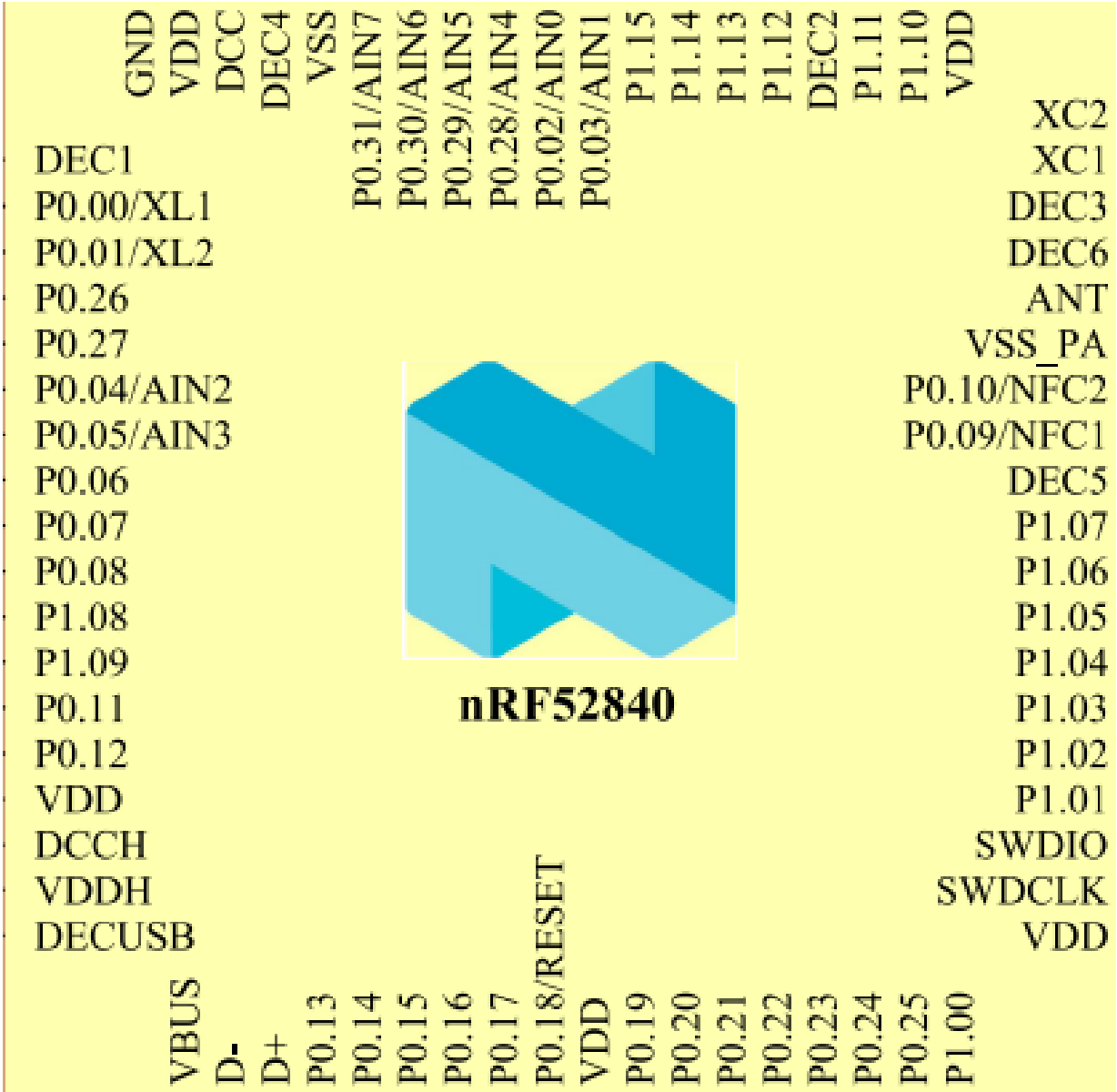


Figura 3: Diagrama de Pines del Microcontrolador nRF5480. [2]

Las caractrísticas eléctricas se encuentran en la figura 4:

	Note	Min.	Max.	Unit
Supply voltages				
VDD		-0.3	+3.9	V
VDDH		-0.3	+5.8	V
VBUS		-0.3	+5.8	V
VSS			0	V
I/O pin voltage				
$V_{I/O}$, VDD \leq 3.6 V		-0.3	VDD + 0.3	V
$V_{I/O}$, VDD > 3.6 V		-0.3	3.9	V
NFC antenna pin current				
$I_{NFC1/2}$			80	mA
Radio				
RF input level			10	dBm
Environmental aQFN package				
Storage temperature		-40	+125	°C
MSL	Moisture Sensitivity Level		2	
ESD HBM	Human Body Model		2	kV
ESD HBM Class	Human Body Model Class		2	
ESD CDM	Charged Device Model		750	V
Environmental WLCSP 3.544 x 3.607 mm package				
Storage temperature		-40	+125	°C
MSL	Moisture Sensitivity Level		1	
ESD HBM	Human Body Model		1	kV
ESD HBM Class	Human Body Model Class		1C	
ESD CDM	Charged Device Model		500	V
Flash memory				
Endurance		10 000		Write/erase cycles

Figura 4: Características de eléctricas del microcontrolador nRF52480. [2]

2.3. Periféricos Utilizados

2.3.1. Función para el manejo de entradas

De acuerdo con las indicaciones proporcionadas en la guía de Arduino [3], se describen las funciones destinadas al manejo de entradas:

1. `pinMode(pin, mode)`: Esta función se utiliza para configurar el modo de un pin digital. El primer parámetro corresponde al número de pin, mientras que el segundo parámetro define el modo deseado (INPUT, OUTPUT o INPUT_PULLUP). Su propósito radica en establecer si un pin se utilizará como entrada o salida digital, al tiempo que configura la resistencia pull-up interna.
2. `analogWrite(pin, state)`: Utilizada para generar una señal de salida analógica en un pin de salida analógica. El primer argumento especifica el número del pin a escribir, y el segundo argumento indica el valor deseado de la señal analógica, en un rango de 0 a 255.
3. `analogRead(pin)`: Diseñada para leer el valor de una señal analógica en un pin de entrada analógica. El parámetro es el número del pin que se desea leer. Esta función devuelve un valor entero que representa la amplitud de la señal analógica en una escala de 0 a 1023.

4. `delay(millisseconds)`: Utilizada para pausar la ejecución del programa durante un intervalo de tiempo determinado en milisegundos. El único parámetro requerido es la cantidad de milisegundos que se desea esperar antes de que continúe la ejecución del programa. Esta función resulta útil para introducir retrasos en el programa, como la generación de un parpadeo en un LED o la temporización de eventos.
5. `map(value, fromLow, fromHigh, toLow, toHigh)`: Aplicada para mapear un valor desde un rango a otro. El primer argumento representa el valor a mapear, los segundo y tercer argumentos indican los límites del rango original, y los cuarto y quinto argumentos establecen los límites del rango deseado. Esta función ejecuta una conversión proporcional del valor de entrada al rango de salida especificado.

2.3.2. Sensor LSM9DSI:

El LSM9DS1 destaca como un sistema integral que engloba un sensor digital de aceleración lineal 3D, un sensor digital de velocidad angular 3D y un sensor digital magnético 3D. Entre sus características notables [4] se encuentran las siguientes:

- **Canal Triplete:** Ofrece tres canales independientes para medir aceleración, velocidad angular y campo magnético.
- **Amplitud Ajustable:** Su capacidad de aceleración lineal abarca una amplitud completa de $\pm 2/\pm 4/\pm 8/\pm 16$ g (gravedad).
- **Campo Magnético Variable:** Permite medir el flujo magnético en una escala completa de $\pm 4/\pm 8/\pm 12/\pm 16$ gauss.
- **Velocidad Angular Ajustable:** La amplitud completa de velocidad angular es de $\pm 245/\pm 500/\pm 2000$ dps.
- **Precisión de Datos:** La salida de datos se realiza con una resolución de 16 bits.
- **Interfaz Versátil:** Dispone de interfaces seriales I2C/SPI para facilitar la conectividad.
- **Rango de Alimentación:** Puede ser alimentado en un rango analógico de 1.9 V a 3.6 V.
- **Modo de Consumo Eficiente:** Incorpora un modo de alimentación eco .Always-on con un consumo de 1.9 mA.
- **Gestión de Interrupciones:** Presenta generadores de interrupciones programables para mejorar la eficiencia.
- **Características Adicionales:** Incluye un sensor de temperatura integrado, así como un FIFO para el almacenamiento de datos.
- **Funciones de Detección Avanzadas:** Ofrece capacidades de detección de posición y movimiento para aplicaciones precisas.
- **Reconocimiento de Actividades:** Incorpora funciones avanzadas como el reconocimiento de clicks y doble-clicks para una interacción más sofisticada.

Su diagrama de bloques se observa en la figura 5.

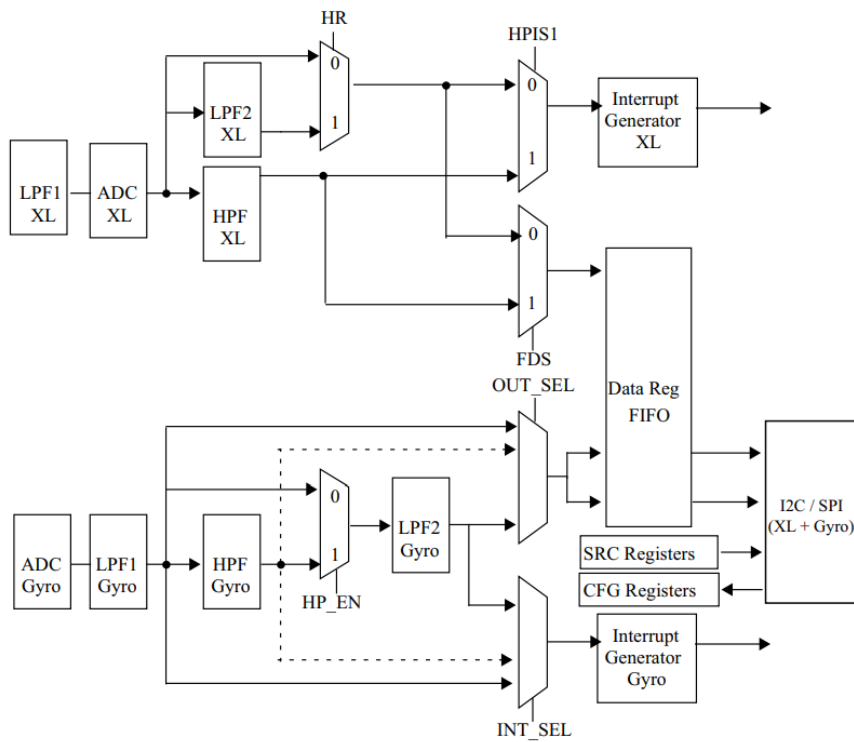


Figura 5: Diagrama de Bloques Sensor LSM9DS1. [4]

Su diagrama de pines se observa en la figura 6.

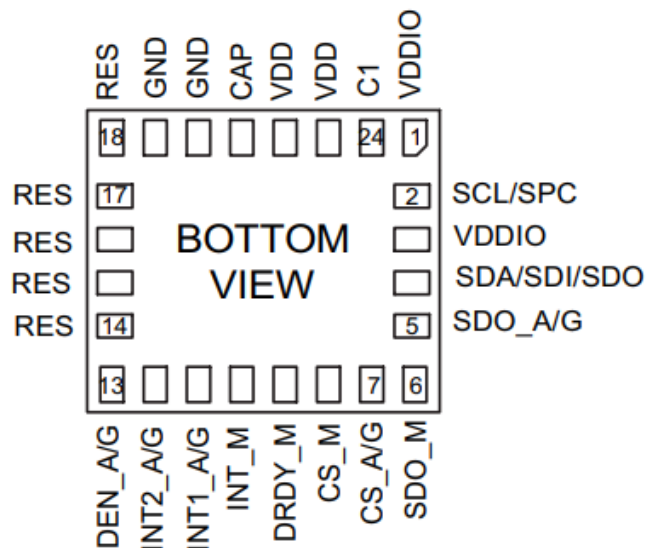


Figura 6: Diagrama de Pines Sensor LSM9DS1. [4]

En las figuras 7 Y 8 se enlistan las características eléctricas de este sensor.

Symbol	Parameter	Test conditions	Min.	Typ. ⁽¹⁾	Max.	Unit
Vdd	Supply voltage		1.9		3.6	V
Vdd_IO	Module power supply for I/O		1.71		Vdd+0.1	
Idd_XM	Current consumption of the accelerometer and magnetic sensor in normal mode ⁽²⁾			600		μA
Idd_G	Gyroscope current consumption in normal mode ⁽³⁾			4.0		mA
Top	Operating temperature range		-40		+85	°C
Trise	Time for power supply rising ⁽⁴⁾		0.01		100	ms
Twait	Time delay between Vdd_IO and Vdd ⁽⁴⁾		0		10	ms

Figura 7: Características Eléctricas Sensor LSM9DSI. Parte I [4]

Symbol	Ratings	Maximum value	Unit
Vdd	Supply voltage	-0.3 to 4.8	V
Vdd_IO	I/O pins supply voltage	-0.3 to 4.8	V
Vin	Input voltage on any control pin (including CS_A/G, CS_M, SCL/SPC, SDA/SDI/SDO, SDO_A/G, SDO_M)	0.3 to Vdd_IO +0.3	V
A _{UNP}	Acceleration (any axis)	3,000 for 0.5 ms	g
		10,000 for 0.1 ms	g
M _{EF}	Maximum exposed field	1000	gauss
ESD	Electrostatic discharge protection (HBM)	2	kV
T _{STG}	Storage temperature range	-40 to +125	°C

Figura 8: Valores Máximos Sensor LSM9DSI. Parte II [4]

2.3.3. Detección de Proximidad y Gestos

El dispositivo APDS-9960 brinda la capacidad de cuantificar la proximidad digital y la intensidad de la luz ambiente. Además, presenta funcionalidades avanzadas al detectar colores y gestos en el espectro RGB [5].

2.4. Edge Impulse

Es un entorno de desarrollo para aprendizaje automático en dispositivos periféricos. Simplifica la creación de soluciones fundamentadas en el aprendizaje automático, ejecutando las fases de recolección, diseño, prueba y despliegue directamente desde un navegador. Proporciona la capacidad de

visualizar el código generado en Python y C/C++, brindando así una interfaz eficaz para el desarrollo en estos entornos[5].

2.5. Protocolos de Comunicaciones

El protocolo SPI, conocido por sus siglas en inglés como Serial Peripheral Interface, desempeña un papel crucial en las comunicaciones entre dispositivos electrónicos digitales. Este protocolo sincrónico se utiliza para la transferencia eficiente de datos entre un microcontrolador y diversos dispositivos periféricos, como sensores, pantallas y convertidores analógico-digitales, entre otros [6].

Fundamentado en una conexión punto a punto, el protocolo utiliza un bus compuesto por 4 señales fundamentales: SCLK (reloj), MOSI (datos de salida del maestro), MISO (datos de entrada del maestro) y SS (señal de selección de esclavo). El maestro regula la velocidad de transferencia de datos mediante la señal de reloj y utiliza la señal de selección de esclavo para interactuar con los dispositivos periféricos conectados. La transmisión de datos es bidireccional, ya que el dispositivo periférico también puede enviar datos al microcontrolador [6].

Por otro lado, el protocolo USART, cuyas siglas en inglés representan Universal Synchronous/Asynchronous Receiver/Transmitter, es un método de comunicación utilizado en sistemas que operan tanto en modo serie síncrono como asíncrono. Facilita la transmisión bidireccional de datos a través de un único canal de comunicación y se utiliza comúnmente en sistemas embebidos para la comunicación entre microcontroladores, periféricos y dispositivos externos. Ofrece soporte para velocidades de transmisión de datos que van desde pocos bits hasta megabits, y permite la configuración de parámetros esenciales como la longitud de palabra, la paridad y el control de flujo, adaptándose a las necesidades específicas de la aplicación [7].

2.6. Diseño

Para la realización de este laboratorio se utilizó la plataforma edge impulse, la cual será de gran ayuda en la recolección de audios, clasificación y entrenamiento de una red neuronal. En primera instancia, se registran cuatro audios de dos minutos cada uno, tres de estos audios incluyen comandos de voz tales como "luces", "puertas", "música", estos con diferentes entonaciones, velocidades distintas. Y un cuarto audio, el cual se recolecta de un programa de televisión para simular ruido y distintas palabras, durante la grabación de este último en ciertos lapsos se indica una de los comandos de voz anteriormente mencionados, esto con el objetivo de ver si la red neuronal es capaz de detectar estos comandos en diferentes condiciones.

DATA COLLECTED 8m 0s		TRAIN / TEST SPLIT 100% / 0%	
Dataset			
Training (4) Test (0)			
SAMPLE NAME	LABEL	ADDED	LENGTH
ruido.4fkku6tt	ruido	Today, 21:55:31	2m 0s
puerta.4fkko98u	puerta	Today, 21:52:17	2m 0s
musica.4fkjfu2	musica	Today, 21:49:40	2m 0s
luces.4fkkevtb	luces	Today, 21:47:12	2m 0s

Figura 9: Audios registrados [Elaboración propia]

Seguido de esto se diseñan los impulsos que se van a dar, en este caso se va utilizar la clasificación de datos, por lo que se va tomar segundo a segundo y realizar la clasificación, como se ve en la figura 10, algo importante es establecer la frecuencia a la frecuencia que puede manejar el microcontrolador, en nuestro caso que se utiliza el Arduino Nano 33 BLE, corresponde a 16000 hz.

El MFCC corresponde a "Human speech". MFCC es una técnica de extracción de características ampliamente utilizada en el procesamiento de voz y audio. Los MFCC se utilizan para representar las características espectrales del sonido de una manera adecuada para diversas tareas de aprendizaje automático, como el reconocimiento de voz y el análisis musical.

El MFCC son particularmente útiles porque enfatizan características de la señal de audio que son importantes para la percepción del habla humana y descartan información menos relevante. Esto los hace eficaces para tareas como el reconocimiento de hablantes, la detección de emociones y la conversión de voz a texto.

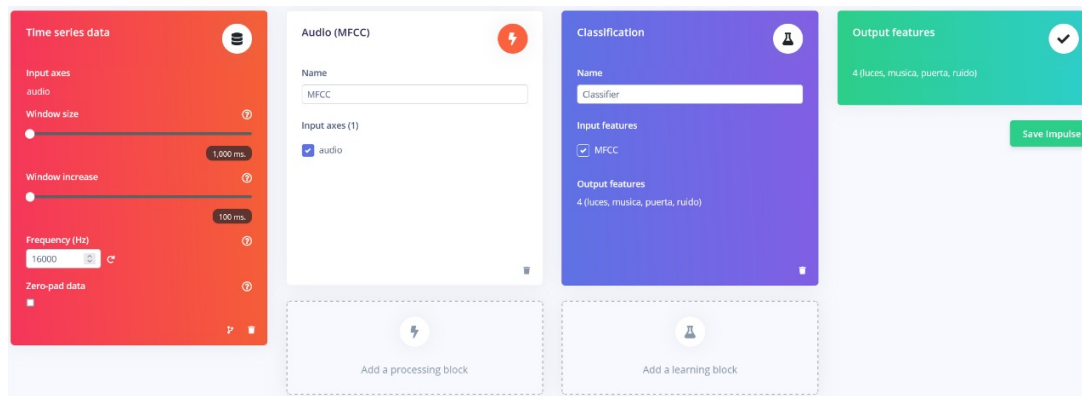


Figura 10: Impulse [Elaboración propia]

Una vez se establecen los impulsos y se entrena la red esta mostrara el análisis de exactitud buscando los comando en los audios suministrados, como se puede ver en la sección de resultados en la figura 12.

La plataforma Edge Impulse es de gran utilidad ya permite exportar el proyecto en un formato que lo pueda detectar y correr en microcontroladores Arduino, esto es posible gracias a que se puede

importar como una librería de Arduino.

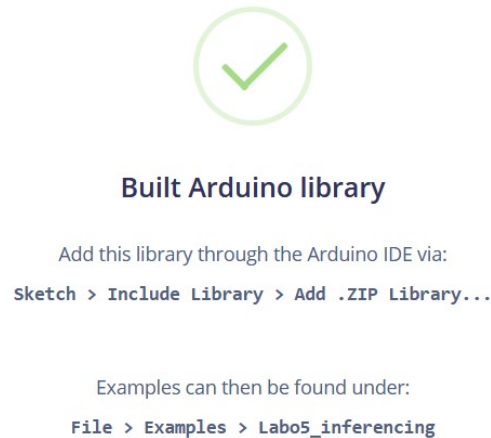


Figura 11: Exportar como librería [Elaboración propia]

Una vez exportado se procede a crear un script de python el cual se encarga de realizar la transmisión IOT a la plataforma ThingsBoard, creando un dashboard respectivo para este laboratorio.

2.7. Resultados

Al finalizar el proceso, se genera una tabla de exactitud, figura 12, la cual muestra que se genera un porcentaje del 86.5 %, donde la que tuvo mas porcentaje de exactitud es el audio el cual contenia ruido con un 98.4 %, seguido del comando "puerta" con un 95.9 %. El porcentaje de exactitud general podria ser mas alto, no obstante, los comando "lucsz" "puerta" tienen un porcentaje no tan alto. Estos detalles se pueden ver de igual forma en la figura 14.



Figura 12: Tabla de exactitud [Elaboración propia]

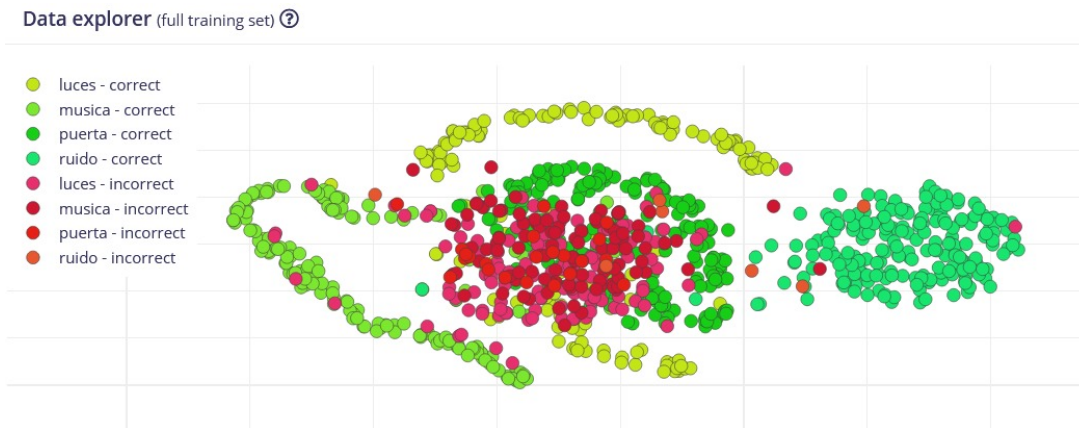


Figura 13: Distribución de los datos [Elaboración propia]

```
C:\Users\josee\Desktop\labo5>python iot.py
Connected to: COM5
Predictions (DSP: 76 ms., Classification: 6 ms., Anomaly: 0 ms.):
luces: 0.16797
musica: 0.07422
puerta: 0.30469
ruido: 0.45312
Predictions (DSP: 76 ms., Classification: 6 ms., Anomaly: 0 ms.):
luces: 0.82812
musica: 0.03125
puerta: 0.14062
ruido: 0.00000
Predictions (DSP: 76 ms., Classification: 6 ms., Anomaly: 0 ms.):
luces: 0.17578
musica: 0.11719
puerta: 0.69922
ruido: 0.00781
```

Figura 14: Ejecucion del script [Elaboración propia]

Link de repositorio: <https://github.com/joseeras98/Laboratorio-5.git>

3. Conclusiones y recomendaciones

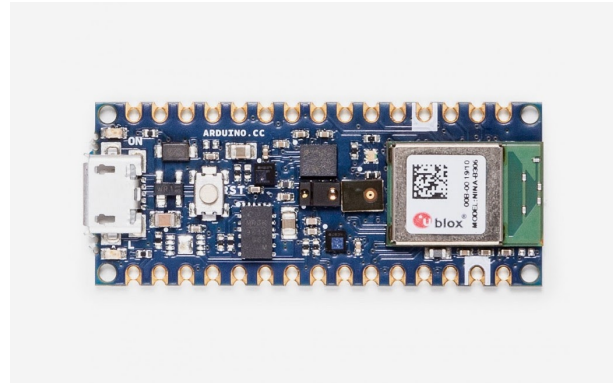
- La plataforma edge impulse es de gran ayuda para múltiples proyectos como la detección de audio o la captura de movimientos con un microcontrolador como el Arduino nano 33 ble.
- Se logro implementar la plataforma de edge impulse para este laboratorio.
- Se logró entrenar correctamente una red neuronal para la clasificación y detección de comandos de vos bajo distintas condiciones.
- No se logró implementar un widget en la plataforma ThingsBoard, esto debido a que no se realizaba ninguna detección de telemetria, y no se logro llegar a la causa raiz de este problema.

- La estudiante Daniela Rios tuvo un problema con la computadora, esta sufrió un daño y no pudo realizar los commits finales en github, no obstante esta colaboro al 100 % en la realizacion de este proyecto.

Referencias

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includepdf[pages=-]nRF52840.pdf

4. Anexos



Description

Nano 33 BLE Sense is a miniature sized module containing a NINA B306 module, based on Nordic nRF52480 and containing a Cortex M4F, a crypto chip which can securely store certificates and pre shared keys and a 9 axis IMU. The module can either be mounted as a DIP component (when mounting pin headers), or as a SMT component, directly soldering it via the castellated pads

Target areas:

Maker, enhancements, IoT application



Features

- **NINA B306 Module**
 - **Processor**
 - 64 MHz Arm® Cortex-M4F (with FPU)
 - 1 MB Flash + 256 KB RAM
 - **Bluetooth® 5 multiprotocol radio**
 - 2 Mbps
 - CSA #2
 - Advertising Extensions
 - Long Range
 - +8 dBm TX power
 - -95 dBm sensitivity
 - 4.8 mA in TX (0 dBm)
 - 4.6 mA in RX (1 Mbps)
 - Integrated balun with 50 Ω single-ended output
 - IEEE 802.15.4 radio support
 - Thread
 - Zigbee
 - **Peripherals**
 - Full-speed 12 Mbps USB
 - NFC-A tag
 - Arm CryptoCell CC310 security subsystem
 - QSPI/SPI/TWI/I²S/PDM/QDEC
 - High speed 32 MHz SPI
 - Quad SPI interface 32 MHz
 - EasyDMA for all digital interfaces
 - 12-bit 200 ksp/s ADC
 - 128 bit AES/ECB/CCM/AAR co-processor
- **LSM9DS1** (9 axis IMU)
 - 3 acceleration channels, 3 angular rate channels, 3 magnetic field channels
 - $\pm 2/\pm 4/\pm 8/\pm 16$ g linear acceleration full scale
 - $\pm 4/\pm 8/\pm 12/\pm 16$ gauss magnetic full scale
 - $\pm 245/\pm 500/\pm 2000$ dps angular rate full scale
 - 16-bit data output
- **LPS22HB** (Barometer and temperature sensor)
 - 260 to 1260 hPa absolute pressure range with 24 bit precision
 - High overpressure capability: 20x full-scale
 - Embedded temperature compensation
 - 16-bit temperature data output
 - 1 Hz to 75 Hz output data rate/Interrupt functions: Data Ready, FIFO flags, pressure thresholds
- **HTS221** (relative humidity sensor)
 - 0-100% relative humidity range
 - High rH sensitivity: 0.004% rH/LSB
 - Humidity accuracy: $\pm 3.5\%$ rH, 20 to +80% rH
 - Temperature accuracy: ± 0.5 °C, 15 to +40 °C
 - 16-bit humidity and temperature output data



- **APDS-9960** (Digital proximity, Ambient light, RGB and Gesture Sensor)
 - Ambient Light and RGB Color Sensing with UV and IR blocking filters
 - Very high sensitivity – Ideally suited for operation behind dark glass
 - Proximity Sensing with Ambient light rejection
 - Complex Gesture Sensing
- **MP34DT05** (Digital Microphone)
 - AOP = 122.5 dB SPL
 - 64 dB signal-to-noise ratio
 - Omnidirectional sensitivity
 - -26 dBFS ± 3 dB sensitivity
- **ATECC608A** (Crypto Chip)
 - Cryptographic co-processor with secure hardware based key storage
 - Protected storage for up to 16 keys, certificates or data
 - ECDH: FIPS SP800-56A Elliptic Curve Diffie-Hellman
 - NIST standard P256 elliptic curve support
 - SHA-256 & HMAC hash including off-chip context save/restore
 - AES-128 encrypt/decrypt, galois field multiply for GCM
- **MPM3610** DC-DC
 - Regulates input voltage from up to 21V with a minimum of 65% efficiency @minimum load
 - More than 85% efficiency @12V



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1 The Board

As all Nano form factor boards, Nano 33 BLE Sense does not have a battery charger but can be powered through USB or headers.

NOTE: Arduino Nano 33 BLE Sense only supports 3.3V I/Os and is **NOT** 5V tolerant so please make sure you are not directly connecting 5V signals to this board or it will be damaged. Also, as opposed to Arduino Nano boards that support 5V operation, the 5V pin does NOT supply voltage but is rather connected, through a jumper, to the USB power input.

1.1 Ratings

1.1.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (40 °F)	85°C (185 °F)

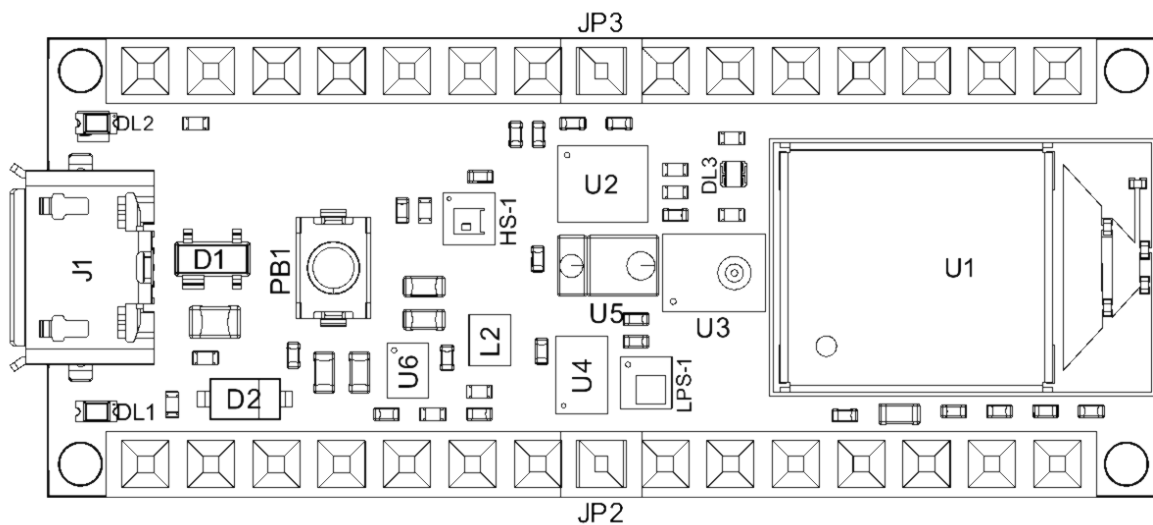
1.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
PBL	Power consumption with busy loop		TBC		mW
PLP	Power consumption in low power mode		TBC		mW
PMAX	Maximum Power Consumption		TBC		mW

2 Functional Overview

2.1 Board Topology

Top:



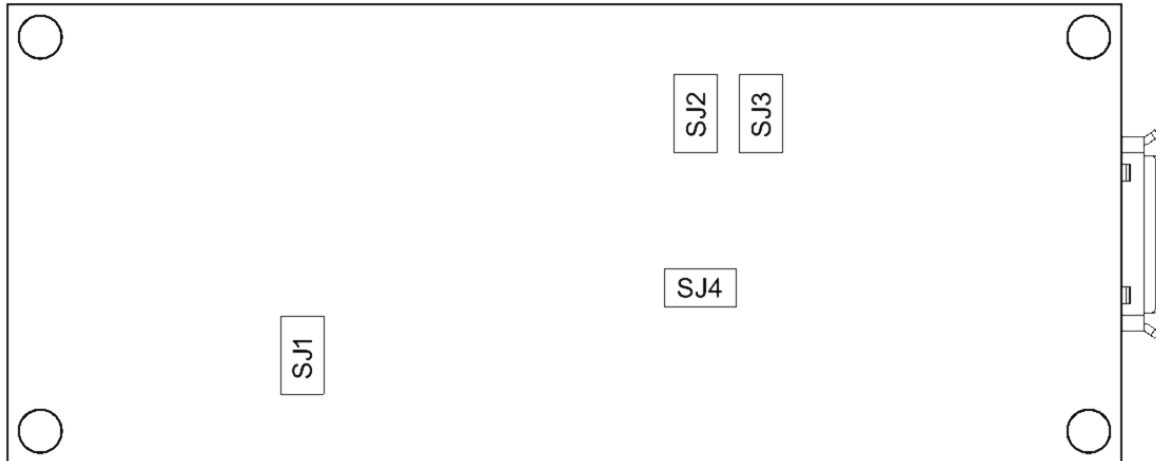
Board topology top

Ref.	Description	Ref.	Description
U1	NINA-B306 Module Bluetooth® Low Energy 5.0 Module	U6	MP2322GQH Step Down Converter
U2	LSM9DS1TR Sensor IMU	PB1	IT-1185AP1C-160G-GTR Push button
U3	MP34DT06JTR Mems Microphone	HS-1	HTS221 Humidity Sensor
U4	ATECC608A Crypto chip	DL1	Led L



Ref.	Description	Ref.	Description
U5	APDS-9660 Ambient Module	DL2	Led Power

Bottom:



Board topology bot

Ref.	Description	Ref.	Description
SJ1	VUSB Jumper	SJ2	D7 Jumper
SJ3	3v3 Jumper	SJ4	D8 Jumper

2.2 Processor

The Main Processor is a Cortex M4F running at up to 64MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the wireless module and the on-board internal I²C peripherals (IMU and Crypto).

NOTE: As opposed to other Arduino Nano boards, pins A4 and A5 have an internal pull up and default to be used as an I²C Bus so usage as analog inputs is not recommended.

2.3 Crypto

The crypto chip in Arduino IoT boards is what makes the difference with other less secure boards as it provides a secure way to store secrets (such as certificates) and accelerates secure protocols while never exposing secrets in plain text.

Source code for the Arduino Library that supports the Crypto is available [\[8\]](#)



2.4 IMU

Arduino Nano 33 BLE has an embedded 9 axis IMU which can be used to measure board orientation (by checking the gravity acceleration vector orientation or by using the 3D compass) or to measure shocks, vibration, acceleration and rotation speed.

Source code for the Arduino Library that supports the IMU is available [\[9\]](#)

2.5 Barometer and Temperature Sensor

The embedded Barometer and temperature sensor allow measuring ambient pressure. The temperature sensor integrated with the barometer can be used to compensate the pressure measurement.

Source code for the Arduino Library that supports the Barometer is available [\[10\]](#)

2.6 Relative Humidity and Temperature Sensor

Relative humidity sensor measures ambient relative humidity. As the Barometer this sensor has an integrated temperature sensor that can be used to compensate for the measurement.

Source code for the Arduino Library that supports the Humidity sensor is available [\[11\]](#)

2.7 Digital Proximity, Ambient Light, RGB and Gesture Sensor

Source code for the Arduino Library that supports the Proximity/gesture/ALS sensor is available [\[12\]](#)

2.7.1 Gesture Detection

Gesture detection utilizes four directional photodiodes to sense reflected IR energy (sourced by the integrated LED) to convert physical motion information (i.e. velocity, direction and distance) to a digital information. The architecture of the gesture engine features automatic activation (based on Proximity engine results), ambient light subtraction, cross-talk cancellation, dual 8-bit data converters, power saving inter-conversion delay, 32-dataset FIFO, and interrupt driven I2C communication. The gesture engine accommodates a wide range of mobile device gesturing requirements: simple UP-DOWN-RIGHT-LEFT gestures or more complex gestures can be accurately sensed. Power consumption and noise are minimized with adjustable IR LED timing.

2.7.2 Proximity Detection

The Proximity detection feature provides distance measurement (E.g. mobile device screen to user's ear) by photodiode detection of reflected IR energy (sourced by the integrated LED). Detect/release events are interrupt driven, and occur whenever proximity result crosses upper and/ or lower threshold settings. The proximity engine features offset adjustment registers to compensate for system offset caused by unwanted IR energy reflections appearing at the sensor. The IR LED intensity is factory trimmed to eliminate the need for end-equipment calibration due to component variations. Proximity results are further improved by automatic ambient light subtraction.



2.7.3 Color and ALS Detection

The Color and ALS detection feature provides red, green, blue and clear light intensity data. Each of the R, G, B, C channels have a UV and IR blocking filter and a dedicated data converter producing 16-bit data simultaneously. This architecture allows applications to accurately measure ambient light and sense color which enables devices to calculate color temperature and control display backlight.

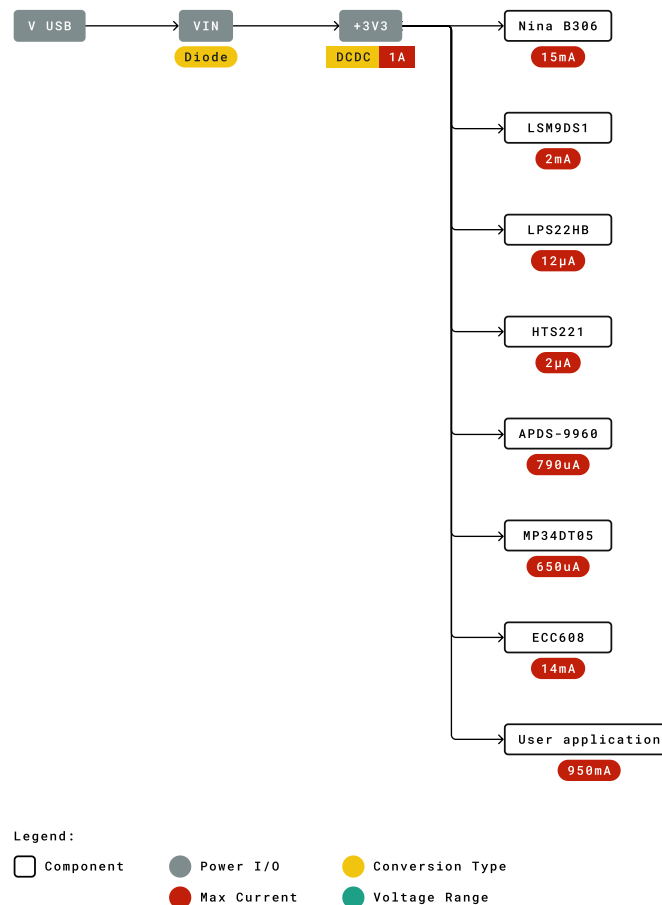
2.8 Digital Microphone

The MP34DT05 is an ultra-compact, low-power, omnidirectional, digital MEMS microphone built with a capacitive sensing element and an IC interface.

The sensing element, capable of detecting acoustic waves, is manufactured using a specialized silicon micromachining process dedicated to produce audio sensors

2.9 Power Tree

The board can be powered via USB connector, V_{IN} or V_{USB} pins on headers.



Power tree

NOTE: Since V_{USB} feeds V_{IN} via a Schottky diode and a DC-DC regulator specified minimum input voltage is 4.5V the minimum supply voltage from USB has to be increased to a voltage in the range between 4.8V to 4.96V depending on the current being drawn.



3 Board Operation

3.1 Getting Started - IDE

If you want to program your Arduino Nano 33 BLE while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino Nano 33 BLE to your computer, you'll need a Micro-B USB cable. This also provides power to the board, as indicated by the LED.

3.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow [3] to start coding on the browser and upload your sketches onto your board.

3.3 Getting Started - Arduino IoT Cloud

All Arduino IoT enabled products are supported on Arduino IoT Cloud which allows you to Log, graph and analyze sensor data, trigger events, and automate your home or business.

3.4 Sample Sketches

Sample sketches for the Arduino Nano 33 BLE can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino Pro website [4]

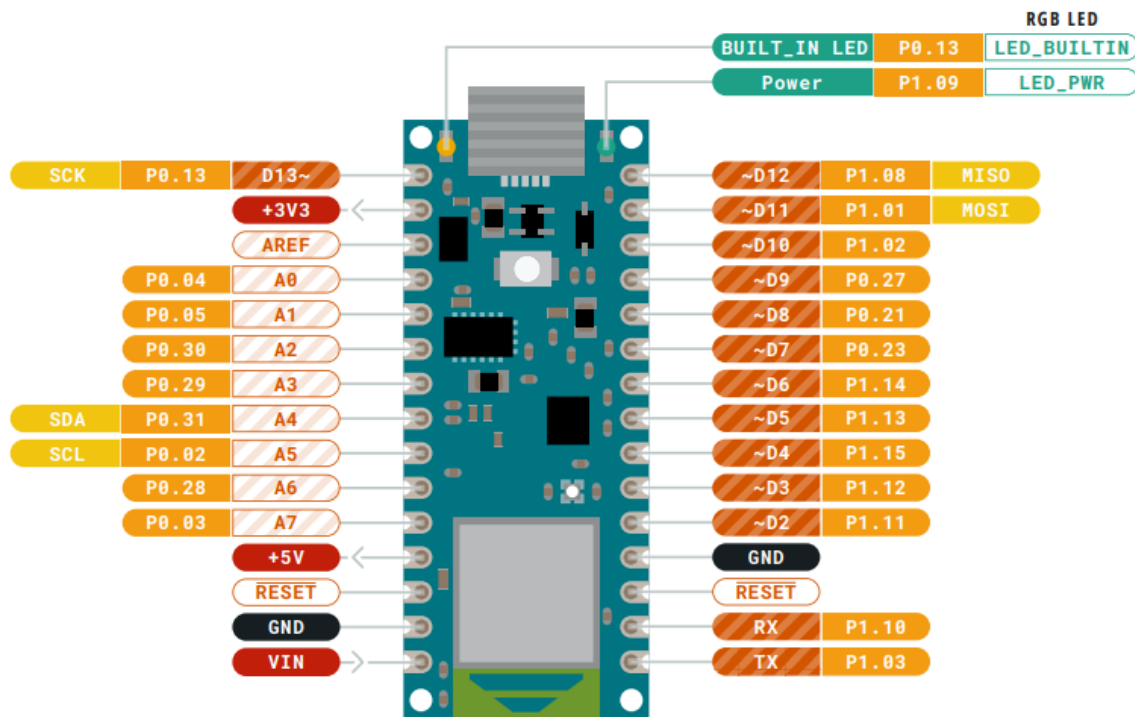
3.5 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on ProjectHub [13], the Arduino Library Reference [14] and the on line store [15] where you will be able to complement your board with sensors, actuators and more.

3.6 Board Recovery

All Arduino boards have a built-in bootloader which allows flashing the board via USB. In case a sketch locks up the processor and the board is not reachable anymore via USB it is possible to enter bootloader mode by double-tapping the reset button right after power up.

4 Connector Pinouts



Pinout

4.1 USB

Pin	Function	Type	Description
1	VUSB	Power	Power Supply Input. If board is powered via VUSB from header this is an Output (1)
2	D-	Differential	USB differential data -
3	D+	Differential	USB differential data +
4	ID	Analog	Selects Host/Device functionality
5	GND	Power	Power Ground

4.2 Headers

The board exposes two 15 pin connectors which can either be assembled with pin headers or soldered through castellated vias.

Pin	Function	Type	Description
1	D13	Digital	GPIO
2	+3V3	Power Out	Internally generated power output to external devices
3	AREF	Analog	Analog Reference; can be used as GPIO
4	A0/DAC0	Analog	ADC in/DAC out; can be used as GPIO
5	A1	Analog	ADC in; can be used as GPIO
6	A2	Analog	ADC in; can be used as GPIO
7	A3	Analog	ADC in; can be used as GPIO
8	A4/SDA	Analog	ADC in; I2C SDA; Can be used as GPIO (1)
9	A5/SCL	Analog	ADC in; I2C SCL; Can be used as GPIO (1)
10	A6	Analog	ADC in; can be used as GPIO
11	A7	Analog	ADC in; can be used as GPIO
12	VUSB	Power In/Out	Normally NC; can be connected to VUSB pin of the USB connector by shorting a jumper
13	RST	Digital In	Active low reset input (duplicate of pin 18)
14	GND	Power	Power Ground



Pin	Function	Type	Description
15	VIN	Power In	Vin Power input
16	TX	Digital	USART TX; can be used as GPIO
17	RX	Digital	USART RX; can be used as GPIO
18	RST	Digital	Active low reset input (duplicate of pin 13)
19	GND	Power	Power Ground
20	D2	Digital	GPIO
21	D3/PWM	Digital	GPIO; can be used as PWM
22	D4	Digital	GPIO
23	D5/PWM	Digital	GPIO; can be used as PWM
24	D6/PWM	Digital	GPIO, can be used as PWM
25	D7	Digital	GPIO
26	D8	Digital	GPIO
27	D9/PWM	Digital	GPIO; can be used as PWM
28	D10/PWM	Digital	GPIO; can be used as PWM
29	D11/MOSI	Digital	SPI MOSI; can be used as GPIO
30	D12/MISO	Digital	SPI MISO; can be used as GPIO

4.3 Debug

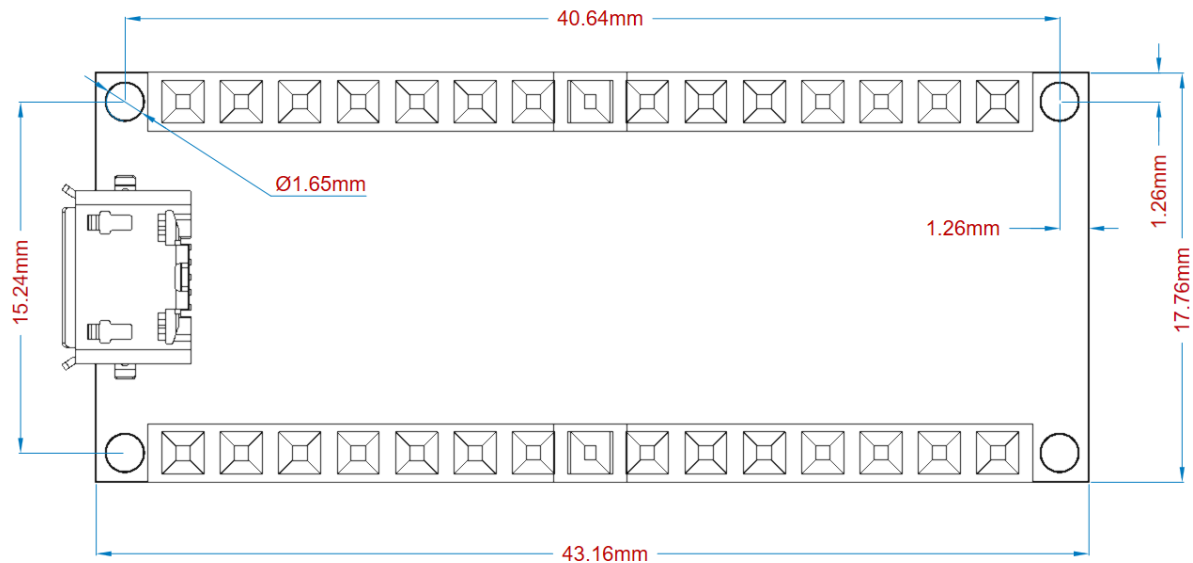
On the bottom side of the board, under the communication module, debug signals are arranged as 3x2 test pads with 100 mil pitch with pin 4 removed. Pin 1 is depicted in Figure 3 – Connector Positions

Pin	Function	Type	Description
1	+3V3	Power Out	Internally generated power output to be used as voltage reference
2	SWD	Digital	nRF52480 Single Wire Debug Data
3	SWCLK	Digital In	nRF52480 Single Wire Debug Clock
5	GND	Power	Power Ground
6	RST	Digital In	Active low reset input

5 Mechanical Information

5.1 Board Outline and Mounting Holes

The board measures are mixed between metric and imperial. Imperial measures are used to maintain 100 mil pitch grid between pin rows to allow them to fit a breadboard whereas board length is Metric



Board layout

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl) phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions : No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (<https://echa.europa.eu/web/guest/candidate-list-table>), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List"



(Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

- (1) This device may not cause harmful interference
- (2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

- (1) this device may not cause interference
- (2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

- (1) l'appareil n' doit pas produire de brouillage
- (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d' au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85°C and shouldn't be lower than -40°C.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

Frequency bands	Maximum output power (ERP)
863-870Mhz	5.47 dBm



8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Forum	http://forum.arduino.cc/
Nina B306	https://content.u-blox.com/sites/default/files/NINA-B3_DataSheet_UBX-17052099.pdf
ECC608	https://ww1.microchip.com/downloads/aemDocuments/documents/SCBU/ProductDocuments/DataSheets/ATECC608A-CryptoAuthentication-Device-Summary-Data-Sheet-DS40001977B.pdf
MPM3610	https://www.monolithicpower.com/pub/media/document/MPM3610_r1.01.pdf
ECC608 Library	https://github.com/arduino-libraries/ArduinoECCX08
LSM6DSL Library	https://github.com/adafruit/Adafruit_LSM9DS1
LPS22HB	https://github.com/stm32duino/LPS22HB
HTS221 Library	https://github.com/stm32duino/HTS221
APDS9960 Library	https://github.com/adafruit/Adafruit_APDS9960
ProjectHub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/

10 Revision History

Date	Revision	Changes
08/03/2022	2	Reference documentation links updates
04/27/2021	1	General datasheet updates

APDS-9960

Digital Proximity, Ambient Light, RGB and Gesture Sensor



Data Sheet



Description

The APDS-9960 device features advanced Gesture detection, Proximity detection, Digital Ambient Light Sense (ALS) and Color Sense (RGBC). The slim modular package, L 3.94 × W 2.36 × H 1.35 mm, incorporates an IR LED and factory calibrated LED driver for drop-in compatibility with existing footprints.

Gesture detection

Gesture detection utilizes four directional photodiodes to sense reflected IR energy (sourced by the integrated LED) to convert physical motion information (i.e. velocity, direction and distance) to a digital information. The architecture of the gesture engine features automatic activation (based on Proximity engine results), ambient light subtraction, cross-talk cancelation, dual 8-bit data converters, power saving inter-conversion delay, 32-dataset FIFO, and interrupt-driven I²C-bus communication. The gesture engine accommodates a wide range of mobile device gesturing requirements: simple UP-DOWN-RIGHT-LEFT gestures or more complex gestures can be accurately sensed. Power consumption and noise are minimized with adjustable IR LED timing.

Description continued on next page...

Applications

- Gesture Detection
- Color Sense
- Ambient Light Sensing
- Cell Phone Touch Screen Disable
- Mechanical Switch Replacement

Ordering Information

Part Number	Packaging	Quantity
APDS-9960	Tape & Reel	5000 per reel

Features

- Ambient Light and RGB Color Sensing, Proximity Sensing, and Gesture Detection in an Optical Module
- Ambient Light and RGB Color Sensing
 - UV and IR blocking filters
 - Programmable gain and integration time
 - Very high sensitivity – Ideally suited for operation behind dark glass
- Proximity Sensing
 - Trimmed to provide consistent reading
 - Ambient light rejection
 - Offset compensation
 - Programmable driver for IR LED current
 - Saturation indicator bit
- Complex Gesture Sensing
 - Four separate diodes sensitive to different directions
 - Ambient light rejection
 - Offset compensation
 - Programmable driver for IR LED current
 - 32 dataset storage FIFO
 - Interrupt driven I²C-bus communication
- I²C-bus Fast Mode Compatible Interface
 - Data Rates up to 400 kHz
 - Dedicated Interrupt Pin
- Small Package L 3.94 × W 2.36 × H 1.35 mm

Description (Cont.)

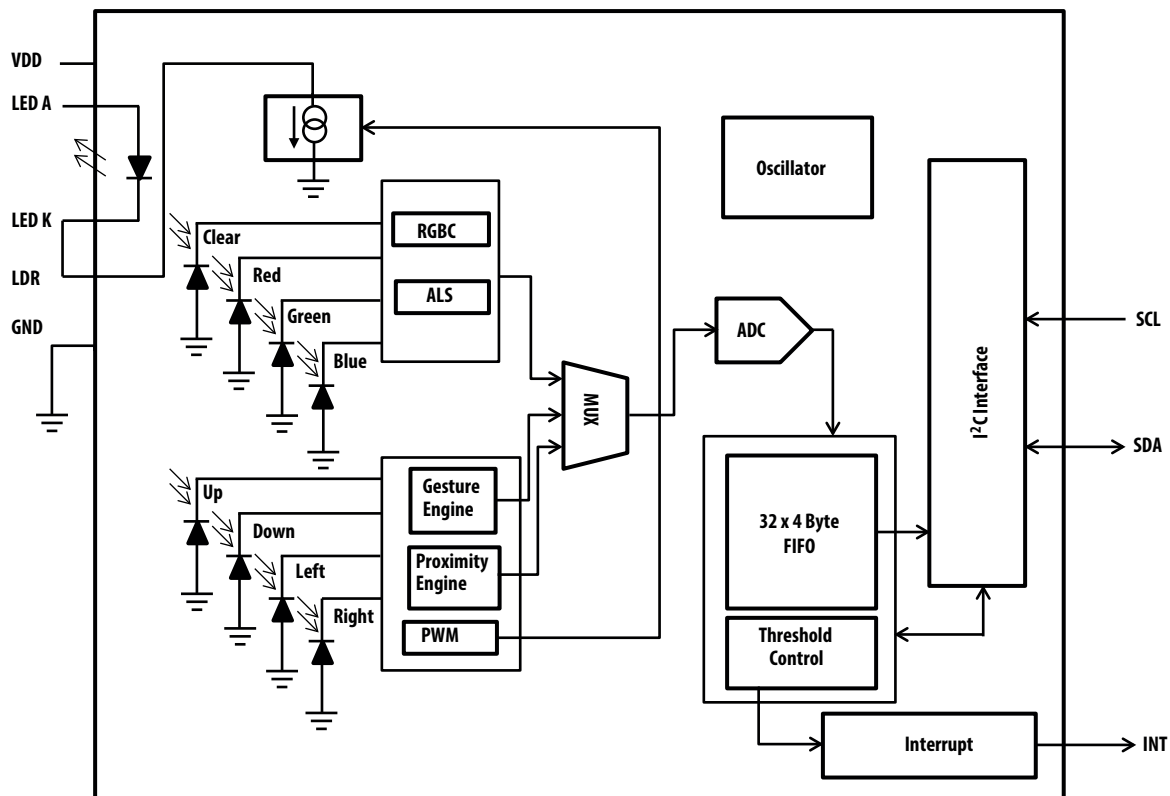
Proximity detection

The Proximity detection feature provides distance measurement (E.g. mobile device screen to user's ear) by photodiode detection of reflected IR energy (sourced by the integrated LED). Detect/release events are interrupt driven, and occur whenever proximity result crosses upper and/or lower threshold settings. The proximity engine features offset adjustment registers to compensate for system offset caused by unwanted IR energy reflections appearing at the sensor. The IR LED intensity is factory trimmed to eliminate the need for end-equipment calibration due to component variations. Proximity results are further improved by automatic ambient light subtraction.

Color and ALS detection

The Color and ALS detection feature provides red, green, blue and clear light intensity data. Each of the R, G, B, C channels have a UV and IR blocking filter and a dedicated data converter producing 16-bit data simultaneously. This architecture allows applications to accurately measure ambient light and sense color which enables devices to calculate color temperature and control display backlight.

Functional Block Diagram



I/O Pins Configuration

Pin	Name	Type	Description
1	SDA	I/O	I ² C serial data I/O terminal - serial data I/O for I ² C-bus
2	INT	O	Interrupt - open drain (active low)
3	LDR		LED driver input for proximity IR LED, constant current source LED driver
4	LEDK		LED Cathode, connect to LDR pin when using internal LED driver circuit
5	LEDA		LED Anode, connect to V _{LEDA} on PCB
6	GND		Power supply ground. All voltages are referenced to GND
7	SCL	I	I ² C serial clock input terminal - clock signal for I ² C serial data
8	V _{DD}		Power supply voltage

Absolute Maximum Ratings over operating free-air temperature range (unless otherwise noted)*

Parameter	Symbol	Min	Max	Units	Conditions
Power supply voltage ^[1]	V _{DD}		3.8	V	
Input voltage range	V _{IN}	-0.5	3.8	V	
Output voltage range	V _{OUT}	-0.3	3.8	V	
Storage temperature range	T _{stg}	-40	85	°C	

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

Note 1. All voltages are with respect to GND.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Units
Operating ambient temperature	T _A	-30		85	°C
Power supply voltage	V _{DD}	2.4	3.0	3.6	V
Supply voltage accuracy, V _{DD} total error including transients		-3		+3	%
LED supply voltage	V _{LEDA}	3.0		4.5	V

Operating Characteristics, V_{DD} = 3 V, T_A = 25 °C (unless otherwise noted)

Parameter	Symbol	Min	Typ	Max	Units	Test Conditions
IDD supply current ^[1]	I _{DD}		200	250	μA	Active ALS state PON = AEN = 1, PEN = 0
			790			Proximity, LDR pulse ON, PPulse = 8 (I _{LDR} not included)
			790			Gesture, LDR pulse ON, GPulse = 8 (I _{LDR} not included)
			38			Wait state PON = 1, AEN = PEN = 0
			1.0	10.0		Sleep state ^[2]
V _{OL} INT, SDA output low voltage	V _{OL}	0		0.4	V	3 mA sink current
I _{LEAK} leakage current, SDA, SCL, INT pins	I _{LEAK}	-5		5	μA	
I _{LEAK} leakage current, LDR P\pin	I _{LEAK}	-10		10	μA	
SCL, SDA input high voltage, V _{IH}	V _{IH}	1.26		V _{DD}	V	
SCL, SDA input low voltage, V _{IL}	V _{IL}			0.54	V	

Notes

1. Values are shown at the VDD pin and do not include current through the IR LED.

2. Sleep state occurs when PON = 0 and I2C bus is idle. If Sleep state has been entered as the result of operational flow, SAI = 1, PON will be high.

Optical Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, $\text{AGAIN} = 16\times$, $\text{AEN} = 1$ (unless otherwise noted)

Parameter	Red Channel		Green Channel		Blue Channel		Units	Test Conditions
	Min	Max	Min	Max	Min	Max		
Irradiance responsivity ^[1]	0	15	10	42	57	100	%	$\lambda_D = 465\text{ nm}$ ^[2]
	4	25	54	85	10	45		$\lambda_D = 525\text{ nm}$ ^[3]
	64	120	0	14	3	29		$\lambda_D = 625\text{ nm}$ ^[4]

Notes:

1. The percentage shown represents the ratio of the respective red, green, or blue channel value to the clear channel value.
2. The 465 nm input irradiance is supplied by an InGaN light-emitting diode with the following characteristics:
dominant wavelength $\lambda_D = 465\text{ nm}$, spectral halfwidth $\Delta\lambda_{1/2} = 22\text{ nm}$.
3. The 525 nm input irradiance is supplied by an InGaN light-emitting diode with the following characteristics:
dominant wavelength $\lambda_D = 525\text{ nm}$, spectral halfwidth $\Delta\lambda_{1/2} = 35\text{ nm}$.
4. The 625 nm input irradiance is supplied by a AlInGaP light-emitting diode with the following characteristics:
dominant wavelength $\lambda_D = 625\text{ nm}$, spectral halfwidth $\Delta\lambda_{1/2} = 15\text{ nm}$.

RGBC Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, $\text{AGAIN} = 16\times$, $\text{AEN} = 1$ (unless otherwise noted)

Parameter	Min	Typ	Max	Units	Test Conditions
Dark ALS count value		0	3	counts	$E_e = 0$, $\text{AGAIN} = 64\times$, $\text{ATIME} = 0\times\text{DB}$ (100 ms)
ADC integration time step size		2.78		ms	$\text{ATIME} = 0\times\text{FF}$
ADC number of integration steps	1		256	steps	
Full scale ADC counts per step			1025	counts	
Full scale ADC count value			65535	counts	$\text{ATIME} = 0\times\text{C0}$ (175 ms)
Gain scaling, relative to $1\times$ gain setting	3.6	4	4.4		$4\times$
	14.4	16	17.6		$16\times$
	57.6	64	70.4		$64\times$
Clear channel irradiance responsivity	18.88	23.60	28.32	counts/ $(\mu\text{W}/\text{cm}^2)$	Neutral white LED, $\lambda = 560\text{ nm}$

Proximity Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, $\text{PEN} = 1$ (unless otherwise noted)

Parameter	Min	Typ	Max	Units	Test Conditions
ADC conversion time step size		696.6		μs	
ADC number of integration steps		1		steps	
Full scale ADC counts			255	counts	
LED pulse count ^[1]	1		64	pulses	
LED pulse width – LED on time ^[2]		4		μs	$\text{PPLEN} = 0$
		8			$\text{PPLEN} = 1$
		16			$\text{PPLEN} = 2$
		32			$\text{PPLEN} = 3$
LED drive current ^[3]		100		mA	$\text{LDRIVE} = 0$
		50			$\text{LDRIVE} = 1$
		25			$\text{LDRIVE} = 2$
		12.5			$\text{LDRIVE} = 3$
LED boost ^[3]		100		%	$\text{LED_BOOST} = 0$
		150			$\text{LED_BOOST} = 1$
		200			$\text{LED_BOOST} = 2$
		300			$\text{LED_BOOST} = 3$
Proximity ADC count value, no object ^[4]		10	25	counts	$V_{\text{LEDA}} = 3\text{ V}$, $\text{LDRIVE} = 100\text{ mA}$, $\text{PPULSE} = 8$, $\text{PGAIN} = 4\times$, $\text{PPLEN} = 8\text{ }\mu\text{s}$, $\text{LED_BOOST} = 100\%$, open view (no glass) and no reflective object above the module.

Table continued on next page...

Proximity Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, PEN = 1 (unless otherwise noted) (continued)

Parameter	Min	Typ	Max	Units	Test Conditions
Proximity ADC count value, 100 mm distance object [5, 6]	96	120	144	counts	Reflecting object – 73 mm × 83 mm Kodak 90% grey card, 100 mm distance, $V_{LEDA} = 3\text{ V}$, $LDRIVE = 100\text{ mA}$, $PPULSE = 8$, $PGAIN = 4x$, $PPLEN = 8\text{ }\mu\text{s}$, $LED_BOOST = 100\%$, open view (no glass) above the module.

Notes:

1. This parameter is ensured by design and characterization and is not 100% tested. 8 pulses are the recommended driving conditions. For other driving conditions, contact Avago Field Sales.
2. Value may be as much as 1.36 μs longer than specified.
3. Value is factory-adjusted to meet the Proximity count specification. Considerable variation (relative to the typical value) is possible after adjustment. LED BOOST increases current setting (as defined by LDRIVE or GLDRIVE). For example, if LDRIVE = 0 and LED BOOST = 100%, LDR current is 100 mA.
4. Proximity offset value varies with power supply characteristics and noise.
5. ILEDA is factory calibrated to achieve this specification. Offset and crosstalk directly sum with this value and is system dependent.
6. No glass or aperture above the module. Tested value is the average of 5 consecutive readings.

Gesture Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, GEN = 1 (unless otherwise noted)

Parameter	Min	Typ	Max	Units	Test Conditions
ADC conversion time step size [1]		1.39		ms	
LED pulse count [2]	1		64	pulses	
LED pulse width – LED on time [3]		4		μs	$GPLEN = 0$
		8			$GPLEN = 1$
		12			$GPLEN = 2$
		16			$GPLEN = 3$
LED drive current [4]		100		mA	$GLDRIVE = 0$
		50			$GLDRIVE = 1$
		25			$GLDRIVE = 2$
		12.5			$GLDRIVE = 3$
LED boost [4]		100		%	$LED_BOOST = 0$
		150			$LED_BOOST = 1$
		200			$LED_BOOST = 2$ [5]
		300			$LED_BOOST = 3$ [5]
Gesture ADC count value, no object [6]		10	25	counts	$V_{LEDA} = 3\text{ V}$, $GLDRIVE = 100\text{ mA}$, $GPULSE = 8$, $GGAIN = 4x$, $GPLEN = 8\text{ }\mu\text{s}$, $LED_BOOST = 100\%$, open view (no glass) and no reflective object above the module, sum of UP & DOWN photodiodes.
Gesture ADC count value [7, 8]	96	120	144	counts	Reflecting object – 73 mm × 83 mm Kodak 90% grey card, 100 mm distance, $V_{LEDA} = 3\text{ V}$, $GLDRIVE = 100\text{ mA}$, $GPULSE = 8$, $GGAIN = 4x$, $GPLEN = 8\text{ }\mu\text{s}$, $LED_BOOST = 100\%$, open view (no glass) above the module, sum of UP & DOWN photodiodes.
Gesture wait step size		2.78		ms	$GTIME = 0x01$

Notes:

1. Each U/D or R/L pair requires a conversion time of 696.6 μs . For all four directions the conversion requires twice as much time.
2. This parameter is ensured by design and characterization and is not 100% tested. 8 pulses are the recommended driving conditions. For other driving conditions, contact Avago Field Sales.
3. Value may be as much as 1.36 μs longer than specified.
4. Value is factory-adjusted to meet the Gesture count specification. Considerable variation (relative to the typical value) is possible after adjustment.
5. When operating at these LED drive conditions, it is recommended to separate the VDD and VLEDA supplies.
6. Gesture offset value varies with power supply characteristics and noise.
7. ILEDA is factory calibrated to achieve this specification. Offset and crosstalk directly sum with this value and is system dependent.
8. No glass or aperture above the module. Tested value is the average of 5 consecutive readings.

IR LED Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$ (unless otherwise noted)

Parameter	Min	Typ	Max	Units	Test Conditions
Peak Wavelength, λ_p		950		nm	$I_F = 20\text{ mA}$
Spectrum Width, Half Power, $\Delta\lambda$		30		nm	$I_F = 20\text{ mA}$
Optical Rise Time, T_R		20		ns	$I_F = 100\text{ mA}$
Optical Fall Time, T_F		20		ns	$I_F = 100\text{ mA}$

Wait Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$, $WEN = 1$ (unless otherwise noted)

Parameter	Min	Typ	Max	Units	Test Conditions
Wait Step Size		2.78		ms	WTIME = 0xFF

AC Electrical Characteristics, $V_{DD} = 3\text{ V}$, $T_A = 25\text{ }^{\circ}\text{C}$ (unless otherwise noted) *

Parameter	Symbol	Min.	Max.	Unit
Clock frequency (I ² C-bus only)	f_{SCL}	0	400	kHz
Bus free time between a STOP and START condition	t_{BUF}	1.3	–	μs
Hold time (repeated) START condition. After this period, the first clock pulse is generated	t_{HDSTA}	0.6	–	μs
Set-up time for a repeated START condition	$t_{SU;STA}$	0.6	–	μs
Set-up time for STOP condition	$t_{SU;STO}$	0.6	–	μs
Data hold time	$t_{HD;DAT}$	30	–	ns
Data set-up time	$t_{SU;DAT}$	100	–	ns
LOW period of the SCL clock	t_{LOW}	1.3	–	μs
HIGH period of the SCL clock	t_{HIGH}	0.6	–	μs
Clock/data fall time	t_f	20	300	ns
Clock/data rise time	t_r	20	300	ns
Input pin capacitance	C_i	–	10	pF

* Specified by design and characterization; not production tested.

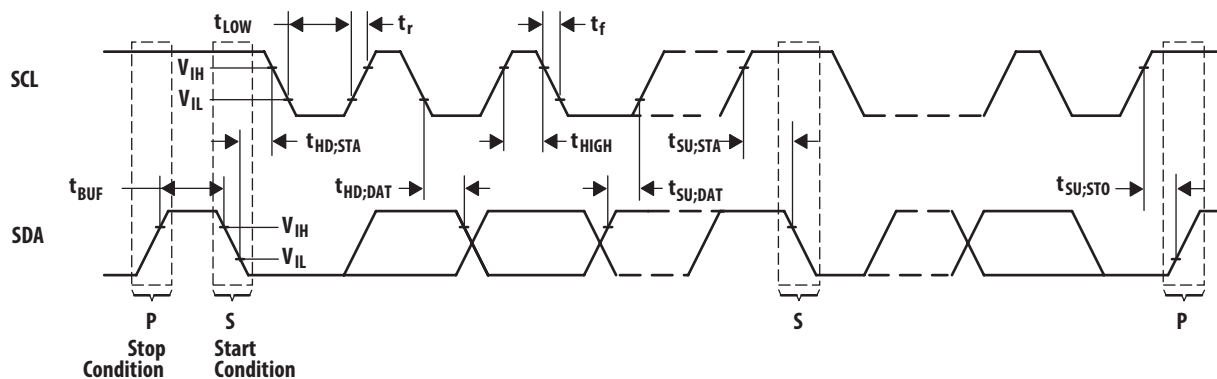


Figure 1. Timing Diagrams

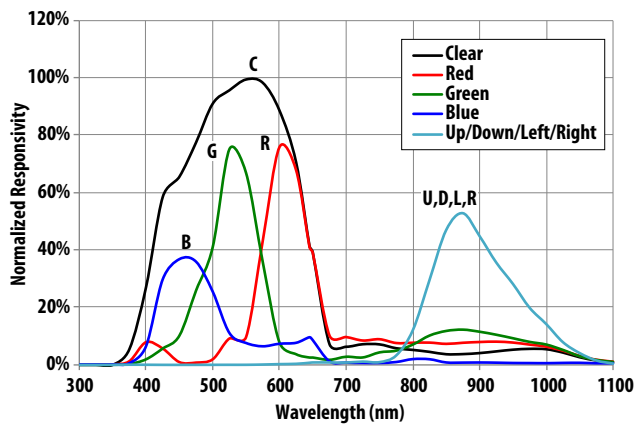


Figure 2. Spectral Response

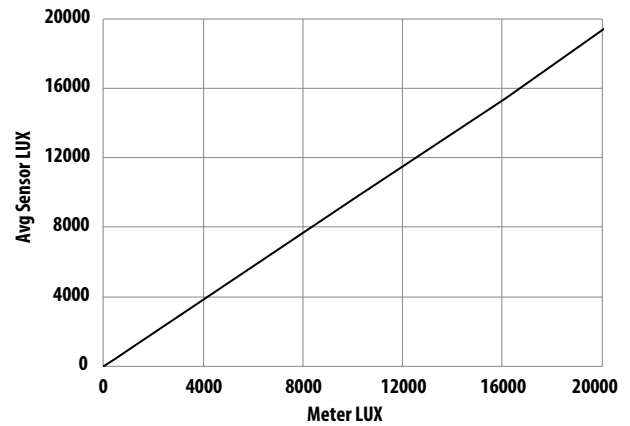


Figure 3a. ALS Sensor LUX vs Meter LUX using White Light

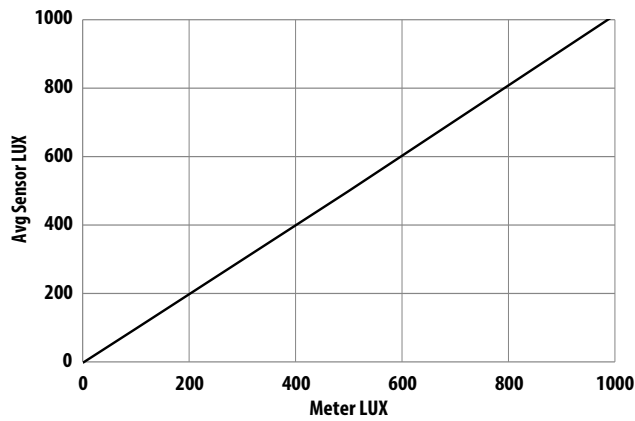


Figure 3b. ALS Sensor LUX vs Meter LUX using Incandescent Light

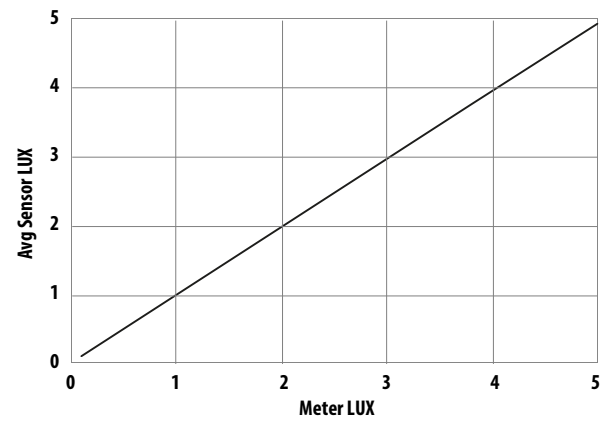


Figure 3c. ALS Sensor LUX vs Meter LUX using White Light

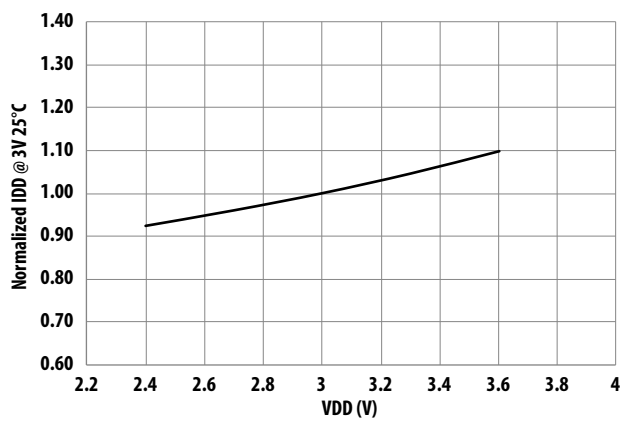


Figure 4a. Normalized IDD vs. VDD

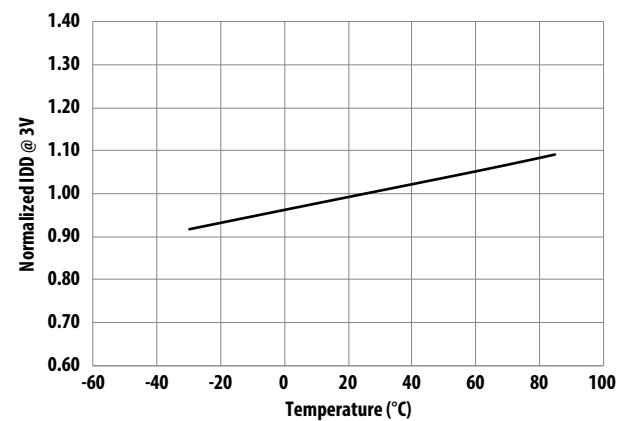


Figure 4b. Normalized IDD vs. Temperature

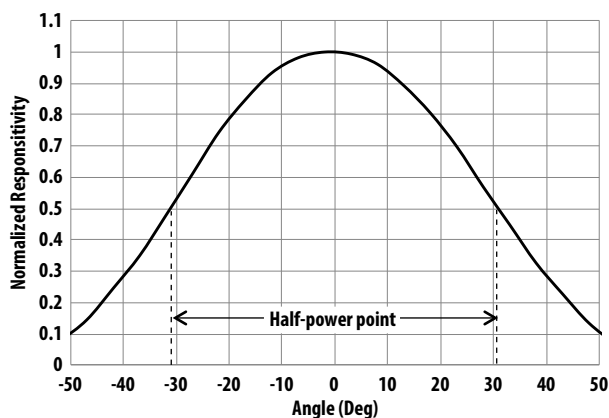


Figure 5a. Normalized PD Responsivity vs. Angular Displacement

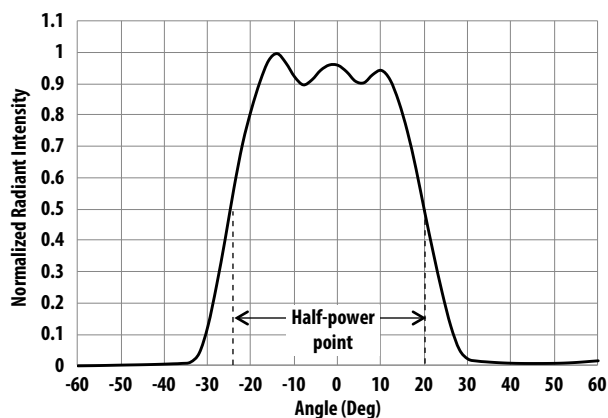




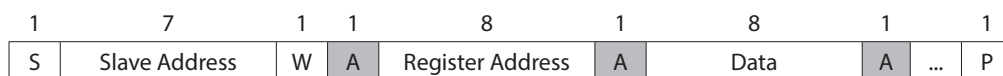
Figure 5b. Normalized LED Angular Emitting Profile

I²C-bus Protocol

Interface and control are accomplished through an I²C-bus serial compatible interface (standard or fast mode) to a set of registers that provide access to device control functions and output data. The devices support the 7-bit I²C-bus addressing protocol.

The device supports a single slave address of 0x39 Hex using 7-bit addressing protocol. (Contact factory for other addressing options.)

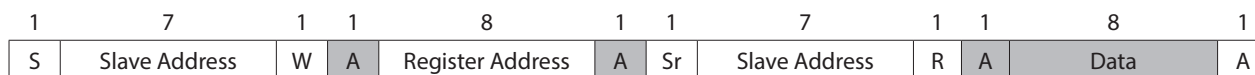
A	Acknowledge (0)
N	Not Acknowledged (1)
P	Stop Condition
R	Read (1)
S	Start Condition
Sr	Repeated Start Condition
W	Write (0)
...	Continuation of protocol
	Master-to-Slave
	Slave-to-Master



I²C-bus Write Protocol



I²C-bus Read Protocol



I²C-bus Read Protocol - Combined Format



The I²C-bus standard provides for three types of bus transaction: read, write, and a combined protocol. During a write operation, the first byte written is a command byte followed by data. In a combined protocol, the first byte written is the command byte followed by reading a series of bytes. If a read command is issued, the register address from the previous command will be used for data access. Likewise, if the MSB of the command is not set, the device will write a series of bytes at the address stored in the last valid command with a register address. The command byte contains either control information or a 5-bit register address. The control commands can also be used to clear interrupts.

The I²C-bus protocol was developed by Philips (now NXP). For a complete description of the I²C-bus protocol, please review the NXP I²C-bus design specification at <http://www.i2c-bus.org/references/>.

Detailed Description

Gesture detection, proximity detection, and RGB color sense/ambient light sense functionality is controlled by a state machine, as depicted in Figure 6, which reconfigures on-chip analog resources when each functional engine is entered. Functional states/engines can be individually included or excluded from the progression of state machine flow. Each functional engine contains controls (E.g., Gain, ADC integration time, wait time, persistence, thresholds, etc.) that govern operation. Control of the Led Drive pin, LDR, is shared between Proximity and Gesture functionality. The color/ALS engine does not use the IR LED, but cross talk from IR LED emissions during an optical pattern transmission may affect results.

The operational cycle of the device for Gesture/Proximity/Color is as depicted in Figure 6 and Figure 7.

Upon power-up, POR, the device initializes and immediately enters the low power SLEEP state. In this operational state the internal oscillator and other circuitry are not active, resulting in ultra-low power consumption. If I²C transaction occurs during this state, the oscillator and I²C core wakeup temporarily to service the communication. Once the Power ON bit, PON, is enabled, the internal oscillator and attendant circuitry are active, but power consumption remains low until one of the functional engine blocks are entered. The first time the SLEEP state is exited and any of the analog engines are enabled (PEN, GEN, AEN)

=1) an EXIT SLEEP pause occurs; followed by an immediate entry into the selected engine. If multiple engines are enabled, then the operational flow progresses in the following order: idle, proximity, gesture (if GMODE = 1), wait, color/ALS, and sleep (if SAI = 1 and INT pin is asserted). The wait operational state functions to reduce the power consumption and data collection rate. If wait is enabled, WEN=1, the delay is adjustable from 2.78 ms to 8.54 s, as set by the value in the WTIME register and WLONG control bit.

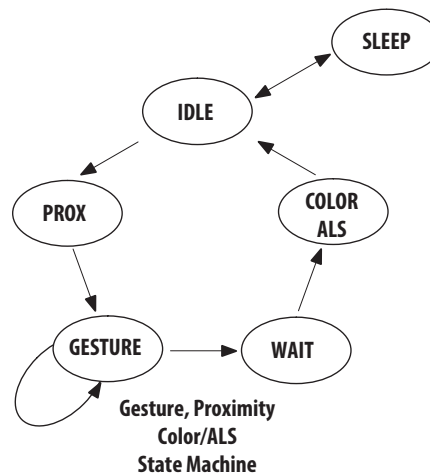


Figure 6. Simplified State Diagram

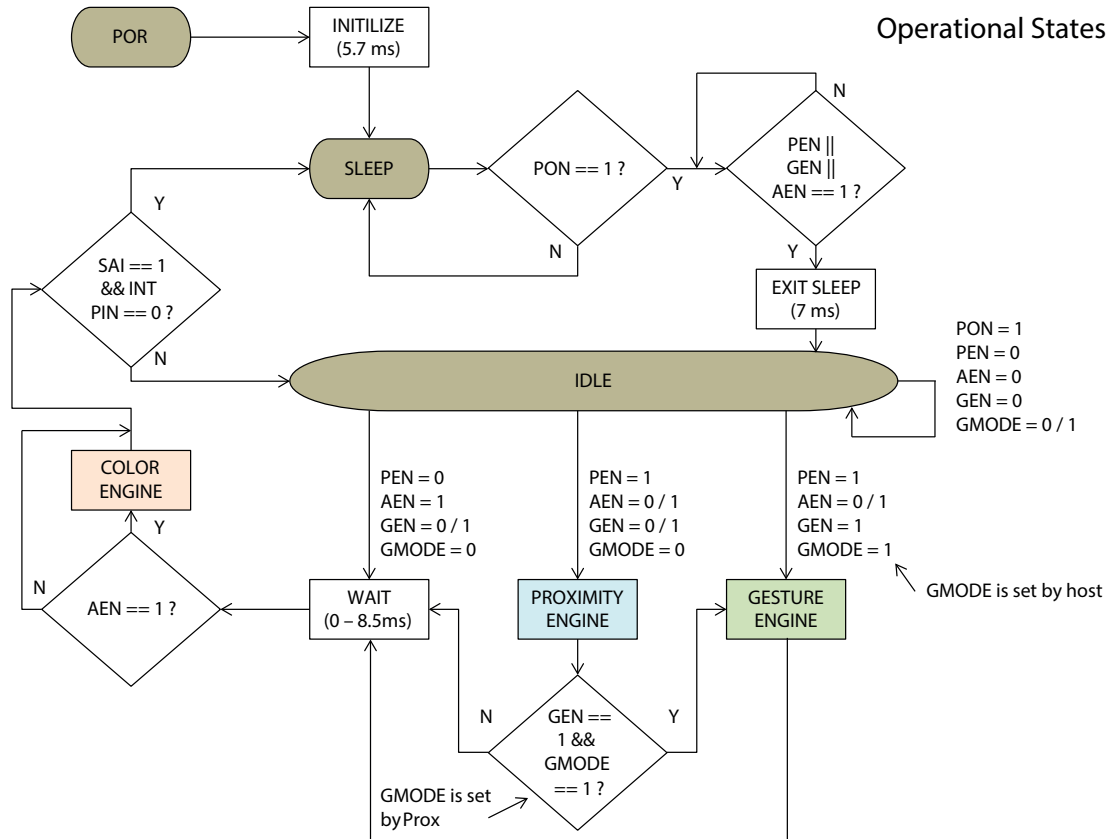


Figure 7. Detailed State Diagram

Sleep After Interrupt Operation

After all the enabled engines/operational states have executed, causing a hardware interrupt, the state machine returns to either IDLE or SLEEP, as selected by the Sleep After Interrupt bit, SAI. SLEEP is entered when two conditions are met: SAI = 1, and the INT pin has been asserted. Entering SLEEP does not automatically change any of the register settings (E.g. PON bit is still high, but the normal operational state is over-ridden by SLEEP state). SLEEP state is terminated by an I²C clear of the INT pin or if SAI bit is cleared.

Proximity Operation

The Proximity detection feature provides distance measurement by photodiode detection of reflected IR energy sourced by the integrated LED. The following registers and control bits govern proximity operation and the operational flow is depicted in Figure 8.

Table 1. Proximity Controls

Register/Bit	Address	Description
ENABLE<PON>	0x80<0>	Power ON
ENABLE<PEN>	0x80<2>	Proximity Enable
ENABLE<PIEN>	0x80<5>	Proximity Interrupt Enable
PILT	0x89	Proximity low threshold
PIHT	0x8B	Proximity high threshold
PERS<PPERS>	0x8C<7:4>	Proximity Interrupt Persistence
PPULSE<PPLEN>	0x8E<7:6>	Proximity Pulse Length
PPULSE<PPULSE>	0x8E<5:0>	Proximity Pulse Count
CONTROL<PGAIN>	0x8F<3:2>	Proximity Gain Control
CONTROL<LDRIVE>	0x8F<7:6>	LED Drive Strength
CONFIG2<PSIEN>	0x90<7>	Proximity Saturation Interrupt Enable
CONFIG2<LEDBOOST>	0x90<5:4>	Proximity/Gesture LED Boost
STATUS<PGSAT>	0x93<6>	Proximity Saturation
STATUS<PINT>	0x93<5>	Proximity Interrupt
STATUS<PVALID>	0x93<1>	Proximity Valid
PDATA	0x9C	Proximity Data
POFFSET_UR	0x9D	Proximity Offset UP/RIGHT
POFFSET_DL	0x9E	Proximity Offset DOWN/LEFT
CONFIG3<PCMP>	0x9F<5>	Proximity Gain Compensation Enable
CONFIG3<PMSK_U>	0x9F<3>	Proximity Mask UP Enable
CONFIG3<PMSK_D>	0x9F<2>	Proximity Mask DOWN Enable
CONFIG3<PMSK_L>	0x9F<1>	Proximity Mask LEFT Enable
CONFIG3<PMSK_R>	0x9F<0>	Proximity Mask RIGHT Enable
PICLEAR	0xE5	Proximity Interrupt Clear
AICLEAR	0xE7	All Non-Gesture Interrupt Clear

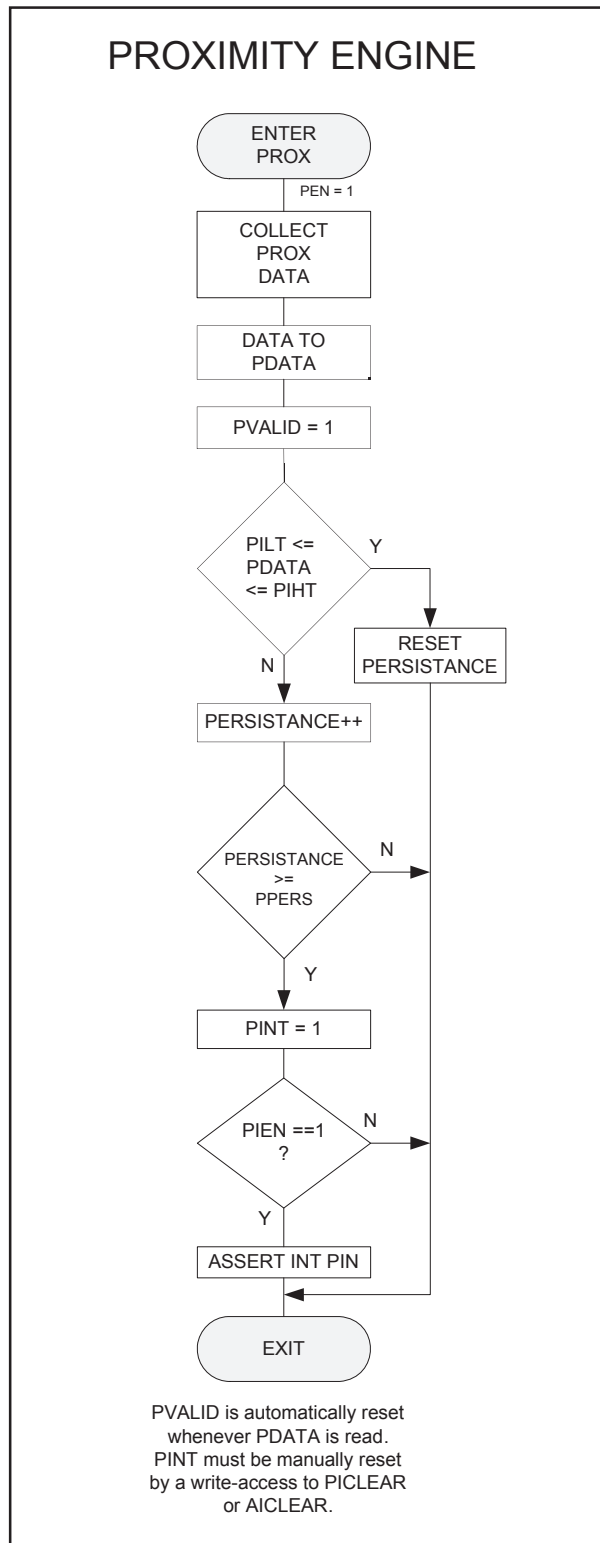


Figure 8. Detailed Proximity Diagram

Proximity results are affected by three fundamental factors: IR LED emission, IR reception, and environmental factors, including target distance and surface reflectivity.

The IR reception signal path begins with IR detection from four [directional gesture] photodiodes and ends with the 8-bit proximity result in PDATA register. Signal from the photodiodes is combined, amplified, and offset adjusted to optimize performance. The same four photodiodes are used for gesture operation as well as proximity operation. Diodes are paired to form two signal paths: UP/RIGHT and DOWN/LEFT. Regardless of pairing, any of the photodiodes can be masked to exclude its contribution to the proximity result. Masking one of the paired diodes effectively reduces the signal by half and causes the full-scale result to be reduced from 255 to 127. To correct this reduction in full-scale, the proximity gain compensation bit, PCMP, can be set, returning F.S. to 255. Gain is adjustable from 1x to 8x using the PGAIN control bits. Offset correction or cross-talk compensation is accomplished by adjustment to the POFFSET_UR and POFSET_DL registers. The analog circuitry of the device applies the offset value as a subtraction to the signal accumulation; therefore a positive offset value has the effect of decreasing the results.

Optically, the IR emission appears as a pulse train. The number of pulses is set by the PPULSE bits and the period of each pulse is adjustable using the PPLEN bits. The intensity of the IR emission is selectable using the LDRIVE control bits; corresponding to four, factory calibrated, current levels. If a higher intensity is required (E.g. longer detection distance or device placement beneath dark glass) then the LEDBOOST bit can be used to boost current up to an additional 300%.

LED duty cycle and subsequent power consumption of the integrated IR LED can be calculated using the following table shown in Table 2, and equations. If proximity events are separated by a wait time, as set by AWAIT and WLONG, then the total LED off time must be increased by the wait time.

Table 2. Approximate Proximity Timing

PPLEN	tINIT (μs)	tLED ON (μs)	tACC (μs)	tCNVT (μs)
4 μs	40.8	5.4	28.6	796.6
8 μs	44.9	9.5	36.73	796.6
16 μs	53.0	17.7	53.1	796.6
32 μs	69.4	34.0	85.7	796.6

$$t_{\text{PROX RESULT}} = t_{\text{INIT}} + t_{\text{CNVT}} + \text{PPULSE} \times t_{\text{ACC}}$$

$$t_{\text{TOTAL LED ON}} = \text{PPULSE} \times t_{\text{LED ON}}$$

$$t_{\text{TOTAL LED OFF}} = t_{\text{PROX RESULT}} - t_{\text{TOTAL LED ON}}$$

An Interrupt can be generated with each new proximity result or whenever proximity results exceed or fall below levels set in the PIHT and/or PILT threshold registers. To prevent premature/ false interrupts an interrupt persistence filter is also included; interrupts will only be asserted if the consecutive number of out-of-threshold results is equal or greater than the value set by PPERS. Each “in-threshold” proximity result, PDATA, will reset the persistence count. If the analog circuitry becomes saturated, the PGSAT bit will be asserted to indicate PDATA results

may not be accurate. The PINT and PGSAT bits are always available for I²C polling, but PIEN bit must be set for PINT to assert a hardware interrupt on the INT pin. Similarly, saturation of the analog data converter can be detected by polling PGSAT bit; to enable this feature the PSIEN bit must be set. PVALID is cleared by reading PDATA. PGSAT, and PINT are cleared by “address accessing” (i.e. I²C transaction consisting of only two bytes: chip address, followed by a register address with R/W=1) PICLEAR or AICLEAR.

Table 3. Color / ALS Controls

Register/Bit	Address	Description
ENABLE<PON>	0x80<0>	Power ON
ENABLE<AEN>	0x80<1>	ALS Enable
ENABLE<AIEN>	0x80<4>	ALS Interrupt Enable
ENABLE<WEN>	0x80<3>	Wait Enable
ATIME	0x81	ALS ADC Integration Time
WTIME	0x83	Wait Time
AILTL	0x84	ALS low threshold, lower byte
AILTH	0x85	ALS low threshold, upper byte
AIHTL	0x86	ALS high threshold, lower byte
AIHTH	0x87	ALS high threshold, upper byte
PERS<APERS>	0x8C<3:0>	ALS Interrupt Persistence
CONFIG1<WLONG>	0x8D<1>	Wait Long Enable
CONTROL<AGAIN>	0x8F<1:0>	ALS Gain Control
CONFIG2<CPSIEN>	0x90<6>	Clear diode Saturation Interrupt Enable
STATUS<CPSAT>	0x93<7>	Clear Diode Saturation
STATUS<AINT>	0x93<4>	ALS Interrupt
STATUS<AVALID>	0x93<0>	ALS Valid
CDATAL	0x94	Clear Data, Low byte
CDATAH	0x95	Clear Data, High byte
RDATAH	0x96	Red Data, Low byte
RDATAH	0x97	Red Data, High byte
GDATAH	0x98	Green Data, Low byte
GDATAH	0x99	Green Data, High byte
BDATAH	0x9A	Blue Data, Low byte
BDATAH	0x9B	Blue Data, High byte
CICLEAR	0xE5	Clear Channel Interrupt Clear
AICLEAR	0xE7	All Non-Gesture Interrupt Clear

Color and Ambient Light Sense Operation

The Color and Ambient Light Sense detection functionality uses an array of color and IR filtered photodiodes to measure red, green, and blue content of light, as well as the non-color filtered clear channel. The following registers and control bits govern Color/ALS operation and the operational flow is depicted in Figure 9.

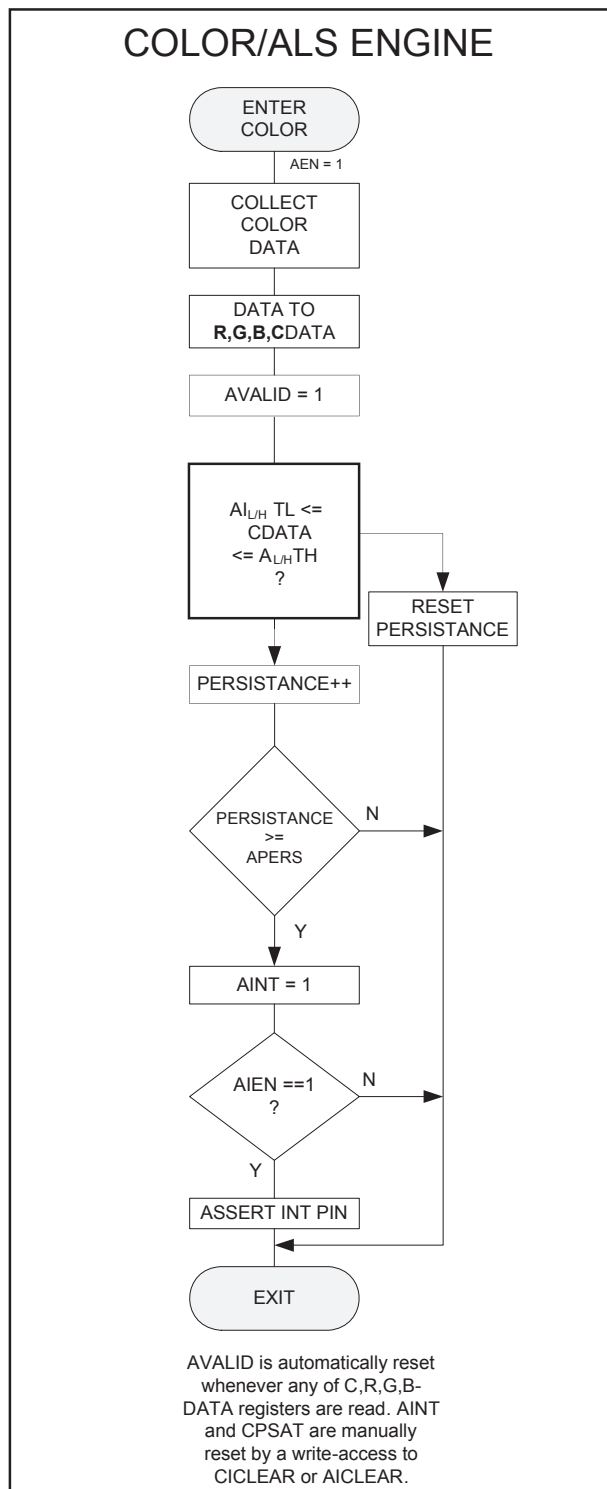


Figure 9. Color / ALS State Diagram

The Color/ALS reception signal path begins with filtered RGBC detection at the photodiodes and ends with the 16-bit results in the RGBC data registers. Signal from the photodiode array accumulates for a period of time set by the value in ATIME before the results are placed into the RGBCDATA registers. Gain is adjustable from 1x to 64x, and is determined by the setting of CONTROL<AGAIN>. Performance characteristics such as accuracy, resolution, conversion speed, and power consumption can be adjusted to meet the needs of the application.

Before entering (re-entering) the Color/ALS engine, an adjustable, low power consumption, delay is entered. The wait time for this delay is selectable using the WEN, WTIME and WLONG control bits and ranges from 0 to 8.54s. During this period the internal oscillator is still running, but all other circuitry is deactivated.

An interrupt can be generated whenever Clear Channel results exceed or fall below levels set in the AILTL/AIHTL and/or AILTH/AIHTH threshold registers. To prevent premature/false interrupts a persistence filter is also included; interrupts will only be asserted if the consecutive number of out-of-threshold results is equal or greater than the value set by APERS. Each "in-threshold" Clear channel result, CDATA, will reset the persistence count. If the analog circuitry becomes saturated, the ASAT bit will be asserted to indicate RGBCDATA results may not be accurate. The AINT and CPSAT bits are always available for I²C polling, but AIEN bit must be set for AINT to assert a hardware interrupt on the INT pin. Similarly, saturation of the analog data converter can be detected by polling CPSAT bit; to enable this feature the CPSIEN bit must be set. AVALID is cleared by reading RGBCDATA. ASAT, and AINT are cleared by "address accessing" (i.e. I²C transaction consisting of only two bytes: chip address, followed by a register address with R/W=1) CICLEAR or AICLEAR. RGBC results can be used to calculate ambient light levels (i.e. Lux) and color temperature (i.e. Kelvin).

Gesture Operation

The Gesture detection feature provides motion detection by utilizing directionally sensitive photodiodes to sense re-
flected IR energy sourced by the integrated LED. The following registers and control bits govern gesture operation and
the operational flow is depicted in Figure 10.

Table 4. Gesture Controls

Register/Bit	Address	Description
ENABLE<PON>	0x80<0>	Power ON
ENABLE<GEN>	0x80<6>	Gesture Enable
GPENTH	0xA0	Gesture Proximity Entry Threshold
GEXTH	0xA1	Gesture Exit Threshold
GCONFIG1<GFIFOTH>	0xA2<7:6>	Gesture FIFO Threshold
GCONFIG1<GEXMSK>	0xA2<5:2>	Gesture Exit Mask
GCONFIG1<GEXPERT>	0xA2<1:0>	Gesture Exit Persistence
GCONFIG2<GGAIN>	0xA3<6:5>	Gesture Gain Control
GCONFIG2<GLDRIVE>	0xA3<4:3>	Gesture LED Drive Strength
GCONFIG2<GWTIME>	0xA3<2:0>	Gesture Wait Time
STATUS<PGSAT>	0x93<6>	Gesture Saturation
CONFIG2<LEDBOOST>	0x90<5:4>	Gesture/Proximity LED Boost
GOFFSET_U	0xA4	Gesture Offset, UP
GOFFSET_D	0xA5	Gesture Offset, DOWN
GOFFSET_L	0xA7	Gesture Offset, LEFT
GOFFSET_R	0xA9	Gesture Offset, RIGHT
GPULSE<GPULSE>	0xA6<5:0>	Pulse Count
GPULSE<GPLEN>	0xA6<7:6>	Gesture Pulse Length
GCONFIG3<GDIMS>	0xAA<1:0>	Gesture Dimension Select
GCONFIG4<GFIFO_CLR>	0xAB<2>	Gesture FIFO Clear
GCONFIG4<GIEN>	0xAB<1>	Gesture Interrupt Enable
GCONFIG4<GMODE>	0xAB<0>	Gesture Mode
GFLVL	0xAE	Gesture FIFO Level
GSTATUS<GFOV>	0xAF<1>	Gesture FIFO Overflow
GSTATUS<GVALID>	0xAF<0>	Gesture Valid
GFIFO_U	0xFC	Gesture FIFO Data, UP
GFIFO_D	0xFD	Gesture FIFO Data, DOWN
GFIFO_L	0xFE	Gesture FIFO Data, LEFT
GFIFO_R	0xFF	Gesture FIFO Data, RIGHT
CONFIG1<LOWPOW>	0x8D	Low Power Clock Mode

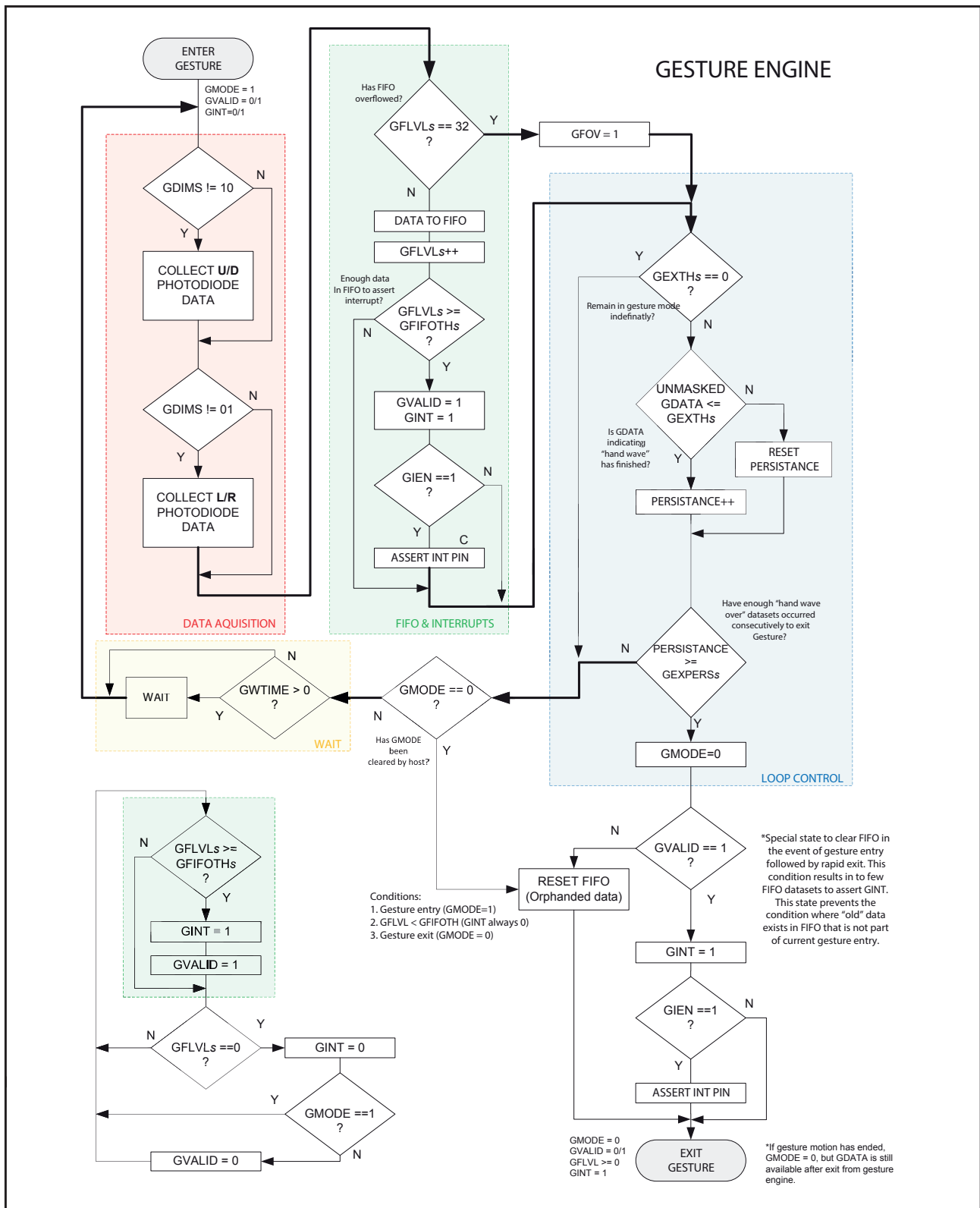


Figure 10. Detailed Gesture Diagram

Gesture results are affected by three fundamental factors: IR LED emission, IR reception, and environmental factors, including motion.

During operation, the Gesture engine is entered when its enable bit, GEN, and the operating mode bit, GMODE, are both set. GMODE can be set/reset manually, via I²C, or becomes set when proximity results, PDATA, is greater or equal to the gesture proximity entry threshold, GPENTH. Exit of the gesture engine will not occur until GMODE is reset to zero. During normal operation, GMODE is reset when all 4-bytes of a gesture dataset fall below the exit threshold, GEXTH, for GEXPERS times. This exit condition is also influenced by the gesture exit mask, GEXMSK, which includes all non-masked datum (i.e. singular 1-byte U, D, L, R points). To prevent premature exit, a persistence filter is also included; exit will only occur if a consecutive number of below-threshold results is greater or equal to the persistence value, GEXPERS. Each dataset result that is above-threshold will reset the persistence count. False or incomplete gestures (engine entry and exit without GVALID transitioning high) will not generate a gesture interrupt, GINT, and FIFO data will automatically be purged.

Once in operating inside the gesture engine, the IR reception signal path begins with IR detection at the photodiodes and ends with the four, 8-bit gesture results corresponding to accumulated signal strength on each diode. Signal from the four photodiodes is amplified, and offset adjusted to optimize performance. Photodiodes are paired to form two signal paths: UP/DOWN and LEFT/RIGHT. Photodiode pairs can be masked to exclude its results from the gesture FIFO data. For example, if only UP-DOWN motions detection is required the gesture dimension control bits, GDIMS, may be set to 0x01. FIFO data will be zero for RIGHT/LEFT results and accumulation/ADC integration time will be approximately halved. Gain is adjustable from

1x to 8x using the GGAIN control bits. Offset correction is accomplished by individual adjustment to GOFFSET_U, GOFFSET_D, GOFFSET_L, GOFFSET_R registers to improve cross-talk performance. The analog circuitry of the device applies offset values as a subtraction to the signal accumulation; therefore a positive offset value has the effect of decreasing the results.

Optically, the IR emission appears as a pulse train. The number of pulses is set by the GPULSE bits and the period of each pulse is adjustable using the GPLEN bits. Pulse train repetition (i.e. the circular flow of operation inside the gesture state machine) can be delayed by setting a non-zero value in the gesture wait time bits, GWTIME. The inclusion of a wait state reduces the both the power consumption and the data rate.

The intensity of the IR emission is selectable using the GLDRIVE control bits; corresponding to four, factory calibrated, current levels. If a higher intensity is required (E.g. longer detection distance or device placement beneath dark glass) then the LEDBOOST bit can be used to boost current up to an additional 300%.

The current consumption of the integrated IR LED is shown in Table 5. (Three examples at various LED drive settings)

Table 5. Simplified Power Calculation

	Case 1	Case 2	Case 3
ILED (mA)	100	150	300
GPULSE (no of pulses)	8	8	8
GPLEN (us)	16	16	32
GWTIME (No of wait state)	2	2	1
Total Current (mA)	3.76	5.49	16.14

An interrupt is generated based on the number of gesture “datasets” results placed in the FIFO. A dataset is defined as 4-byte directional data corresponding to U-D-L-R. The FIFO can buffer up to 32 datasets before it overflows. If the FIFO overflows (host did not read quickly enough) then the most recent data will be lost. If the FIFO level, GFLVL, becomes greater or equal to the threshold value set by GFIFOTH, then the GVALID bit is set, indicating valid data is available; the gesture interrupt bit, GINT, is asserted, and if GIEN bit is set a hardware interrupt on the INT pin will also assert. Before exit of gesture engine, one final interrupt will always occur if GVALID is asserted, signaling data remains in the FIFO. Gesture Interrupts flags: GINT, GVALID, and GFLVL are cleared by emptying FIFO (i.e., all data has been read).

The correlation of motion to FIFO data and direction characteristics) is not obvious at first glance. As depicted in Figure 12, the four directional sensors are placed in an orthogonal pattern optically lensed aperture. Diodes are designated as: U, D, L, R; the 8-bit results corresponding to each diode is available at the following sequential FIFO locations: 0xFC, 0xFD, 0xFE, and 0xFF.

Ideally, gesture detection works by capturing and comparing the amplitude and phase difference between directional sensor results. The directional sensors are arranged such that the diode opposite to the directional motion receives a larger portion of the reflected IR signal upon entry, then a smaller portion upon exit. In the example illustration, a downward or rightward motion of a target is illustrated per the respective arrows in Figure 11.

Directional Orientation

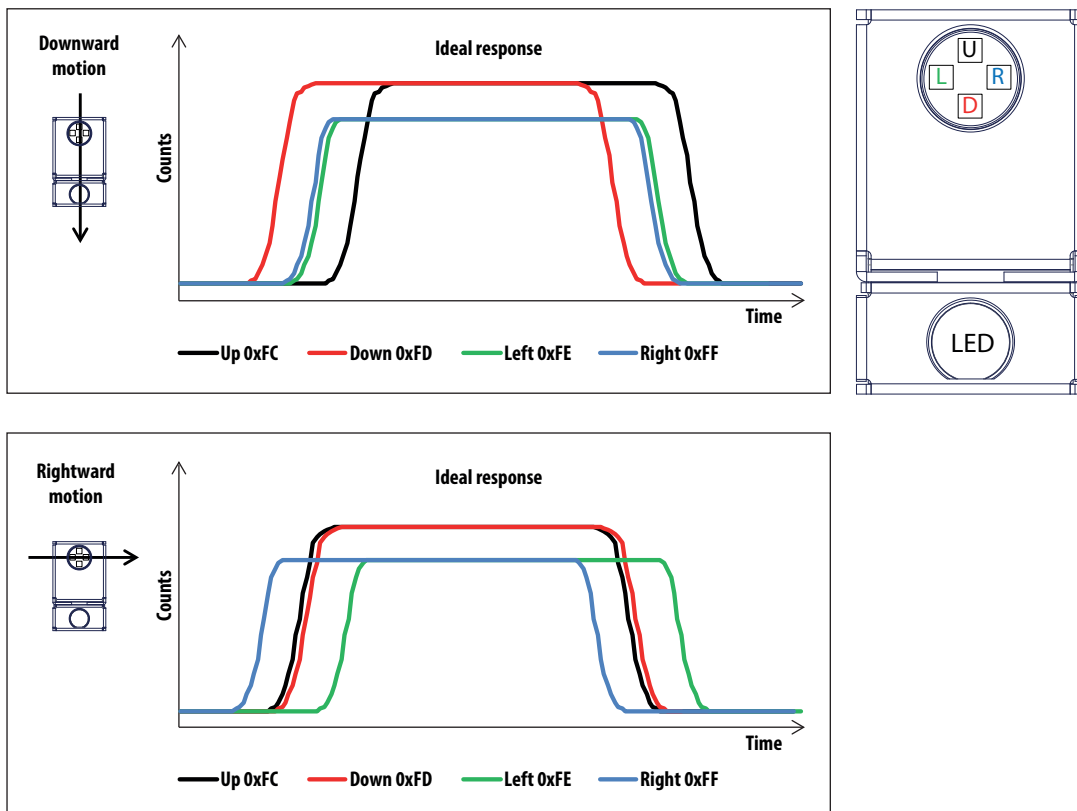


Figure 11. Directional Orientation

Optical and Mechanical Design Consideration

Optical Transmittance of Window Material

Windows with an IR transmittance of at least 80% (measured at 950 nm) are recommended for use with the APDS-9960. Note that for aesthetic reasons, the window's material could be tinted or coated with a dark ink. For example, a 20% (measured at 550 nm) visible transmittance window with 80% IR transmittance can be used. Such a coating would have transmittance spectral response with low transmittance within the visible range and a high transmittance in the infrared range. This low to high transmittance transition wavelength should be shorter than 650 nm to minimize crosstalk.

Examples of recommended window material part numbers are shown in Table 6.

Table 6. Recommended Plastic Materials

Material number	Visible light transmission	Refractive index
Makrolon LQ2647	87%	1.587
Makrolon LQ3147	87%	1.587
Makrolon LQ3187	85%	1.587
Lexan OQ92S	88 - 90%	-
Lexan OQ4120R	88 - 90%	1.586
Lexan OQ4320R	88 - 90%	1.586

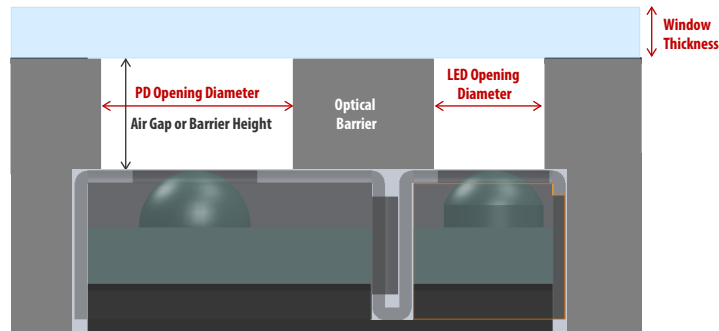


Figure 12. Rubber Barrier

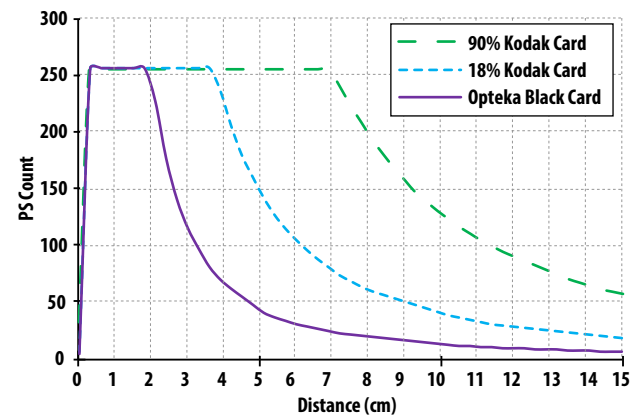


Figure 13a. PS Output vs. Distance at LDRIVE = 100 mA, PPULSE = 8, PGAIN = 4x, PPLEN = 8 μ s, LED_BOOST = 100% with various objects. No glass in front of the module

Crosstalk and Window Air Gap

Crosstalk is PS or Gesture output caused by unwanted LED IR rays reflection without any object present. To control crosstalk when operating the sensor in gesture mode, we recommend that a rubber isolating barrier be fitted over the sensor. A possible design is shown in Figure 12.

The rubber consists of two cylindrical openings, one for the LED and the other for the Photodetector. The window thickness should not be more than 1 mm. When assembled the rubber barrier should form a good optical seal to the bottom of the window.

Recommended dimensions of the barrier are:

Air Gap	PD Opening Diameter	LED Opening Diameter
1 mm	2 mm	1.5 mm

Residual crosstalk of the Up, Down, Left and Right Gesture output may be reduced by writing to the individual GOFFSET registers. Such calibration is necessary to ensure good gesture sensing performance.

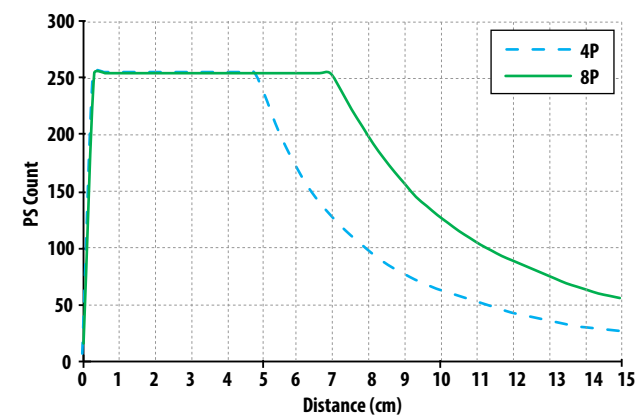


Figure 13b. PS Output vs. Distance at LDRIVE = 100 mA, PGAIN = 4x, PPLEN = 8 μ s, LED_BOOST = 100% with various pulses. No glass in front of the module

Register Set

The APDS-9960 is controlled and monitored by data registers and a command register accessed through the serial interface. These registers provide for a variety of control functions and can be read to determine results of the ADC conversions.

Address	Register Name	Type	Register Function	Reset Value
0x00 – 0x7F	RAM	R/W	RAM	0x00
0x80	ENABLE	R/W	Enable states and interrupts	0x00
0x81	ATIME	R/W	ADC integration time	0xFF
0x83	WTIME	R/W	Wait time (non-gesture)	0xFF
0x84	AILTL	R/W	ALS interrupt low threshold low byte	--
0x85	AILTH	R/W	ALS interrupt low threshold high byte	--
0x86	AIHTL	R/W	ALS interrupt high threshold low byte	0x00
0x87	AIHTH	R/W	ALS interrupt high threshold high byte	0x00
0x89	PILT	R/W	Proximity interrupt low threshold	0x00
0x8B	PIHT	R/W	Proximity interrupt high threshold	0x00
0x8C	PERS	R/W	Interrupt persistence filters (non-gesture)	0x00
0x8D	CONFIG1	R/W	Configuration register one	0x60
0x8E	PPULSE	R/W	Proximity pulse count and length	0x40
0x8F	CONTROL	R/W	Gain control	0x00
0x90	CONFIG2	R/W	Configuration register two	0x01
0x92	ID	R	Device ID	ID
0x93	STATUS	R	Device status	0x00
0x94	CDATA1	R	Low byte of clear channel data	0x00
0x95	CDATAH	R	High byte of clear channel data	0x00
0x96	RDATA1	R	Low byte of red channel data	0x00
0x97	RDATAH	R	High byte of red channel data	0x00
0x98	GDATA1	R	Low byte of green channel data	0x00
0x99	GDATAH	R	High byte of green channel data	0x00
0x9A	BDATA1	R	Low byte of blue channel data	0x00
0x9B	BDATAH	R	High byte of blue channel data	0x00
0x9C	PDATA	R	Proximity data	0x00
0x9D	POFFSET_UR	R/W	Proximity offset for UP and RIGHT photodiodes	0x00
0x9E	POFFSET_DL	R/W	Proximity offset for DOWN and LEFT photodiodes	0x00
0x9F	CONFIG3	R/W	Configuration register three	0x00
0xA0	GPENTH	R/W	Gesture proximity enter threshold	0x00
0xA1	GEXTH	R/W	Gesture exit threshold	0x00
0xA2	GCONF1	R/W	Gesture configuration one	0x00
0xA3	GCONF2	R/W	Gesture configuration two	0x00
0xA4	GOFFSET_U	R/W	Gesture UP offset register	0x00
0xA5	GOFFSET_D	R/W	Gesture DOWN offset register	0x00
0xA7	GOFFSET_L	R/W	Gesture LEFT offset register	0x00
0xA9	GOFFSET_R	R/W	Gesture RIGHT offset register	0x00
0xA6	GPULSE	R/W	Gesture pulse count and length	0x40
0xAA	GCONF3	R/W	Gesture configuration three	0x00
0xAB	GCONF4	R/W	Gesture configuration four	0x00
0xAE	GFLVL	R	Gesture FIFO level	0x00
0xAF	GSTATUS	R	Gesture status	0x00
0xE4 (1)	IFORCE	W	Force interrupt	0x00
0xE5 (1)	PICLEAR	W	Proximity interrupt clear	0x00
0xE6 (1)	CICLEAR	W	ALS clear channel interrupt clear	0x00
0xE7 (1)	AICLEAR	W	All non-gesture interrupts clear	0x00
0xFC	GFIFO_U	R	Gesture FIFO UP value	0x00
0xFD	GFIFO_D	R	Gesture FIFO DOWN value	0x00
0xFE	GFIFO_L	R	Gesture FIFO LEFT value	0x00
0xFF	GFIFO_R	R	Gesture FIFO RIGHT value	0x00

Note

1. Interrupt clear and force registers require a special I2C “address accessing” transaction. Please refer to the Register Description section for details.

Enable Register (0x80)

The ENABLE register is used to power the device on/off, enable functions and interrupts.

Field	Bits	Description
Reserved	7	Reserved. Write as 0.
GEN	6	Gesture Enable. When asserted, the gesture state machine can be activated. Activation is subject to the states of PEN and GMODE bits.
PIEN	5	Proximity Interrupt Enable. When asserted, it permits proximity interrupts to be generated, subject to the persistence filter settings.
AIEN	4	ALS Interrupt Enable. When asserted, it permits ALS interrupts to be generated, subject to the persistence filter settings.
WEN	3	Wait Enable. This bit activates the wait feature. Writing a one activates the wait timer. Writing a zero disables the wait timer.
PEN	2	Proximity Detect Enable. This field activates the proximity detection. Writing a one activates the proximity. Writing a zero disables the proximity.
AEN	1	ALS Enable. This field activates ALS function. Writing a one activates the ALS. Writing a zero disables the ALS.
PON	0	Power ON. This field activates the internal oscillator to permit the timers and ADC channels to operate. Writing a one activates the oscillator. Writing a zero disables the oscillator and puts the device into a low power sleep mode. During reads and writes over the I2C interface, this bit is temporarily overridden and the oscillator is enabled, independent of the state of PON.

Note: Before enabling Gesture, Proximity, or ALS, all of the bits associated with control of the desired function must be set. Changing control register values while operating may result in invalid results.

ADC Integration Time Register (0x81)

The ATIME register controls the internal integration time of ALS/Color analog to digital converters. Upon power up, the ADC integration time register is set to 0xFF.

The maximum count (or saturation) value can be calculated based upon the integration time and the size of the count register (i.e. 16 bits). For ALS/Color, the maximum count will be the lesser of either:

- 65535 (based on the 16 bit register size) or
- The result of equation: $\text{CountMAX} = 1025 \times \text{CYCLES}$

Field	Bits	Description
ATIME	7:0	FIELD VALUE
		CYCLES
		TIME
		MAX COUNT
		0
		256
		712 ms
		65535
		182
		72
		200 ms
		65535
		= 256 – TIME / 2.78 ms
		...
		...
		...
		219
		37
		103 ms
		37889
		246
		10
		27.8 ms
		10241
		255
		1
		2.78 ms
		1025

Note: The ATIME register is only applicable to ALS/Color engine (16-bit data). The integration time for the 8-bit Proximity/Gesture engine, is a factor of four less than the nominal time (2.78ms), resulting in a fixed time of 0.696ms.

Wait Time Register (0x83)

The WTIME controls the amount of time in a low power mode between Proximity and/or ALS cycles. It is set 2.78ms increments unless the WLONG bit is asserted in which case the wait times are 12× longer. WTIME is programmed as a 2's complement number. Upon power up, the wait time register is set to 0xFF.

Field	Bits	Description			
WTIME	7:0	FIELD VALUE	WAIT TIME	TIME (WLONG = 0)	TIME (WLONG = 1)
		0	256	712 ms	8.54 s
		= 256 – TIME / 2.78 ms	
		171	85	236 ms	2.84 s
		255	1	2.78 ms	0.03 s

Notes:

1. The wait time register should be configured before AEN and/or PEN is asserted.
2. During any Proximity and/or ALS cycle, the wait state, depicted in the functional block diagram, is entered. For example, Prox only, Prox and ALS, or ALS only cycles always enter the WAIT state and are separated by the time defined by WTIME.

ALS Interrupt Threshold Register (0x84 – 0x87)

ALS level detection uses data generated by the Clear Channel. The ALS Interrupt Threshold registers provide 16-bit values to be used as the high and low thresholds for comparison to the 16-bit CDATE values. If AIEN is enabled and CDATE is greater than AILTH/AIHTH or less than AILTL/AIHTL for the number of consecutive samples specified in APERS an interrupt is asserted on the interrupt pin.

Field	Address	Bits	Description
AILTL	0x84	7:0	This register provides the low byte of the low interrupt threshold.
AILTH	0x85	7:0	This register provides the high byte of the low interrupt threshold.
AIHTL	0x86	7:0	This register provides the low byte of the high interrupt threshold.
AIHTH	0x87	7:0	This register provides the high byte of the high interrupt threshold.

Proximity Interrupt Threshold Register (0x89/0x8B)

The Proximity Interrupt Threshold Registers set the high and low trigger points for the comparison function which generates an interrupt. If PDATA, the value generated by proximity channel, crosses below the lower threshold specified, or above the higher threshold, an interrupt may be signaled to the host processor. Interrupt generation is subject to the value set in persistence (PERS).

Field	Address	Bits	Description
PILT	0x89	7:0	This register provides the low interrupt threshold.
PIHT	0x8B	7:0	This register provides the high interrupt threshold.

Persistence Register (0x8C)

The Interrupt Persistence Register sets a value which is compared with the accumulated amount of ALS or Proximity cycles in which results were outside threshold values. Any Proximity or ALS result that is inside threshold values resets the count.

Separate counters are provided for proximity and ALS persistence detection.

Field	Bits	Description
PPERS	7:4	Proximity Interrupt Persistence. Controls rate of proximity interrupt to the host processor.
		FIELD VALUE INTERRUPT GENERATED WHEN...
		0 Every proximity cycle
		1 Any proximity value outside of threshold range
		2 2 consecutive proximity values out of range
		3 3 consecutive proximity values out of range
	
		15 15 consecutive proximity values out of range
APERS	3:0	ALS Interrupt Persistence. Controls rate of Clear channel interrupt to the host processor.
		FIELD VALUE INTERRUPT GENERATED WHEN...
		0 Every ALS cycle
		1 Any ALS value outside of threshold range
		2 2 consecutive ALS values out of range
		3 3 consecutive ALS values out of range
		4 5 ...
		5 10 ...
		6 15 ...
		7 20 ...
		8 25 ...
		9 30 ...
		10 35 ...
		11 40 ...
		12 45 ...
		13 50 ...
		14 55 ...
		15 60 consecutive ALS values out of range

Configuration Register One (0x8D)

The CONFIG1 register sets the wait long time. The register is set to 0x40 at power up.

Field	Bits	Description
Reserved	7	Reserved. Write as 0.
Reserved	6	Reserved. Write as 1.
Reserved	5	Reserved. Write as 1.
Reserved	4	Reserved. Write as 0.
Reserved	3	Reserved. Write as 0.
Reserved	2	Reserved. Write as 0.
WLONG	1	Wait Long. When asserted, the wait cycle is increased by a factor 12x from that programmed in the WTIME register.
Reserved	0	Reserved. Write as 0.

Notes:

1. Bit 6 is reserved, and is automatically set to 1 at POR.
2. Bit 5 is reserved, and is automatically set to 1 at POR. If this bit is not set, power consumption will increase during wait states.

Proximity Pulse Count Register (0x8E)

The Proximity Pulse Count Register sets Pulse Width Modified current during a Proximity Pulse. The proximity pulse count register bits set the number of pulses to be output on the LDR pin. The Proximity Length register bits set the amount of time the LDR pin is sinking current during a proximity pulse.

Field	Bits	Description
PPLEN	7:6	Proximity Pulse Length. Sets the LED-ON pulse width during a proximity LDR pulse.
		FIELD VALUE PULSE LENGTH
		0 4 μ s
		1 8 μ s (default)
		2 16 μ s
		3 32 μ s
PPULSE	5:0	Proximity Pulse Count. Specifies the number of proximity pulses to be generated on LDR. Number of pulses is set by PPULSE value plus 1.
		FIELD VALUE NUMBER OF PULSES
		0 1
		1 2
		2 3
		...
		63 64

Notes:

1. The time described by PPLEN is the actual signal integration time. The LED will be activated slightly longer (typically 1.36 μ s) than the integration time.
2. The Proximity Pulse Count Register resets to 0x40

Control Register One (0x8F)

Field	Bits	Description
LDRIVE	7:6	LED Drive Strength.
		FIELD VALUE LED CURRENT
		0 100 mA
		1 50 mA
		2 25 mA
		3 12.5 mA
Reserved	5	Reserved. Write as 0.
Reserved	4	Reserved. Write as 0.
PGAIN	3:2	Proximity Gain Control.
		FIELD VALUE GAIN VALUE
		0 1x
		1 2x
		2 4x
		3 8x
AGAIN	1:0	ALS and Color Gain Control.
		FIELD VALUE GAIN VALUE
		0 1x
		1 4x
		2 16x
		3 64x

Configuration Register Two (0x90)

The Configuration Register Two independently enables or disables the saturation interrupts for Proximity and Clear channel. Saturation Interrupts are cleared by accessing the Clear Interrupt registers at 0xE5, 0xE6 and 0xE7. The LED_BOOST bits allow the LDR pin to sink more current above the maximum setting by LDRIVE and GLDRIVE.

Field	Bits	Description
PSIEN	7	Proximity Saturation Interrupt Enable. 0 = Proximity saturation interrupt disabled 1 = Proximity saturation interrupt enabled
CPSIEN	6	Clear Photodiode Saturation Interrupt Enable. 0 = ALS Saturation Interrupt disabled 1 = ALS Saturation Interrupt enabled
LED_BOOST	5:4	Additional LDR current during proximity and gesture LED pulses. Current value, set by LDRIVE, is increased by the percentage of LED_BOOST.
		FIELD VALUE LED BOOST CURRENT
		0 100%
		1 150%
		2 200%
		3 300%
RESERVED	3:1	Reserved. Write as 0.
RESERVED	0	Reserved. Write as 1. Set high by default during POR.

Note: A LED_BOOST value of 0 results in 100% of the current as set by LDRIVE (no additional current).

ID Register (0x92)

The read-only ID Register provides the device identification.

Field	Bits	Description
ID	7:0	Part number identification. 0xAB = APDS-9960

Status Register (0x93)

The read-only Status Register provides the status of the device. The register is set to 0x04 at power-up.

Field	Bits	Description
CPSAT	7	Clear Photodiode Saturation. When asserted, the analog sensor was at the upper end of its dynamic range. The bit can be de-asserted by sending a Clear channel interrupt command (0xE6 CICLEAR) or by disabling the ADC (AEN=0). This bit triggers an interrupt if CPSIEN is set.
PGSAT	6	Indicates that an analog saturation event occurred during a previous proximity or gesture cycle. Once set, this bit remains set until cleared by clear proximity interrupt special function command (0xE5 PICLEAR) or by disabling Prox (PEN=0). This bit triggers an interrupt if PSIEN is set.
PINT	5	Proximity Interrupt. This bit triggers an interrupt if PIEN in ENABLE is set.
AINT	4	ALS Interrupt. This bit triggers an interrupt if AIEN in ENABLE is set.
RESERVED	3	Do not care.
GINT	2	Gesture Interrupt. GINT is asserted when GFVLV becomes greater than GFIFOTH or if GVALID has become asserted when GMODE transitioned to zero. The bit is reset when FIFO is completely emptied (read).
PVALID	1	Proximity Valid. Indicates that a proximity cycle has completed since PEN was asserted or since PDATA was last read. A read of PDATA automatically clears PVALID.
AVALID	0	ALS Valid. Indicates that an ALS cycle has completed since AEN was asserted or since a read from any of the ALS/Color data registers.

RGBC Data Register (0x94 – 0x9B)

Red, green, blue, and clear data is stored as 16-bit values. The read sequence must read byte pairs (low followed by high) starting on an even address boundary (0x94, 0x96, 0x98, or 0x9A) inside the RGBC Data Register block. When the lower byte register is read, the upper eight bits are stored into a shadow register, which is read by a subsequent read to the upper byte. The upper register will read the correct value even if additional ADC integration cycles end between the reading of the lower and upper registers.

Field	Address	Bits	Description
CDATAL	0x94	7:0	Low Byte of clear channel data.
CDATAH	0x95	7:0	High Byte of clear channel data.
RDATAH	0x96	7:0	Low Byte of red channel data.
RDATAH	0x97	7:0	High Byte of red channel data.
GDATAH	0x98	7:0	Low Byte of green channel data.
GDATAH	0x99	7:0	High Byte of green channel data.
BDATAH	0x9A	7:0	Low Byte of blue channel data.
BDATAH	0x9B	7:0	High Byte of blue channel data.

Note: When reading register contents, a read of the lower byte data automatically latches the corresponding higher byte data (16 bit latch). This feature guarantees that the high byte value has not been updated by the ADC between I2C reads. In addition, reading CDATAL register not only latches CDATAH but also latches all eight RGBC register simultaneously (64 bit latch).

Proximity Data Register (0x9C)

Proximity data is stored as an 8-bit value.

Field	Address	Bits	Description
PDATA	0x9C	7:0	Proximity data.

Proximity Offset UP / RIGHT Register (0x9D)

In proximity mode, the UP and RIGHT photodiodes are connected forming a diode pair. The POFFSET_UR is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description
POFFSET_UR	7:0	FIELD VALUE
		Offset Correction Factor
		01111111 127
	
		00000001 1
		00000000 0
		10000001 -1
	
		11111111 -127

Proximity Offset DOWN / LEFT Register (0x9E)

In Proximity mode, the DOWN and LEFT photodiodes are connected forming a diode pair. The POFFSET_DL is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description
POFFSET_DL	7:0	FIELD VALUE
		Offset Correction Factor
		01111111 127
	
		00000001 1
		00000000 0
		10000001 -1
	
		11111111 -127

Configuration Three Register (0x9F)

The CONFIG3 register is used to select which photodiodes are used for proximity. Two photodiodes are paired to provide signal. In proximity mode, UP and RIGHT photodiodes are connected forming a diode pair; similarly the DOWN and LEFT photodiodes form a diode pair.

Field	Bits	Description																
RESERVED	7:6	Reserved. Write as 0.																
PCMP	5	Proximity Gain Compensation Enable. This bit provides gain compensation when proximity photodiode signal is reduced as a result of sensor masking. If only one diode of the diode pair is contributing, then only half of the signal is available at the ADC; this results in a maximum ADC value of 127. Enabling PCMP enables an additional gain of 2X, resulting in a maximum ADC value of 255.																
		<table><tr><th>PMASK_X (U, D, L, R)</th><th>PCMP</th></tr><tr><td>0, 1, 1, 1</td><td>1</td></tr><tr><td>1, 0, 1, 1</td><td>1</td></tr><tr><td>1, 1, 0, 1</td><td>1</td></tr><tr><td>1, 1, 1, 0</td><td>1</td></tr><tr><td>0, 1, 0, 1</td><td>1</td></tr><tr><td>1, 0, 1, 0</td><td>1</td></tr><tr><td>All Others</td><td>0</td></tr></table>	PMASK_X (U, D, L, R)	PCMP	0, 1, 1, 1	1	1, 0, 1, 1	1	1, 1, 0, 1	1	1, 1, 1, 0	1	0, 1, 0, 1	1	1, 0, 1, 0	1	All Others	0
PMASK_X (U, D, L, R)	PCMP																	
0, 1, 1, 1	1																	
1, 0, 1, 1	1																	
1, 1, 0, 1	1																	
1, 1, 1, 0	1																	
0, 1, 0, 1	1																	
1, 0, 1, 0	1																	
All Others	0																	
SAI	4	Sleep After Interrupt. When enabled, the device will automatically enter low power mode when the INT pin is asserted and the state machine has progressed to the SAI decision block. Normal operation is resumed when INT pin is cleared over I2C.																
PMASK_U	3	Proximity Mask UP Enable. Writing a 1 disables this photodiode.																
PMASK_D	2	Proximity Mask DOWN Enable. Writing a 1 disables this photodiode.																
PMASK_L	1	Proximity Mask LEFT Enable. Writing a 1 disables this photodiode.																
PMASK_R	0	Proximity Mask RIGHT Enable. Writing a 1 disables this photodiode.																

Gesture Proximity Enter Threshold Register (0xA0)

The Gesture Proximity Enter Threshold Register value is compared with Proximity value, PDATA, to determine if the gesture state machine is entered. The proximity persistence filter, PPERS, is not used to determine gesture state machine entry.

Field	Bits	Description
GPENTH	7:0	Gesture Proximity Entry Threshold. This register sets the Proximity threshold value used to determine a “gesture start” and subsequent entry into the gesture state machine.

Note: Bit 4 must be set to 0.

Gesture Exit Threshold Register (0xA1)

The Gesture Proximity Exit Threshold Register value compares all non-masked gesture detection photodiodes (UDLR). Gesture state machine exit is also governed by the value in the Gesture Exit Persistence register, GEPERS.

Field	Bits	Description
GEXTH	7:0	Gesture Exit Threshold. This register sets the threshold value used to determine a “gesture end” and subsequent exit of the gesture state machine. Setting GTHR_OUT to 0x00 will prevent gesture exit until GMODE is set to 0.

Gesture Configuration One Register (0xA2)

The Gesture Configuration One Register contains settings that govern gesture detector masking, FIFO interrupt generation and gesture exit persistence filter.

Field	Bits	Description	
GFIFOTH	7:6	Gesture FIFO Threshold. This value is compared with the FIFO Level (i.e. the number of UDLR datasets) to generate an interrupt (if enabled).	
		FIELD VALUE	THRESHOLD
		0	Interrupt is generated after 1 dataset is added to FIFO
		1	Interrupt is generated after 4 datasets are added to FIFO
		2	Interrupt is generated after 8 datasets are added to FIFO
GEXMSK	5:2	3	Interrupt is generated after 16 datasets are added to FIFO
		Gesture Exit Mask. Controls which of the gesture detector photodiodes (UDLR) will be included to determine a “gesture end” and subsequent exit of the gesture state machine. Unmasked UDLR data will be compared with the value in GTHR_OUT. Field value bits correspond to UDLR detectors.	
		FIELD VALUE	EXIT MASK
		0000	All UDLR detector data will be included in sum
		0001	R detector data will not be included in sum
		0010	L detector data will not be included in sum
		0100	D detector data will not be included in sum
		1000	U detector data will not be included in sum
		0101	...
0110	L and D detector data will not be included in sum		
GEXPERS	1:0	1111	All UDLR detector data will not be included in sum
		Gesture Exit Persistence. When a number of consecutive “gesture end” occurrences become equal or greater to the GEPERS value, the Gesture state machine is exited.	
		FIELD VALUE	PERSISTENCE
		0	1st 'gesture end' occurrence results in gesture state machine exit.
		1	2nd 'gesture end' occurrence results in gesture state machine exit.
		2	4th 'gesture end' occurrence results in gesture state machine exit.
		3	7th 'gesture end' occurrence results in gesture state machine exit.

Gesture Configuration Two Register (0xA3)

The Gesture Configuration Two register contains settings that govern wait time, LDR drive current strength and Gesture gain control. The GWTIME controls the amount of time in a low power mode between gesture detection cycles. GPDRIVE sets the LDR drive current strength governing LED intensity. GGAIN sets the analog gain associated with the photodiode output.

Field	Bits	Description
RESERVED	7	Reserved. Write as 0.
GGAIN	6:5	Gesture Gain Control. Sets the gain of the proximity receiver in gesture mode.
		FIELD VALUE GAIN VALUE
		0 1x
		1 2x
		2 4x
		3 8x
GLDRIVE	4:3	Gesture LED Drive Strength. Sets LED Drive Strength in gesture mode.
		FIELD VALUE LED CURRENT
		0 100 mA
		1 50 mA
		2 25 mA
		3 12.5 mA
GWTIME	2:0	Gesture Wait Time. The GWTIME controls the amount of time in a low power mode between gesture detection cycles.
		FIELD VALUE WAIT TIME
		0 0 ms
		1 2.8 ms
		2 5.6 ms
		3 8.4 ms
		4 14.0 ms
		5 22.4 ms
		6 30.8 ms
		7 39.2 ms

Notes:

1. The wait time register should be configured before GEN is asserted.
2. The time described by GTIME is the actual signal integration time. The LED will be activated slightly longer (typically 1.33 μ s) than the integration time.

Gesture UP Offset Register (0xA4)

The GOFFSET_U is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description	
GOFFSET_U	7:0	FIELD VALUE	Offset Correction Factor
		01111111	127
	
		00000001	1
		00000000	0
		10000001	-1
	
		11111111	-127

Gesture DOWN Offset Register (0xA5)

The GOFFSET_D is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description	
GOFFSET_D	7:0	FIELD VALUE	Offset Correction Factor
		01111111	127
	
		00000001	1
		00000000	0
		10000001	-1
	
		11111111	-127

Gesture LEFT Offset Register (0xA7)

The GOFFSET_L is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description	
GOFFSET_L	7:0	FIELD VALUE	Offset Correction Factor
		01111111	127
	
		00000001	1
		00000000	0
		10000001	-1
	
		11111111	-127

Gesture RIGHT Offset Register (0xA9)

The GOFFSET_R is an 8-bit value used to scale an internal offset correction factor to compensate for crosstalk in the application. This value is encoded in sign/magnitude format.

Field	Bits	Description	
GOFFSET_L	7:0	FIELD VALUE	Offset Correction Factor
		01111111	127
	
		00000001	1
		00000000	0
		10000001	-1
	
		11111111	-127

Gesture Pulse Count and Length Register (0xA6)

The Gesture Pulse Count Register sets Pulse Width Modified current during a Gesture Pulse. The Gesture pulse count register bits set the number of pulses to be output on the LDR pin. The Gesture Length register bits set the amount of time the LDR pin is sinking current during a gesture pulse.

Field	Bits	Description	
GPEN	7:6	Gesture Pulse Length. Sets the LED_ON pulse width during a Gesture LDR Pulse.	
		FIELD VALUE	PULSE LENGTH
		0	4 μ s
		1	8 μ s (default)
		2	16 μ s
		3	32 μ s
GPULSE	5:0	Number of Gesture Pulses. Specifies the number of pulses to be generated on LDR. Number of pulses is set by GPULSE value plus 1.	
		FIELD VALUE	Number OF PULSES
		0	1
		1	2
		2	3
	
		63	64

Note:

1. The Gesture Pulse Count Register resets to 0x40 at initial power up (POR).

Gesture Configuration Three Register (0xAA)

The Gesture Configuration Three Register contains settings that govern which gesture photodiode pair: UP-DOWN and/or RIGHT-LEFT will be enabled (have valid data in FIFO) while the gesture state machine is collecting directional data. Normal mode enables all four gesture photodiodes and places data into FIFO as expected. Disabling a photodiode pair, essentially allows the enabled pair to collect data twice as fast. Data stored in the FIFO for a disabled pair is not valid. This feature is useful to improve reliability and accuracy of gesture detection when only one-dimensional gestures are expected.

Field	Bits	Description										
RESERVED	7:2	Reserved. Write as 0.										
GDIMS	1:0	Gesture Dimension Select. Selects which gesture photodiode pairs are enabled to gather results during gesture.										
		<table><tr><th>FIELD VALUE</th><th>GESTURE DIRECTION</th></tr><tr><td>0</td><td>Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.</td></tr><tr><td>1</td><td>Only the UP-DOWN pair is active. Ignore LEFT-RIGHT data in FIFO.</td></tr><tr><td>2</td><td>Only the LEFT-RIGHT pair is active. Ignore UP-DOWN data in FIFO.</td></tr><tr><td>3</td><td>Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.</td></tr></table>	FIELD VALUE	GESTURE DIRECTION	0	Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.	1	Only the UP-DOWN pair is active. Ignore LEFT-RIGHT data in FIFO.	2	Only the LEFT-RIGHT pair is active. Ignore UP-DOWN data in FIFO.	3	Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.
		FIELD VALUE	GESTURE DIRECTION									
		0	Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.									
		1	Only the UP-DOWN pair is active. Ignore LEFT-RIGHT data in FIFO.									
2	Only the LEFT-RIGHT pair is active. Ignore UP-DOWN data in FIFO.											
3	Both pairs are active. UP-DOWN and LEFT-RIGHT FIFO data is valid.											

Gesture Configuration Four Register (0xAB)

The Gesture Configuration Four Register contains settings that govern Gesture interrupts and interrupt clearing/reset as well as operation mode control and status.

Field	Bits	Description
RESERVED	7:3	Reserved. Write as 0.
GFIFO_CLR	2	Setting this bit to '1' clears GFIFO, GINT, GVALID, GFIFO_OV and GFIFO_LVL.
GIEN	1	Gesture interrupt enable. Gesture Interrupt Enable. When asserted, all gesture related interrupts are unmasked.
GMODE	0	Gesture Mode. Reading this bit reports if the gesture state machine is actively running, 1 = Gesture, 0= ALS, Proximity, Color. Writing a 1 to this bit causes immediate entry in to the gesture state machine (as if GPENTH had been exceeded). Writing a 0 to this bit causes exit of gesture when current analog conversion has finished (as if GEXTH had been exceeded).

Gesture FIFO Level Register (0xAE)

The GFLVL Register indicates the number of datasets that are currently available in the FIFO for read. Reading a complete FIFO dataset (from address 0xFC to 0xFF) constitutes the reduction of the GPENTH register by one.

Field	Bits	Description
GFLVL	7:0	Gesture FIFO Level. This register indicates how many four byte data points - UDLR are ready for read over I2C. One four-byte dataset is equivalent to a single count in GFLVL.

Gesture Status Register (0xAF)

The GSTATUS Register indicates the operational condition of the gesture state machine.

Field	Bits	Description
RESERVED	7:2	Do not care.
GFOV	1	Gesture FIFO Overflow. A setting of 1 indicates that the FIFO has filled to capacity and that new gesture detector data has been lost.
GVALID	0	Gesture FIFO Data. GVALID bit is sent when GFLVL becomes greater than GFIFOTH (i.e. FIFO has enough data to set GINT). GFIFOD is reset when GMODE = 0 and the GFLVL=0 (i.e., All FIFO data has been read).

Note: If GINT (irrespective of GVALID) remains set after the FIFO has been read GFLVL times, this indicates that new data has been added to FIFO during the last FIFO read.

Clear Interrupt Registers (0xE4 – 0xE7)

Interrupts are cleared by “address accessing” the appropriate register. This is special I2C transaction consisting of only two bytes: chip address with R/W = 0, followed by a register address.

Registers	Address	Bits	Description
IFORCE	0xE4	7:0	Forces an interrupt (any value)
PICLEAR	0xE5	7:0	Proximity interrupt clear (any value)
CICLEAR	0xE6	7:0	ALS interrupt clear (any value)
AICLEAR	0xE7	7:0	Clears all non-gesture interrupts (any value)

Gesture FIFO Register (0xFC – 0xFF)

In Gesture mode, the RAM area is repurposed as a 32 x 4 byte FIFO. Data is stored in four byte blocks. Each block, called a dataset, contains one integration cycle of UP, DOWN, LEFT, & RIGHT gesture data. Thirty-two separate datasets are stored within the FIFO before wrap-around overflow. If the FIFO overflows (i.e., 33 datasets before host/system can empty FIFO) new datasets will not replace existing datasets; instead an overflow flag will be set and new data will be lost.

Host/Systems acquire gesture data by reading addresses: 0xFC, 0xFD, 0xFE, & 0xFF, which directly correspond to UP, DOWN, LEFT, & RIGHT data points. Data can be read a single byte at a time (four consecutive I2C transactions) or by using a page read.

The internal FIFO read pointer and the FIFO Level register, GFLVL, values are updated when address 0xFF is accessed (single byte transactions) or when every fourth byte, corresponding to address 0xFF, is accessed in in page mode. If the FIFO continues to be accessed after GFLVL register is zero, dataset will be read as zero values.

The recommended procedure for reading data stored in the FIFO begins when a gesture interrupt is generated (GFLVL > GFIFOTH). Next, the host reads the FIFO Level register, GFLVL, to determine the amount of valid data in the FIFO.

Finally, the host begins to read address 0xFC (page read), and continues to read (clock-out data) until the FIFO is empty (Number of bytes is 4X GFLVL). For example, if GFLVL = 2, then the host should initiate a read at address 0xFC, and sequentially read all eight bytes. As the four-byte blocks are read, GFLVL register is decremented and the internal FIFO pointers are updated.

Field	Address	Bits	Description
GFIFO_U	0xFC	7:0	Gesture FIFO UP value.
GFIFO_D	0xFD	7:0	Gesture FIFO DOWN value.
GFIFO_L	0xFE	7:0	Gesture FIFO LEFT value.
GFIFO_R	0xFF	7:0	Gesture FIFO RIGHT value.

Application Information Hardware

In a proximity sensing system, the internal IR LED can be pulsed by more than 100 mA of rapidly switching current, therefore, a few design considerations must be kept in mind to get the best performance. The key goal is to reduce the power supply noise coupled back into the device during the LED pulses.

In many systems, there is a quiet analog supply and a noisy digital supply. By connecting the quiet supply to the VDD pin and the noisy supply to the LED, the key goal can be met. Place a $1\ \mu\text{F}$ low-ESR decoupling capacitor as close as possible to the VDD pin and another at the LEDA pin, along with a bulk storage capacitor ($\geq 10\ \mu\text{F}$) at the output of the LED voltage regulator to supply the current surge.

If operating from a single supply, use a $22\ \Omega$ resistor in series with the VDD supply line and a $1\ \mu\text{F}$ low ESR capacitor to filter any power supply noise. The previous capacitor placement considerations apply. However note that where LED current is boosted beyond 100 mA, it is recommended that the LEDA pin be connected to a separate power supply.

VBUS in the figures refers to the I^2C -bus voltage. The I^2C -bus signals and the Interrupt are open-drain outputs and require pull-up resistors. The pull-up resistor (R_P) value is a function of the I^2C -bus speed, the I^2C -bus voltage, and the capacitive load. A $10\text{-k}\Omega$ pull-up resistor (R_{PI}) can be used for the interrupt line.

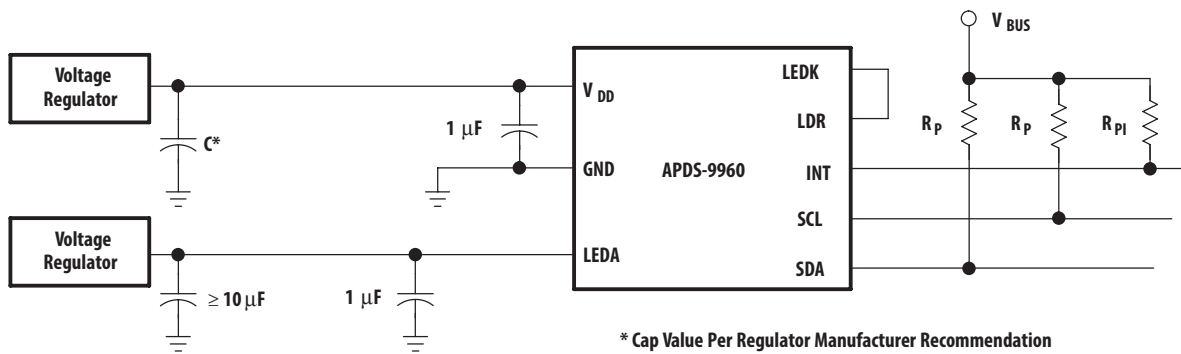


Figure 14a. Circuit Implementation using Separate Power Supplies

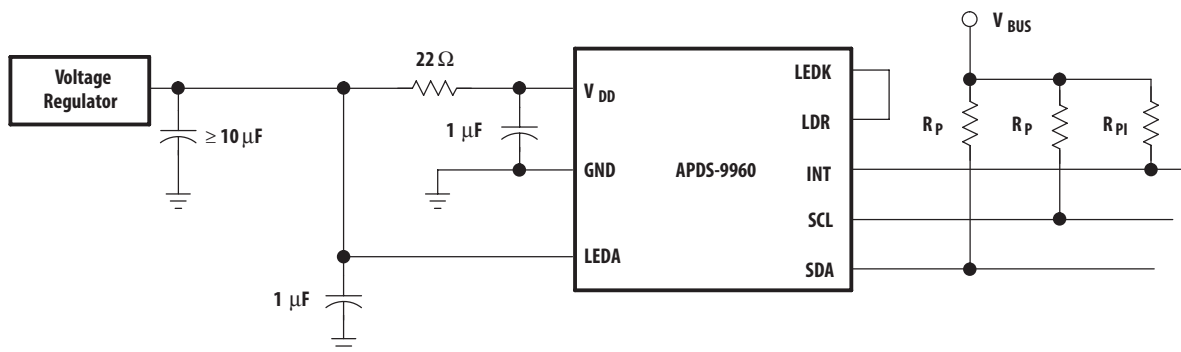
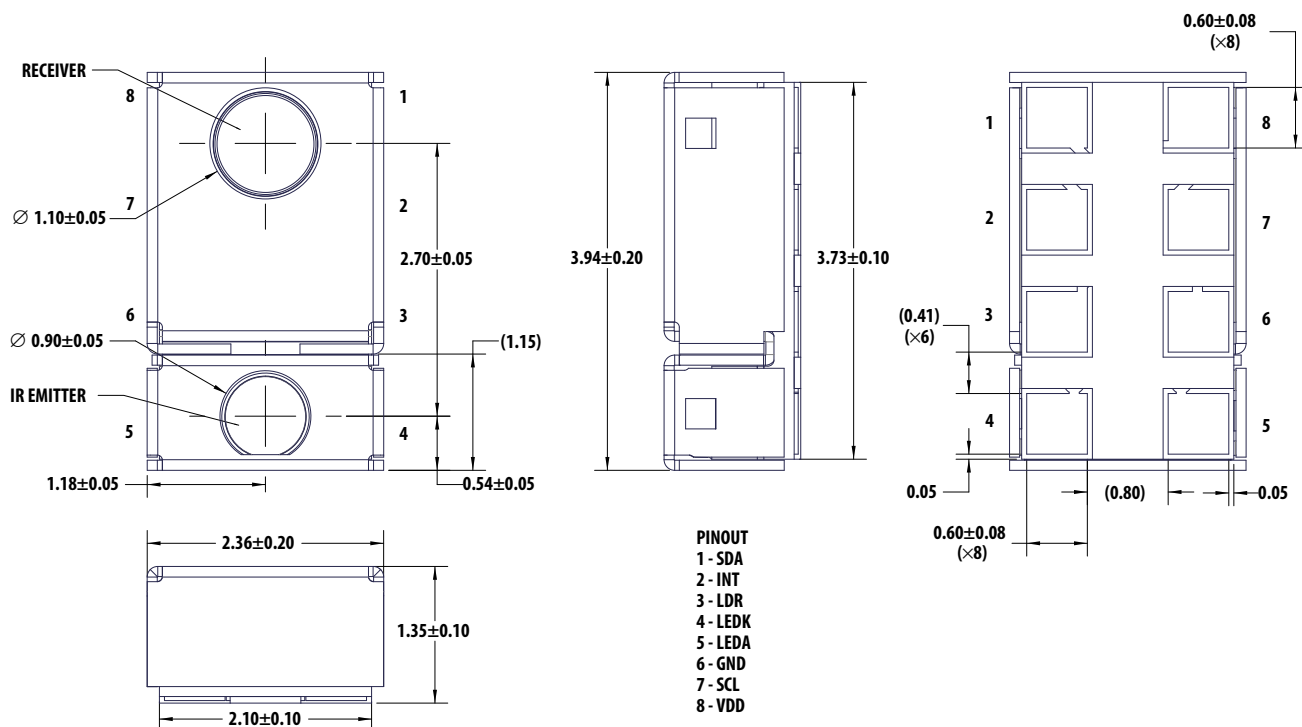


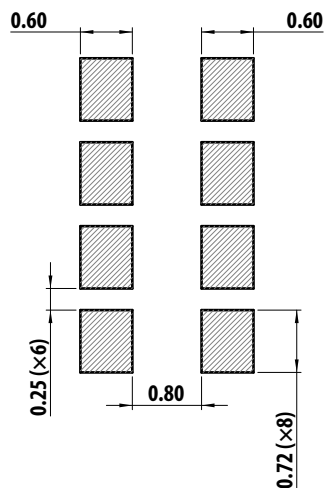
Figure 14b. Circuit Implementation using Single Power Supply

Package Outline Dimensions



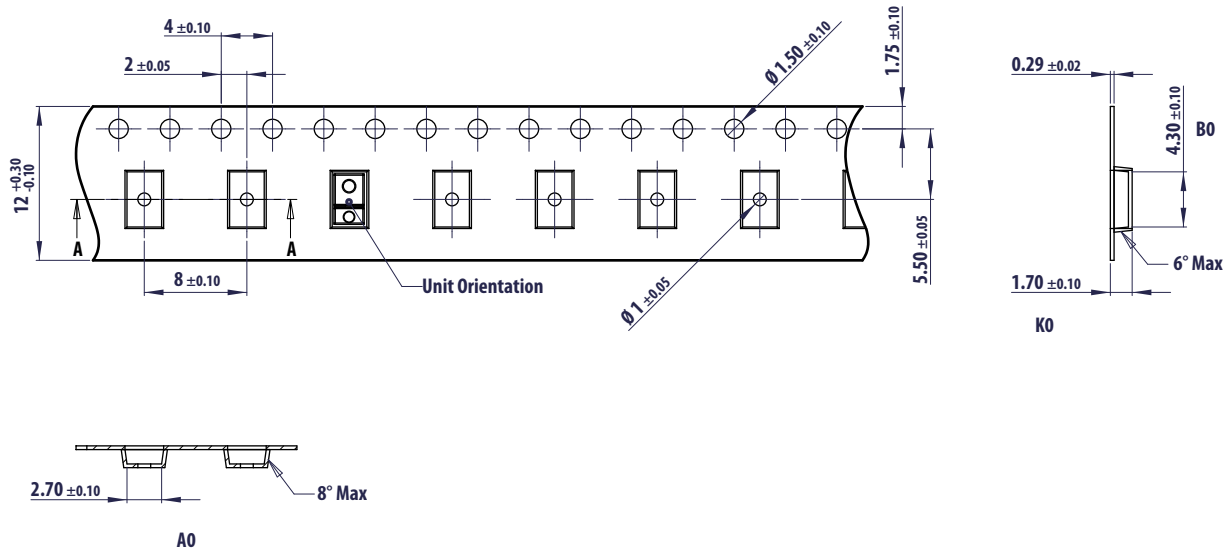
PCB Pad Layout

Suggested PCB pad layout guidelines for the Dual Flat No-Lead surface mount package are shown as follows:

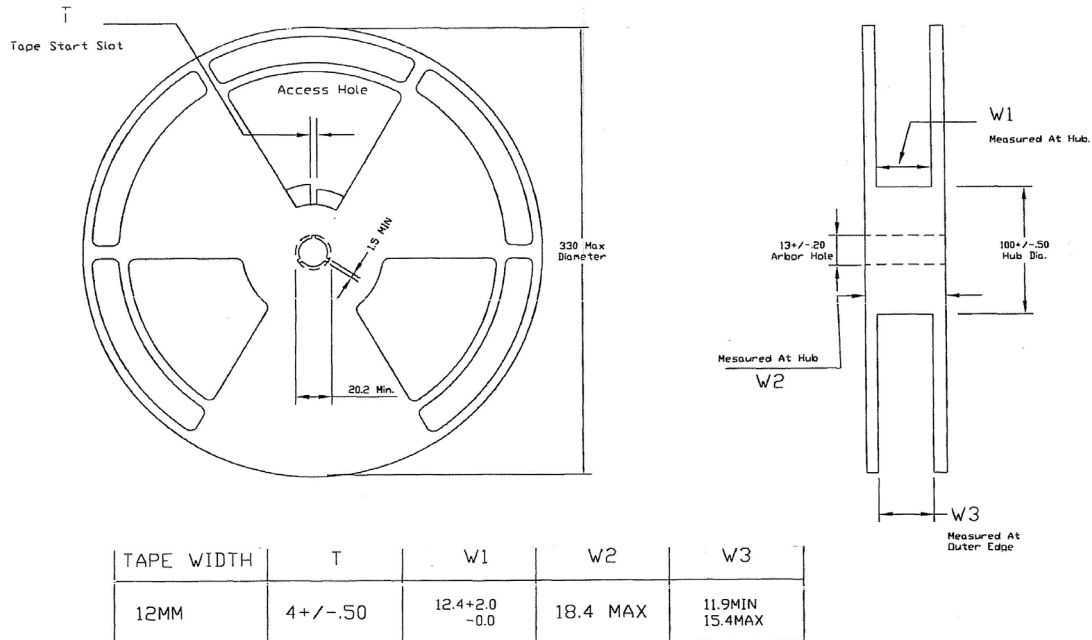


Note: All linear dimensions are in mm.

Tape Dimensions

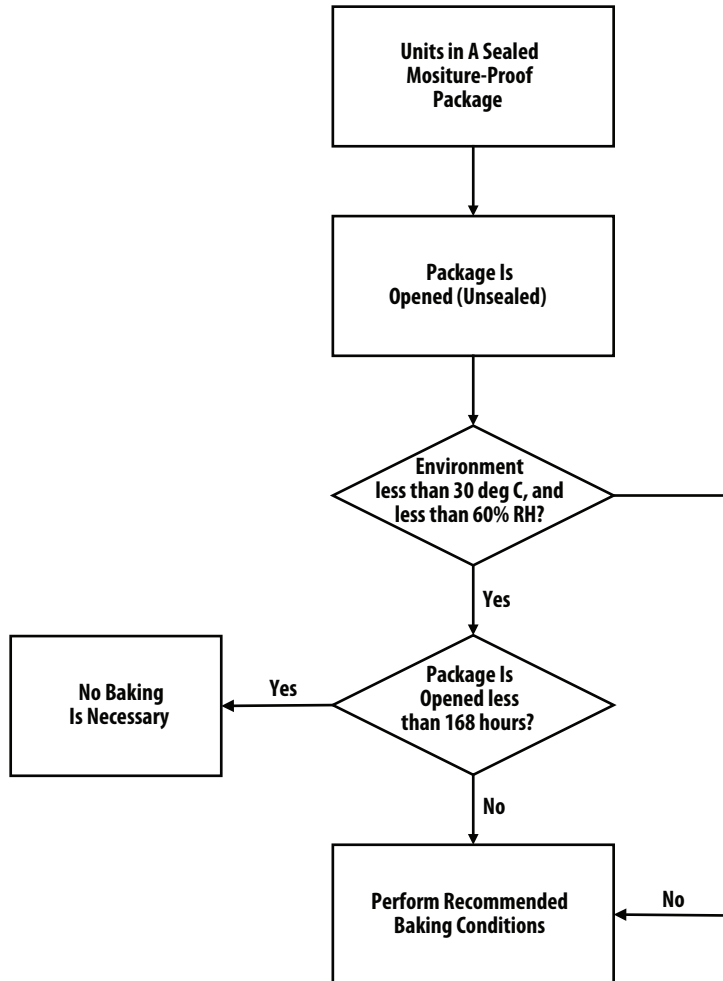


Reel Dimensions



Moisture Proof Packaging

All APDS-9960 options are shipped in moisture proof package. Once opened, moisture absorption begins. This part is compliant to JEDEC MSL 3.



Baking Conditions

Package	Temperature	Time
In Reel	60 °C	48 hours
In Bulk	100 °C	4 hours

If the parts are not stored in dry conditions, they must be baked before reflow to prevent damage to the parts.

Baking should only be done once.

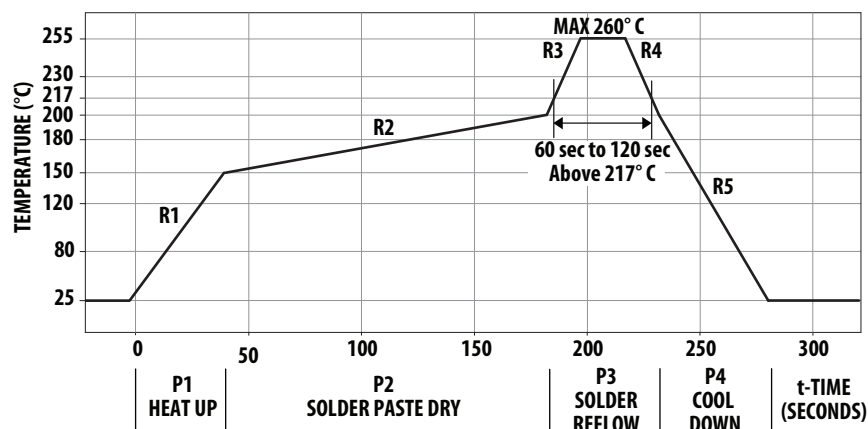
Recommended Storage Conditions

Storage Temperature	10 °C to 30 °C
Relative Humidity	below 60% RH

Time from unsealing to soldering

After removal from the bag, the parts should be soldered within 168 hours if stored at the recommended storage conditions. If times longer than 168 hours are needed, the parts must be stored in a dry box.

Recommended Reflow Profile



Process Zone	Symbol	ΔT	Maximum $\Delta T/\Delta \text{time}$ or Duration
Heat Up	P1, R1	25 °C to 150 °C	3 °C/s
Solder Paste Dry	P2, R2	150 °C to 200 °C	100 s to 180 s
Solder Reflow	P3, R3	200 °C to 260 °C	3 °C/s
	P3, R4	260 °C to 200 °C	-6 °C/s
Cool Down	P4, R5	200 °C to 25 °C	-6 °C/s
Time maintained above liquidus point , 217 °C		> 217 °C	60 s to 120 s
Peak Temperature		260 °C	–
Time within 5 °C of actual Peak Temperature		> 255 °C	20 s to 40 s
Time 25 °C to Peak Temperature		25 °C to 260 °C	8 mins

The reflow profile is a straight-line representation of a nominal temperature profile for a convective reflow solder process. The temperature profile is divided into four process zones, each with different $\Delta T/\Delta \text{time}$ temperature change rates or duration. The $\Delta T/\Delta \text{time}$ rates or duration are detailed in the above table. The temperatures are measured at the component to printed circuit board connections.

In process zone P1, the PC board and component pins are heated to a temperature of 150 °C to activate the flux in the solder paste. The temperature ramp up rate, R1, is limited to 3 °C per second to allow for even heating of both the PC board and component pins.

Process zone P2 should be of sufficient time duration (100 to 180 seconds) to dry the solder paste. The temperature is raised to a level just below the liquidus point of the solder.

Process zone P3 is the solder reflow zone. In zone P3, the temperature is quickly raised above the liquidus point of

solder to 260 °C (500 °F) for optimum results. The dwell time above the liquidus point of solder should be between 60 and 120 seconds. This is to assure proper coalescing of the solder paste into liquid solder and the formation of good solder connections. Beyond the recommended dwell time the intermetallic growth within the solder connections becomes excessive, resulting in the formation of weak and unreliable connections. The temperature is then rapidly reduced to a point below the solidus temperature of the solder to allow the solder within the connections to freeze solid.

Process zone P4 is the cool down after solder freeze. The cool down rate, R5, from the liquidus point of the solder to 25 °C (77 °F) should not exceed 6 °C per second maximum. This limitation is necessary to allow the PC board and component pins to change dimensions evenly, putting minimal stresses on the component.

It is recommended to perform reflow soldering no more than twice.

For product information and a complete list of distributors, please go to our web site: www.avagotech.com

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