

High-performance Ultrasonic Time-of-Flight Range Sensor

ICU-10201 HIGHLIGHTS

ICU-10201 is a high-performance, miniature, ultra-low power, long-range ultrasonic Time-of-Flight (ToF) transceiver. Based on Chirp's patented MEMS technology, the ICU-10201 is a system-in-package that integrates a nominally 175 kHz PMUT (Piezoelectric Micromachined Ultrasonic Transducer) together with a 2nd generation ultra-low power SoC (System on Chip) in a miniature, reflowable package.

The SoC is designed for overall low system power and for ease of use with external host processors. Low power is achieved through custom digital circuitry to process and buffer the raw sensor readings. This keeps the integrated microcontroller in a low power idle state until needed. For ease of use, the microcontroller can process the raw sensor readings into high level signals, such as range to nearby target(s), or events, such as presence, which can be directly read by the host processor. The SoC communicates with the host processor over SPI at up to 13 MHz at either 1.8 or 3.3 V.

Complementing Chirp's other ultrasonic ToF sensor products, ICU-10201 provides accurate range measurements to targets at distances up to 1.2 m. Based on ultrasonic pulse-echo measurements, the sensor works in any lighting condition, including full sunlight, and provides millimeter-accurate range measurements independent of the target's color and optical transparency. The sensor's Field-Of-View (FOV) can be customized using a horn. ICU-10201 is capable of simultaneous range measurements to multiple objects in the FOV. Several available algorithms can further process the echo information for a variety of usage cases in a range of applications (listed below).



DEVICE INFORMATION

PART NUMBER	PACKAGE	LID OPENING
ICU-10201-00	3.5 x 3.5 x 1.26 mm LGA	1-Hole
ICU-10201-02†	3.5 x 3.5 x 1.26 mm LGA	1-Hole

† Pitch-Catch variant || RoHS and Green-Compliant Package

APPLICATIONS

- Floor type detection for robotic vacuums
- Cliff detection for robotic vacuums
- <1 m presence detection
- 3D tracking
- Pitch-catch ranging between wireless nodes

FEATURES

- Fast, accurate range-finding
 - 40 MHz integrated CPU enables on-chip algorithms including rangefinding, human presence, and wake-on approach
 - Operating range from 10 cm to 1.2 m
 - Detection of moving objects closer than 10cm
 - Programmable modes optimized for long or short-range sensing applications
 - Customizable field of view (FoV) up to 180°
 - Multi-object detection
 - Works in any lighting condition, including full sunlight to complete darkness
 - Insensitive to object color, detects optically transparent surfaces (glass, clear plastics etc.)
- Easy to integrate
 - Single sound port for receive and transmit
 - 1.8 V or 3.3 V I/O voltage
 - Low power 1.8V core operating voltage
 - 13 MHz SPI interface allows baseband data stream out at full measurement rate
 - Optional 32 kHz reference clock input
 - Optional measurement clock input
 - Two programmable open drain I/O for triggering the sensor or waking the host
 - Platform-independent software driver enables turnkey range-finding
 - Field of view can be customized through design of the acoustic port
- Miniature integrated package
 - 3.5 mm x 3.5 mm x 1.26 mm, 14-pin LGA
 - Compatible with standard SMD reflow
 - Operating temperature range: -40°C to 85°C
- Low supply current
 - 1 sample/s:
 - 14 μ A (0.5 m max range)
 - 17 μ A (1 m max range)
 - 50 samples/s:
 - 212 μ A (0.5 m max range)
 - 320 μ A (1 m max range)

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1 SIMPLIFIED BLOCK DIAGRAM & PIN OUT

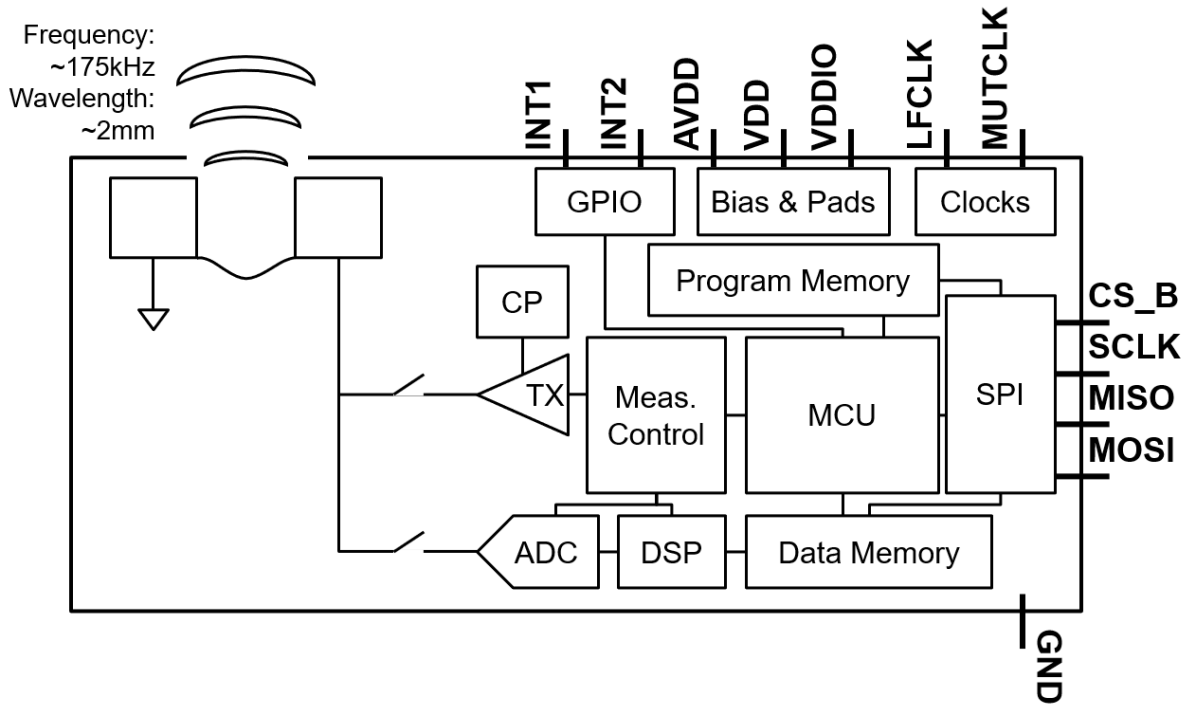


Figure 1. Simplified Block Diagram

1.1 PIN DESCRIPTIONS

PIN	NAME	DESCRIPTION
1	GND	Ground
2	SCLK	SPI Interface Clock (from external SPI host) CPOL=1, CPHA=1
3	MOSI	<u>MCU Out</u> <u>Sensor In</u> serial data (from external SPI host)
4	MISO	<u>MCU In</u> <u>Sensor Out</u> serial data (to external SPI host)
5	CS_B	SPI Chip Select (active-low, from external SPI host)
6	INT1	Interrupt Request Open Drain Input/Output 1
7	INT2	Interrupt Request Open Drain Input/Output 2
8	GND	Ground
9	LFCLK	External Input/Output Low Frequency Reference Clock - 32.768 kHz typical (optional)
10	MUTCLK	External Input/Output 16x Operating Frequency Reference Clock (optional)
11	GND	Ground
12	VDD	Digital Logic Supply. Connect to externally regulated 1.8 V +/-5% supply. Suggest common connection to AVDD. If not connected locally to AVDD, bypass with a 0.1 μF capacitor close to VDD & GND pad.
13	AVDD	Analog Power Supply. Connect to externally regulated 1.8 V +/-5% supply. Bypass with a 0.1 μF capacitor close to AVDD & GND pad.
14	VDDIO	I/O Power Supply. Connect to externally regulated 1.8 V +/-5% or 3.3 V +/-10% supply. Bypass with a 1μF capacitor close to VDDIO & GND pad.

Table 1. Pin Descriptions

2 ELECTRICAL CHARACTERISTICS

2.1 ABSOLUTE MAXIMUM RATINGS

PARAMETER	MIN	TYP	MAX	UNIT
AVDD/VDD to GND	-0.3		2.2	V
VDDIO to GND	-0.3		4.0	V
Digital I/O pins to GND	-0.3			V
Digital I/O pins to VDDIO			0.3	V
Electrostatic Discharge (ESD)	Human Body Model (HBM) ⁽¹⁾	-2	2	kV
	Charge Device Model (CDM) ⁽²⁾	-500	500	V
Latchup	-100		100	mA
Temperature, Operating	-40		85	°C
Relative Humidity, Storage			90	%RH
Continuous Input Current (Any Pin)	-20		20	mA
Soldering Temperature (reflow)			260	°C

1. HBM Tests conducted in compliance with ANSI/ESDA/JEDEC JS-001-2024 Or JESD22-A114E
2. CDM Tests conducted in compliance with JESD22-C101.

2.2 ULTRASONIC TRANSCIVER CHARACTERISTICS

(AVDD = VDD = 1.8 VDC, VDDIO = 3.3 V, GND = 0 V, T_A = +25°C, min/max are from T_A = -40°C to +85°C, unless otherwise specified.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
POWER SUPPLY						
Analog Power Supply	AVDD		1.71	1.8	1.89	V
Digital Power Supply	VDD		1.71	1.8	1.89	V
IO Power Supply	VDDIO		1.71		3.63	V
Operating Temperature			-40	25	85	°C
ULTRASONIC TRANSMIT CHANNEL						
Operating Frequency	f _{op}	ICU-10201-00	173.3 ⁽¹⁾		181.2 ⁽¹⁾	kHz
Operating Frequency	f _{op}	ICU-10201-02	176 ⁽¹⁾		178 ⁽¹⁾	kHz
TxRx OPERATION⁽²⁾						
Maximum Range	Max Range	Wall Target		1.7 ⁽³⁾		m
		58 mm Diameter Post		1.1 ⁽³⁾		m
Minimum Range	Min Range		0.1 ⁽⁴⁾			m
		Transmit signal optimized		0.03 ⁽⁵⁾		m
Baseband I/Q Output Sample Rate		Output Data Rate ODR=2 ODR=3 ODR=4 ODR=5 ODR=6		f _{op} /32 f _{op} /16 f _{op} /8 f _{op} /4 f _{op} /2		Samples/s
Measuring Rate (Sample/sec)	MR	0.3 m max range			250	Measurements/s
		1 m max range			130	Measurements/s
Field of View	FoV			Configurable up to 180°		deg
Current Consumption (AVDD + VDD) ⁽⁶⁾	I _s	MR=1 Meas/s, Range=0.5 m		14		µA
		MR=1 Meas/s, Range=1 m		17		µA
		MR=50 Meas/s, Range=0.5 m		212		µA
		MR=50 Meas/s, Range=1 m		320		µA
Idle Current (AVDD+VDD)	I _i	T=+25°C, VDD=AVDD=1.8V Sensor Idle, FW programmed.		9	18	µA
Measurement Latency ⁽⁷⁾		1 m max range		7.5		ms
Programming Time				5 ⁽⁸⁾		ms

Notes:

- 100% tested; some shift is normal after SMT
- General Purpose Transceiver Firmware loaded; ODR=4 unless otherwise noted
- By characterization, tested using 45° FoV conical horn with a particle ingress filter (PIF). The type of horn & PIF used can influence the maximum range.
- By characterization, tested with a stationary target. While objects closer than 10 cm can be detected, the range measurement is not ensured.
- By characterization, tested with a stationary target. Transmit signal optimization must be run before achieving the minimum range.
- ODR = 4
- By characterization, from start of measurement to data ready signal on INT line
- By characterization, tested with SCLK frequency of 12.5MHz

2.3 I/O CHARACTERISTICS

(AVDD = VDD = 1.8 VDC, VDDIO = 3.3 V, GND = 0 V, TA = +25°C, min/max are from TA = -40°C to +85°C, unless otherwise specified.)

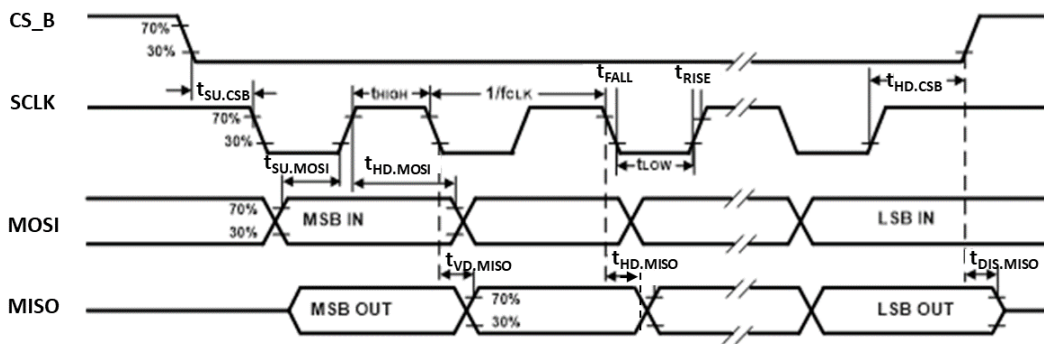
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DIGITAL INPUTS (MOSI, CS_B, SCLK, MUTCLK, LFCLK, INT1, INT2)						
V _{IH} , High Level Input Voltage	V _{IH}		0.7*V _{VDDIO}			V
V _{IL} , Low Level Input Voltage	V _{IL}			0.3*V _{VDDIO}		V
Input Capacitance	C _I			<10		pF
DIGITAL OUTPUT (MISO, MUTCLK, LFCLK, INT1, INT2)						
High Level Output Voltage	V _{OH}	R _{LOAD} =1 MΩ	0.9*V _{VDDIO}			V
Low Level Output Voltage	V _{OL}	R _{LOAD} =1 MΩ		0.1*V _{VDDIO}		V
Output Leakage Current		OPEN=1		±100		nA

2.4 SPI TIMING CHARACTERISTICS – 4-WIRE SPI MODE

(AVDD = VDD = 1.8VDC, VDDIO=1.8V or 3.3V, GND = 0V, TA = +25°C, min/max are from TA = -40°C to +85°C, unless otherwise specified.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DIGITAL I/O CHARACTERISTICS						
SCLK Clock Frequency	f _{CLK}			13		MHz
SCLK Low Period	t _{LOW}		11			ns
SCLK High Period	t _{HIGH}		11			ns
CS_B Setup Time	t _{SU.CSB}		80			ns
CS_B Hold Time	t _{HD.CSB}		80			ns
MOSI Setup Time	t _{SU.MOSI}		2			ns
MOSI Hold Time	t _{HD.MOSI}		2			ns
MISO Valid Time	t _{VD.MISO}	C _{load} = 20pF			28	ns
MISO Hold Time	t _{HD.MISO}	C _{load} = 20pF	2			ns
MISO Output Disable Time	t _{DIS.MISO}				3	ns

Note: Based on characterization of 10 parts from 3 typical and 2 corner lots. Measured over temperature and voltage as mounted in sockets.

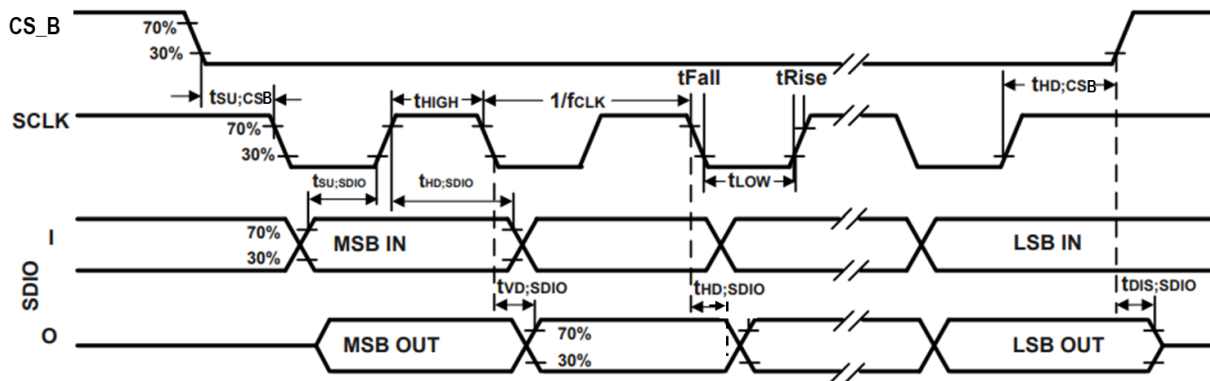


2.5 SPI TIMING CHARACTERISTICS – 3-WIRE SPI MODE

(AVDD = VDD = 1.8VDC, VDDIO=1.8V or 3.3V, GND = 0V, T_A = +25°C, min/max are from T_A = -40°C to +85°C, unless otherwise specified.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DIGITAL I/O CHARACTERISTICS						
SCLK Clock Frequency	f _{CLK}			13		MHz
SCLK Low Period	t _{LOW}		11			ns
SCLK High Period	t _{HIGH}		11			ns
CS_B Setup Time	t _{SU,CSB}		80			ns
CS_B Hold Time	t _{HD,CSB}		80			ns
SDIO Input Setup Time	t _{SU,SDIO}		2			ns
SDIO Input Hold Time	t _{HD,SDIO}		2			ns
SDIO Output Valid Time	t _{VD,SDIO}	C _{load} = 20pF		21.5		ns
SDIO Output Hold Time	t _{HD,SDIO}	C _{load} = 20pF	2			ns
SDIO Output Disable Time	t _{DIS,SDIO}			3		ns

Note: Based on characterization of 10 parts from 3 typical and 2 corner lots. Measured over temperature and voltage as mounted in sockets.



3 DETAILED DESCRIPTION

3.1 THEORY OF OPERATION

The ICU-10201 is an autonomous, digital output ultrasonic transceiver. The Simplified Block Diagram in Figure 1 shows the main components at the package-level. The package includes a piezoelectric micro-machined ultrasonic transducer (PMUT) and system-on-chip (SoC). The SoC controls the PMUT to produce pulses of ultrasound at an operational frequency f_{op} that reflect off targets in the sensor’s Field of View (FoV). The reflections are received by the same PMUT after a short time delay, amplified by sensitive electronics, digitized, and stored as I/Q baseband data in the on-chip data memory. Software defined algorithms can process the I/Q data to detect targets using the on-chip microcontroller (MCU), and these algorithms can be tuned to detect stationary or moving targets preferentially. I/Q data can also be transferred to a larger host or application processor (AP) for further processing.

3.1.1 Ultrasonic Transducer

The PMUT within ICU-10201 is positioned directly below the acoustic port on the top of the device. The PMUT can transmit and receive ultrasound. During the transmitting process, a high voltage pulse train is applied to the PMUT and the PMUT transmits a sound wave into the air in front of ICU-10201. During the receive process, the sound waves impinging on the PMUT create a small current which is amplified and digitized and stored in the on-chip memory.

The frequency of the PMUT varies as a function of the MEMS process; TDK’s patented frequency locking algorithm ensures that the transmitting and receiving operational frequency f_{op} is tuned to the PMUT frequency and the transmitting and receiving sensitivities are optimized.

ICU-10201’s acoustic port provides a nearly hemispherical radiation pattern. Some applications require a narrower FoV and so will use a horn to focus the sound. Somewhat unintuitively, wider diameter horns provide narrower FoV beam patterns. TDK has several horn 3D models readily available for customer design-in.

3.1.2 Measurement Process

ICU-10201’s measurement state machine (MSM) is the core of the ultrasonic transceiver measurement process. The MSM, once triggered by the MCU, fetches specialized instructions from memory and executes those instructions, causing specific actions to be performed by the transceiver. Instructions consist of a command, interrupt configuration, command specific configuration, and a length. The supported commands are transmit, receive, count, and end-of-file (EOF). Each command is executed for the length of the instruction, which is specified in counts of the measurement clock, which operates at $16 f_{op}$.

Taken together, several instructions form a measurement queue, which defines the measurement to be taken by the transceiver. The measurement queue can be adapted to address specific requirements posed by an application. Typically, the penultimate instruction will consist of a receive instruction with the DONE_IEN bit set, and the last instruction will be EOF. The MCU will then wake up at the conclusion of the measurement and process the I/Q data or forward it to the host for processing.

CMD[1:0]	Description
00	Count
01	Transmit
10	Receive
11	End of file

Table 2. PMUT Commands

Byte	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Byte 0	X	X	RX_BIAS_EN	RX_RESET	DONE_IEN	RDY_IEN	0	0
Byte 1	X	X	X	X	X	X	X	X
Byte 2	LENGTH[7:0]							
Byte 3	LENGTH[15:8]							

Table 3: Count instruction format

Byte	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Byte 0	X	X	RX_BIAS_EN	RX_RESET	DONE_IEN	RDY_IEN	0	1
Byte 1	Phase[3:0]				X	Pulse_Width[2:0]		
Byte 2	LENGTH[7:0]							
Byte 3	LENGTH[15:8]							

Table 4: TX instruction format

Byte	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Byte 0	0	1	RX_BIAS_EN=1	RX_RESET	DONE_IEN	RDY_IEN	1	0
Byte 1	X	RX_ATTEN[1:0]			RX_GAIN_REDUCTION[4:0]			
Byte 2	LENGTH[7:0]							
Byte 3	LENGTH[15:8]							

Table 5: RX instruction format

Byte	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Byte 0	X	X	X	X	DONE_IEN	RDY_IEN	1	1
Byte 1	X	X	X	X	X	X	X	X
Byte 2	0xXX							
Byte 3	0xXX							

Table 6: EOF instruction format

3.1.3 I/Q Baseband data

The received signal is amplified, digitized, and downconverted (multiplied) to the baseband (dc) by sine and cosine components of a digital carrier signal at the operational frequency f_{op} . The component of the signal that is in-phase with the cosine demodulator is called in-phase (I) and the component that is in-phase with the sine demodulator is called quadrature (Q). I and Q signals are then filtered and downsampled to a lower sample rate by a digital comb filter.

The I/Q baseband data contains amplitude (calculated by $\sqrt{I^2 + Q^2}$), representing the envelope of the signal, and phase ($\text{atan2}(Q, I)$), representing the relative contribution of the I and Q parts of the signal. I/Q data contains all the information necessary to reconstruct the ultrasonic signal; however, efficient digital signal processing is best done in the complex baseband. Many algorithms calculate amplitude and discard the phase information, detecting rising edge(s) in the amplitude data which correspond to echoes or pulses from other transceivers. In certain applications, the phase data may provide additional information (i.e., to refine the range estimate) or provide the primary source of information (e.g., in an ultrasonic interferometer).

After the comb filter outputs a sample of the I/Q data, the measurement state machine (MSM) writes the I/Q data directly to the data memory as two signed 16-bit integers. The sample rate of the I/Q data is set by the ODR setting and can be $f_{op}/32$, $/16$, $/8$, $/4$, or $/2$. Generally, lower ODR is used for low-power presence sensing applications; medium ODR is used for rangefinding up to 1.2 m, and higher ODR is used for short range sensing.

3.1.4 Rangefinding

The time it takes the ultrasound pulse to propagate from the PMUT to a target and back is called the time-of-flight (ToF). The distance to the target is found by calculating the time-of-flight using a rangefinding algorithm, multiplying the time-of-flight by the speed of sound, and dividing by two (to account for the round-trip). The speed of sound in air is approximately 343 m/s. The speed of sound is not a constant, but it is stable enough (0.2%/°C) to give measurement accuracies within a few percent error.

The rangefinding algorithm typically looks for a rising edge in the amplitude (envelope) of the I/Q data; as the data is smooth at nearly all sample rates except the lowest ODR, interpolation is typically used to refine the ToF estimate. The general-purpose transceiver (GPT) firmware outputs an unsigned 16-bit integer to represent time-of-flight; the time resolution of the time-of-flight is $\frac{1}{8 \cdot 2^{ODR} \cdot f_{op}}$ or 45ns for ODR=4 and $f_{op}=175\text{kHz}$.

3.1.5 Low power systems

ICU-10201 has several features that enable low power operation of a system. A low-power, on-chip real-time clock (RTC) sets the sample rate and provides the reference for the time-of-flight measurement. The host processor does not need to provide any stimulus to the ICU-10201 during normal operation, allowing the host processor to be shut down into its lowest power mode until the ICU-10201 generates a wake-up interrupt. The two general-purpose input/output (INT1 and INT2) pins can be used as a system wake-up source when a measurement is ready. The interrupt pins can be configured to wake up the host when a target is detected.

3.1.6 Clock Calibration

ICU-10201 has 3 internal clocks, the LFCLK, the MUTCLK, and the CPUCLK. The LFCLK is nominally 30kHz and can be measured using the pulse-timer peripheral and the SonicLib driver. Alternatively, a crystal-derived 32.768 kHz (or other known frequency) low frequency clock can be input through the LFCLK pin of ICU-10201. Once the LFCLK frequency is known (by pulse-timer or RTC input), it can be used to measure the frequency of MUTCLK and CPUCLK using the frequency timer peripheral.

The CPUCLK is nominally 40 MHz and can be tuned to increase algorithm runtime consistency between ICU-10201.

The MUTCLK is digitally controlled to 16 times the operating (transmit and receive) frequency f_{op} , and the PMUT is most sensitive at the PMUT resonant frequency f_n , which typically ranges between 170 kHz and 180 kHz; therefore, MUTCLK is typically in the range of 2.72 MHz to 2.88 kHz.

The ICU-10201's SonicLib C driver includes a method to measure the LFCLK frequency using the pulse timer feature. The host MCU will configure the pulse timer, pulse the INT1 line low, wait for a known duration (this delay, typically 100ms, must be generated by a crystal or a trimmed oscillator), and then pulse the INT1 line low again. The LFCLK frequency will then be known to the driver.

The SonicLib driver also includes methods to measure the CPUCLK and MUTCLK frequencies (relative to the LFCLK frequency) using the frequency counter feature in ICU-10201.

Ultimately, the time-of-flight and I/Q data read from ICU-10201 is produced from the MUTCLK time base, and the MUTCLK frequency (and by extension the LFCLK frequency) must be known to have an accurate time-of-flight measurement.

3.2 DEVICE CONFIGURATION

An ICU-10201 program file must be loaded into the on-chip memory at initial power-on. The program, or firmware, is loaded through the SPI interface by the SonicLib C driver. The GPT firmware enables autonomous range finding operation of the ICU-10201. It also supports hardware-triggering of the ICU-10201 for applications requiring multiple transceivers. Chip configuration can also be tailored to the customer's application using the ICU-10201 EVK. Contact TDK support for more information.

4 APPLICATIONS

4.1 TYPICAL OPERATING CHARACTERISTICS

AVDD = VDD = VDDIO = 1.8 VDC, GND = 0 V, T_A = +25°C, unless otherwise specified.

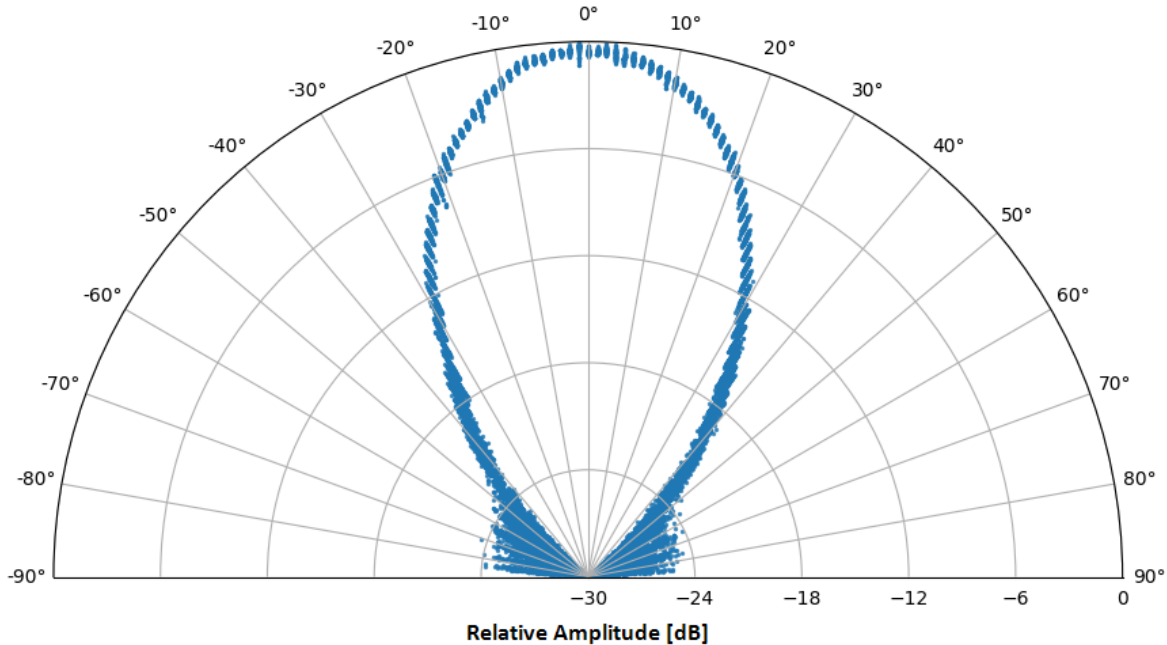


Figure 2. Typical Beam Pattern – MOD-ICU-10201-00-01 45 deg FoV module
(Measured with a 1 m² flat plate target at 0.6 m range)

4.2 SONICLIB DRIVER

Chirp provides a compiler- and microcontroller-independent C driver for the ICU-10201 which greatly simplifies integration. The ICU-10201 driver implements high-level control of one or more ICU-10201s attached to one or more SPI ports on the host processor. The ICU-10201 driver allows the user to program, configure, trigger, and readout data from the ICU-10201 through use of C function calls without direct interaction with the ICU-10201 SPI registers. The ICU-10201 driver only requires the customer to implement an I/O layer which communicates with the host processor’s SPI hardware and GPIO hardware. Chirp highly recommends that all designs use the ICU-10201 driver.

4.3 OBJECT DETECTION

Detecting the presence of objects or people can be optimized via software, by setting the sensor’s full-scale range (FSR), and via hardware, using an acoustic housing to narrow or widen the sensor’s field-of-view. The former means that the user may set the maximum distance at which the sensor will detect an object. FSR values refer to the one-way distance to a detected object.

In practice, the FSR setting controls the amount of time that the sensor spends in the listening (receiving) period during a measurement cycle. Therefore, the FSR setting affects the time required to complete a measurement. Longer full-scale range values will require more time for a measurement to complete.

Ultrasonic signal processing using the ICU-10201's GPT Firmware will detect echoes that bounce off the first target in the Field-of-View. The size, position, and material composition of the target will affect the maximum range at which the sensor can detect the target. Large targets, such as walls, are much easier to detect than smaller targets. Thus, the associated operating range for smaller targets will be shorter. The range to detect a hand or a person's head will be affected by a variety of factors such as a person's size, clothing, orientation to the sensor and the sensor's field-of-view.

4.4 DEVICE MODES OF OPERATION

4.4.1 Free-Running Mode

In the free-running measurement mode, the ICU-10201 runs autonomously at a user specified measurement rate derived from either the internal LFCLK or the external LFCLK pin. In this mode, the INT1 or INT2 pin is configured as an output. The ICU-10201 pulses the INT pin low when a new range sample is available. At this point, the host processor may read the sample data from the ICU-10201 over the SPI interface. When in free-running mode using the internal LFCLK, there must not be another ICU-10201 within range of the device, otherwise interference may occur, as each device will operate at slightly different measurement rates.

4.4.2 Hardware-Triggered Mode

In the hardware triggered mode, one of the INT1/2 pins is used to trigger the start of a measurement. The ICU-10201 remains in an idle condition until triggered by pulsing the INT pin low. The measurement will start with deterministic latency relative to the falling edge on INT. This mode is most useful for synchronizing several ICU-10201 transceivers. The host controller can use the individual INT pins of several transceivers to coordinate the exact timing. A single INT1/2 pin can be used bi-directionally, or the transceiver can be configured to accept a trigger on one INT pin and indicate data ready on another.

4.4.3 Software-Triggered Mode

In the software triggered mode, the host processor triggers the start of a measurement by a SPI write to the transceiver. INT1 or INT2 are pulsed low by ICU-10201 when the measurement is complete. By chip selecting and writing to several ICU-10201 simultaneously, it is possible to synchronize the start of a measurement using this method as well; however, hardware trigger mode is recommended for best performance.

4.5 COEXISTENCE NEAR OTHER ICU-10201

Nearby ICU-10201 which have similar f_{op} can receive sound from one another if they are within 4 m of each other. When ICU-10201 has an algorithm loaded that ignores stationary targets (e.g., static target rejection mode or presence FW), it is possible for multiple ICU-10201 to co-exist in the same space without detecting the other device as a target, if each ICU-10201 is triggered at a precise measurement rate (such as 10Hz).

The measurement rate must be derived from a quality crystal- or MEMS-based oscillator. When ICU-10201 receives a pulse from a nearby ICU-10201, it will interpret it as a stationary target. The reason is that both ICU-10201 will be running at nearly the same measurement rate (excepting the tolerance of the crystals used), so the receiving ICU-10201 will hear the other ICU-10201's pulse at nearly the same time during each measurement.

There are two recommended methods to operate ICU-10201 at a precise measurement rate to ensure good coexistence behavior are a) to use Hardware-triggered mode with a timer driven by a crystal-derived clock; or b) to use Free-running mode with a crystal-derived clock input to the LFCLK pin and ICU-10201 configured appropriately. In both cases, the crystal-derived clock must match the clock used by the 2nd ICU-10201 to ensure that ICU-10201 will not detect the nearby device.

4.6 PITCH-CATCH OPERATION

ICU-10201-02 can be used to transmit ultrasound from one ICU-10201 to another. In this mode of operation, ICU-10201 is usually hardware-triggered, and the transmitter is triggered simultaneously with the receiver. Enabling the receiver connects the PMUT to the receiver, causing a ringdown signal which typically persists for up to 1ms. For best short-range operation, the SonicLib driver can pre-trigger the receiver to allow it to reach a quiescent state before the pulse from the transmitter arrives.

ICU-10201-02 contains several features to improve pitch-catch operation. First, the SonicLib driver can configure ICU-10201 to operate at a common frequency by tuning each of the on-chip MUTCLK oscillators to run at approximately the same frequency.

In some applications, true single frequency operation may be desirable to ensure that the received I/Q data is sampled at the same time on each chip. In this configuration, the MUTCLK pin is used to route the (approximately) 2.8 MHz MUTCLK from a primary ICU-10201-02 device to one or more secondary ICU-10201-02 sensors. In this way, all connected ICU-10201-02 sensors will transmit and receive at the frequency of the primary ICU-10201-02's MUTCLK oscillator.

Alternatively, the host system can supply the MUTCLK to all of the connected ICU-10201-02. In this case, it is important to determine the resonant frequency of each of the ICU-10201-02, and then set the MUTCLK frequency to 16x the mean frequency of the connected ICU-10201-02.

4.7 PCB REFLOW RECOMMENDATIONS:

See App Note AN-000159 CH101 and CH201 Ultrasonic Transceiver Handling and Assembly Guidelines.

4.8 3-WIRE SPI MODE

ICU-10201 supports 3-wire SPI mode, with MOSI and MISO using a single data line. Communication with ICU-10201 is always single duplex, with either MISO or MOSI carrying data. When MISO is not active, its output driver is disabled and it is kept in a high-z state. As such, in order to use ICU-10201 in 3-wire SPI mode, no special configuration is required; simply short MISO and MOSI nearby the ICU-10201 package and configure the host to operate in 3-wire SPI mode with a single shared data line.

4.9 TYPICAL OPERATING CIRCUITS

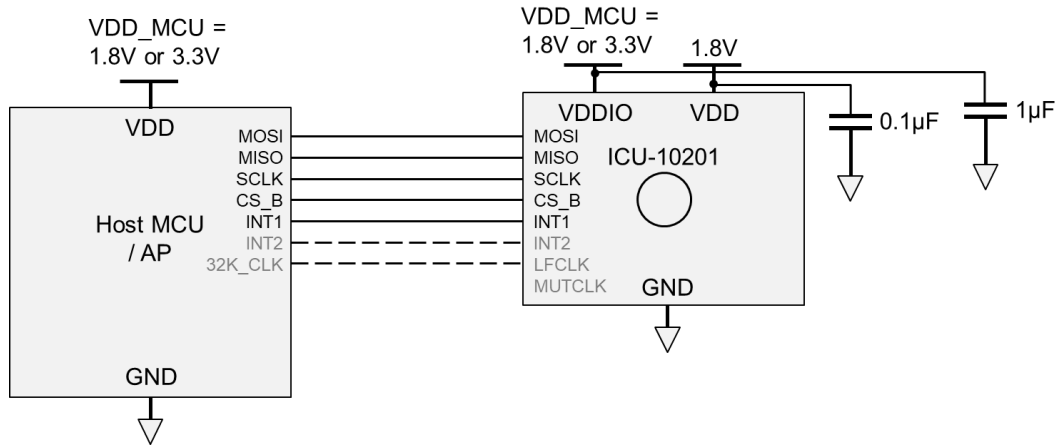


Figure 3. Single Transceiver Operation. Dashed connections are optional. For 3-wire SPI operation, simply short MOSI and MISO near ICU-10201.

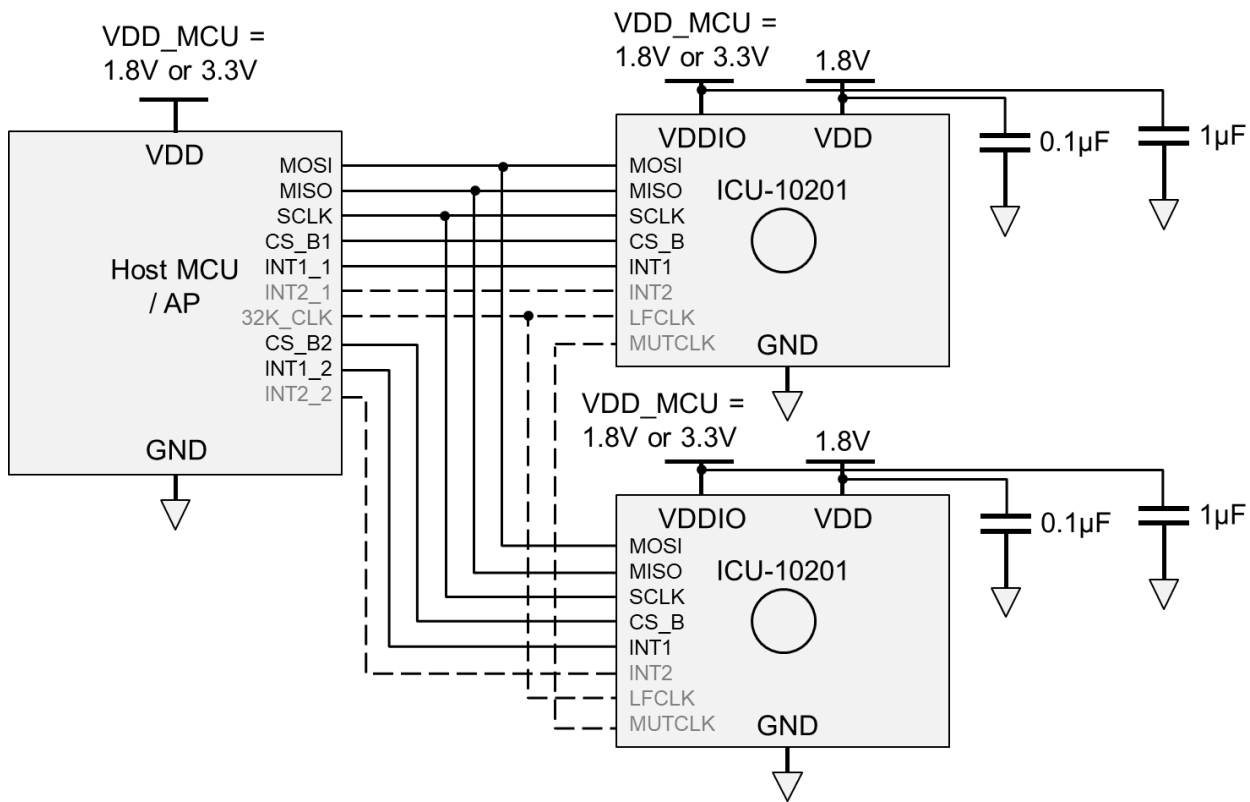


Figure 4. Multi-Transceiver Operation. Dashed connections are optional. Add additional transceivers by adding CS_B and INT1 for each additional transceiver and sharing common MOSI/MISO/SCLK connections. For 3-wire SPI operation, simply short MOSI and MISO near ICU-10201.

4.10 RECOMMENDED PCBA LAYOUT

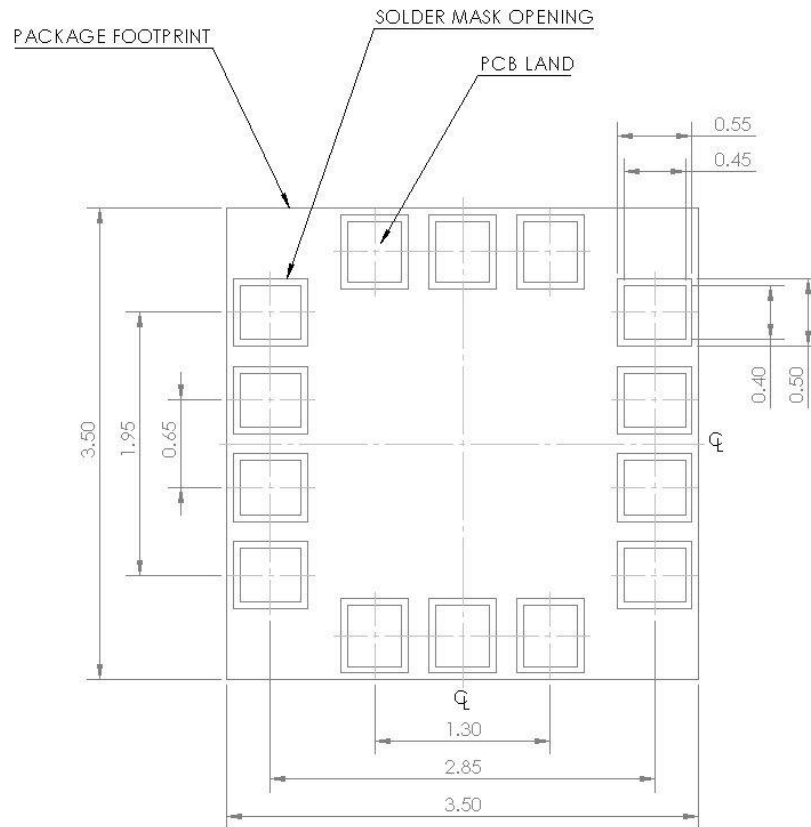


Figure 5. Recommended SMT dimensions for solder mask and PCB land pads

The PCB layout for ICU-10201 should adhere to the following recommendations:

- PCB design should be as symmetrical as possible
 - Since the transceiver has very low power consumption, large VDD and GND traces are not required
 - Do not place vias or traces on the top metal layer within the transceiver footprint
- PCB land and connecting traces should be symmetrical
- PCB land height and width should be equal the transceiver pad height and width (Figure 5)
- Solder mask opening should exceed PCB land height and width by 0.1mm (Figure 5)
- Placement of the transceiver on the PCB should avoid locations close to hot spots such as microprocessors and points of mechanical stress such as pushbuttons and screws

5 PACKAGE INFORMATION

5.1 PIN CONFIGURATION

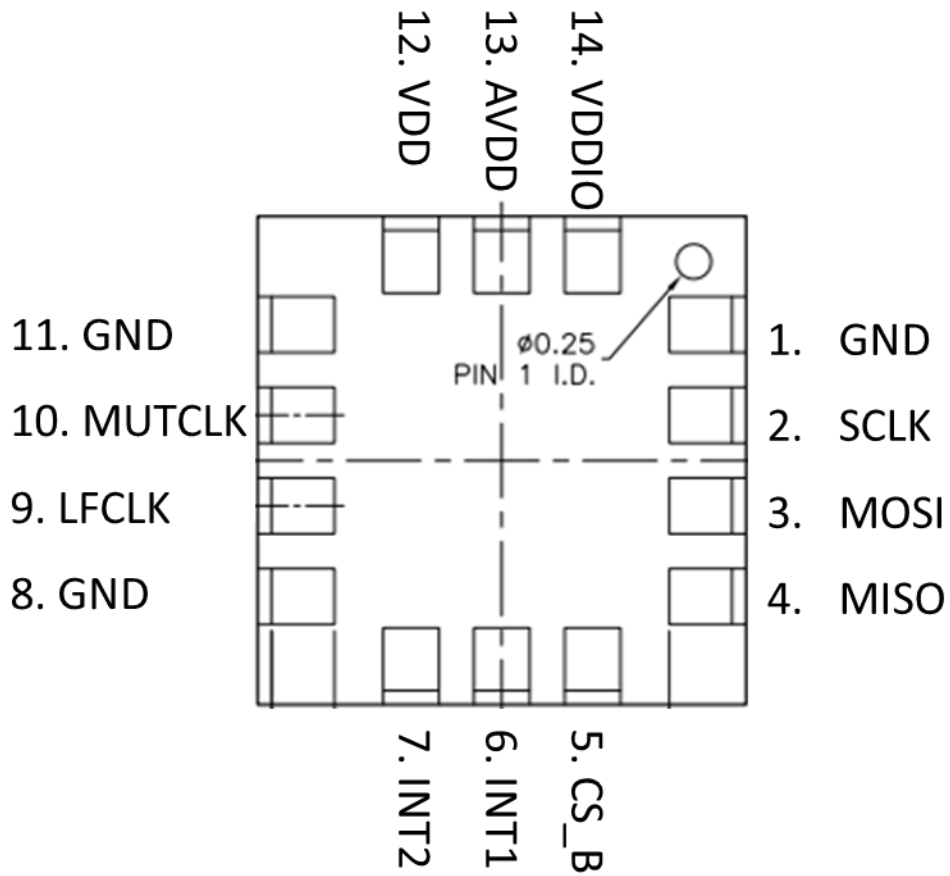
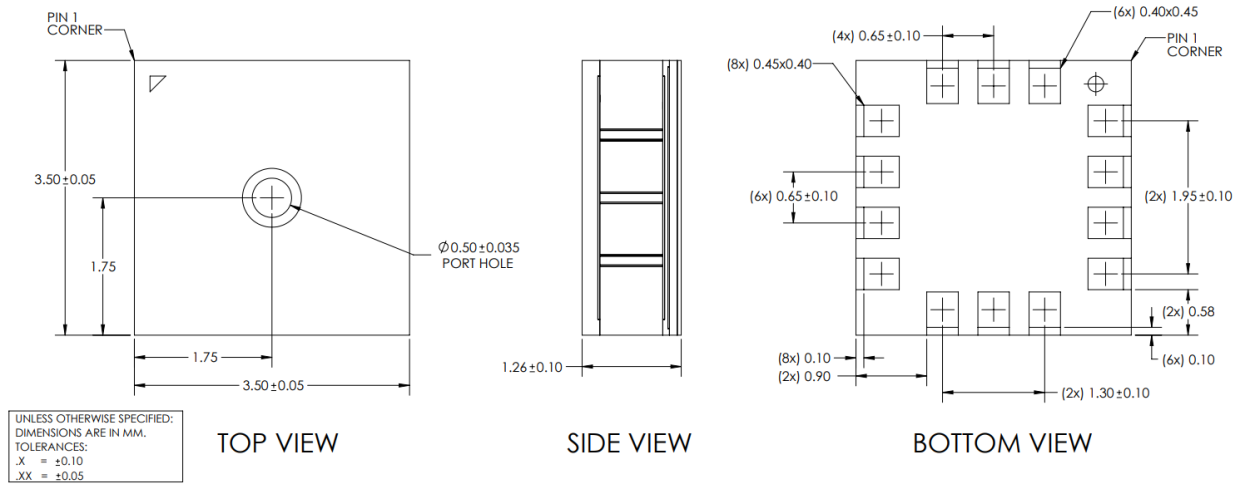


Figure 6. ICU-10201 Package Bottom View

5.2 PACKAGE DIMENSIONS



Note: All dimensions and tolerances conform to ANSI Y14.5M-1994.

Figure 7. Package dimensions

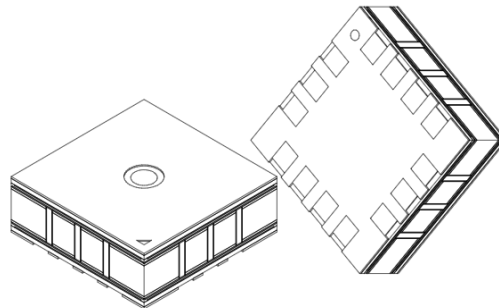


Figure 8: 3D view

6 ORDERING INFORMATION

6.1 PART NUMBER DESIGNATION

This datasheet specifies the following part numbers:

PART NUMBER	PACKAGE BODY	QUANTITY	PACKAGING
ICU-10201-00	3.5 mm x 3.5 mm x 1.26 mm LGA-8L	1,000	7" Tape and Reel
ICU-10201-02	3.5 mm x 3.5 mm x 1.26 mm LGA-8L	1,000	7" Tape and Reel

Table 7. ICU-10201 Part Number

6.2 PACKAGE MARKING

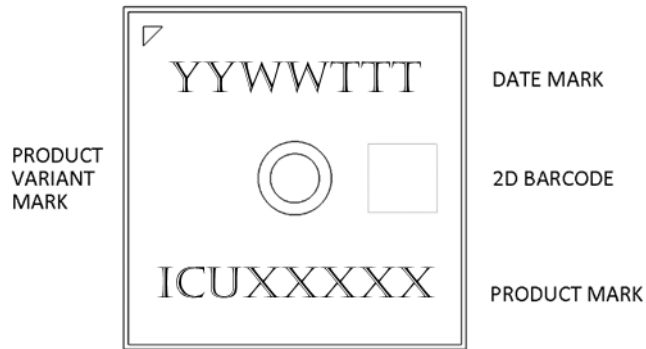
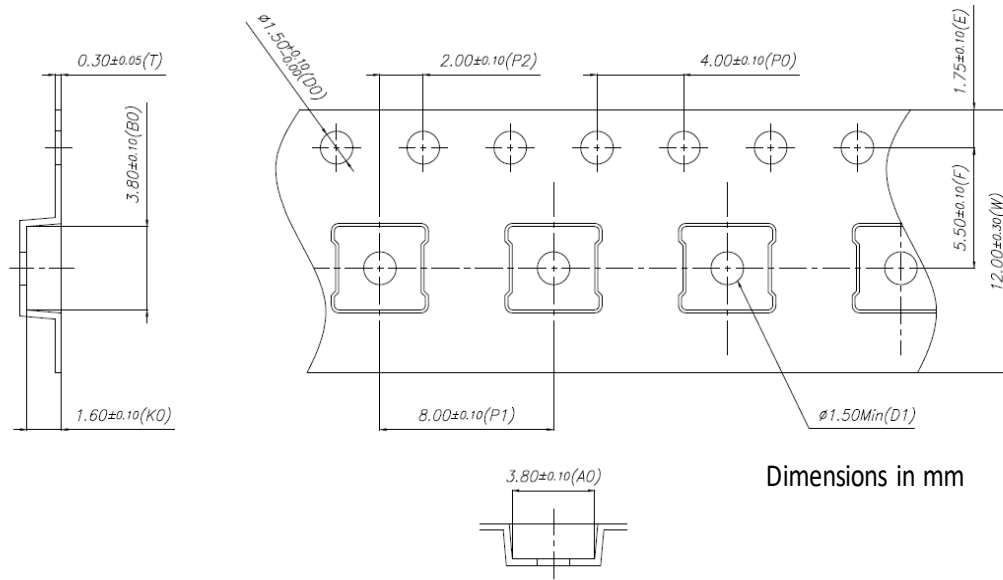


Figure 9. Packaging Marking

6.3 TAPE & REEL SPECIFICATION



Dimensions in mm

Figure 10. Tape & Reel Specifications

6.4 SHIPPING LABEL

A Shipping Label will be attached to the reel, bag and box. The information provided on the label is as follows:

- Device: This is the full part number
- Lot Number: TDK/InvenSense manufacturing lot number
- Date Code: Date the lot was sealed in the moisture proof bag
- Quantity: Number of components on the reel
- 2D Barcode: Contains Lot No., quantity and reel/bag/box number



Figure 11. Shipping Label

7 REVISION HISTORY

DATE	REVISION	CHANGES
10/25/2022	1.0	Preliminary Release
2/14/2023	1.1	Safe Launch Release
2/21/2023	1.2	Updated VDDIO operating range
11/09/2023	1.3	Update frequency range for both Pulse Echo and Pitch & Catch
01/09/2024	1.4	Remove “Preliminary” watermark on first page
11/21/2024	1.5	Fixed word wrapping issue in Section 2.3: Low Level Input Voltage and Low Level Output Voltage have maximum specifications, not minimum specifications Added section 4.7 3-wire SPI mode Minor formatting cleanup. Updated disclaimer.
12/5/2024	1.6	Changed orderable part numbers from ICU-10201 and ICU-10201-PC to ICU-10201-00 and ICU-10201-02, respectively

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