User Manual

uRAD DOPPLER



Product

Hardware: uRAD Doppler v1.0

Firmware: SDK v1.0

Manufacturer

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Original document

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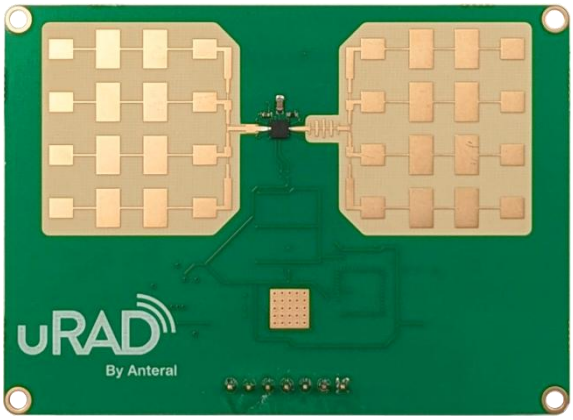
Hardware Description 1

uRAD is manufactured using PCB technology on a high-frequency substrate. It is a multi-layer printed circuit board with several integrated chips.

- The top layer includes the uRAD core, a 24 GHz transceiver, and the transmitter and receiver antennas. The radar signal is emitted perpendicular to this layer, so you must point this side in the direction of interest. Be careful because it does not emit backwards.
- The lower layer consists of power supply and signal processing elements, which are managed by a powerful microcontroller.
- It has a JST male connector for power supply, UART communication with a master device, and two digital GPIO outputs for sending speed alarms.
- It has four holes in the corners connected to GND for M3 screws at a spacing of 72 mm and 51 mm.



Top view



Bottom view

ATTENTION: DO NOT cover the antennas with any metallic or electronic elements, or electromagnetic absorbers, as the radar signal will not be able to pass through them. Most thin plastics are practically invisible to the emission.

Technical Specifications 2

RF Parameters	
Frequency	Transmission between 24.005 and 24.245 GHz (ISM free transmission band)
Modulation	CW continuous wave
Emitting power	19 dBm (PIRE, includes antenna gain)
Field of view	30º x 30º

Power Supply	
Voltage	3.5 V to 6 V DC
Connector	B7B-XH-A by JST (1x7P 2.5 mm
Consumption	0.7 W

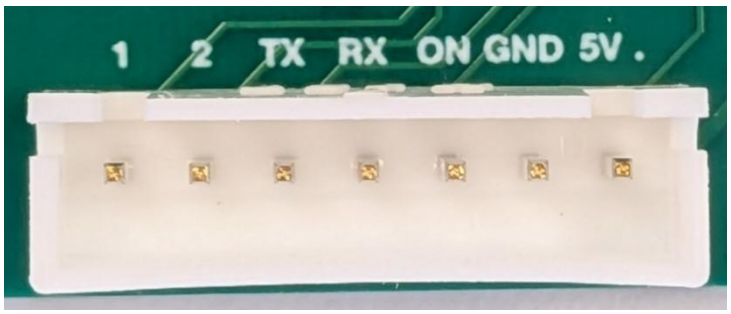
Mechanical Parameters	
Dimensions	76 x 55 x 10 mm
Weight	8 g

Other Parameters	
Communication	UART 0-3.3V 2 x GPIO 0-3.3V
Operating temperature	-20ºC to +85ºC

Performance	
Velocity range	±2 m/s to ±90 m/s (322 km/h)
Velocity accuracy	±0.18 m/s (0.66 km/h)
Update rate	3 modes: 20, 10 and 4 samples per second
Output data	Positive and negative velocity IQ RAW data
Range	170 m (car)
Sensitivity	10 configurable sensitivity levels

Connector 3

The device has a 7-pin male connector with 2.5 mm spacing.



The pins are marked on the board according to their function:

- 1: GPIO1 which is activated at a high level of 3.3V when a target with positive speed (moving away) greater than the limit set in the configuration is detected.
- 2: GPIO2 which activates at a high level of 3.3V when a target with negative speed (approaching) greater than the limit set in the configuration is detected.
- TX: UART TX transmission line at 0-3.3V.
- RX: UART RX reception line at 0-3.3V
- ON: digital pin to switch off the radar. Low level (0V) switches off the radar. It has a 10k pull-up resistor which, by default, keeps it switched on.
- GND: analogue and digital ground
- 5V: power pin

The connector reference is:

- MPN: B7B-XH-A.
- Fabricante: JST Sales America.
- MPN compatible female for assembly: XHP-7.

Operation 4

General

The device is a Doppler radar, so it only transmits the speed of the detected targets.

By default, when the radar is powered up, it starts in a stop state. Using a communication protocol, you can change the configuration, start and stop transmission.

The radar sends two detected speed values (if any) in each frame. It sends a positive speed value (target moving away from the radar) and a negative speed value (target moving towards the radar). If several targets are detected in the same direction, the radar sends the speed of the target that returns the signal with the highest amplitude.

In addition, the device activates digital pins if the detected speed exceeds a threshold.

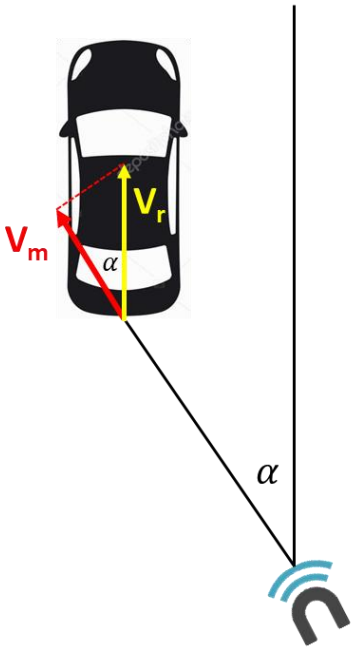
Configuration parameters

Seven configuration parameters can be set:

- **Minimum velocity**: limits the minimum detectable speed. The minimum value is 8 km/h. It does not take the sign into account, so it applies to both positive and negative speeds.
- **Maximum velocity**: limits the maximum detectable speed. The maximum value is 322 km/h.
- **Sensitivity**: sets the radar sensitivity level to one of 10 levels. 1 is least sensitive and 10 is most sensitive. The more sensitive the radar is, the smaller and more distant the targets it can detect.
- **Positive threshold velocity**: limit value that activates GPIO1 if a target moving away exceeds that limit.
- **Negative threshold velocity**: limit value that activates GPIO2 if a target approaching exceeds that limit.
- **Frame rate**: mode that determines the number of samples per second sent by the radar. Three modes can be configured:
  Mode 1 = 20 samples per second.
  Mode 2 = 10 samples per second.
  Mode 3 = 4 samples per second.
  In modes 2 and 3, averaging techniques are used, so the speed values are more stable.
  - **Angle**: the installation angle of the radar. The maximum value is 45 degrees. It is used to correct the speed when the object is not moving

perpendicular to the radar. This is because the radar is only capable of measuring the radial speed of the target. Therefore, the actual speed must be corrected by the cosine of the angle.

$$Velocity_{real} = Velocity_{measured} / \cos \alpha$$



The default configuration values are:

Configuration parameter	Default value
Minimum velocity	8 km/h
Maximum velocity	322 km/h
Sensitivity	9
Positive threshold velocity	+322 km/h
Negative threshold velocity	-322 km/h
Frame rate	3 (4 samples/s)
Angle	0 º

Communication protocol

Serial Port Configuration

Connection Parameters:

- Baudrate: 921600 bps
- Read timeout: 1 second
- Write timeout: 1 second
- Format: 8 data bits, no parity, 1 stop bit (standard)

Available Commands

Communication is based on sending 2-byte commands in format big-endian (>H).

Command	Hexadecimal value	Decimal value	Description
START	0x965D	38493	Start acquisition of processed data
STOP	0x68E9	26857	Stops any active mode
CONFIG	0x5CE4	23780	Configure radar parameters
RAW DATA	0x1D3B	7483	Start acquisition of raw I/Q data

Sending Commands

Commands are sent as **uint16_t** in **big-endian**:

```python
import struct
CMD_START = 0x965D
serial_port.write(struct.pack(">H", CMD_START))
```

STOP mode

- Description

Stops data acquisition and puts the radar into standby mode.

- Procedure

Send STOP command (0x68E9).

Wait for response from device ending in **\r\n**

- Expected Response

Text message ending in **\r\n** confirming the arrest.

CONFIGURATION mode

- Description

Configure the radar operating parameters. The radar must be in the STOP state beforehand in order to be configured correctly.

- Procedure

1. Step 1: Send the CONFIG command.

   Send the CONFIG command (0x5CE4) as a big-endian uint16_t.

2. Step 2: Await confirmation.

   The device will respond with a message ending in **\r\n**

3. Step 3: Send parameters (19 bytes).

   Send 19 bytes with the following structure in big-endian format:

Byte Range	Parameter	Type	Bytes size	Range	Description
0-3	Vmin	uint32	4	8 to 322	Minimum detectable velocity (km/h)
4-7	Vmax	uint32	4	8 to 322	Maximum detectable velocity (km/h)
8	Sensitivity	uint8	1	1 to 10	Detector sensitivity
9-12	Vth_pos	int32	4	8 to 322	Positive velocity threshold (km/h)
13-16	Vth_neg	int32	4	-322 to -8	Negative velocity threshold (km/h)
17	Frame_rate	uint8	1	1 to 3	Frame rate mode 1: 20 frames/seg 2: 10 frames/seg 3: 4 frames/seg
18	Angle	int8	1	0 to 45	Radar installation angle (degrees))

Packaged format:

```python
config_data = struct.pack(
    ">IIBiiBb",
    vmin,           # uint32_t
    vmax,           # uint32_t
    sensitivity,    # uint8_t
    vth_pos,        # int32_t
    vth_neg,        # int32_t
    frame_rate,     # uint8_t
    angle           # int8_t
)
serial_port.write(config_data)
```

Configuration example:

```python
vmin = 10
vmax = 100
sensitivity = 10
vth_pos = 50
vth_neg = -30
frame_rate = 3
angle = 0

config_data = struct.pack(">IIBiiBb", vmin, vmax, sensitivity,
                          vth_pos, vth_neg, frame_rate, angle)
# Resultado: 19 bytes
```

Modo START

- Description

Begin acquiring processed data from the Doppler radar. The device continuously sends frames with speed information.

- Procedure

1. Step 1: Send the START command.

   Send the START command (0x965D) as uint16_t big-endian.

```python
CMD_START = 0x965D
serial_port.write(struct.pack(">H", CMD_START))
```

2. Step 2: Receive initial response.

The device will respond with a confirmation message ending in **\r\n**.

3. Step 3: Continuous reception of frames.

   Each frame has 16 bytes with the following structure:

Sync Word (4 bytes) 1928	Frame Number (4 bytes) uint32	Velocity+ (km/h) (4 bytes) float	Velocity- (km/h) (4 bytes) float

- Synchronization

The synchronization word is 1928 (0x00000788 in hexadecimal), encoded as uint32_t little-endian.

```python
SYNC_WORD_START = 1928
SYNC_BYTES_START = struct.pack("I", SYNC_WORD_START)  # Little-endian
# Resultado: b'\x88\x07\x00\x00'
```

- Reading Process

1. Read data continuously from the serial port.
2. Search for the synchronization word (1928) in the buffer.
3. Once found, extract the 20 bytes of the complete frame.
4. Decoding the data:

```python
# Verificar sync word
sync_word = struct.unpack("I", buffer[0:4])[0]  # Debe ser 1928

# Extraer datos
frame_number = struct.unpack("I", buffer[4:8])[0]
velocity_pos, velocity_neg = struct.unpack("ff", buffer[8:16])
```

- Synchronization Error Management

If the buffer does not begin with the synchronization word:

1. Search for the synchronization word in the buffer.
2. Discard all bytes preceding it.
3. Increase synchronization error counter.
4. Continue processing.

RAW DATA mode

- Description

Acquires raw (unprocessed) I/Q data from the radar. Useful for custom processing or advanced analysis.

- Procedure

1. Step 1: Send RAW DATA command.

   Send the RAW DATA command (0x1D3B) as uint16_t big-endian.

```python
CMD_RAW_DATA = 0x1D3B
serial_port.write(struct.pack(">H", CMD_RAW_DATA))
```

2. Step 2: Clean buffers.

```python
serial_port.reset_input_buffer()
serial_port.reset_output_buffer()
```

3. Step 3: Receive initial response.

   The device will respond with a confirmation message ending in **\r\n**.

4. Step 4: Continuous reception of frames.

   Each frame has 4104 bytes with the following structure:

Sync Word (4 bytes) 5000	Frame Number (4 bytes) uint32_t	I Data (2048 bytes) 1024 x uint16	Q Data (2048 bytes) 1024 x uint16

- I/Q Data Structure

The data values are organized as follows:

1. First 1024 values: Component I (In-phase)
2. Next 1024 values: Q component (Quadrature)

$$[I_0, I_1, I_2, \ldots, I_{1023}, Q_0, Q_1, Q_2, \ldots, Q_{1023}]$$

- Synchronization

The synchronization word is 5000 (0x00001388 in hexadecimal), encoded as uint32_t little-endian.

```python
SYNC_WORD_RAW = 5000
SYNC_BYTES_RAW = struct.pack("I", SYNC_WORD_RAW)  # Little-endian
# Resultado: b'\x88\x13\x00\x00'
```

Reading Process

1. Read data continuously from the serial port.
2. Buffer until you have at least 4104 bytes.
3. Search for synchronization word (5000).
4. Extract complete frame:

```python
# Verificar sync word
sync_word = struct.unpack("I", buffer[0:4])[0]  # Debe ser 5000

# Extraer frame number
frame_number = struct.unpack("I", buffer[4:8])[0]

# Extraer 2048 muestras I/Q (little-endian)
raw_samples = struct.unpack('<2048H', buffer[8:4104])

# Separar componentes I y Q
i_data = raw_samples[:1024]  # Primeros 1024 valores
q_data = raw_samples[1024:]  # Siguientes 1024 valores
```

- Synchronization Management

The protocol implements a robust synchronization system:

1. Synchronization search: If the buffer does not start with the synchronization word, the entire buffer is searched.
2. Recovery: Upon finding it, the previous bytes are discarded.
3. Safety buffer: The last 3 bytes are retained if no synchronization is found (in case it is divided between readings).
4. Error counter: Synchronization errors are recorded.

Communication Flow Diagram

Typical Configuration Sequence:

```
1. Conectar puerto serie (921600 bps)
   ↓
2. Enviar STOP para asegurar estado limpio
   ↓
3. Enviar CONFIG + parámetros (19 bytes)
   ↓
4. Enviar START o RAW DATA
   ↓
5. Recibir y procesar frames continuamente
   ↓
6. Enviar STOP cuando se desee finalizar
```

Example of a Complete Session:

```python
import serial
import struct

# 1. Conectar
port = serial.Serial('COM3', 921600, timeout=1)

# 2. Detener operaciones previas
port.write(struct.pack(">H", 0x68E9))  # STOP

# 3. Configurar
port.write(struct.pack(">H", 0x5CE4))  # CONFIG
config = struct.pack(">IIBiiBb", 10, 100, 10, 50, -30, 3, 0)
port.write(config)

# 4. Iniciar adquisición
port.write(struct.pack(">H", 0x965D))  # START

# 5. Leer frames
while True:
    data = port.read(port.in_waiting)
    # Procesar datos...

# 6. Detener
port.write(struct.pack(">H", 0x68E9))  # STOP
```

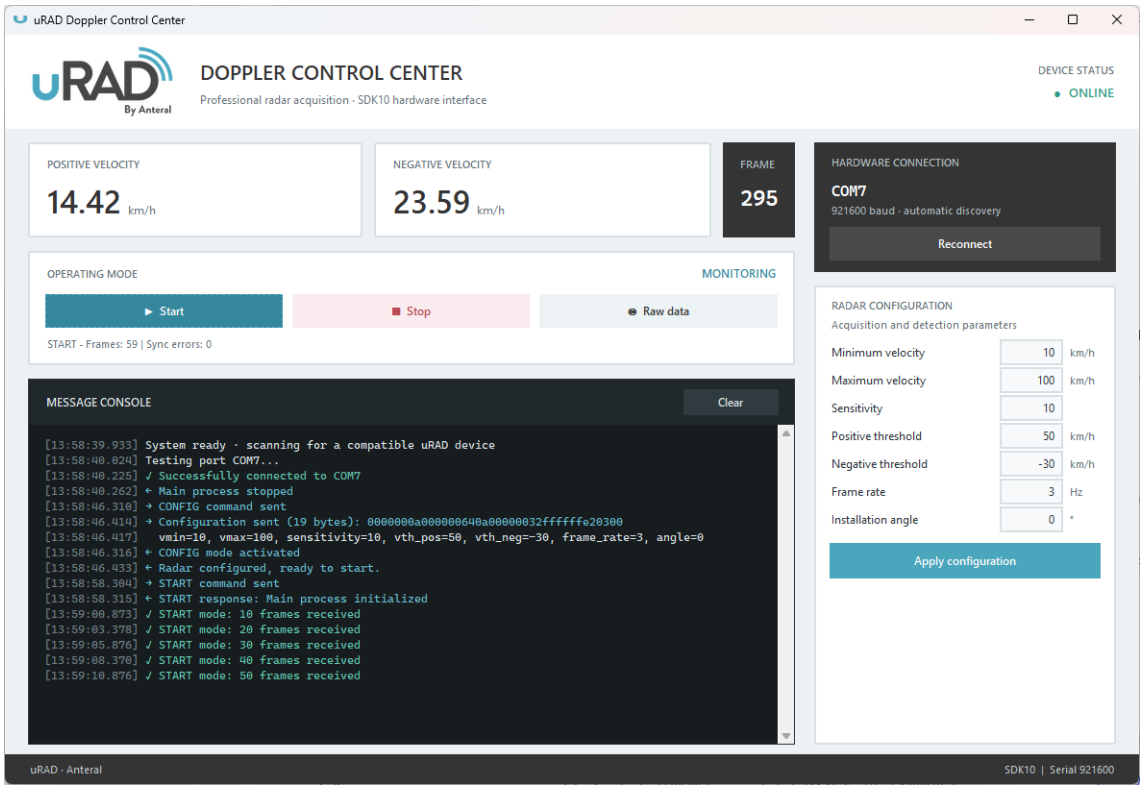
SDK and Graphical Interface 5

An SDK and graphical interface are provided with the purchase to facilitate the handling and integration of the device.

The SDK consists of two Python scripts:

- **uRAD_doppler_SDKxx.py**: contains the functions necessary to configure and operate the sensor
- **uRAD_doppler_SDKxx_examples.py**: contains three working examples.
  1. Example 1: Basic use with START mode
  2. Example 2: saving data in a .csv file
  3. Example 3: RAW DATA mode

The graphical user interface (GUI) is a Python script that, when executed, opens the following application.



Data Storage Format

When START mode or RAW DATA mode is executed using the graphical interface, the received data is automatically saved in CSV files in the same folder.

CSV files in START mode

- Name: results_YYYY-MM-DD_HH-MM-SS-mmm.csv
- Estructura: timestamp, frame_number, vel_pos, vel_neg

CSV files in RAW DATA mode

- Name: raw_data_YYYY-MM-DD_HH-MM-SS-mmm.csv
- Structure:

```csv
frame_number,I0,I1,...,I1023,Q0,Q1,...,Q1023
1,2048,2051,2049,...,2047,2050,2048,...
2,2049,2052,2048,...,2048,2051,2049,...
```

Each row contains:

- 1 value: frame number.
- 1024 values: component I.
- 1024 values: Q component.

Total: 2049 columns per row.

Safety & Handling 6

Read all safety and handling information below as well as the operating instructions before using uRAD products in order to avoid any injury or damage.

Keep this user guide on hand for future reference.

Important Safety Information



WARNING: Failure to follow this safety instructions could result in fire, electric shock, or other injury or damage.

Proper handling uRAD contains sensitive electronic components. Do not drop, disassemble, crush, bend, deform, puncture, shred, microwave, incinerate, paint, or insert foreign objects into uRAD.

Water and wet locations Do not expose any sensitive components of uRAD to water or rain, or handled near washbasins or other wet locations without a proper case. Take care not to spill any food or liquid on uRAD. In case uRAD gets wet, allow it to dry thoroughly before turning it on again. Do not attempt to dry uRAD with an external heat source, such as a microwave oven or hair dryer.

uRAD repairs Never attempt to repair or modify uRAD by yourself. Disassembling may cause damage that is not covered under the warranty. If uRAD is damaged, malfunctions, or comes in contact with liquid, contact us at contact@urad.es.

Radio frequency interference Observe signs and notices that prohibit or restrict the use of radio frequency devices. Emissions from uRAD can negatively affect the operation of other radio frequency equipment operating in the same frequency band. Turn off uRAD when use is prohibited, such as traveling in aircraft, or when asked to do so by authorities.

Important Handling Information



WARNING: Failure to follow this handling instructions could result in damage to uRAD or other property.

Carrying uRAD contains sensitive electronic components. Do not bend, drop or crush it.

Cleaning To clean use a soft lint-free tip and isopropyl alcohol. Dust can be removed with compressed air of low power.

Plugging Never force the connectors or apply excessive pressure because this may cause damage that is not covered under the warranty. Check for obstructions.

Operating Temperature Keeping uRAD within acceptable temperatures. uRAD components operate from -40ºC to 85ºC but we recommend operates uRAD in the range from -20ºC to 65ºC.

Disposal and Recycling Information Your uRAD must be disposed of properly according to local laws and regulations. Because this product contains electric components, the product must be disposed of separately from household waste. Contact your local authorities to learn about recycling options.

Product Warranty 7

Manufacturing

All components and solder alloys used in this product comply with the RoHS Directive. The RoHS Directive prevents all new electrical and electronic equipment placed on the market in the European Economic Area from containing more than agreed levels of lead, cadmium, mercury, hexavalent chromium, poly-brominated biphenyls (PBB) and poly-brominated diphenyl ethers (PBDE).

Certification

uRAD Industrial module is **CE marked** under EU-Type examination certificate n. 803416897303 and fulfills with the corresponding directives:

- RED Article 3.1 (a): Health and Safety of the User
  Test EN 62368-1: 2014 +AC: 2015 Safety
  Test EN 62311:2008 - EMF Human exposure
- RED Article 3.1 (b): Electromagnetic compatibility
  Test EN 301 489-3 V2.1.1 EMC Short-Range Devices SRD
- RED Article 3.2 :Effective use of spectrum allocated
  Test EN 305 550-2 V1.2.1_Radio equip. 40 GHz to 246 GHz
- Notified body
  EU-Type Examination Certificate RED - N.B. 2559 (en)
- RoHS
  Test EN 63000: 2018 RoHS documental assesment

Testing

Each uRAD shield is subject to strict tests to make sure they are not faulty:

- First, it is thoroughly tested for short circuits and open connections.
- Second, it is powered to check there are no over-range voltage.
- Then, the microcontroller is programmed and debugged.
- Finally, the board is plugged in a computer and several test programs are run to check its overall functionality.

Limited Warranty Statement

IMPORTANT: BY USING uRAD PRODUCTS YOU ARE AGREEING TO BE BOUNDED BY THE TERMS OF THIS LIMITED WARRANTY STATEMENT. DO NOT USE YOUR PRODUCTS UNTIL YOU HAVE READ THE TERMS OF THE

WARRANTY. IF YOU DO NOT AGREE TO THE TERMS OF WARRANTY, DO NOT USE THE PRODUCTS AND RETURN THEM. THIS LIMITED WARRANTY IS THE END-USER'S SOLE AND EXCLUSIVE REMEDY AGAINST uRAD, WHERE PERMITTED BY LAW.

1. Warranties

1.1 uRAD warrants that its products will conform the specifications detailed in the corresponding datasheet. Warranty lasts for 1 year from the date of sale if the shield is bought outside the EU and last for 2 years if bought in the EU. uRAD shall not be liable for any defects that are caused by neglect, misuse or mistreatment, including any products that have been altered or modified by any way by the Customer.

1.2 If any uRAD product fails to conform to the warranty set forth above, uRAD's sole liability shall be to replace or repair such products. uRAD's liability shall be limited to products that are determined by uRAD not to conform to such warranty. If uRAD elects to replace or repair such products, uRAD shall be given a reasonable time to provide replacements. Replaced or repaired products shall be warranted for a new full warranty period.

1.3 The Customer agrees no to use uRAD products for any applications or in any components used in life support devices or to operate nuclear facilities or for use in other mission-critical applications or components where human life or property may be at stake. The Customer acknowledges and agrees that any such use is solely at the Customer's risk, and that the Customer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

1.4 uRAD may provide technical, applications or design advice. The Customer acknowledges and agrees that providing these services shall not expand or otherwise alter uRAD's warranties, as set forth above, and that no additional obligations or liabilities shall arise from uRAD providing such services.

1.5 uRAD disclaims all other warranties, expressed or implied, regarding products, including, but not limited to, any implied warranties of merchantability or fitness for a particular purpose.

1.6 The Customer acknowledges and agrees that the Customer is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning the products and any use of uRAD products in the Customer's applications, not with- standing any applications-related information or support that may be provided by uRAD.

1.7 In no event shall uRAD be liable to the Customer or any third parties for any special, collateral, indirect, punitive, incidental, consequential or exemplary damages in connection with or arising out of the products provided hereunder, regardless of whether uRAD has been advised of the possibility of such damages. This section will survive the termination of the warranty period.

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