Technical documentation

Frequently asked questions for 24 GHz industrial radar

What is radar?

Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects. A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, an emitting antenna, a receiving antenna (separate or the same as the previous one) to capture any returns from objects in the path of the emitted signal, a receiver and processor to determine properties of the object(s).

What product family is available?

The BGT24M/L family is the largest and highest integrated 24 GHz ISM band radar transceiver family currently in the market. It saves ~30 percent board space compared to discrete line ups. Infineon offers 4 different components, the BGT24MTR11 which combines one transmit and one receive channel, the BGT24MTR12 which comprises one transmit and two receive channels, and the BGT24MR2, a chip with 2 receive channels, combinable with both chipsets. Infineon recently released a new lower power, smaller form factor radar transceiver called BGT24LTR11 which comprises of one transmit and one receive channel.

What applications can radar be used in?

› Drones-soft landing and collision avoidance
› Street lighting projects
› Intelligent door openers
› Home automation
› Speed meters
› Robotics
› Internet of things

What are the radar processing technologies?

<table>
<thead>
<tr>
<th>Technique</th>
<th>Complexity</th>
<th>Movement</th>
<th>Speed</th>
<th>Distance of moving objects</th>
<th>Distance of static objects</th>
<th>Angle of moving objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler</td>
<td>Low</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FSK</td>
<td>Medium</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMCW</td>
<td>High</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Monopulse</td>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔️</td>
</tr>
</tbody>
</table>

Monopulse is an additional option for all the above operating modes

www.infineon.com/24GHz
What are some of the main features of the products available?

› Highest integration currently in the market
› Multiple combination Tx/Rx configurations available
› Fully packaged solution

› Low cost TSNP-16-9 package
› Distance detection up to 100 m
› Smallest packaged radar chip on the market

What is radar transceiver?

Radar transceiver (transmitter receiver)
› Transmits low energy radio frequency signal over Tx antenna (24 GHz, max. 100 mW)
› Receives reflected signal over Rx antenna

› Moving target generates low frequency Doppler output signal (so called IF)

How does radar detect movement?

Basic movement detector
› Output becomes active as soon as Doppler signals are present
› Implemented with discrete components or simple microcontroller
What is the Doppler effect?

Doppler effect

Calculating the Doppler frequency

\[
f_d = \frac{2 \times f_{\text{Tx}} \times v \times \cos \alpha}{c_0}
\]

or

\[
v = \frac{c_0 \times f_d}{2 \times f_{\text{Tx}} \times \cos \alpha}
\]

At a transmit frequency of \(f_{\text{Tx}} = 24.125\ \text{GHz}\) we get a Doppler frequency for a moving object at the IF output of

\[
f_d = v[\text{km/h}] \times 44\ \text{Hz} \times \cos \alpha \quad \text{or} \quad f_d = v[\text{m/s}] \times 161\ \text{Hz} \times \cos \alpha
\]

How does Doppler processing calculate speed?

Speed display

› Frequency (= speed) and direction are detected by complex FFT
› Implemented with FFT (Fast Fourier Transform)
How does radar measure distances?

Typical measurement methods

Distance measurement always needs bandwidth/modulated carrier

**Pulse radar**
- Sends out a very short, powerful pulse
- Measures time of flight of reflected pulse
- Needs high bandwidth → not usable in K-band

**Continuous wave methods**
No pulse, but a continuous, frequency modulated carrier is sent

- **FMCW**: used to detect stationary and moving objects.
  A so called chirp is sent and mixed with the received signal.
  Low frequency output represents distance.
- **FSK**: used to get distances of moving objects.
  2 frequencies are sequentially sent.
  2 phase shifted Doppler signals represent distance.

What is the difference between FMCW and FSK?

**FMCW and FSK**
Measuring distances need modulation of carrier → bandwidth

<table>
<thead>
<tr>
<th></th>
<th>FMCW (Frequency Modulation Continuous Wave)</th>
<th>FSK (Frequency Shift Keying)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use</strong></td>
<td>For stationary and moving objects</td>
<td>For moving objects only</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Formula</strong></td>
<td>[ R = \frac{c_0}{2} \cdot \frac{f_b}{T_M} \cdot \frac{T_M}{2} ]</td>
<td>[ R = \frac{c_0 \cdot \Delta \phi}{4\pi \cdot (f_a - f_b)} ]</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>1 m, limited by K-band bandwidth 250 MHz</td>
<td>1–100 cm, depending on signal processing Limited by the system SNR and can only detect one target at a given speed</td>
</tr>
</tbody>
</table>
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**How can we measure speed with single chirp FMCW?**

<table>
<thead>
<tr>
<th>Transmitted and received FMCW signal</th>
<th>IF signal at the mixer output</th>
</tr>
</thead>
</table>
| ![Transmitted and received FMCW signal diagram](image1)

Modulation

<table>
<thead>
<tr>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R = \frac{c T_p}{2B} \times \frac{f_1 + f_2}{2}$</td>
</tr>
<tr>
<td>$v_r = \frac{c}{2f_c} \times \frac{f_1 - f_2}{2}$</td>
</tr>
</tbody>
</table>

**How can we measure speed with multi chirp FMCW?**

Multi chirp FMCW is the standard when it comes to detecting and tracking the position and speed of multiple targets.

$v_1 \text{ km/h}$

$v_2 \text{ km/h}$

![Transmitted and received FMCW signal diagram](image2)

N number of chirps are used to create a frame

![Transmitted and received FMCW signal diagram](image3)

The time between two chirps are refered as Pulse Repetition Time (PRT). The maximum unambiguous Doppler that we can detect is $\pm \frac{1}{2 \text{PRT}}$. The consecutive chirps/pulses time to estimate velocity is refered to as Coherent Pulse Interval (CPI). The minimum velocity that we can detect is $\pm \frac{1}{2 \text{CPI}}$. 

![Transmitted and received FMCW signal diagram](image4)
How is the data processed in a multi chirp FMCW?

An FFT is applied along the single chirp to provide the different range bins, this is referred to as fast time.

A second FFT is applied along the chirps for a single range bin, to provide the velocity information; this is referred to as fast time.

Repeating this for each range bin ultimately provides the range-doppler map.
How can the angle be estimated?

Phase mono-pulse angle estimation

Two antenna elements separated by a distance \( d \) and receiving reflection from angle \( \theta \) would mean one antenna would incur an additional path length of \( d \sin(\theta) \) which translated to phase difference of

\[
\delta \phi = \left( \frac{2\pi}{\lambda} \right) d \sin(\theta)
\]

between signals at the two Rx antennas. Hence, the angle of arrival can be estimated as

\[
\hat{\theta} = \sin^{-1} \left( \frac{\delta \phi \lambda}{2\pi d} \right)
\]

This is referred as the phase mono-pulse technique.

Amplitude monopulse angle estimation

The sum and difference of the received signal on the two received antennas followed by taking ratio leads to

\[
\frac{\Delta}{\Sigma} = -j \tan \left( \frac{\pi d \lambda}{\lambda} \cdot \sin(\theta) \right)
\]

So in case of amplitude monopulse the angle estimation becomes

\[
\hat{\theta} = \sin^{-1} \left( \frac{\lambda}{\pi d} \cdot \tan^{-1} \left( -\text{imag} \left( \frac{\Delta}{\Sigma} \right) \right) \right)
\]
What is current system availability?

There are 3 demo boards available now. Please see below description and images.

<table>
<thead>
<tr>
<th>Sense2GoL</th>
<th>Distance2Go</th>
<th>Position2Go</th>
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</thead>
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<tr>
<td>(BGT24LTR11 + XMC1300)</td>
<td>(BGT24MTR11 + XMC4200)</td>
<td>(BGT24MTR12 + XMC4700)¹</td>
</tr>
<tr>
<td>▶ Capability to detect motion, speed and direction of movement (approaching or retreating)</td>
<td>▶ Capability to detect distance of multiple targets</td>
<td>▶ Capability to detect position of multiple targets</td>
</tr>
<tr>
<td>▶ Precise measurement of object detection compared to PIR</td>
<td>▶ Capability to detect motion, speed and direction of movement (approaching or retreating)</td>
<td>▶ Capability to detect distance of multiple targets</td>
</tr>
<tr>
<td>▶ Operates in harsh environments and detects through non-metallic materials</td>
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<td>▶ Operates in harsh environments and detects through non-metallic materials</td>
</tr>
<tr>
<td>▶ Low power mode for enhanced battery life</td>
<td>▶ BGT24MTR11 – 24 GHz highly integrate RF MMIC</td>
<td>▶ BGT24MTR12 – 24 GHz highly integrate RF MMIC</td>
</tr>
<tr>
<td>▶ One of the world’s smallest complete radar + MCU development kit</td>
<td>▶ XMC1300 ARM® Cortex®-M0 – 32-bit industrial microcontroller</td>
<td>▶ XMC4700 ARM® Cortex®-M4 – 32-bit industrial microcontroller</td>
</tr>
<tr>
<td>▶ BGT24LTR11 – 24 GHz highly integrated RF MMIC</td>
<td>▶ Debug over cortex 10 pin debug connector</td>
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</tr>
<tr>
<td>▶ XMC1300 ARM® Cortex®-M0 – 32-bit industrial microcontroller</td>
<td>▶ Integrated multiple element patch antennas</td>
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</tr>
<tr>
<td>▶ Debug over cortex 10 pin debug connector</td>
<td>▶ Main applications</td>
<td>▶ Main applications</td>
</tr>
<tr>
<td>▶ Integrated multiple element patch antennas</td>
<td>▶ ▶ Drone: soft landing/obstacle avoidance</td>
<td>▶ ▶ Drone/robots: obstacle avoidance</td>
</tr>
<tr>
<td>▶ ▶ Security</td>
<td>▶ ▶ Smart toilets</td>
<td>▶ ▶ Security</td>
</tr>
<tr>
<td>▶ ▶ Lighting control</td>
<td>▶ ▶ Tank level sensing</td>
<td>▶ ▶ People tracking (IoT, smart home)</td>
</tr>
<tr>
<td>▶ ▶ Automatic door opener</td>
<td>▶ ▶ Intelligent switches</td>
<td>▶ ▶ Vital sensing</td>
</tr>
<tr>
<td>▶ ▶ Vital sensing</td>
<td>▶ ▶ Board dimensions</td>
<td>▶ ▶ Board dimensions</td>
</tr>
<tr>
<td>▶ ▶ Board 36 mm x 45 mm</td>
<td>▶ ▶ Kit contents</td>
<td>▶ ▶ Kit contents</td>
</tr>
<tr>
<td>▶ ▶ Kit contents</td>
<td>▶ ▶ ▶ User’s manual</td>
<td>▶ ▶ ▶ User’s manual</td>
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<tr>
<td>▶ ▶ User’s manual</td>
<td>▶ ▶ ▶ SW GUI to operate kit</td>
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<tr>
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<td>▶ ▶ ▶ FMCW FW and SW ²</td>
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</tr>
<tr>
<td>▶ ▶ Schematic and bill-of-materials of module</td>
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</tr>
</tbody>
</table>

1) Coming soon
2) Usage of the FMCW and/or Doppler FW and SW requires agreeing to Infineon’s user’s agreement and licensing terms.
Is there a block diagram available for the Sense2GoL?

What are the key features of the Sense2GoL demo board?

**Features**
- Capability to detect motion, speed and direction of movement (approaching or retreating)
- BGT24LTR11 – 24 GHz highly integrated low power RF MMIC
- XMC1302 ARM® Cortex®-M0 – 32-bit industrial microcontroller
- Integrated patch antennas
- Segger debugger break off board for reprogramming

**Kit contains**
- User manual
- SW GUI to operate kit
- Precompiled C libraries provided
- PCB schematic and Gerber files
Is this available as an MMIC or complete module?

<table>
<thead>
<tr>
<th>MMIC</th>
<th>Module suppliers using Infineon chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Features</td>
<td>Technical benefits</td>
</tr>
<tr>
<td>› Radar-based motion detector operating in the 24 GHz ISM-band</td>
<td>› Large coverage areas such as warehouses, parking lots, etc.</td>
</tr>
<tr>
<td>› Long range distance detection of moving objects up to 30 m</td>
<td>› Robust against harsh conditions (rain, dust and temperature)</td>
</tr>
<tr>
<td>› Wide range speed detection up to more than ±100 km/h</td>
<td>› Precise presence detection</td>
</tr>
</tbody>
</table>

Where do I go for additional information?

www.infineon.com/24GHz

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