LD2410
24 GHz Radar Sensor

Why 24 GHz Radio Waves?

1 Good Balance of Range and Resolution

Higher frequencies (like 24 GHz) allow for better detection of small movements compared to lower frequencies (like 5 GHz Wi-Fi).

It provides a good mix of detection range (a few meters) and sensitivity (can sense tiny movements).

2 Penetration Through Objects

24 GHz waves can pass through thin materials (like clothing, walls, or plastic) but are still sensitive enough to detect human presence.

3 Regulatory & Practical Choice

Unlike higher frequencies (e.g., 60 GHz), 24 GHz is widely allowed for consumer radar applications without strict licensing.

It’s a common frequency for mm Wave radar sensors, balancing performance and cost.

What is FMCW (Frequency-Modulated Continuous Wave)?

FMCW is the technique used by the LD2410 to detect human bodies in motion and stationary states.

1 The Radar Sends a Changing Frequency Signal (known as chirp signal)

Instead of sending a single fixed frequency (like a steady beep), the LD2410 sends a signal that sweeps up and down in frequency over time.

2 The Signal Bounces Back from Objects (known as echo signal)

When the radio waves hit a person (or any object), they reflect back to the LD2410.

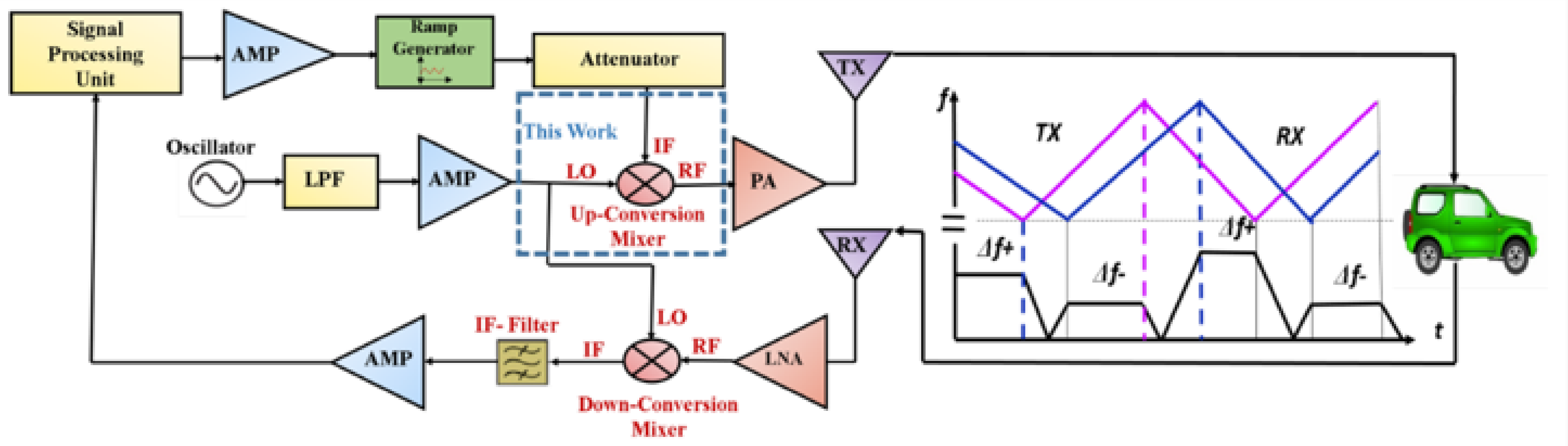
3 Comparing Chirp & Echo Signals:

The sensor compares the original chirp signal and the echo signal to determine:

Distance: By measuring the frequency difference (beat frequency) between chirp and echo signals.

Speed (Movement): By measuring the doppler frequency caused by moving objects, like a person walking).

Block Diagram of a Typical Radar Transceiver



FMCW Radar Distance Calculation

- **The radar transmits a chirp: frequency sweeps from f_0 to f_0+B over time T.**
- **The beat frequency f_b (difference between chirp and echo frequencies after mixing) is proportional to the time delay τ.**
- **Distance d is calculated by:**

$$d = \frac{c \times T \times f_b}{2B}$$

where

- c = speed of light (approx. 3×10^8 m/s)
- T = chirp duration (seconds)
- B = bandwidth (Hz)
- f_b = beat frequency (Hz)

Given parameters (typical values for 24 GHz FMCW radar):

Parameter	Symbol	Value	Units
Start frequency	f_0	24 GHz	24×10^9 Hz
Bandwidth	B	500 MHz	5×10^8 Hz
Chirp duration	T	50 μs	50×10^{-6} s
Speed of light	c	3×10^8	m/s

Example 1: Beat frequency = 1 MHz

- $f_b = 1 \times 10^6$ Hz

Calculate distance d:

$$d = \frac{3 \times 10^8 \times 50 \times 10^{-6} \times 1 \times 10^6}{2 \times 5 \times 10^8}$$

Calculate numerator:

$$3 \times 10^8 \times 50 \times 10^{-6} \times 1 \times 10^6 = 3 \times 10^8 \times 50 \times 10^0 = 1.5 \times 10^{10}$$

Calculate denominator:

$$2 \times 5 \times 10^8 = 1 \times 10^9$$

Distance:

$$d = \frac{1.5 \times 10^{10}}{1 \times 10^9} = 15 \text{ meters}$$

Example 2: Beat frequency = 0.3 MHz (300 kHz)

- $f_b = 3 \times 10^5$ Hz

Distance:

$$d = \frac{3 \times 10^8 \times 50 \times 10^{-6} \times 3 \times 10^5}{2 \times 5 \times 10^8} = \frac{3 \times 10^8 \times 50 \times 10^{-6} \times 3 \times 10^5}{1 \times 10^9}$$

Numerator:

$$3 \times 10^8 \times 50 \times 10^{-6} \times 3 \times 10^5 = 3 \times 10^8 \times 15 = 4.5 \times 10^9$$

Distance:

$$d = \frac{4.5 \times 10^9}{1 \times 10^9} = 4.5 \text{ meters}$$

Summary table:

Beat Frequency f_b (Hz)	Distance d (meters)
1,000,000 (1 MHz)	15
300,000 (0.3 MHz)	4.5
5,000,000 (5 MHz)	75

Summary of relationship:

Target distance d	Echo delay τ	Beat frequency f_b
Larger (farther)	Larger (longer)	Larger (higher)
Smaller (closer)	Smaller (shorter)	Smaller (lower)

How does the LD2410 determine an object's velocity?

The LD2410 processes the Doppler frequency shift f_d to calculate the velocity v using:

$$v = \frac{c \times f_d}{2 \times f_0}$$

where

- c = speed of light (3×10^8 m/s)
- f_d = Doppler frequency shift (Hz)
- f_0 = carrier frequency (~24 GHz = 24×10^9 Hz)

Numerical example:

Suppose LD2410 measures a Doppler frequency shift $f_d = 500$ Hz from a moving object.

Calculate velocity v:

$$v = \frac{3 \times 10^8 \times 500}{2 \times 24 \times 10^9} = \frac{1.5 \times 10^{11}}{4.8 \times 10^{10}} \approx 3.125 \text{ m/s}$$

So the object is moving at approximately **3.13 meters per second** toward or away from the radar (sign depends on direction).

Another example:

If the Doppler frequency shift is $f_d = 2000$ Hz:

$$v = \frac{3 \times 10^8 \times 2000}{2 \times 24 \times 10^9} = \frac{6 \times 10^{11}}{4.8 \times 10^{10}} = 12.5 \text{ m/s}$$

The object moves at **12.5 m/s**.

Summary:

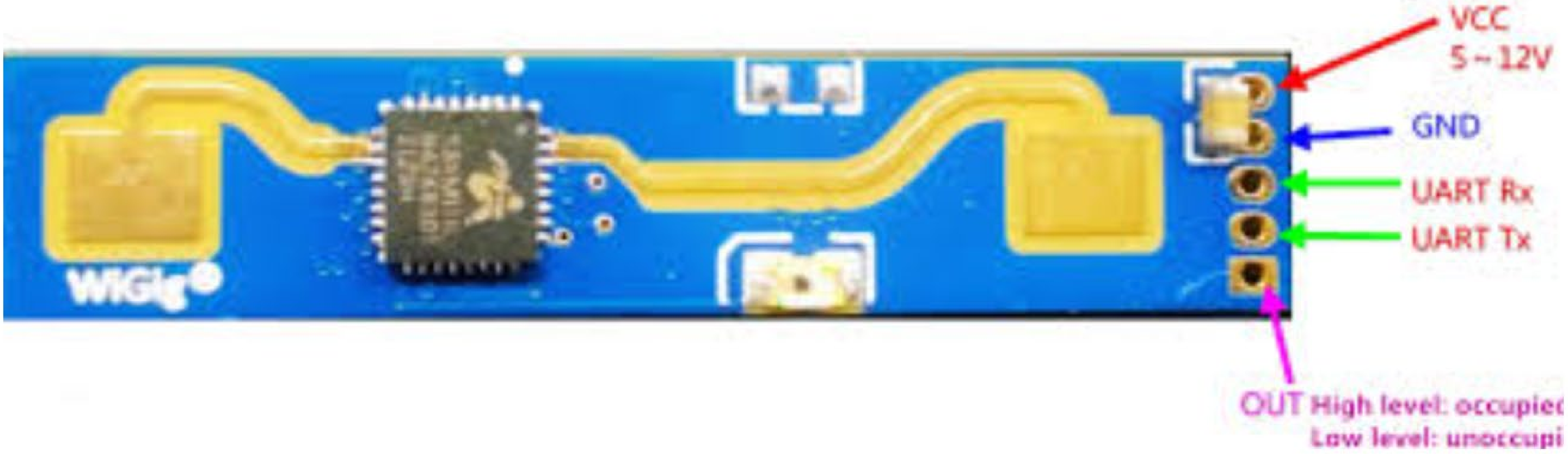
Doppler Shift f_d (Hz)	Velocity v (m/s)
500	3.13
2000	12.5

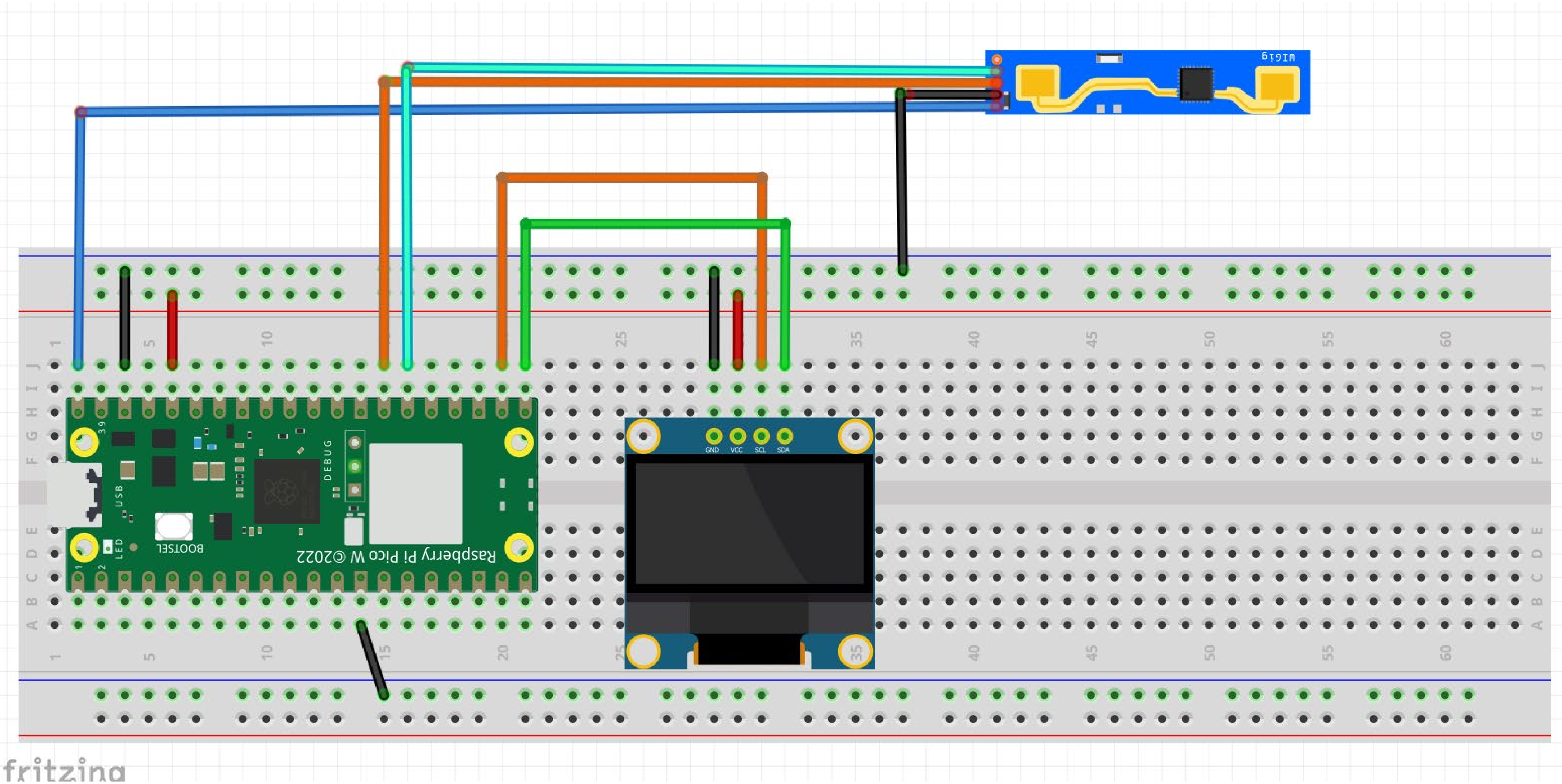
Notes:

- The sign of f_d indicates whether the object is approaching (positive shift) or receding (negative shift).
- LD2410 internally performs the mixing and signal processing to output velocity data.

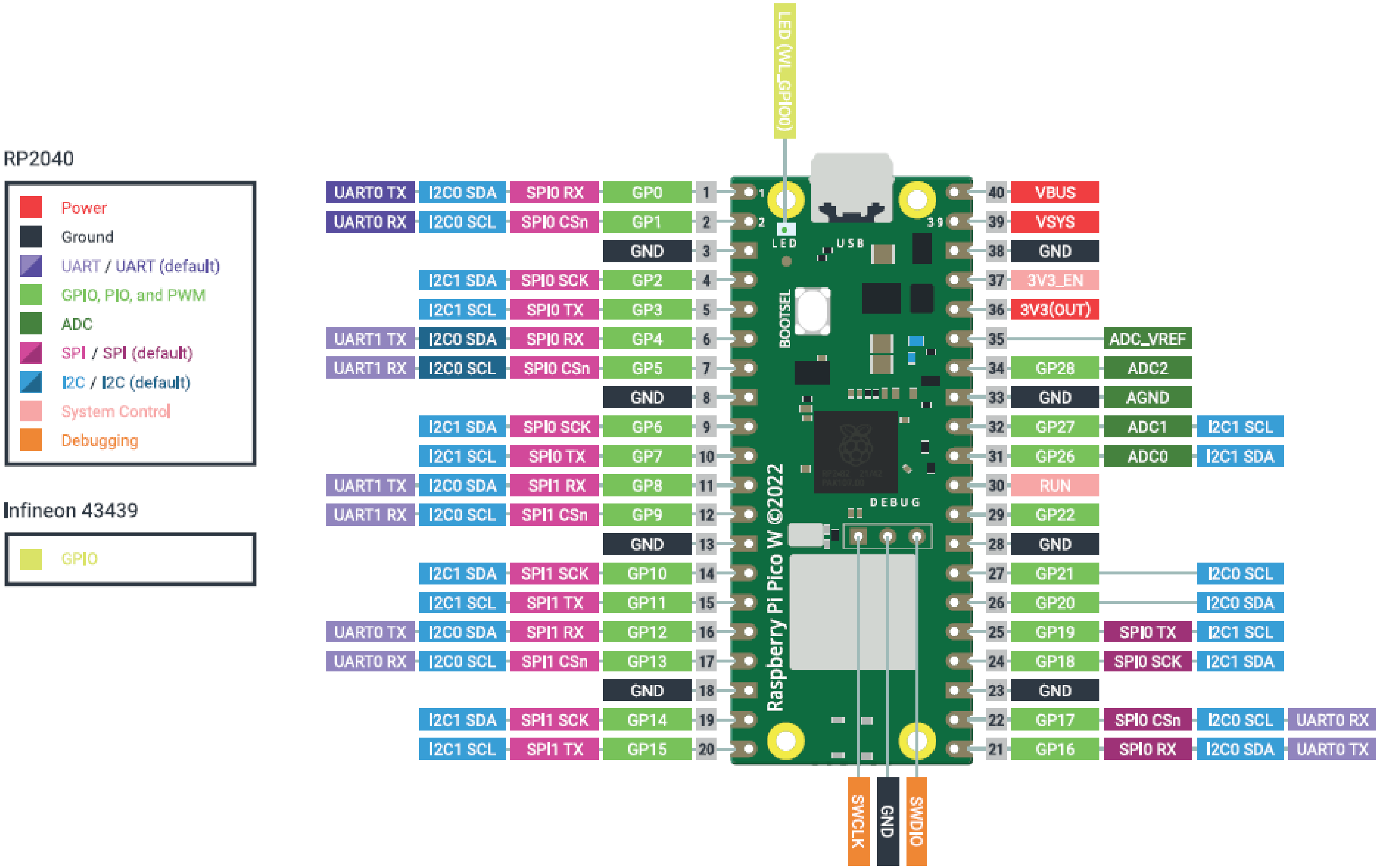
Feature	CW Radar	Pulsed Radar	FMCW Radar
Signal Type	Continuous Wave with fixed frequency	Short pulses of RF energy at intervals	Continuous wave with frequency modulation (chirp)
Distance Measurement	Cannot measure distance directly	Measures distance by timing pulse return	Measures distance by beat frequency from chirp delay
Velocity Measurement	Measures velocity via Doppler shift	Limited Doppler measurement capability (needs special processing)	Measures velocity via Doppler shift combined with beat frequency
Range Resolution	Poor (no range info)	Good; depends on pulse width	High; depends on chirp bandwidth
Max Range	Limited by transmitter power and receiver sensitivity	Can achieve very long range (km+) depending on pulse power	Moderate range; suited for short to medium range (meters to hundreds of meters)
Hardware Complexity	Simplest; no pulse generation or modulation needed	More complex; requires fast pulse generation and precise timing	Moderately complex; requires precise frequency modulation and mixing
Signal Processing	Simple frequency analysis (Doppler)	Requires time-of-flight measurement and pulse processing	Requires mixing and frequency analysis of beat frequency
Power Efficiency	Continuous power output, often lower peak power	High peak power pulses, low duty cycle	Continuous low-to-moderate power with modulation
Typical Applications	Speed measurement (e.g., police radar guns), simple motion detectors	Air traffic control, weather radar, long-range surveillance	Automotive radar, industrial sensing, level measurement
Pros	Simple and cheap, good velocity accuracy	Excellent range and resolution, versatile	Accurate range and velocity simultaneously, compact design
Cons	No distance info, susceptible to interference	Expensive and bulky hardware, complex timing	Limited max range, requires precise modulation

LD2410 Presence Sensor Pinout Diagram




GND
VCC
SCL
SDA
Raspberry Pi Pico W ©2022
BOOTSEL
USB
DEBUG
LED
fritzing

Raspberry Pi Pico W Pinout



Interactive FMCW Radar System Visualization

End of Presentation