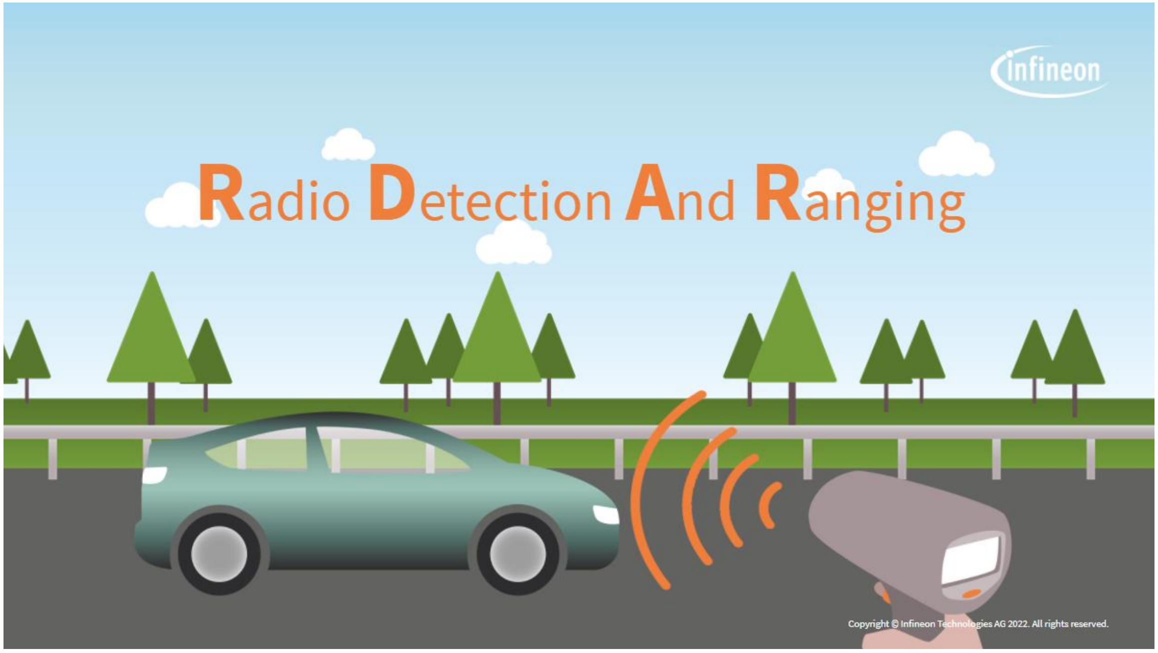
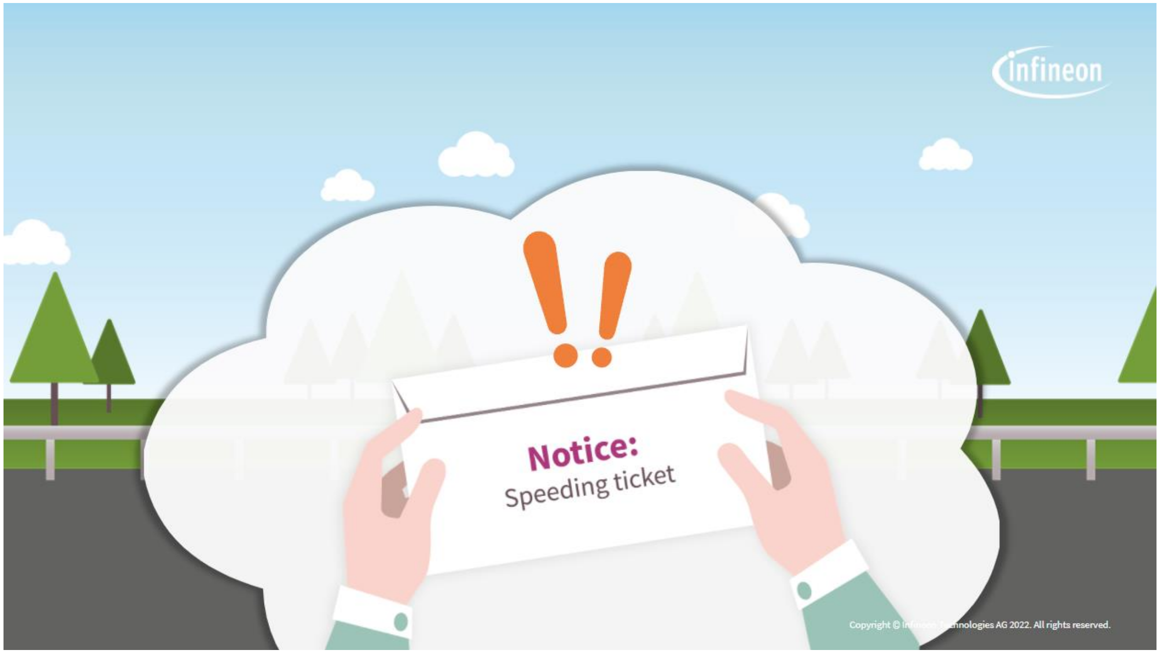
RADAR basics (FMCW)

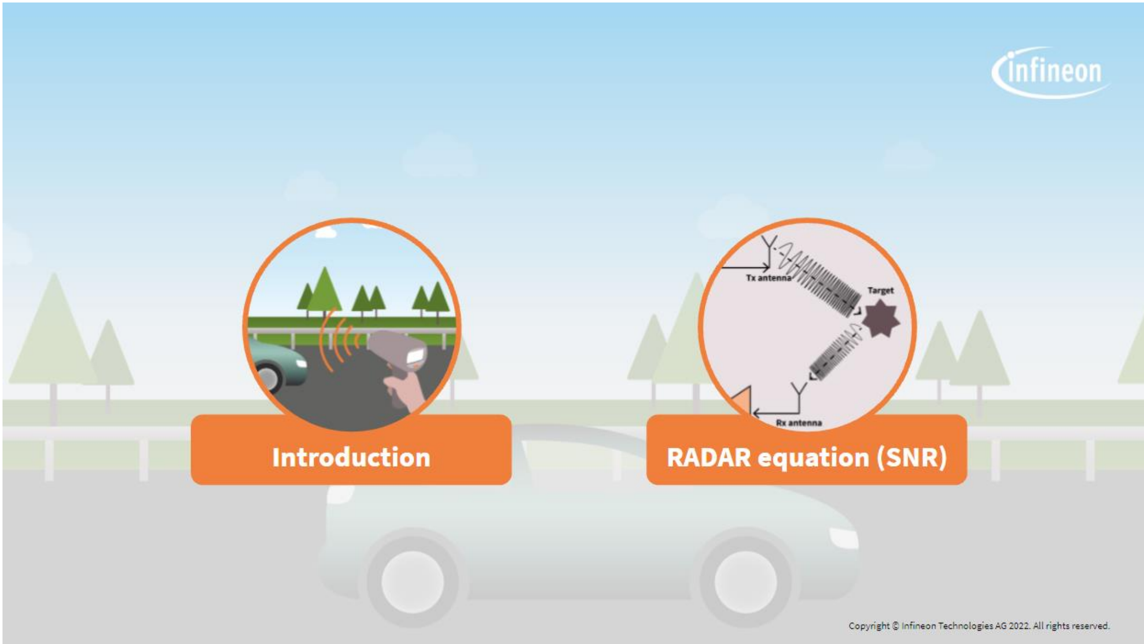


We have all heard of, if not experienced, the RADAR principle.



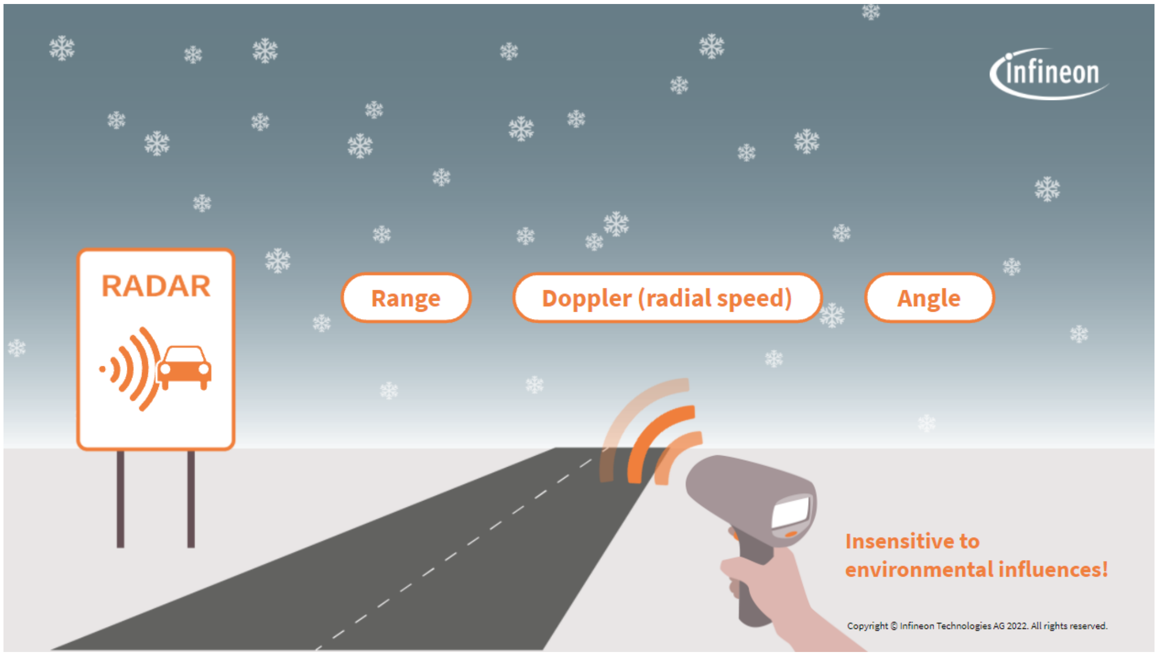
The experience might not always be fascinating, but the technology is for sure!

Want to know more about it?

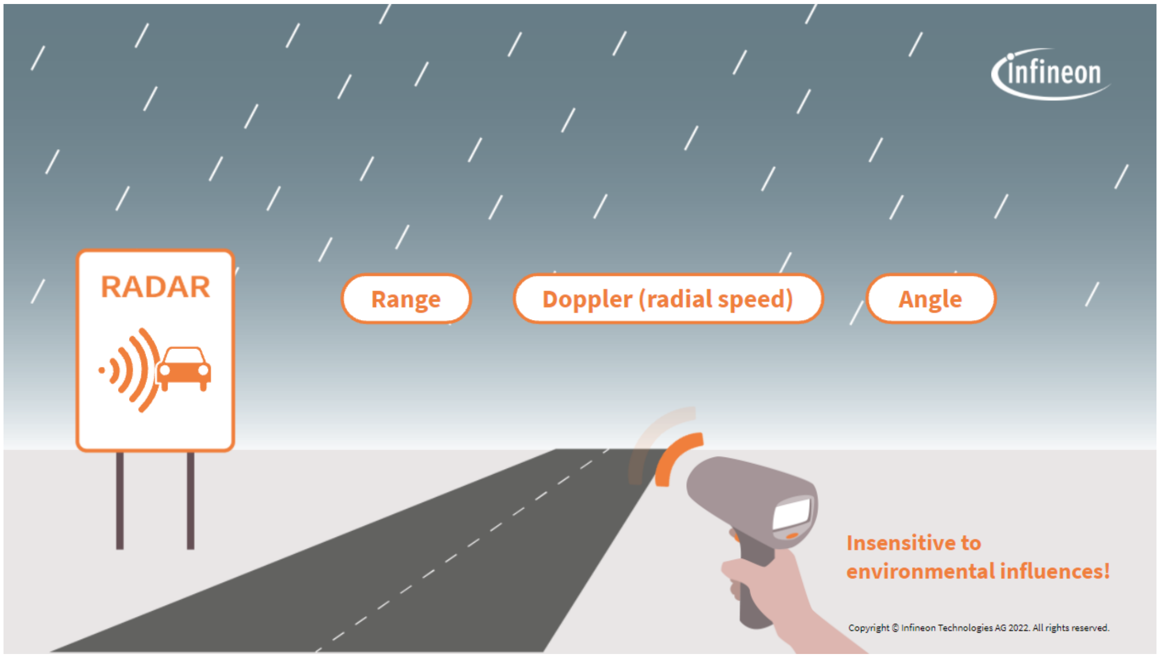


In this training, you will get an introduction to the RADAR principle, and then we will deep dive into the RADAR equation.

Let's start!



A RADAR makes use of radio signals to detect an object's range, doppler speed, and angle, no matter whether it snows…


RADAR
Range
Doppler (radial speed)
Angle
Insensitive to
environmental influences!
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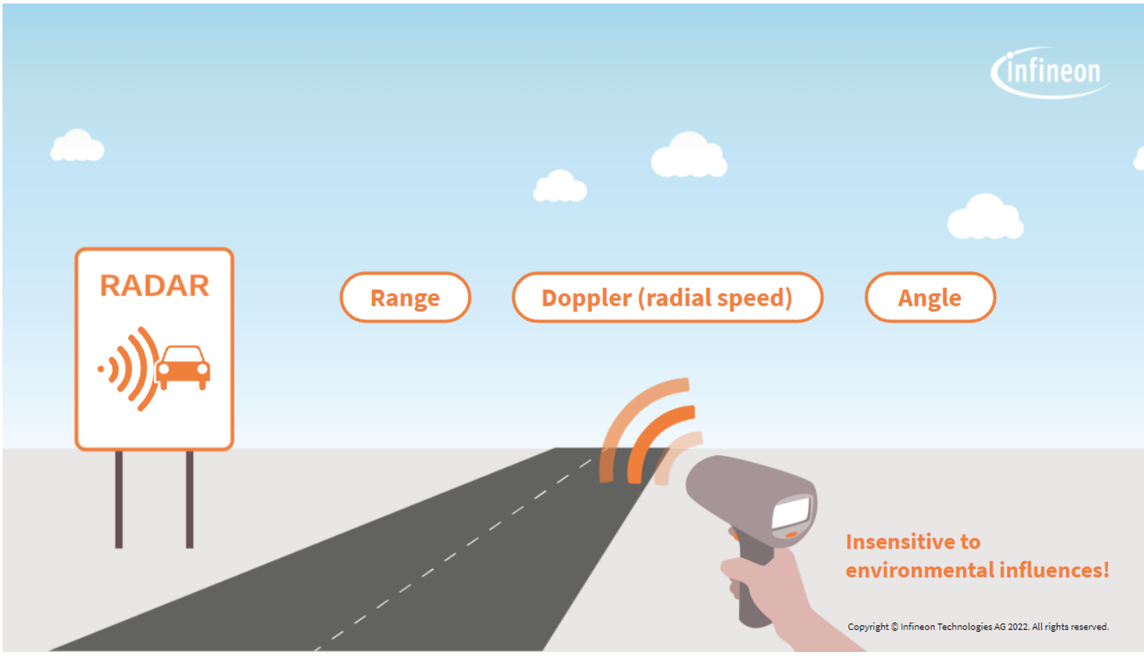
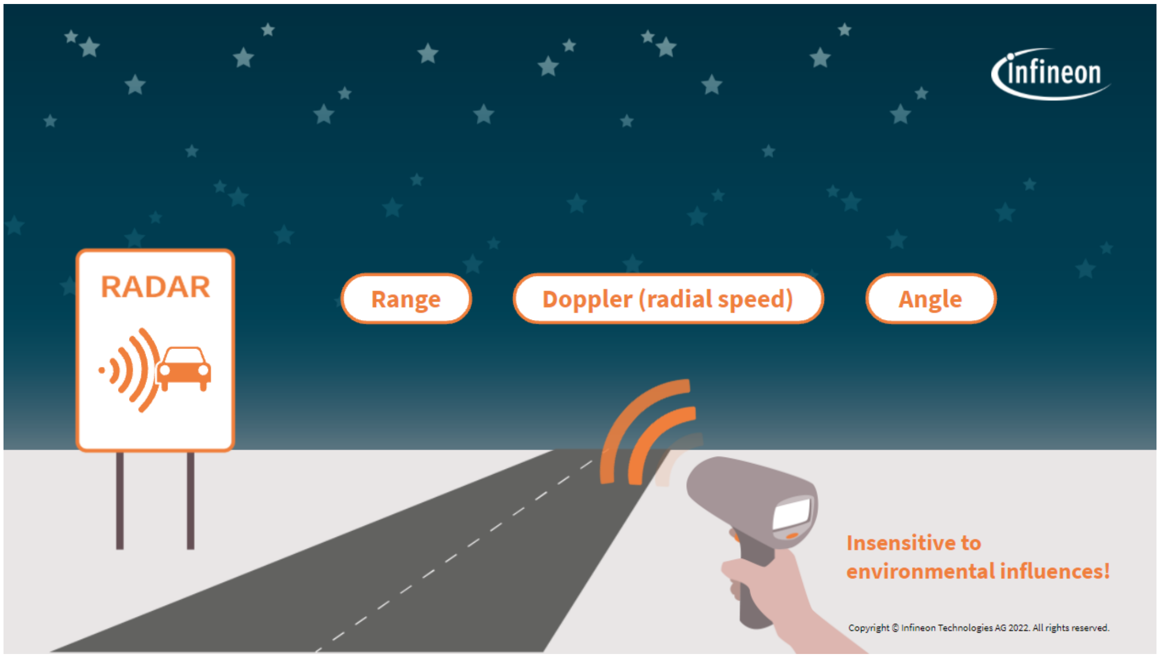
or rains…

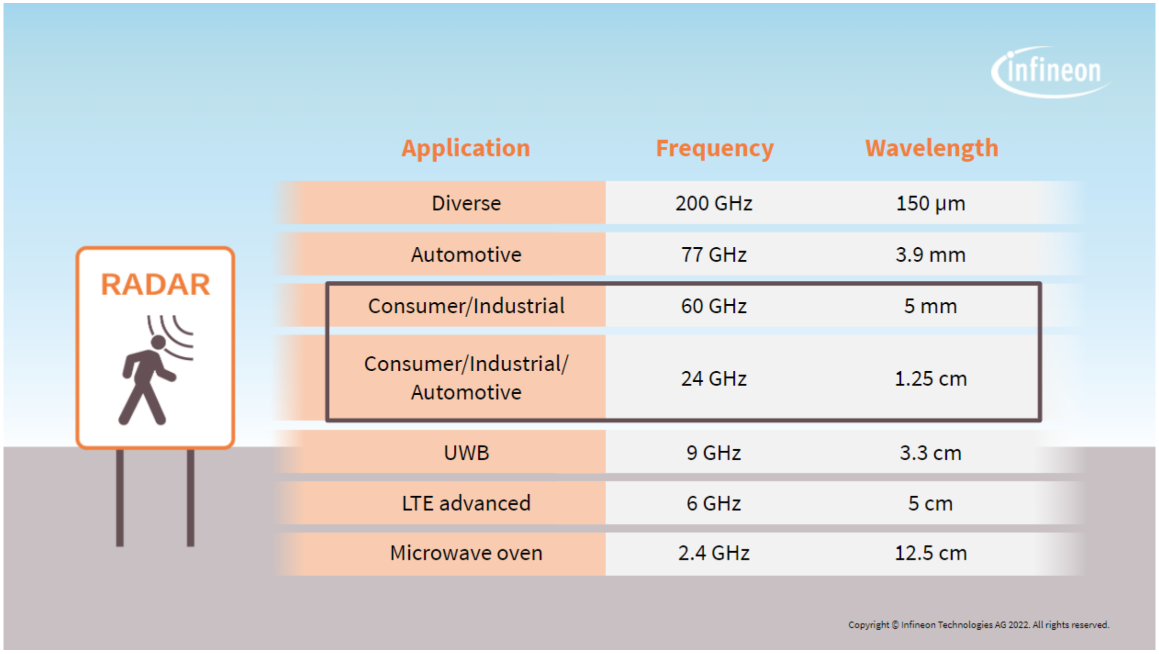


or if it’s light…



… or dark outside.

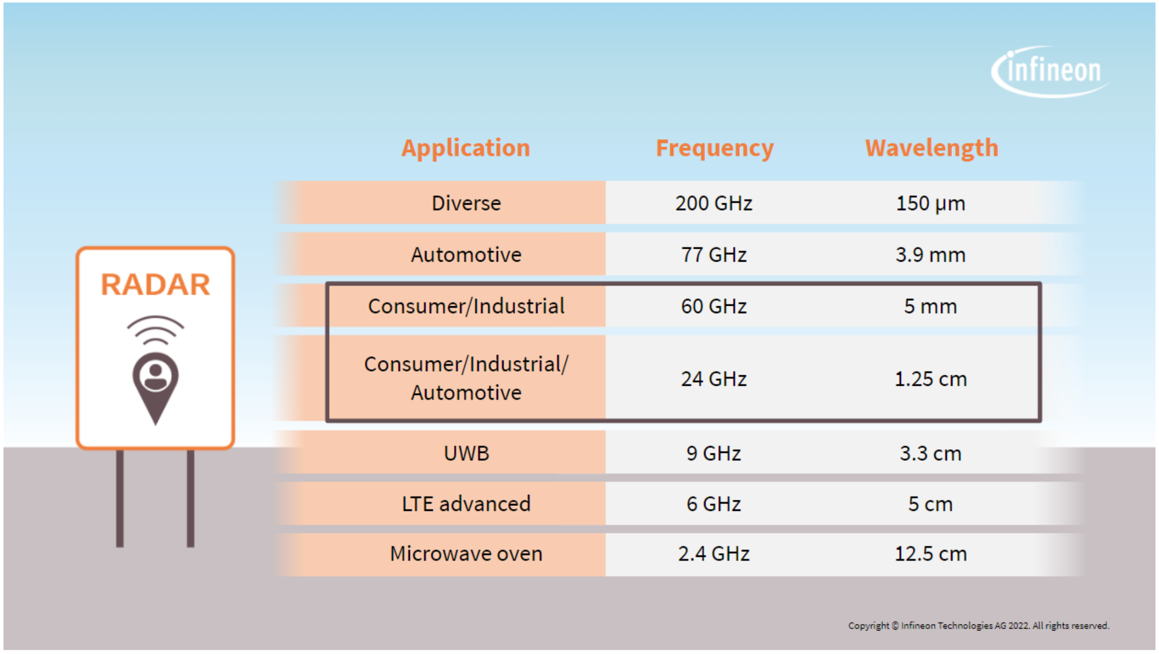
RADAR basics (FMCW)



Application	Frequency	Wavelength
Diverse	200 GHz	150 µm
Automotive	77 GHz	3.9 mm
Consumer/Industrial	60 GHz	5 mm
Consumer/Industrial/ Automotive	24 GHz	1.25 cm
UWB	9 GHz	3.3 cm
LTE advanced	6 GHz	5 cm
Microwave oven	2.4 GHz	12.5 cm

This can be useful for automotive, consumer, and industrial applications, as it allows not only highly sensitive motion and presence detection…

RADAR basics (FMCW)



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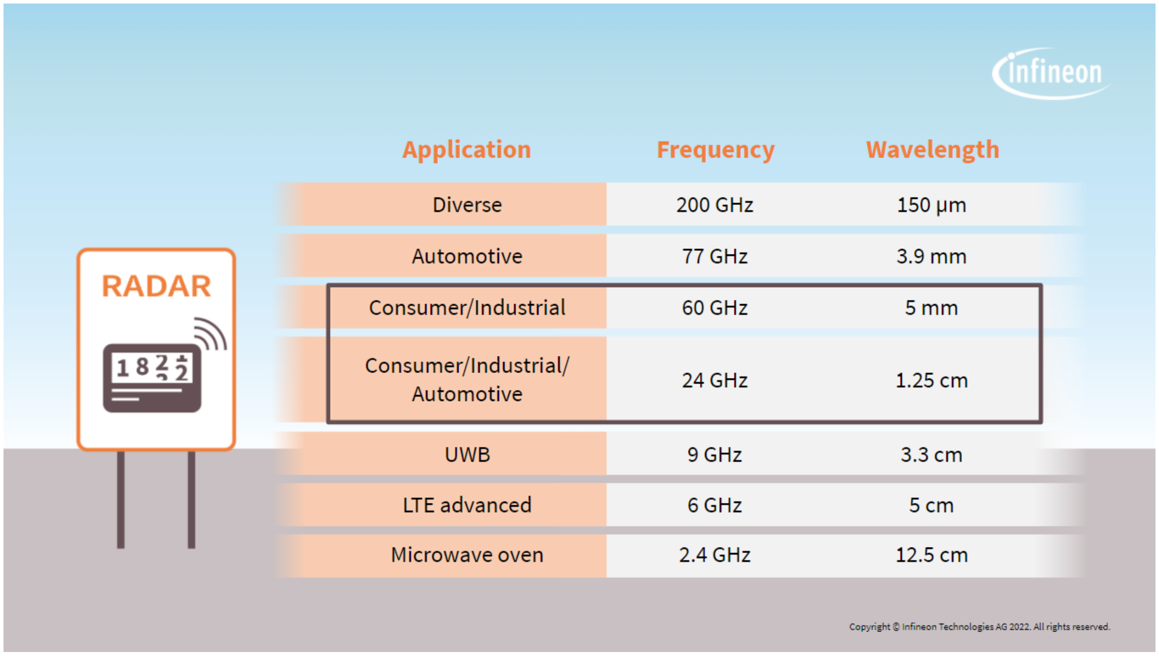
Consumer/Industrial/ Automotive	24 GHz	1.25 cm
UWB	9 GHz	3.3 cm
LTE advanced	6 GHz	5 cm
Microwave oven	2.4 GHz	12.5 cm

… but also more advanced use cases like people tracking…



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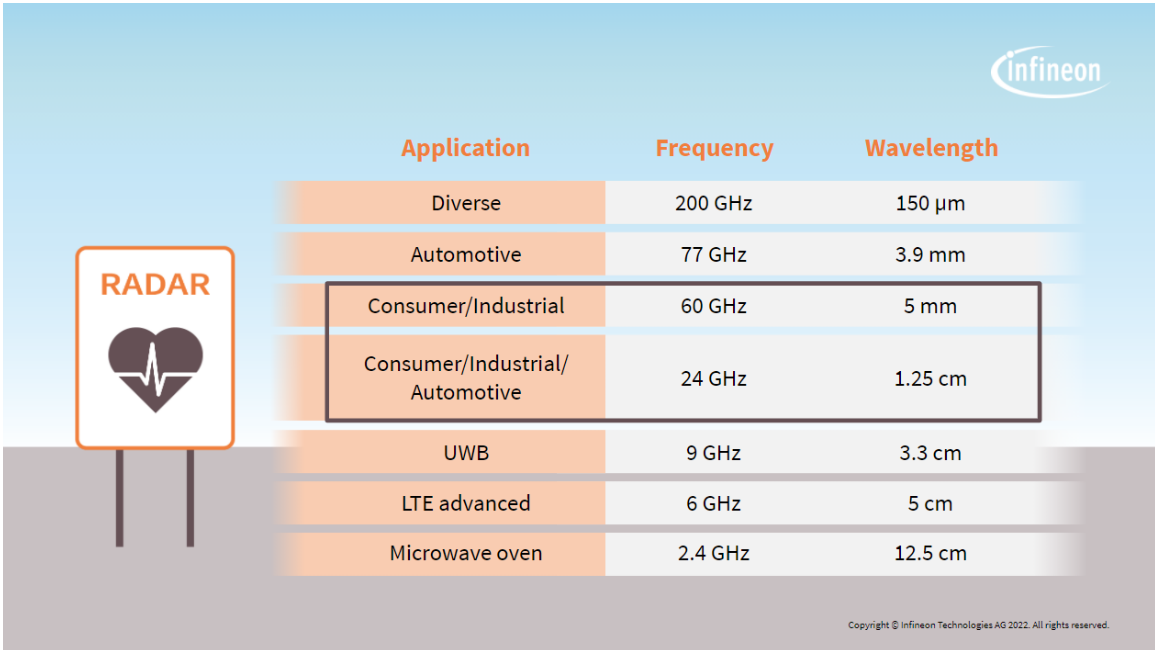
LTE advanced	6 GHz	5 cm
Microwave oven	2.4 GHz	12.5 cm

… and entrance counter…

Application	Frequency	Wavelength
Diverse	200 GHz	150 µm
Automotive	77 GHz	3.9 mm
Consumer/Industrial	60 GHz	5 mm
Consumer/Industrial/ Automotive	24 GHz	1.25 cm
UWB	9 GHz	3.3 cm
LTE advanced	6 GHz	5 cm
Microwave oven	2.4 GHz	12.5 cm

… sensing finger movements for gesture control…

RADAR basics (FMCW)



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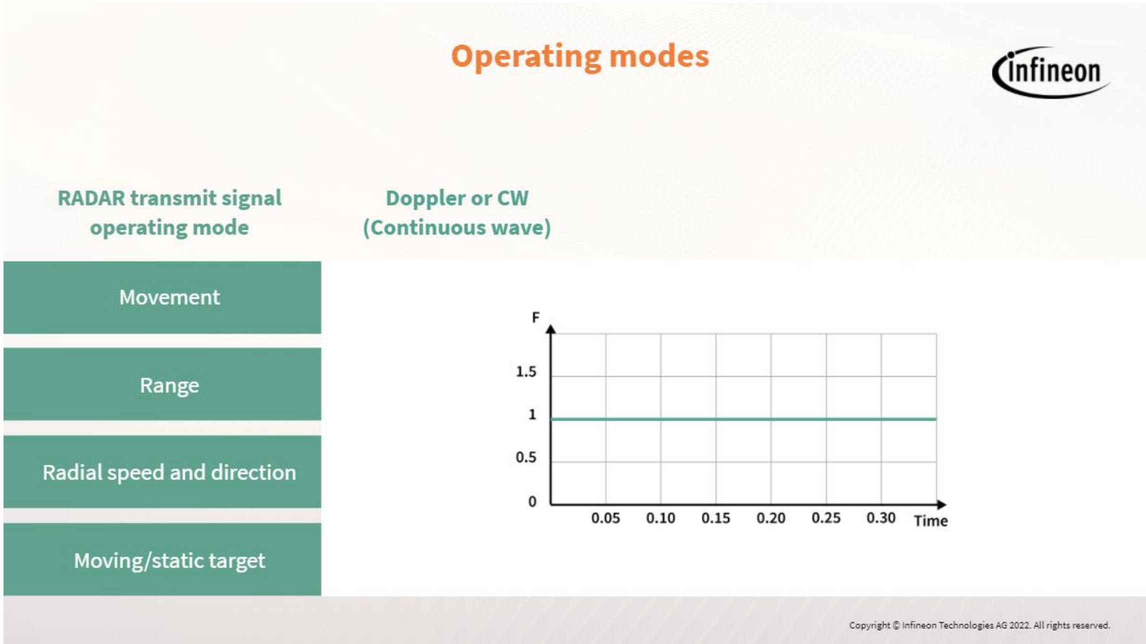
Microwave oven	2.4 GHz	12.5 cm

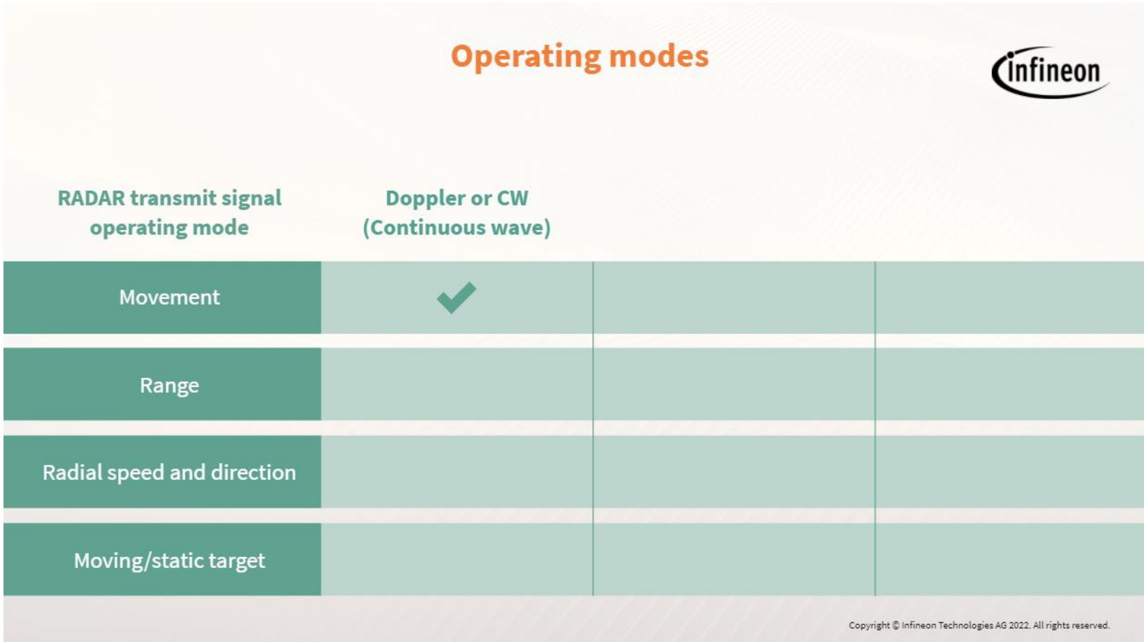
… or monitoring vital functions such as breath and heartbeat remotely.



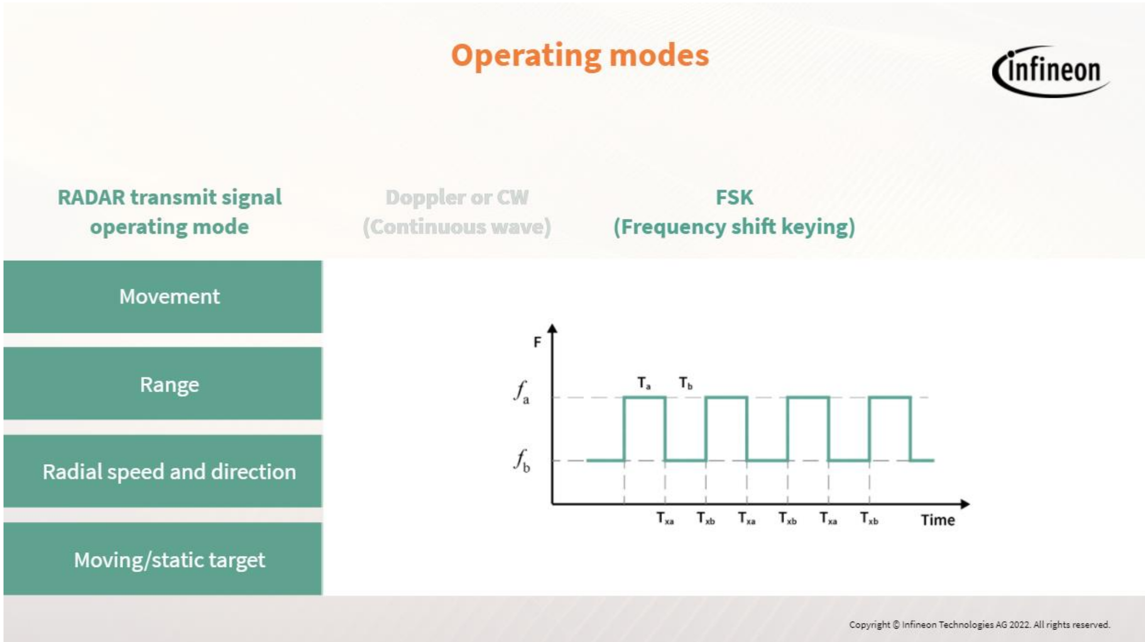
Depending on the transmit signal operating mode, RADAR can work in numerous ways.

Typical operating modes are:

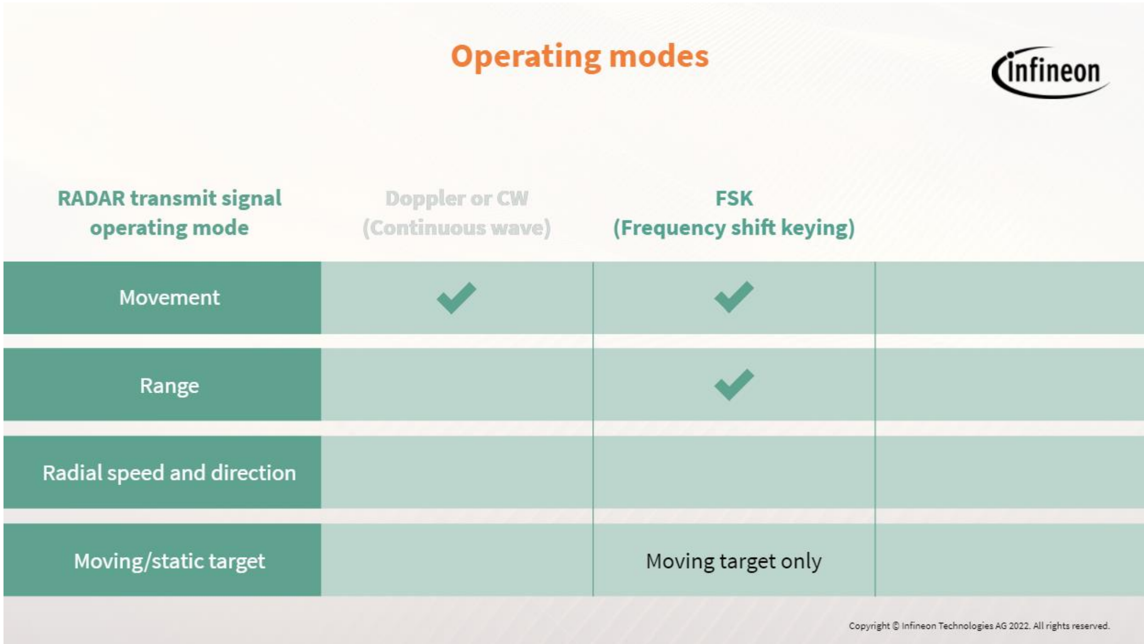
- Doppler or continuous wave, which transmits a single frequency…



… and allows you to measure the objects' movement.

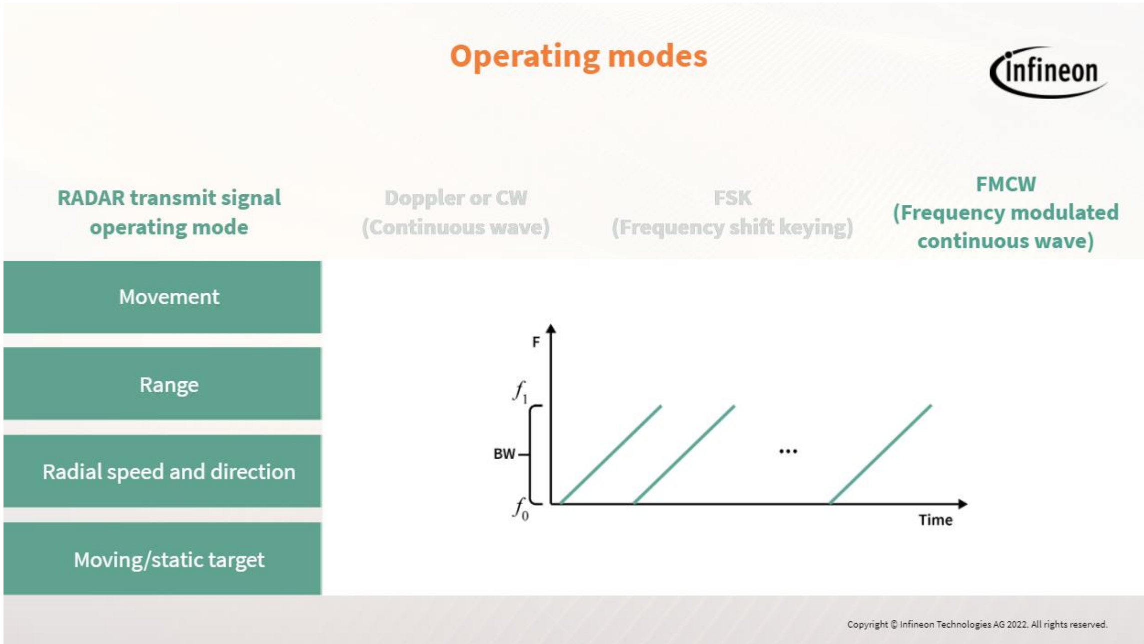


- Frequency shift keying, which uses two frequencies…



RADAR transmit signal operating mode	Doppler or CW (Continuous wave)	FSK (Frequency shift keying)	
Movement	✔	✔	
Range		✔	
Radial speed and direction			
Moving/static target		Moving target only	

… and enables you not only to measure the objects' movement but also the range.



- And frequency modulated continuous wave, which modulates the frequencies, for example, linearly between f0 and f1.

Operating modes

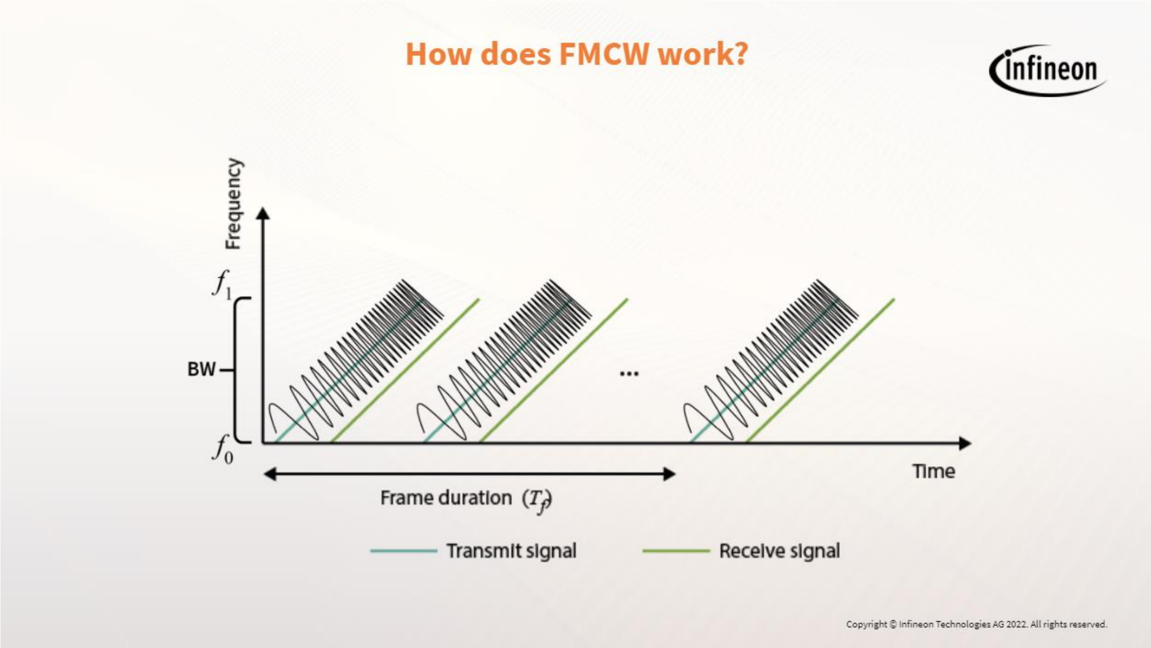
RADAR transmit signal operating mode	Doppler or CW (Continuous wave)	FSK (Frequency shift keying)	FMCW (Frequency modulated continuous wave)
Movement	✔	✔	✔
Range		✔	✔
Radial speed and direction			✔
Moving/static target		Moving target only	Moving and static target

This allows you not only to measure movement but also range and doppler speed of both moving and static objects.

Operating modes

RADAR transmit signal operating mode	Doppler or CW (Continuous wave)	FSK (Frequency shift keying)	FMCW (Frequency modulated continuous wave)
Movement	✔	✔	✔
Range		✔	✔
Radial speed and direction			✔
Moving/static target		Moving target only	Moving and static target

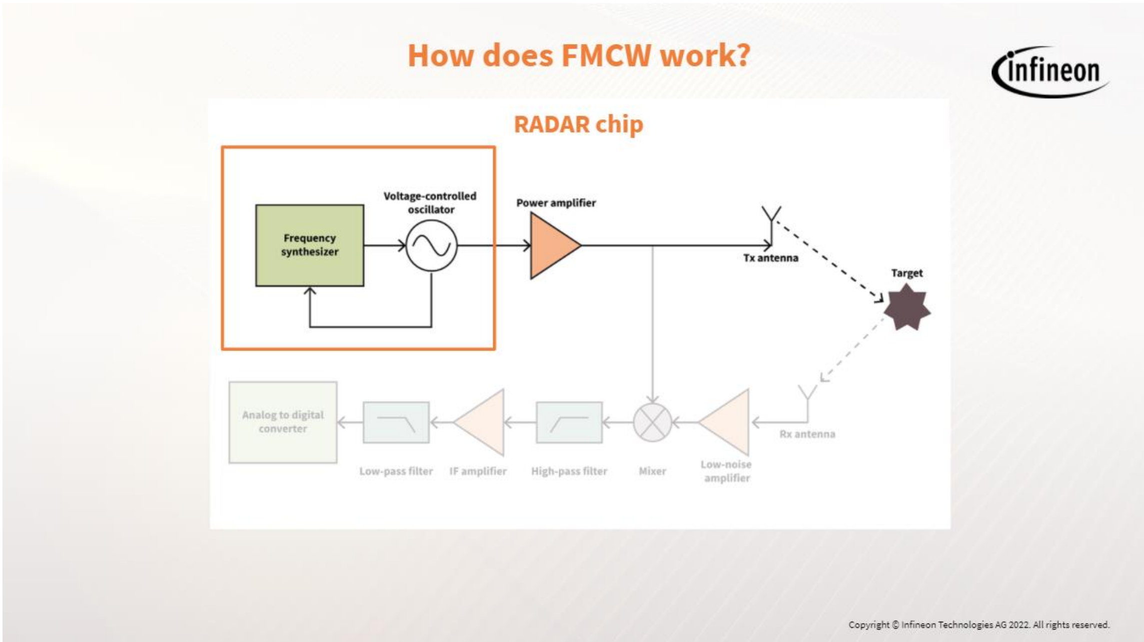
Let’s look at this last mode, also known as FMCW more closely!



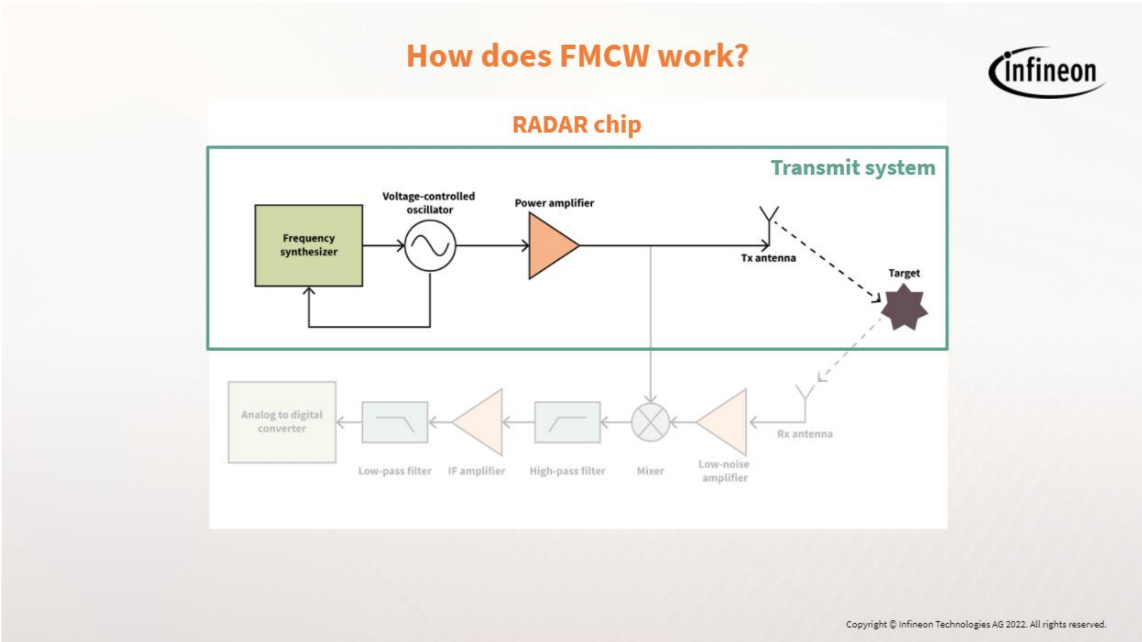
How does it detect moving and static objects and measure their range and doppler speed?

By continuously transmitting signals over a defined period of time - linearly modulated in frequency within a certain frequency bandwidth.

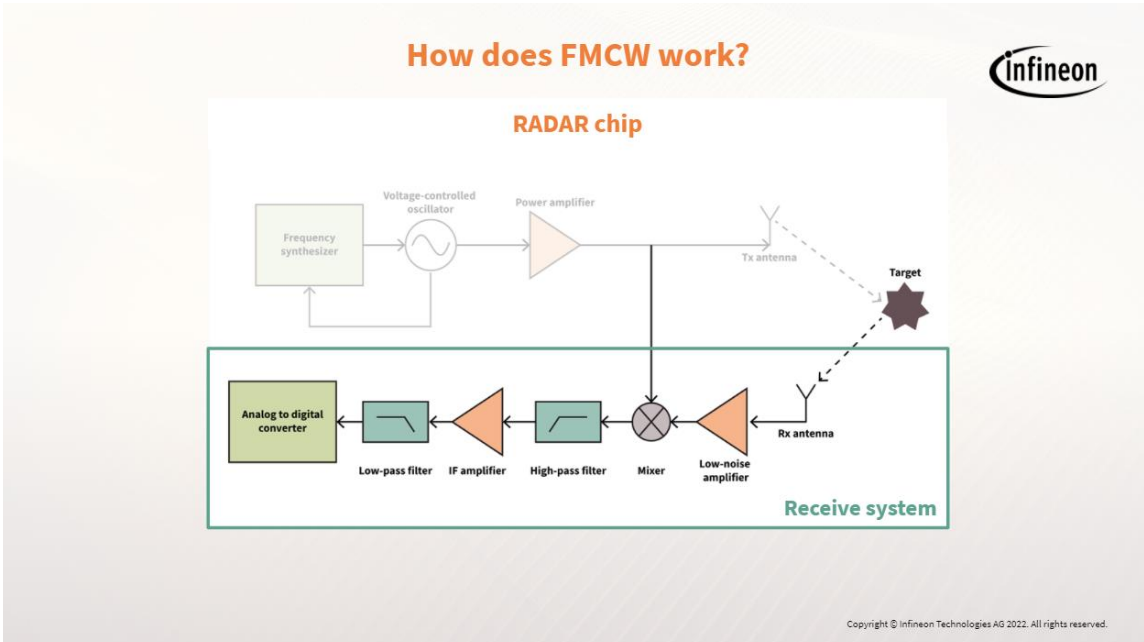
Sounds like a textbook sentence, right?



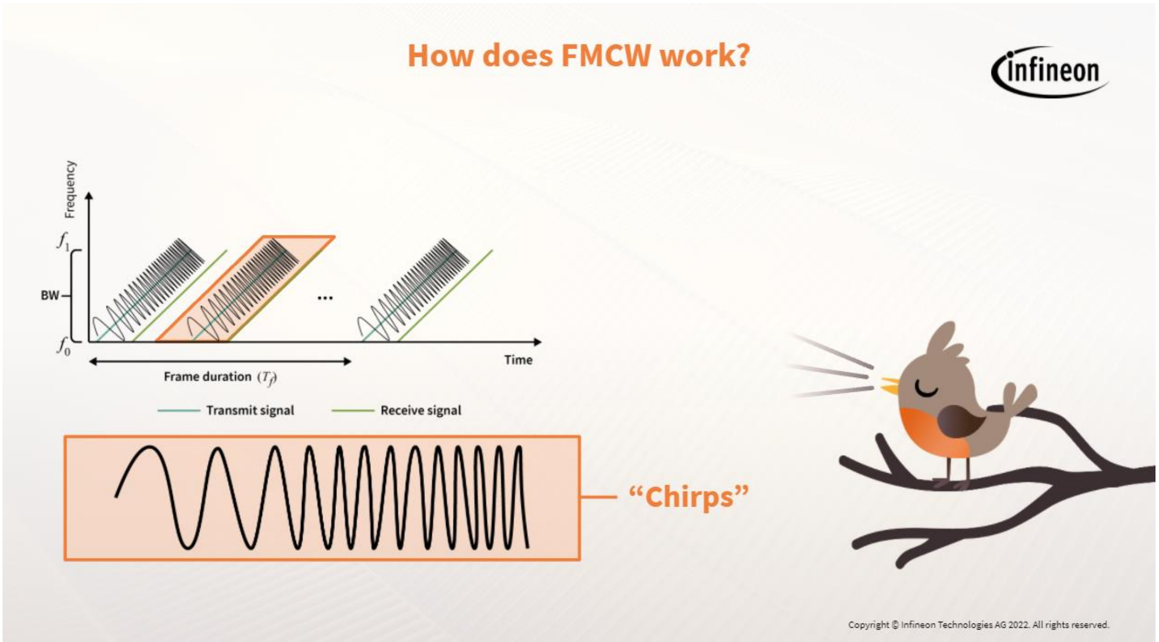
Practically speaking, such modulated transmit frequencies are produced by a phase-locked loop (PLL) frequency synthesizer and a voltage-controlled oscillator…



… which are part of the transmit system.

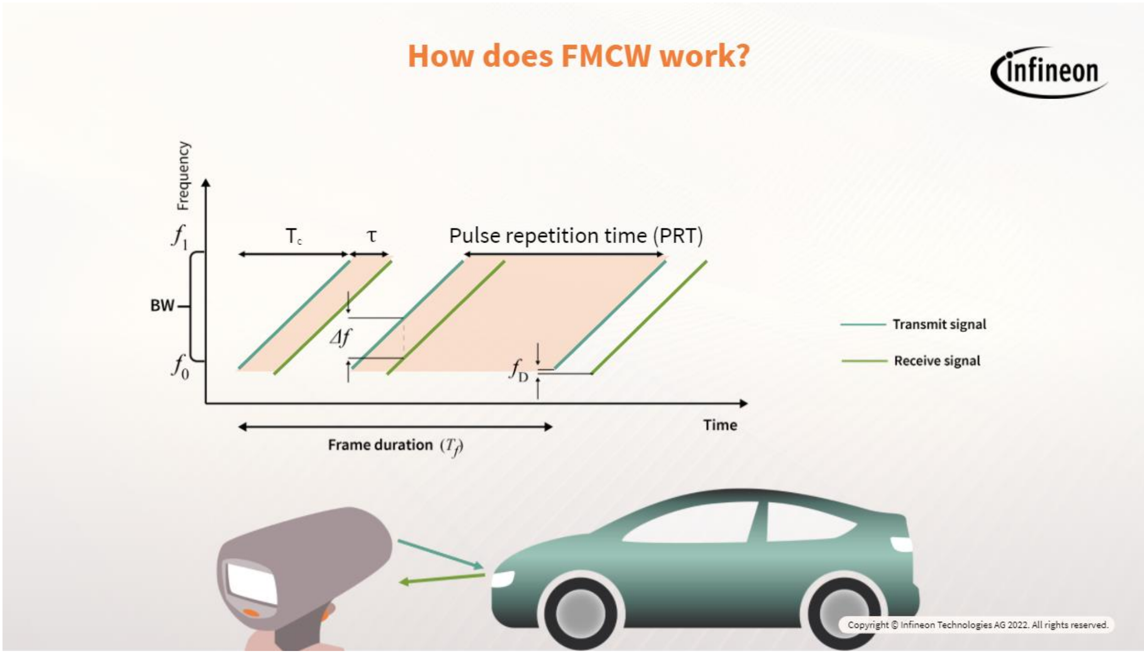


In addition, a RADAR chip also includes a receive system.



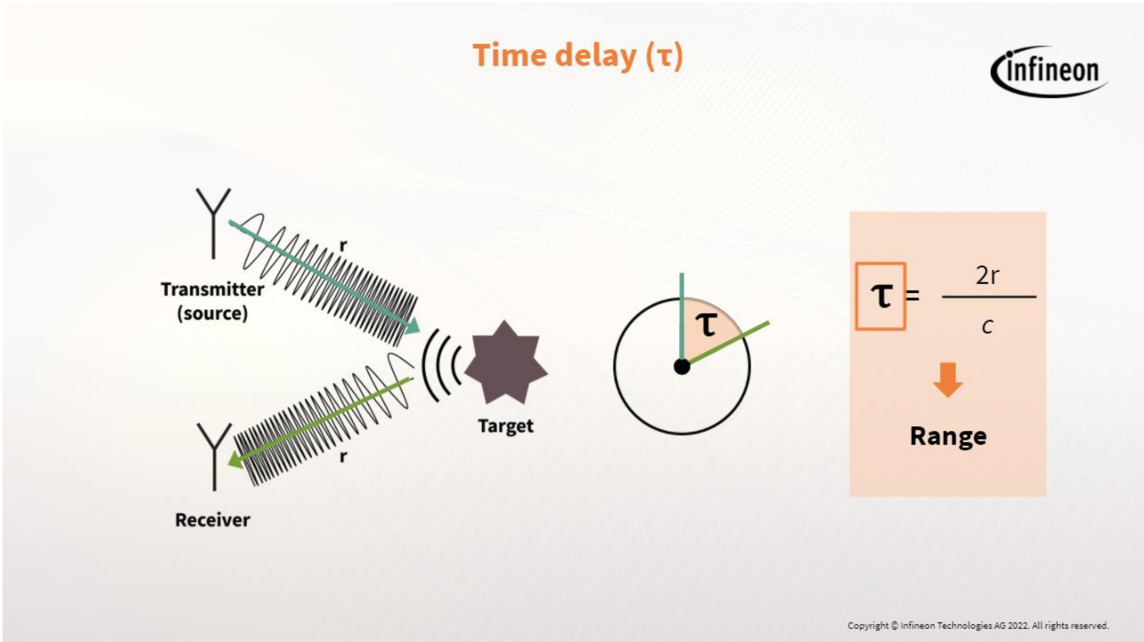
But back to the signal itself – doesn't it look like a bird sound wave?

Exactly! This is why we call such signals "chirps".

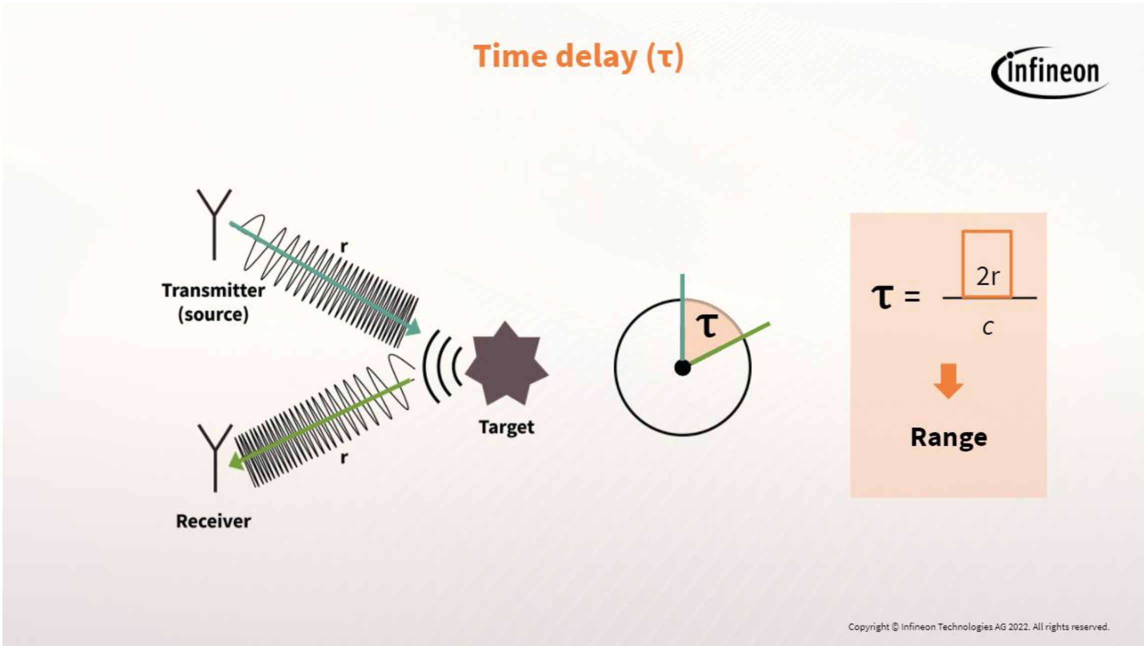


The transmitted chirps are reflected by a target and then received again with a time delay "tau".

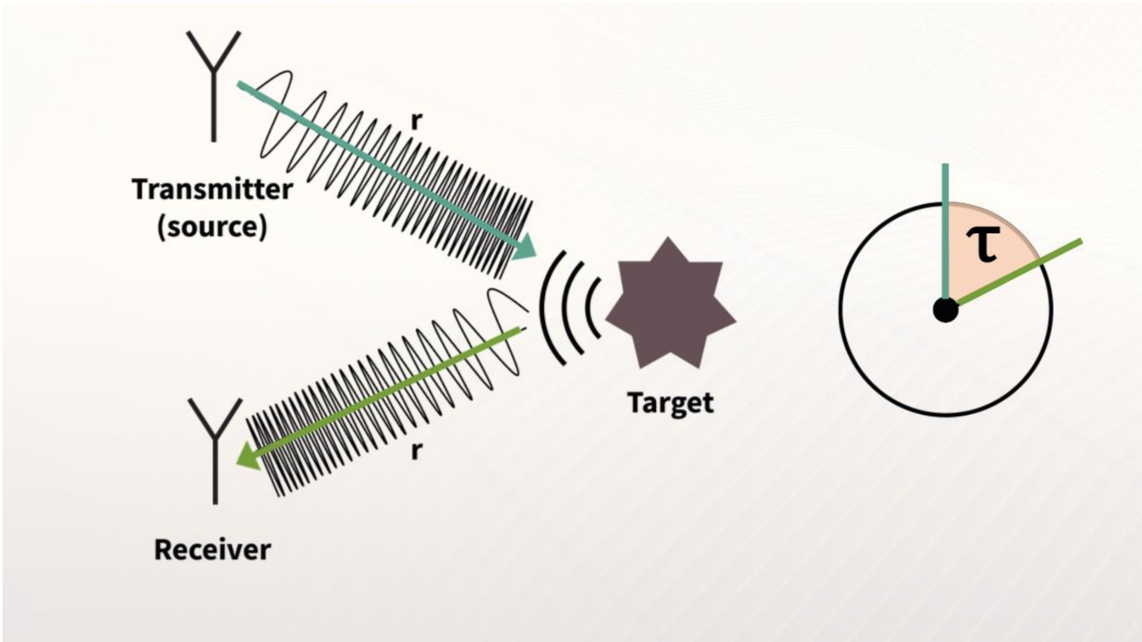
The time between two consecutive chirps is called pulse repetition time.



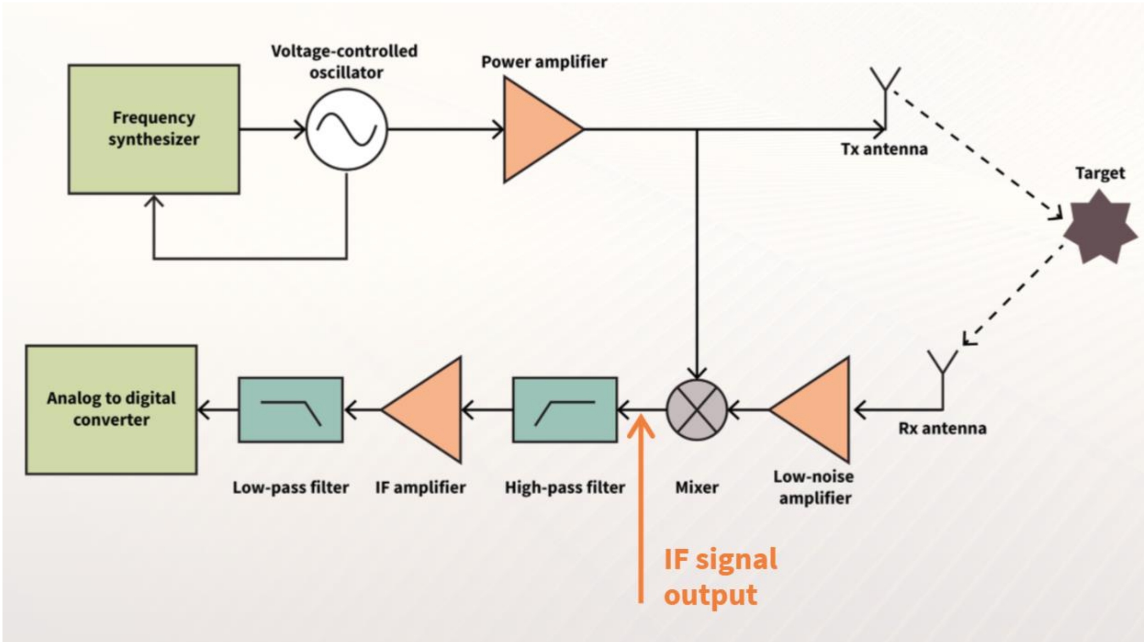
So, by measuring time delay “tau”, we can estimate the range of the target with respect to the sensor…



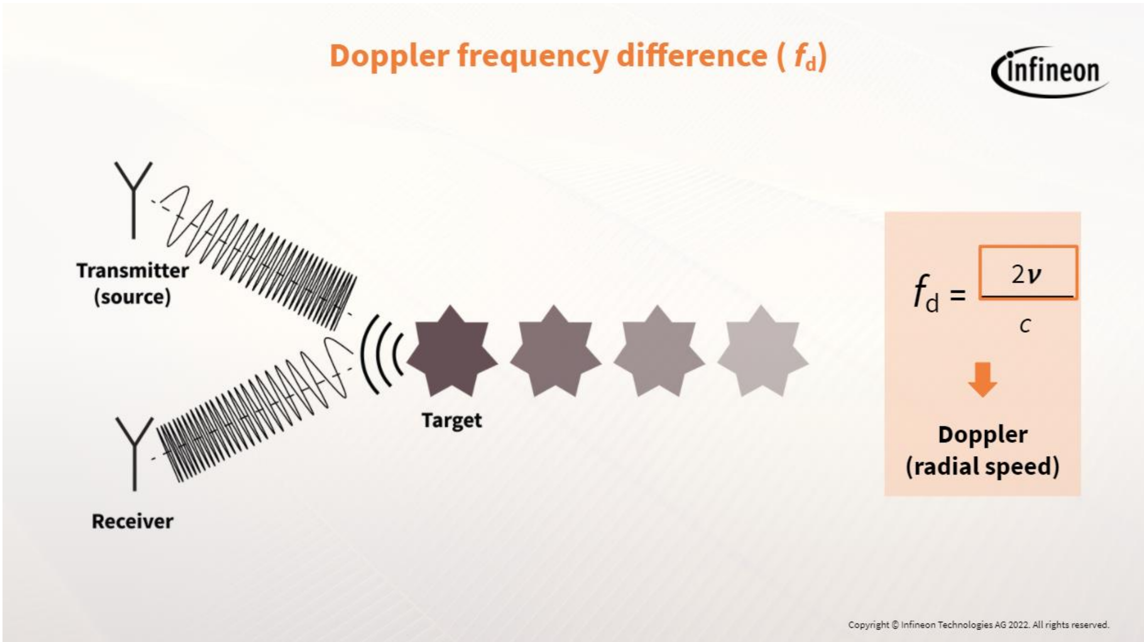
… since the time delay is proportional to the two-way distance between the target and the RADAR system.



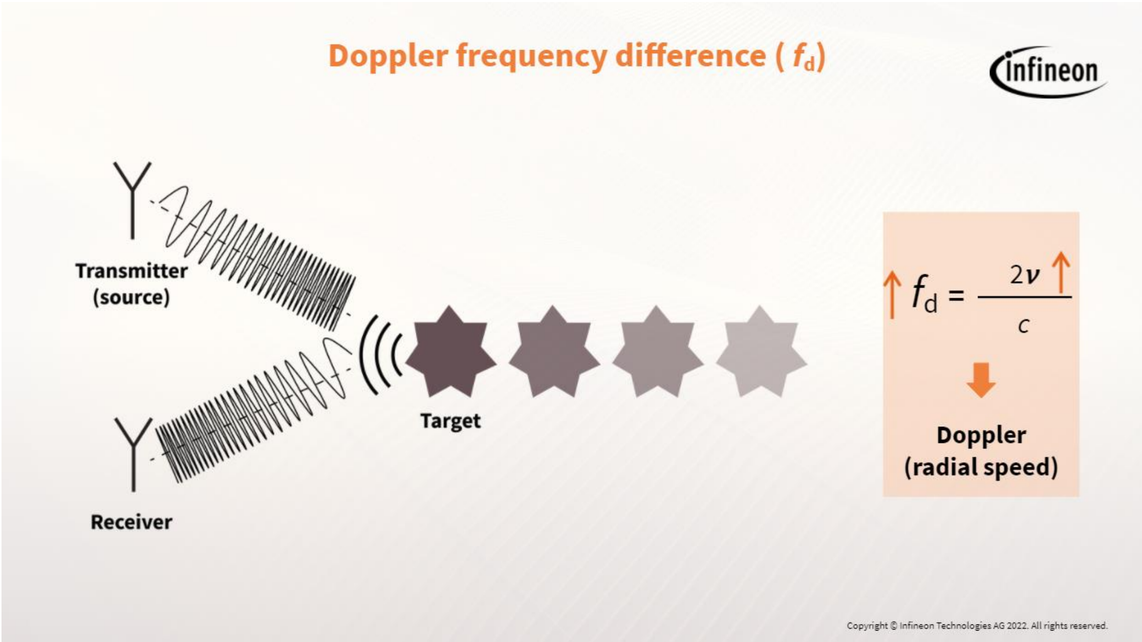
Note that, in FMCW, this time delay “tau” is estimated by measuring the frequency shift in the received signal, known as beat frequency.



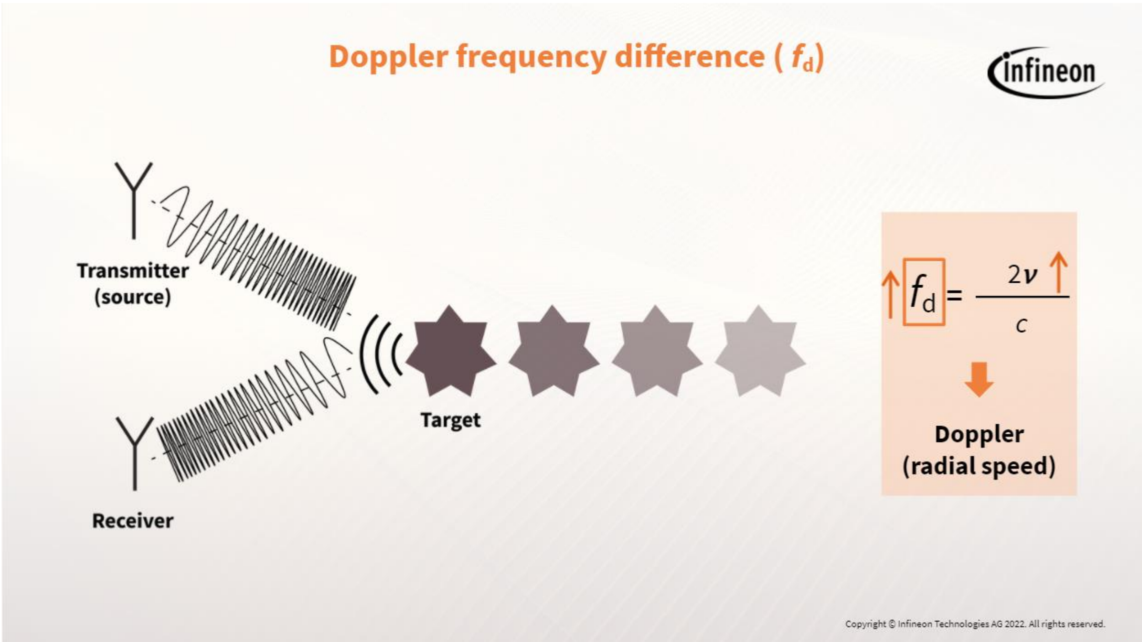
The intermediate frequency signal produced after the mixer consists of this beat frequency.



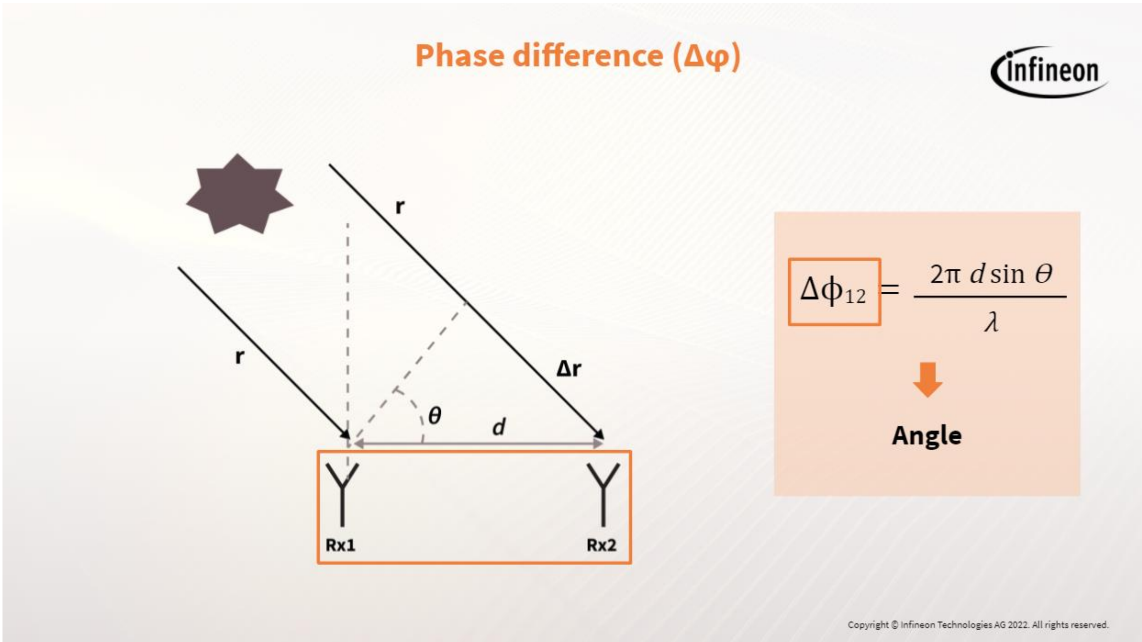
Similarly, an additional shift in the frequency of the reflected signal in comparison to the originally transmitted one reveals to us the Doppler speed of an object… only if it's moving, of course.



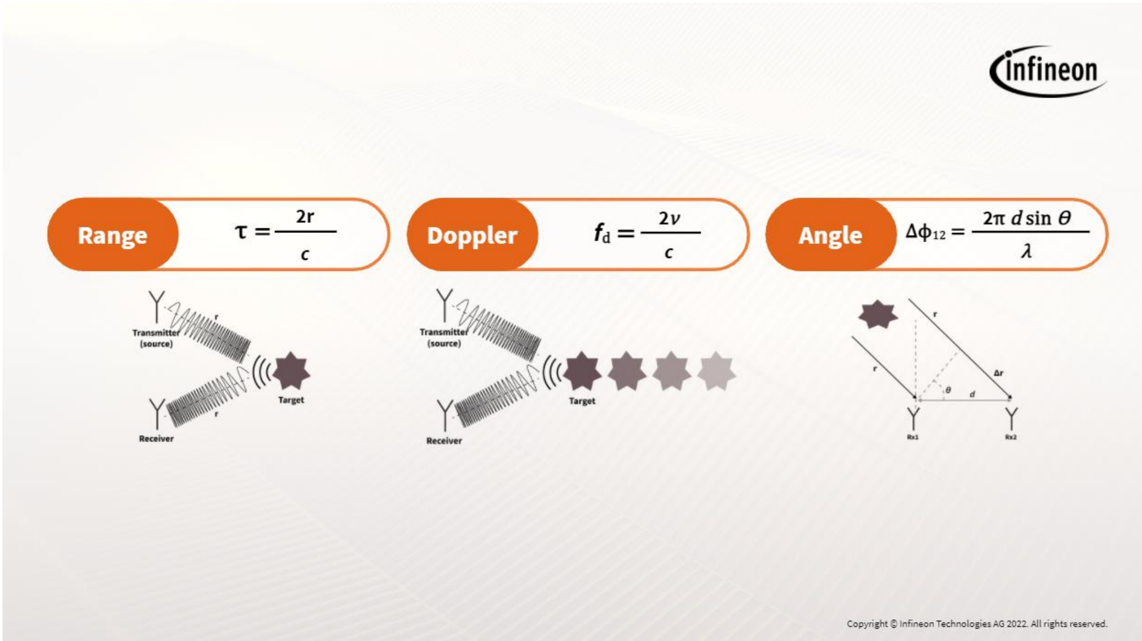
The higher the frequency difference, the faster the object is moving!



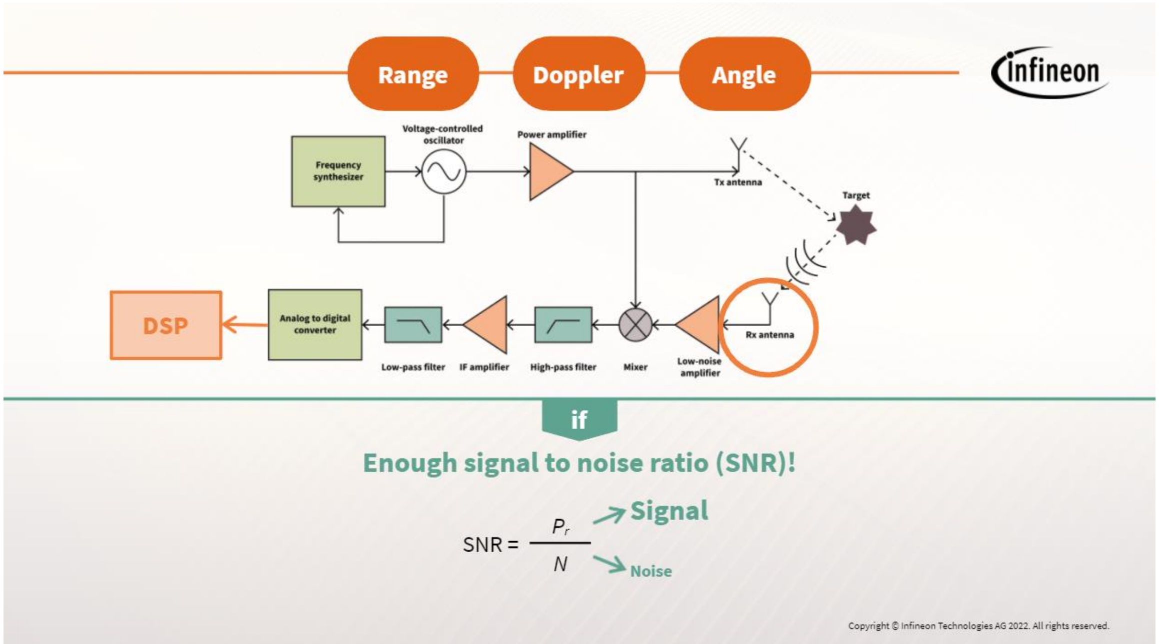
In the FMCW system, multiple transmitted chirps separated by the pulse repetition time are used to measure this Doppler frequency, and therefore the target's radial speed.



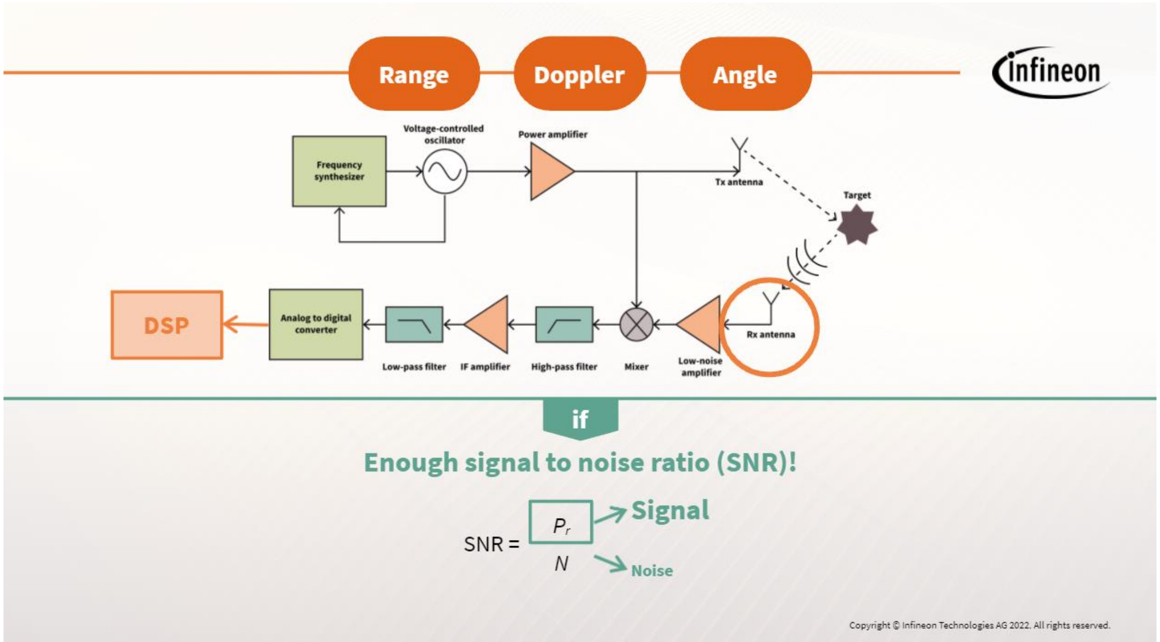
The phase difference between multiple receiving channels, on the other hand, tells us the angle of the target.



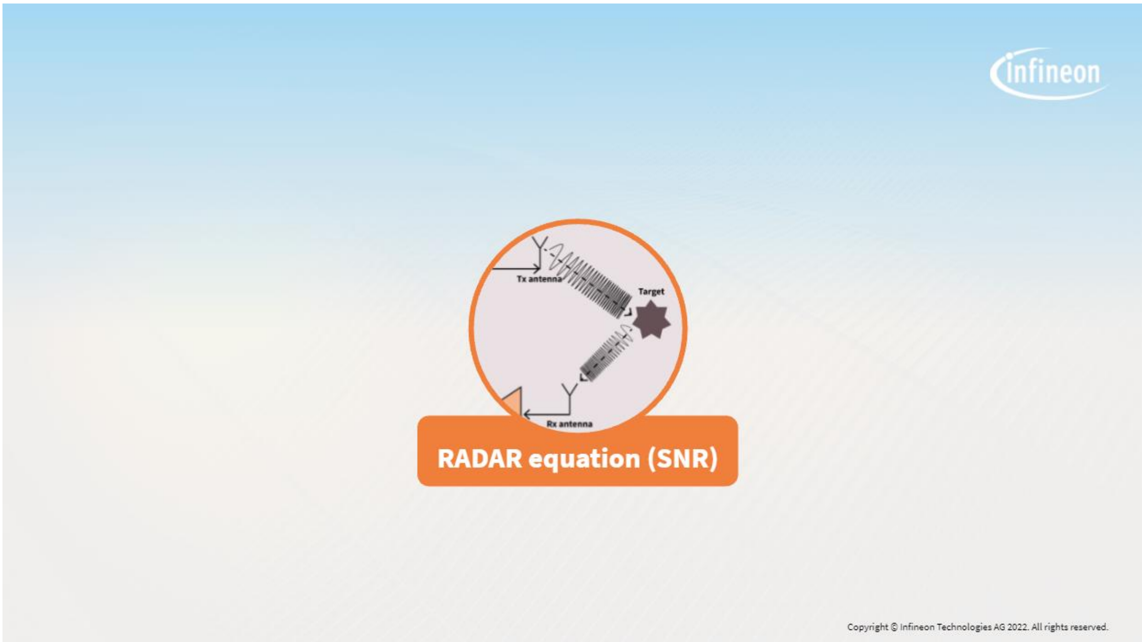
But of course, the estimation of range, doppler speed, and angle…



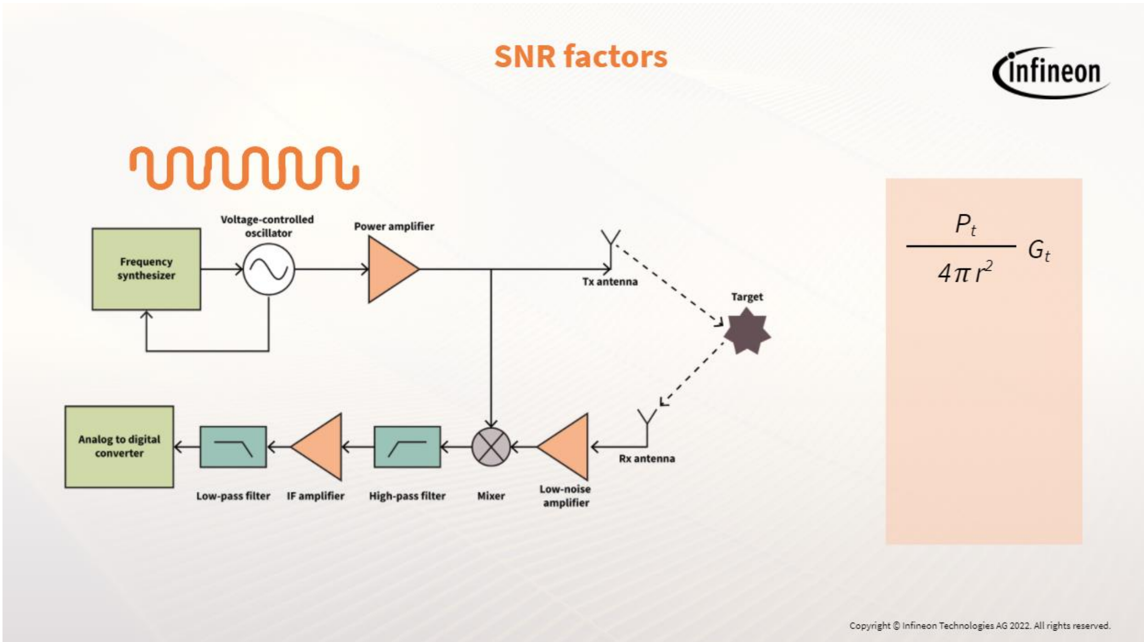
… which is done outside the transmit and receive system via digital processing, only works if there is enough signal-to-noise (SNR) ratio at the receiver side - which means much more signal than noise.



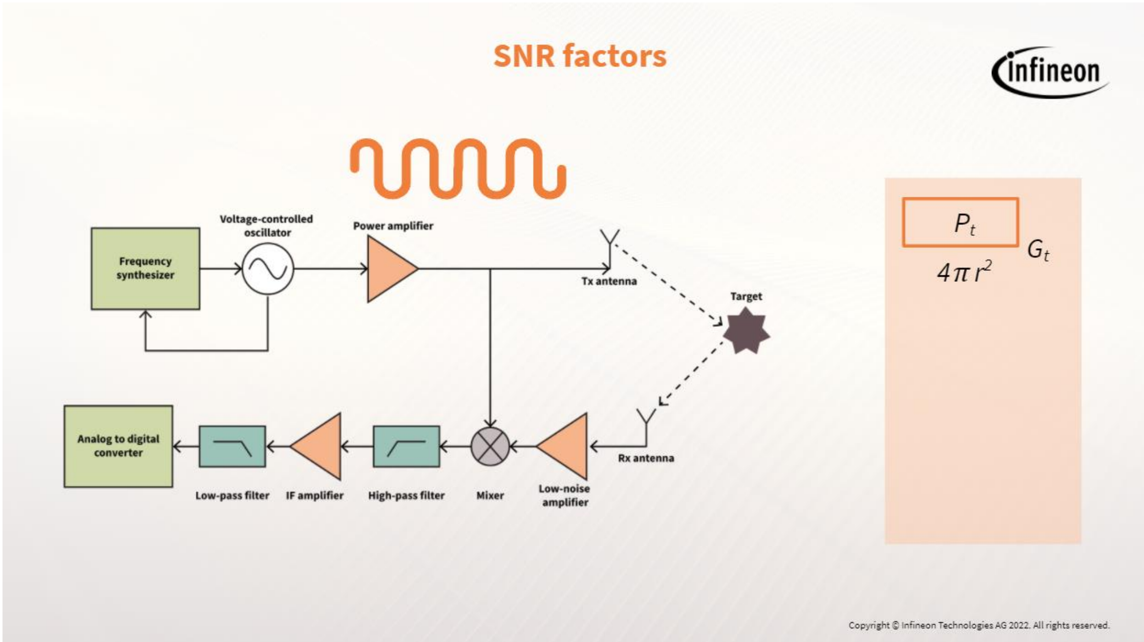
This mainly depends on the received power.



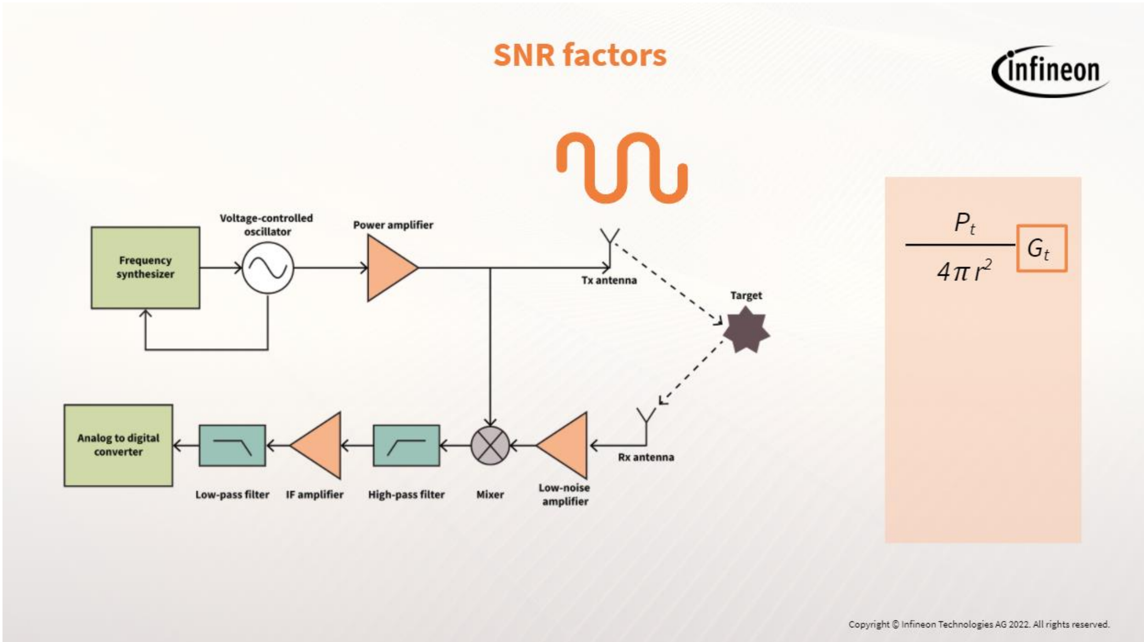
Now, let’s see step by step which factors influence the SNR!



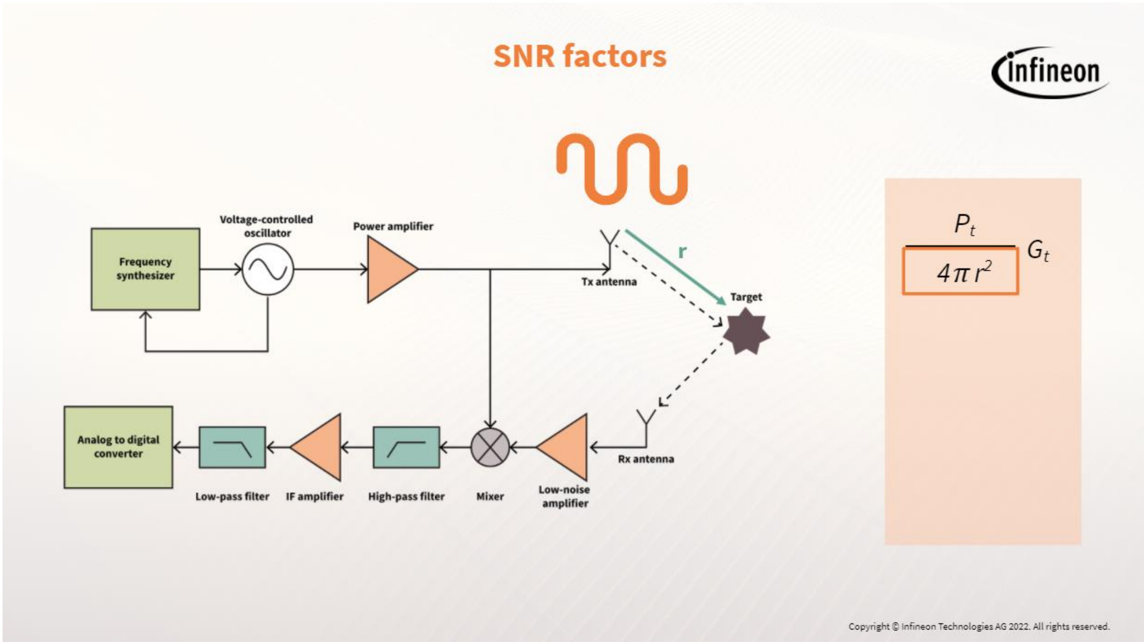
First of all, the transmit signal produced by the voltage-controlled oscillator…



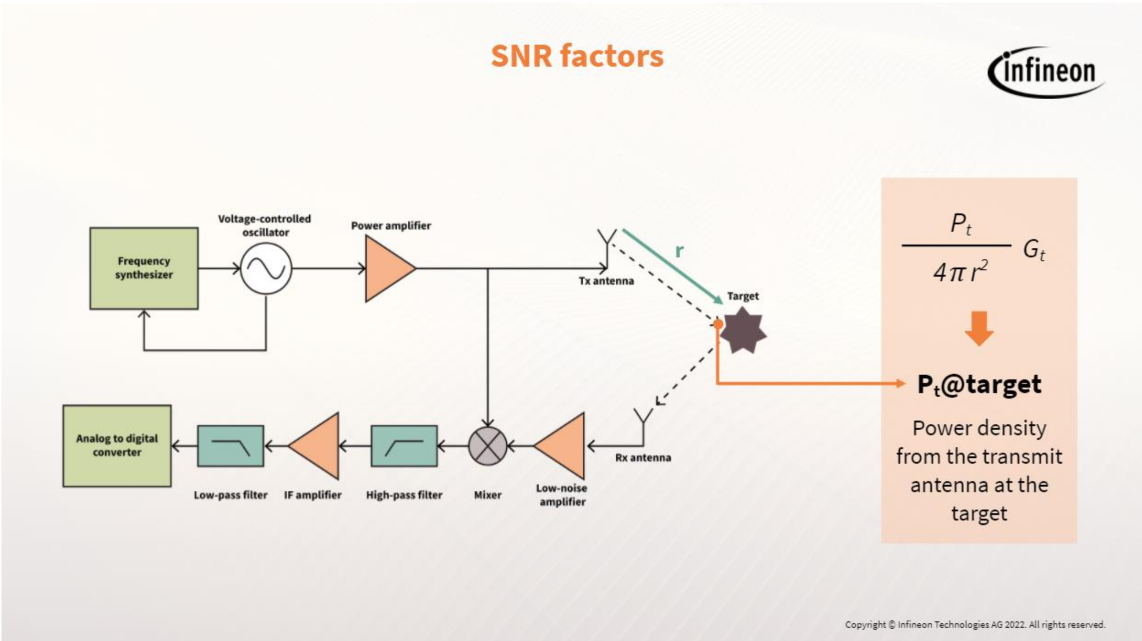
… is amplified by the power amplifier to create a signal with a power P_t.



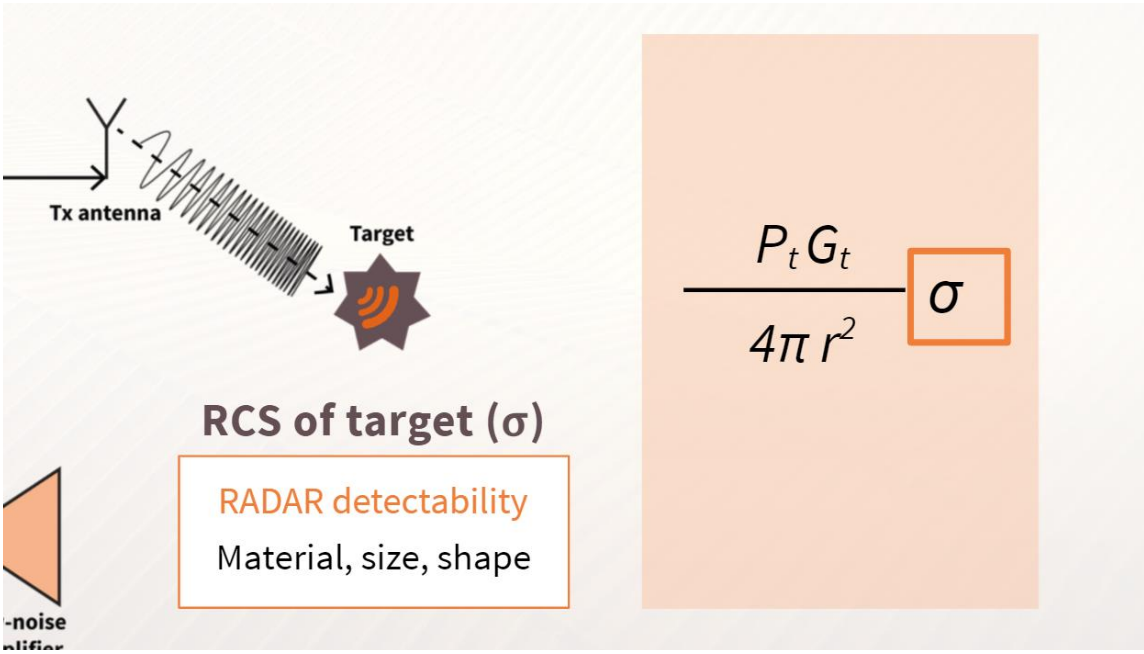
The transmit antenna, an array of antennas that radiates the transmit signal, further amplifies the total transmit power along the antenna direction with its gain G_t …



… towards the target at a distance R.

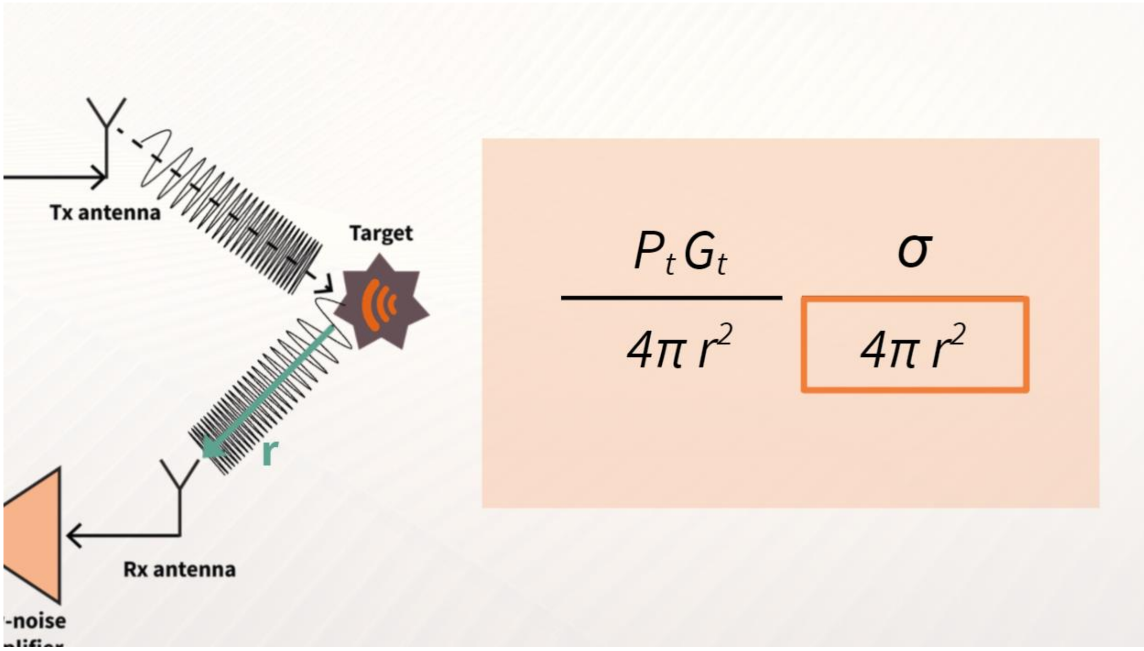


These factors make up the transmit power density at the target, which is at a distance R.



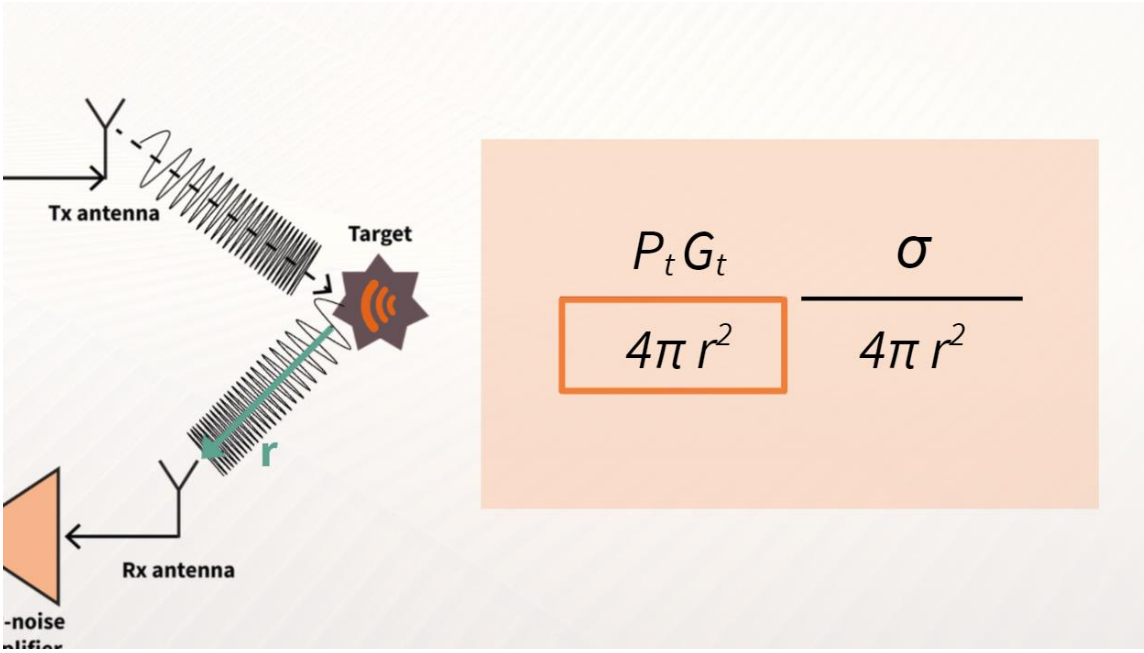
However, only a certain amount of this power is reflected back - the received power density, therefore, depends on a parameter called RADAR cross section (RCS) of the target or sigma.

The RCS is a measure of how detectable an object is by the RADAR and is dependent on the object's material, size, and shape.



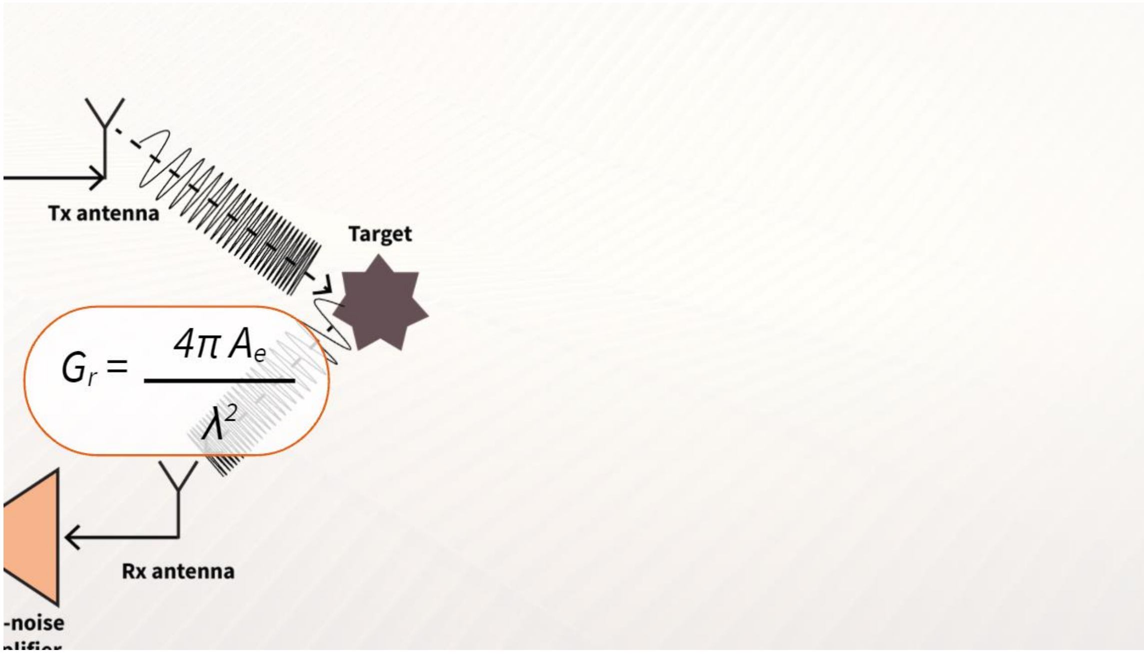
The reflected signal from the target is then propagated back to the receiver antenna after traveling a distance R.

The propagation loss is presented here…

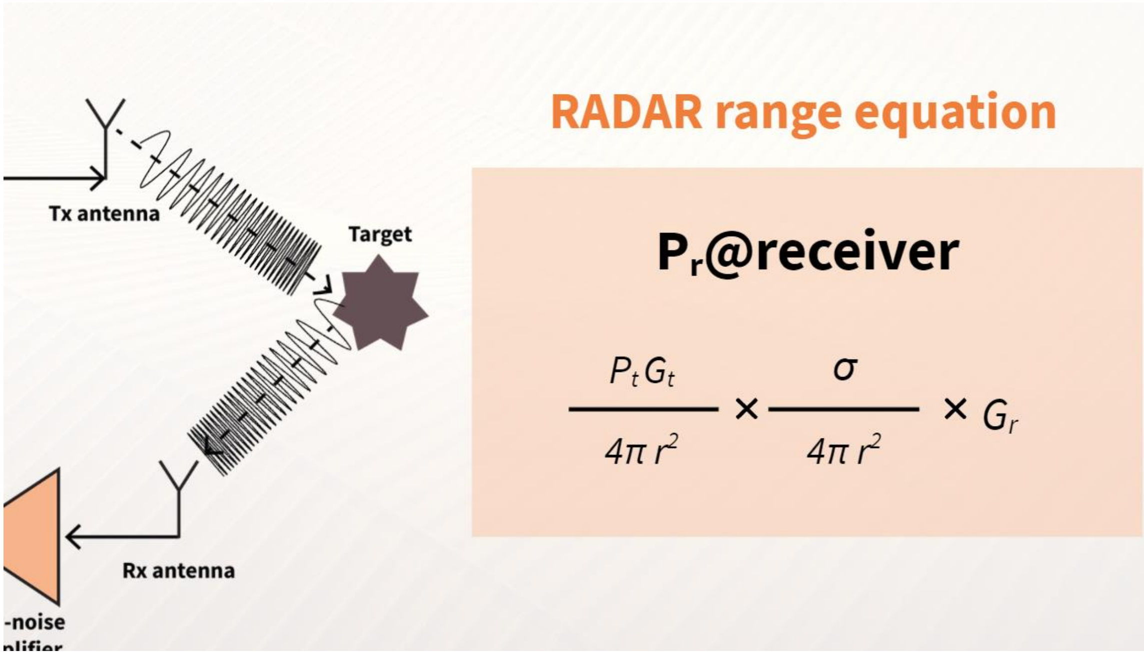


… just like we presented it for the transmit signal traveling towards the target.

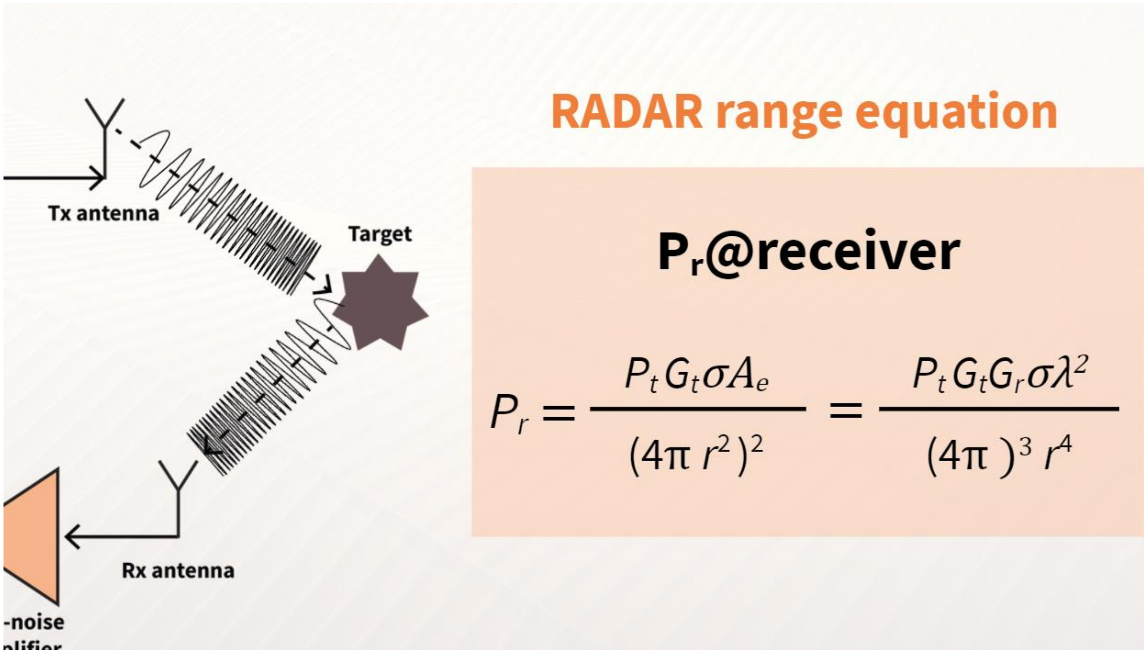
Lastly, the signal at the receiver is collected over the area of the receiving antenna…



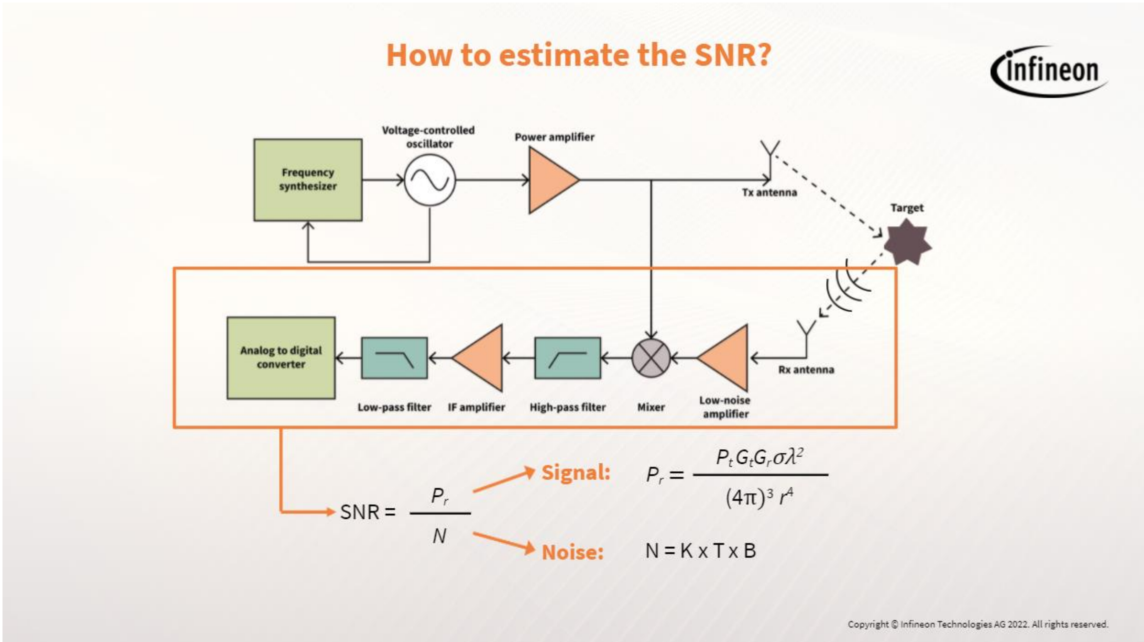
… that has an antenna gain of Gr with an effective antenna area of A_e.



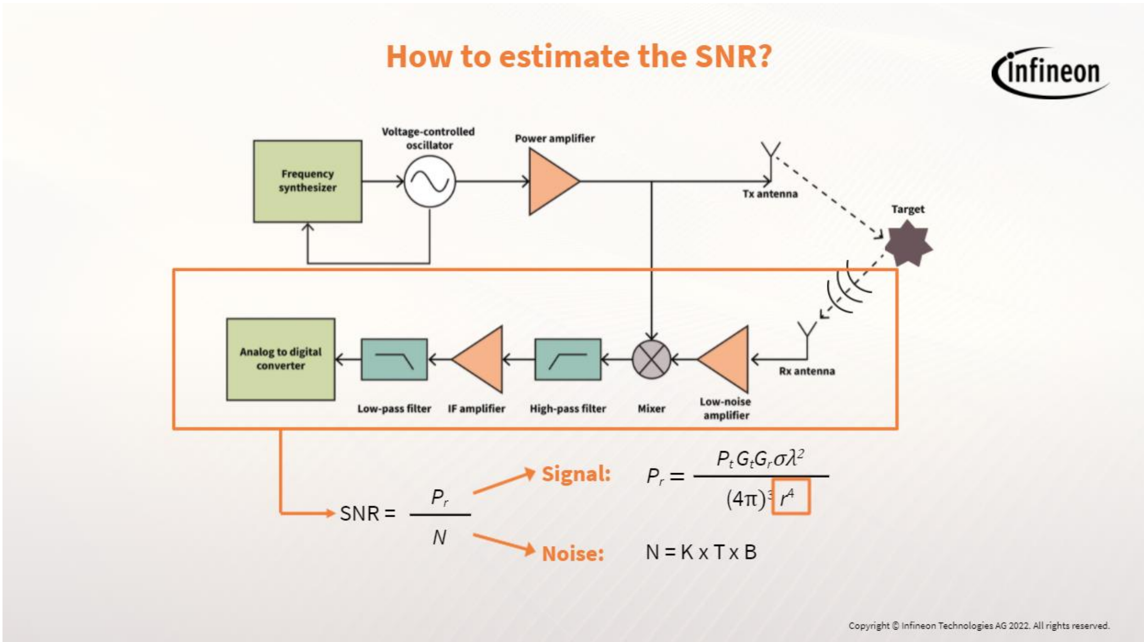
This results in a system level equation, also known as RADAR range equation…



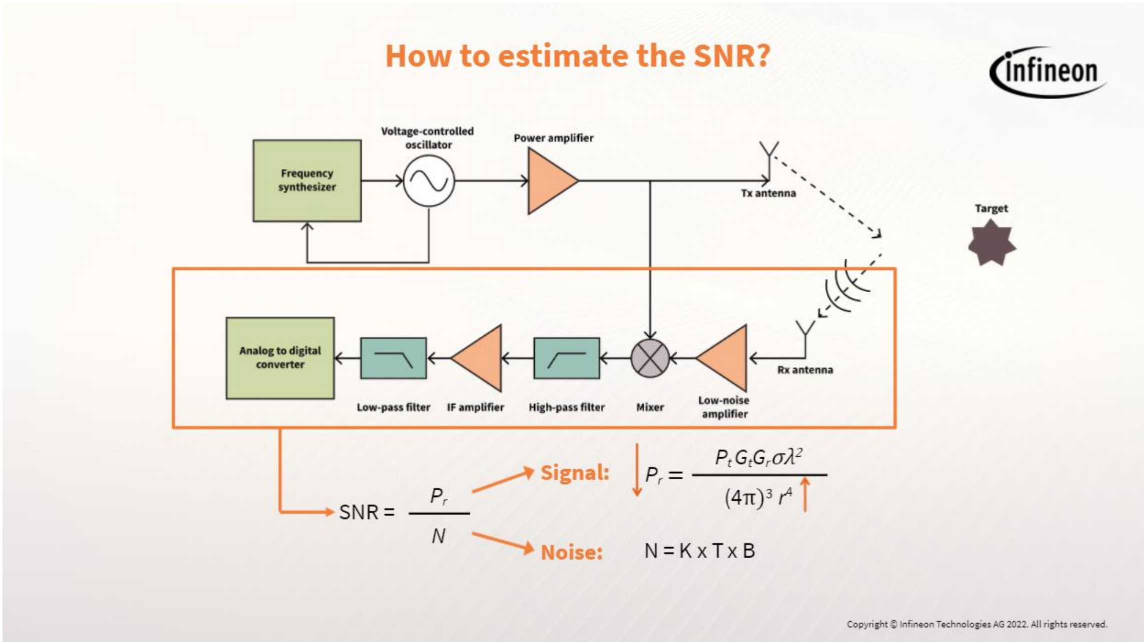
… which shows all the factors that impact the overall received signal power.



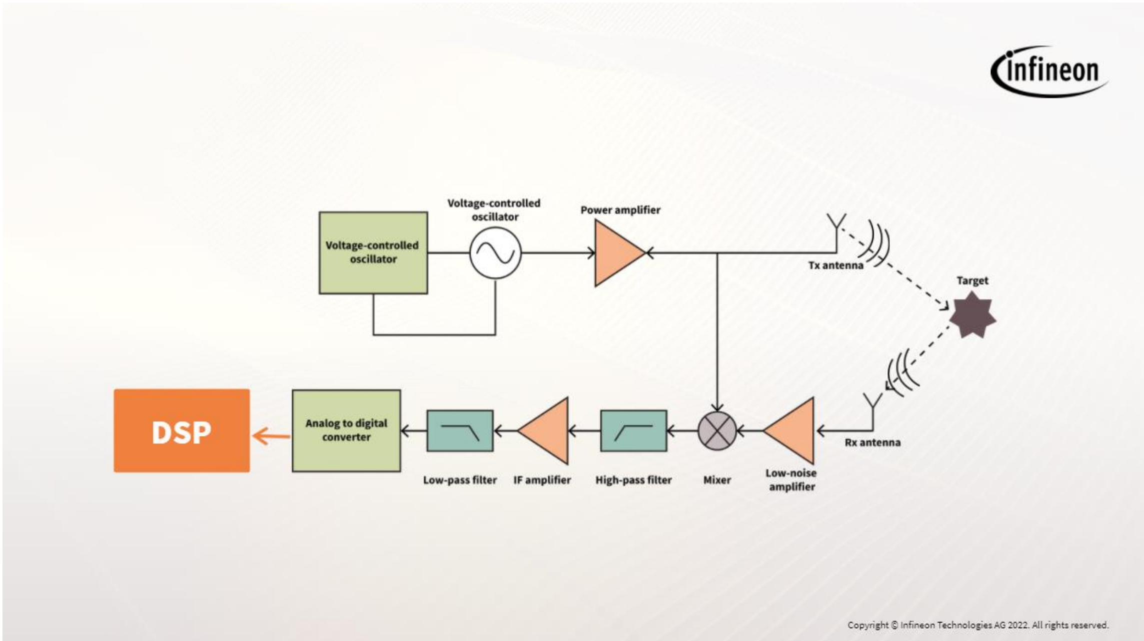
Then, the SNR ratio can be derived by knowing that the noise at the receiver is dependent on the Boltzmann constant (K), the temperature at which the receiver is operating (T), and the bandwidth of the signal at the receiver (B).



So, now we know that the signal is strongest when the object is close by.

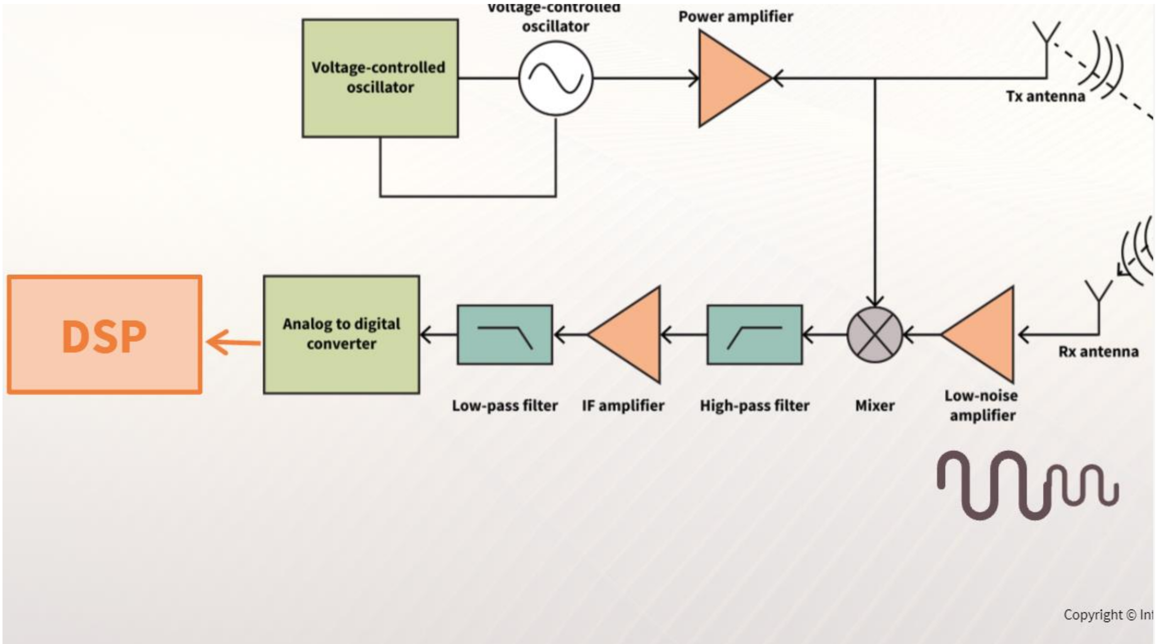


If, on the contrary, the object moves away from the receiver, the signal intensity decreases by a fourth.



So far so good, right?

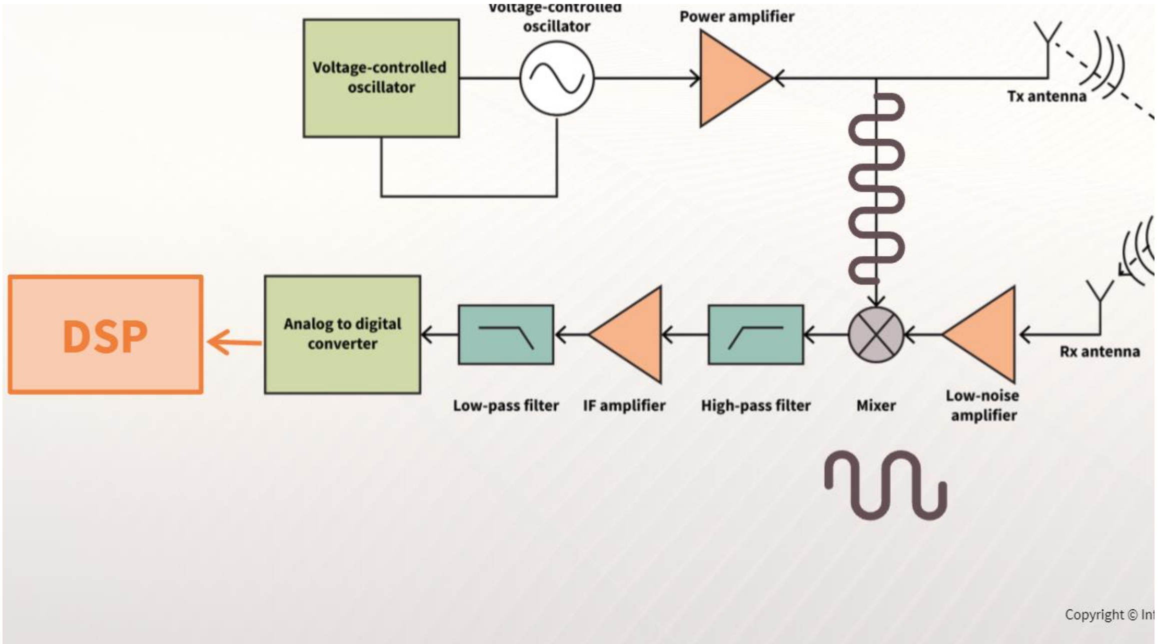
Let's then prepare the received signal for the digital signal processing (DSP) the best way possible.



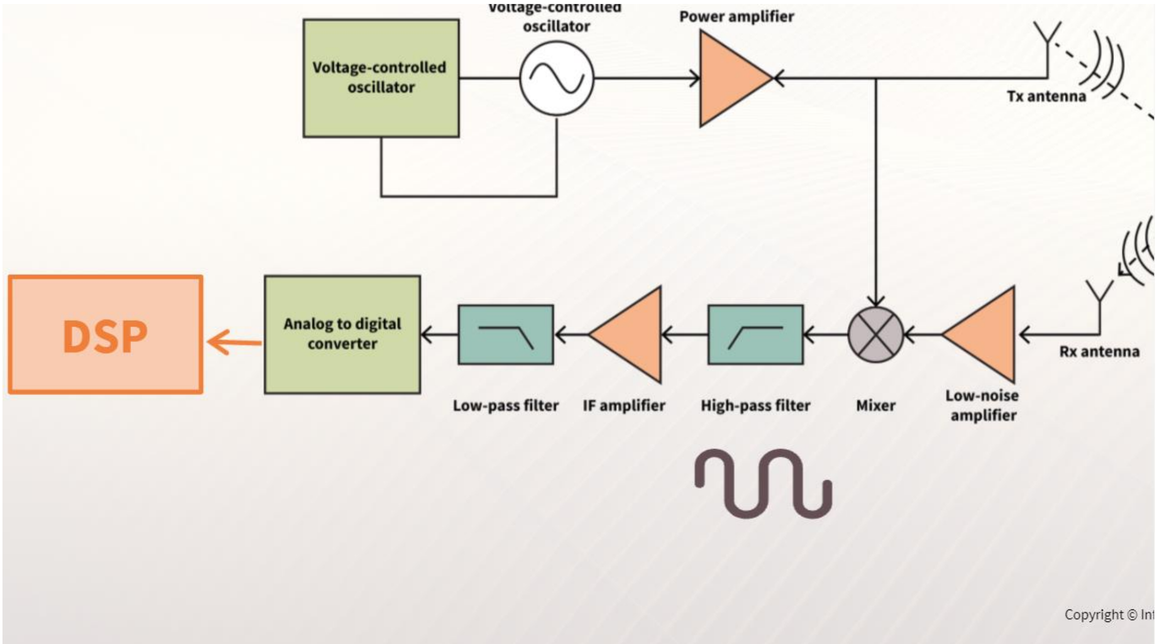
For this, we need to have more analog blocks on the receiver side.

These are:

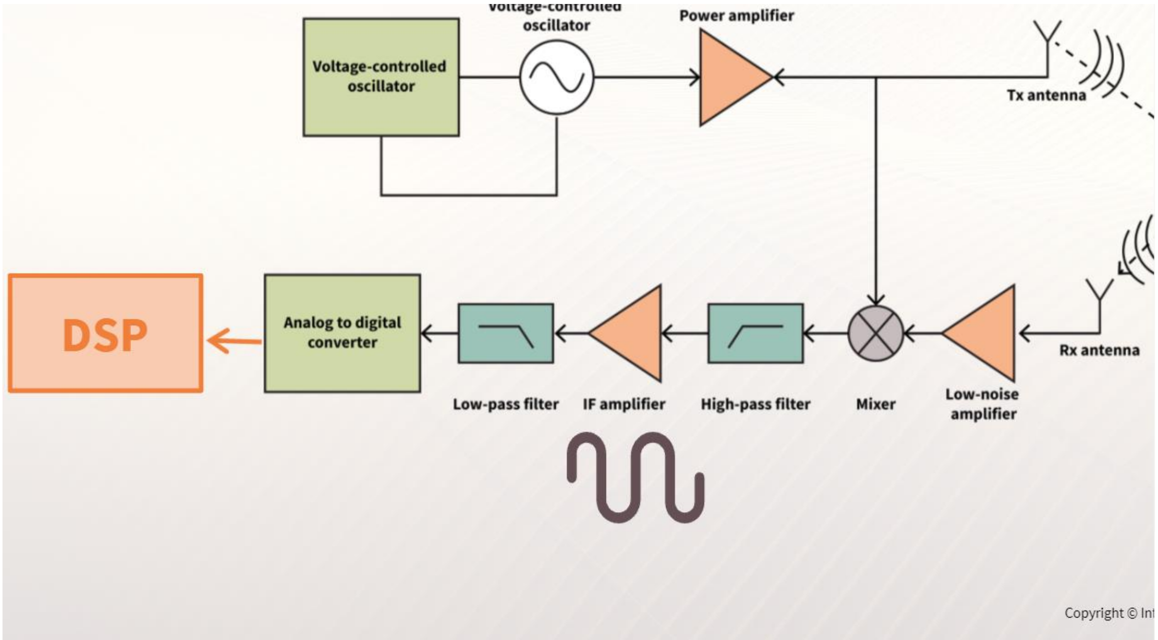
- A low noise amplifier, which amplifies the received signal



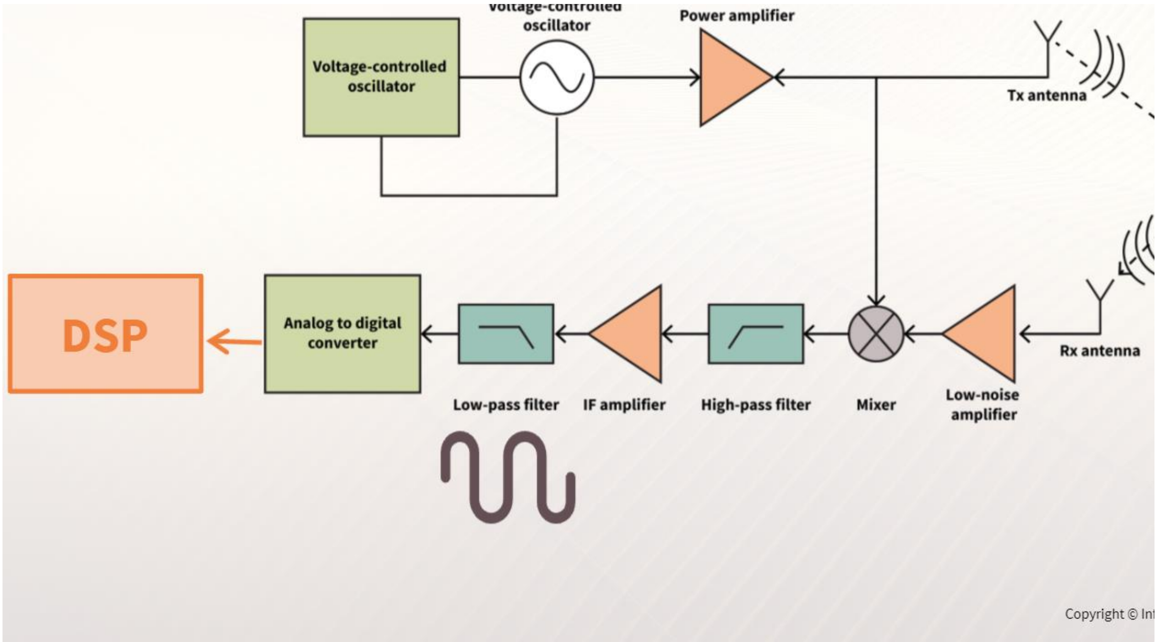
- A mixer, which mixes the transmit and receive signal to produce an intermediate frequency (IF) signal



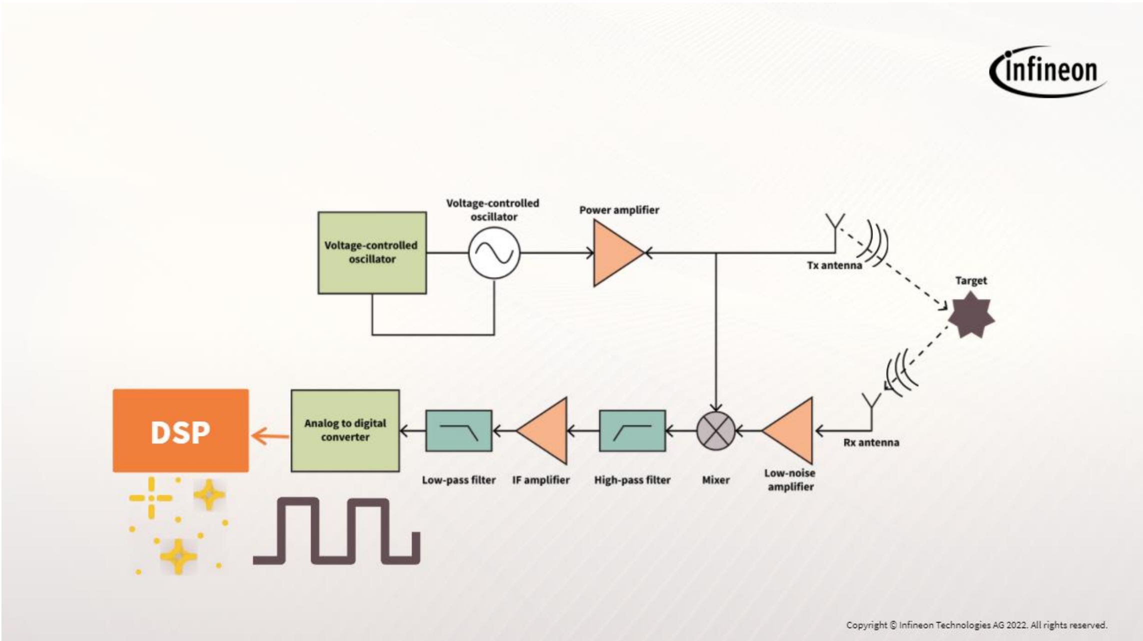
- A high pass filter, which has a cut-off frequency set to remove the strong leakage from the transmit signal



› An IF amplifier, which amplifies the IF signal strength

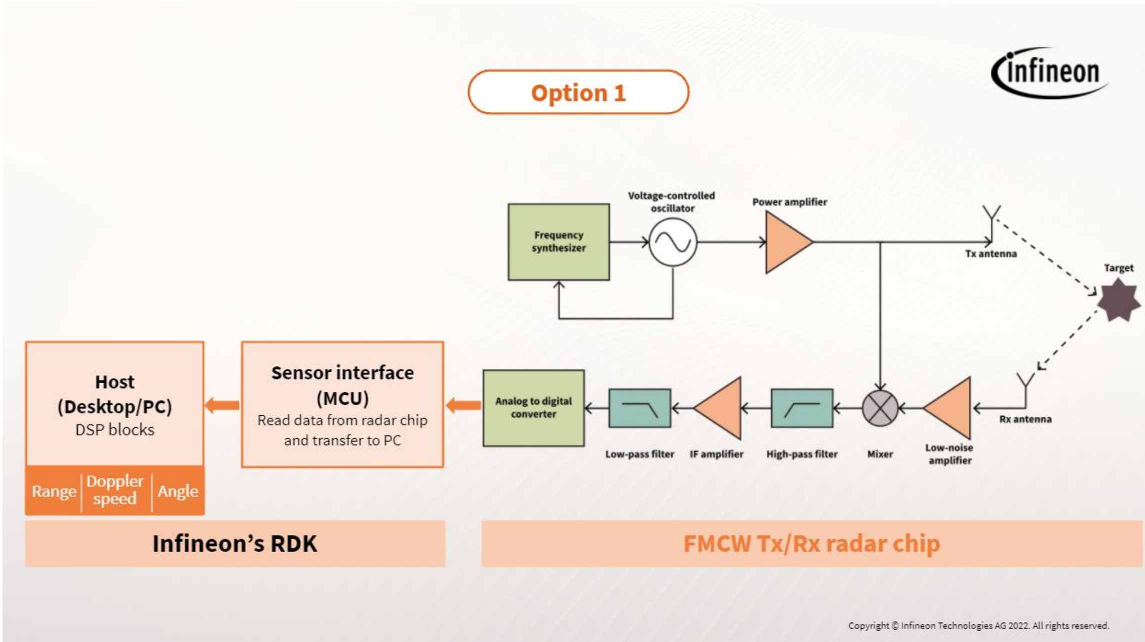


- And a low pass filter, whose cut-off sets the maximum intermediate or beat frequency



Finally, an analog to digital converter (ADC) block then converts the analog signal to a digital one.

This is when the DSP magic starts!



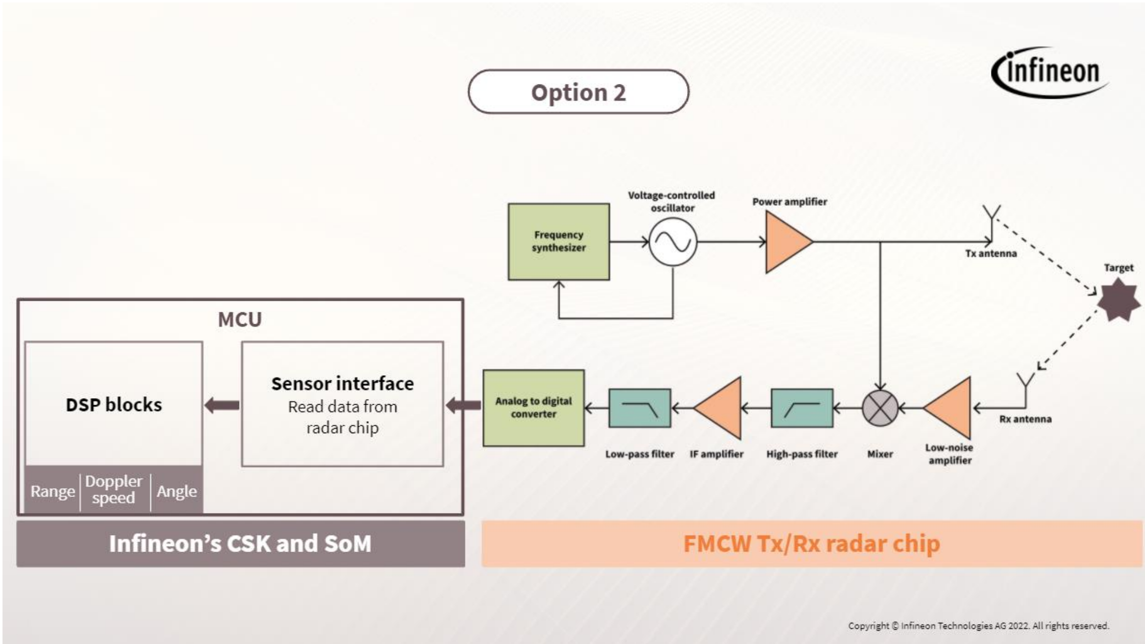
For this, you have two options.

You can either:

1. Process the digital signal within a separated system that contains:

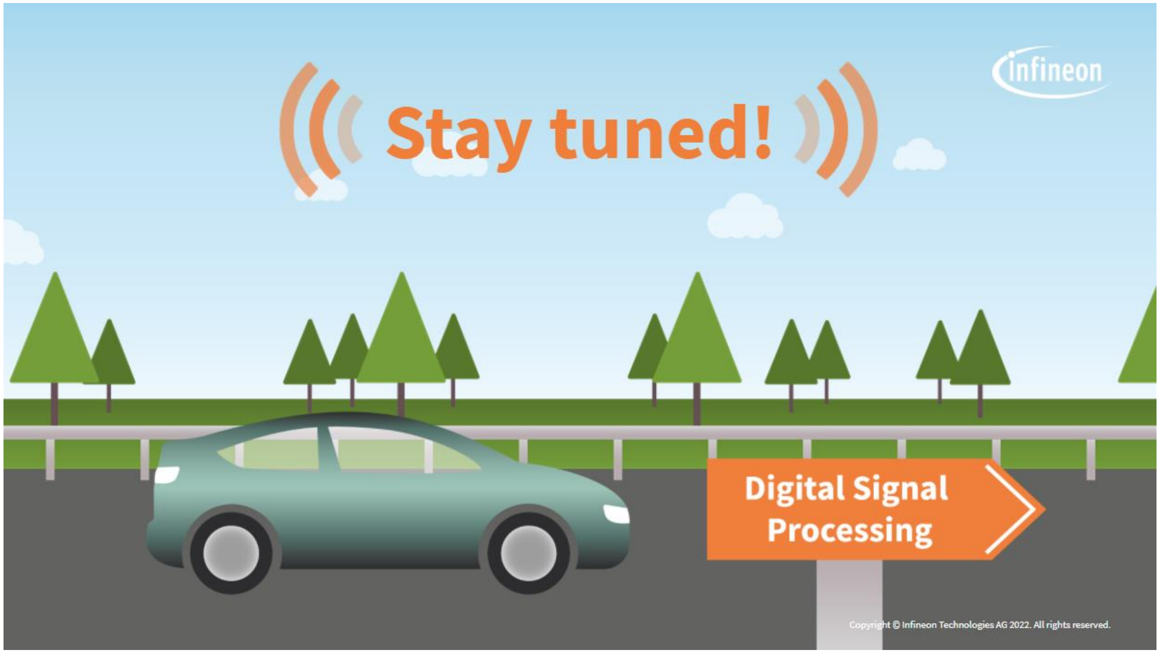
- A microcontroller unit, in short MCU, acting only as the sensor interface, which reads and transmits the ADC data,
- And an extra host like a desktop or PC, which hosts the DSP blocks where the range, doppler speed, and angle estimates are computed.

At Infineon, we offer the RADAR development kit (RDK), which is a host application that runs on PC suitable for option 1.



2. Or have a combined system, in which the MCU does not only read and transmit the data from the ADC output, but also acts as a processing unit by implementing additional DSP blocks

This second option is how the Infineon connected sensor kit (CSK) and RADAR system on module (SoM) work.



With this basic knowledge of system architecture, you are now ready to deep dive into the individual blocks of the DSP flow.

So, stay tuned for our next training!

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