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SENSORS

3. K-BAND RADAR TRANSCEIVERS

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What does K-band mean? K-band stands for the radio frequency range of 18 … 27 GHz. A portion of this range from 24 … 24.250 GHz is a so called ISM (Industrial, Science and Medical) radio band. RFbeam sensors use the ISM K-band. The ISM K-band allows operating our sensors in nearly all countries worldwide.

What does "Radar transceiver" mean?

Transceivers are devices containing a transmitter and a receiver. RFbeam radar devices contain always a transmitter and at least one receiver in order to send an electromagnetic wave and to receive the echo of this wave. Radar transceivers are often simply called radar sensors.

Radar transceivers can be operated in different modes (Doppler, FMCW, FSK, ...) depending on the physical quantity that has to be detected, e. g. speed, distance, presence of objects.

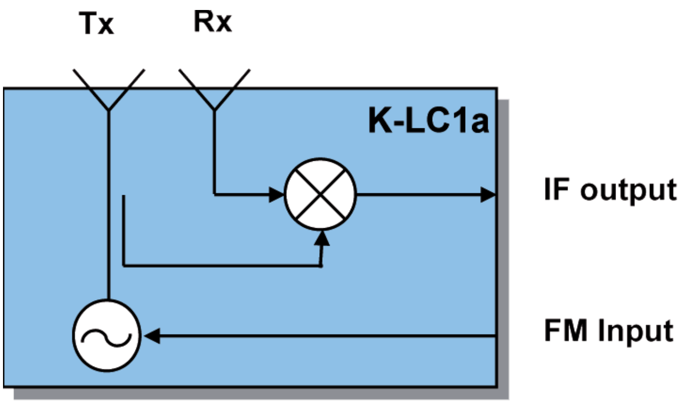


Fig. 1 - Typical radar transceiver

What does Doppler sensor mean?

Doppler Radar is used to detect moving objects and evaluate their velocity. A reflective moving object in sight of the sensor generates a low frequency sine wave at the sensor output. The amplitude depends on the distance and the reflectivity of the moving objects. The output frequency is proportional to the object speed: 158 Hz per m/s or 44 Hz per km/h for a radial moving object. Some RFbeam sensors are "stereo" sensors with 2 outputs, called I (In phase) and Q (Quadrature). These sensors allow detecting the moving direction (approaching, receding).

About Doppler radar

A more precise title would be, "CW (Continuous Wave) Doppler Radar", when using RFbeam radar sensors. These sensors do not produce pulses, but send continuously in the K-band (24.125 GHz).

RFbeam radar transceivers (Fig. 1) return a so called IF signal, that is a mix-product of the transmitted (Tx) and the received (Rx) frequency. A moving object generates a slightly higher or lower frequency at the receiver. The IF signal is the absolute value of the difference between transmitted and received frequency. These transceivers operate in the CW (Continuous Wave) mode as opposed to the pulse radars, that measure time of flight. CW radars can operate with very low transmitting power (< 20 dBm resp. 100 mW).

Calculating the Doppler frequency

$$f_d = \frac{2 \cdot f_{Tx} \cdot v}{c_0} \cdot \cos\alpha \quad (1)$$

or

$$v = \frac{c_0 \cdot f_d}{2 \cdot f_{Tx} \cdot \cos\alpha} \quad (2)$$

f_d = Doppler frequency
f_{Tx} = Transmitting frequency (24 GHz)
c_0 = Speed of light (3×10^8 m/s)
v = Object speed in m/s
α = Angle between beam and object moving direction (see Fig. 2)

At a transmitting frequency of f_{Tx} = 24 GHz we get a Doppler frequency for a moving object at the IF output of

$$f_d = v \, \frac{44\ \text{Hz}}{\text{km/h}} \cdot \cos\alpha \, .$$

The angle α reduces the measured speed by a factor of cos α. This angle varies with the distance of the object. To evaluate the correct speed, you need a trigger criteria at a known point. This can be accomplished by measuring the distance with the radar sensor (e.g. using FSK technology) or by measuring the angle using a monopulse radar such as K-MC4.

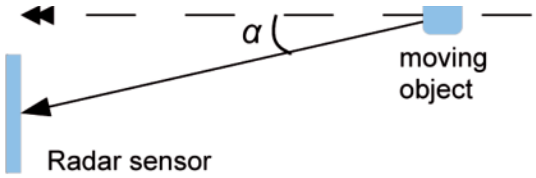


Fig. 2 – Definition of angle a

About FMCW

FMCW stands for Frequency Modulated Continuous Wave. This technique allows the detection of stationary objects. FMCW needs radar sensors with an FM input. This input accepts a voltage that causes a frequency change. There are also sensors with digital frequency control based on digital PLL designs. Modulation depth is normally a very small amount of the carrier frequency. In the K-band most countries allow a maximum frequency range of 250 MHz. Description of many effects such as velocity-range unambiguities go beyond the scope of this paper. Please refer to radar literature for more detailed explanations.

Triangle modulation

The transmitting frequency is modulated by a linear up and down ramp. Figs. 3a+3b show a typical signal f_{Rx} returned by stationary and constantly moving objects. Note, that the difference frequency f_b is constant throughout nearly the whole ramp up time. At the output of the radar transceiver we get a low frequency signal f_b called beat frequency. This is the result of mixing (=multiplying) transmitted and received frequencies.

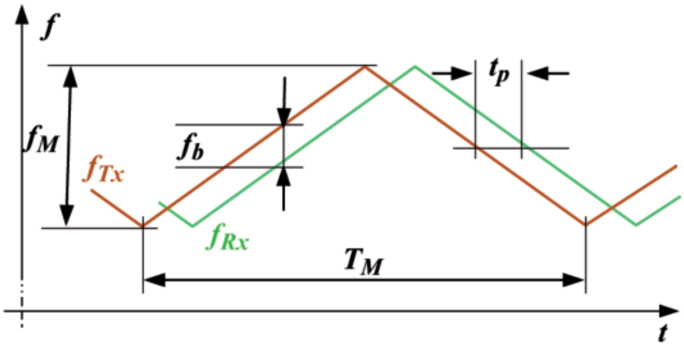


Fig. 3a – Triangle modulation – stationary object

Returned echo from stationary object

f_M	Modulation depth
T_M	Modulation period
f_{Tx}	Transmitted frequency
f_{Rx}	Received frequency
t_p	Signal propagation time (time of flight)
f_b	Beat frequency f_{Tx} - f_{Rx}
f_d	Doppler frequency

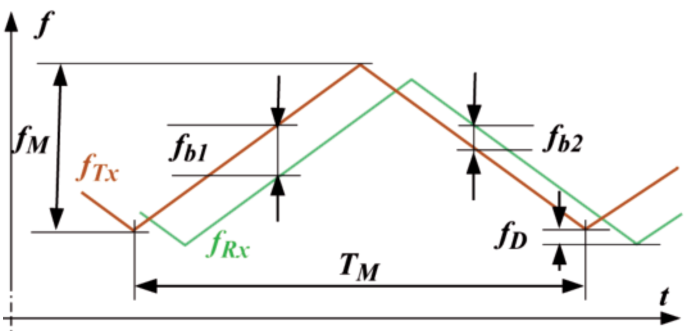


Fig. 3b – Triangle modulation – moving object

Returned echo from moving object

The received frequency f_{Rx} is shifted by f_d. This is the Doppler frequency caused by a receding object moving at a constant speed.

By measuring during up and down ramp, the Doppler frequency f_d is the diffence between f_{b1} and f_{b2}.

Distance can be calculated as follows

$$R = \frac{c_0}{2} \cdot \frac{f_b}{f_M} \cdot \frac{T_M}{2}$$

For legend refer to Fig. 3a

R = Range, distance to target

c_0 = Speed of light (3×10^8 m/s)

Maximum unambiguous range

$$R_{max} = \frac{c_0}{2} \cdot \frac{T_M}{2}$$

For legend refer to Fig. 3a
R_{max} = Max. unambiguous target distance
c_0 = Speed of light (3×10^8 m/s)

Distance and resolution

In K-Band (24 GHz), the maximum allowed frequency modulation depth f_M is <250 MHz. We also have to take in account tolerances and temperature influences. This limits the usable frequency shift f_M to typically 150 MHz.

For measuring f_b to evaluate distance we need at least one period of f_b during T_M, the range resolution is limited to

$$R_{min} = \frac{c_0}{2 \cdot f_M} = \frac{3^8 \text{ m/s}}{2 \cdot 250 \text{ MHz}} = 0.6 \text{ m}$$

This is a theoretical value, because we have to consider drifts and tolerances in order to stay in the allowed frequency band. Working with the more realistic value of f_M = 150 MHz, we get a minimum distance and resolution of R = 1 m.
Resolution may be enhanced by using phase conditions, correlation and other sophisticated algorithms.

About FSK mode

FSK stands for Frequency Shift Keying. FSK uses two discrete carrier frequencies f_a and f_b, (Fig. 4) while FMCW uses linear ramps.

For each carrier frequency, separate IF signals must be sampled in order to get 2 buffers for separate FFT processing. Due to the very small step f_a-f_b a moving target will appear nearly with the same Doppler frequency at both carriers, but with a different phase (Fig. 5). Phase shift due to the modulation timing and sampling must also be taken into account.

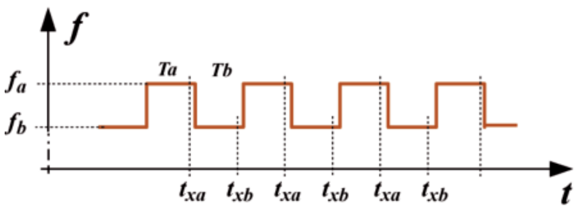


Fig. 4 - FSK modulation scheme

f_a Carrier Frequency a
f_b Carrier Frequency b
t_{xa} Sampling point for Doppler a
t_{xb} Sampling point for Doppler b

Switching must be performed at a sampling rate high enough to meeting the Nyquist criteria for the Doppler signal acquisition.

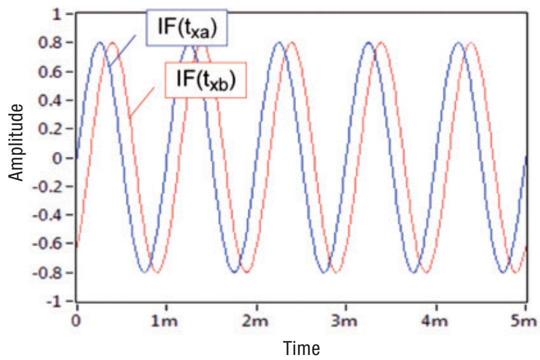


Fig. 5 - Resulting Doppler frequencies

$IF(t_{xa})$ Sensor output signal at carrier frequency f_a
$IF(t_{xb})$ Sensor output signal at carrier frequency f_b

Doppler signals of the same moving target have thesame frequency, but are phase shifted by $\Delta\varphi$.
For both IF signals, phase must be determined at the spectral peak of the object.

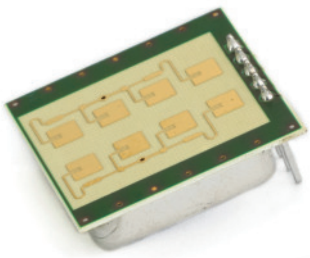
$$R = \frac{c_0 \cdot \Delta\varphi}{4\pi \cdot (f_a - f_b)}$$

$\Delta\varphi$ = Phase shift of $IF(t_{xa})$ and $IF(t_{xb})$

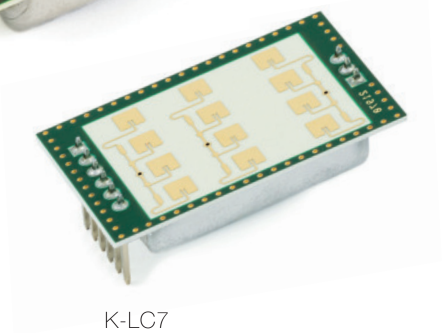
The smaller the frequency step, the higher the maximum range. To achieve an unambigous distance range of 150 m, a frequency step of 1MHz is required.

Remarks

- FSK can only be used for moving objects
- Multiple objects at different speeds may be detected
- Distance resolution depends mainly on signal processing and is not limited by the carrier bandwidth limitations
- FSK has the advantage of simple modulation and does not suffer from linearity problems
- VCO signal generation is simple, but sampling and phase measurement is challenging

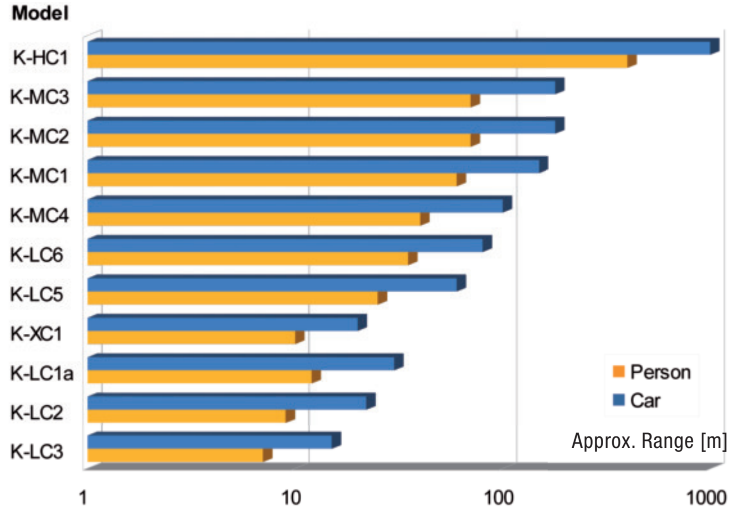


K-LC1a



K-LC7

Selection by detection range



Selection by parameters

PART NUMBER	TYP. DETECT. RANGE PERSON [m] (1)	TYP. DETECT. RANGE CAR [m]	HORIZ. -3 dB BEAMWIDTH / E-PLANE [°]	VERT. -3 dB BEAMWIDTH / H-PLANE [°]	VCO	OUTPUT I/Q (2)	IF AMPLIFIER	SUPPLY VOLTAGE [VDC]	SUPPLY CURRENT [mA]	INTEGRATED SIGNAL PROCESSING	SIZE [mm x mm x mm]
K-LC3	7	15	138	132				5	35		25 × 25 × 7
K-LC3_V2	7	15	138	132				3.3	35		25 × 25 × 7
K-LC4	7	15	138	132	✓	✓		5	35		25 × 25 × 7
K-XC1_Ant	8	15	25	12	✓	✓	✓	12 … 24	300	✓	89 × 77 × 19
K-LC2	12	30	80	34	✓	✓		5	35		25 × 25 × 7
K-LC1a	12	30	80	34	✓			5	35		25 × 25 × 7
K-LC1a_V2	12	30	80	34				5	35		25 × 25 × 7
K-LC1a_V4	12	30	80	34	✓			3.3	35		25 × 25 × 7
K-LC1a_V5	12	30	80	34				3.3	35		25 × 25 × 7
K-LC7	12	30	80	34	✓	✓✓		3.3 … 5	75		38 × 25 × 7
K-LD2	15	30	80	34		✓		3.3 … 5	55	✓	25 × 25 × 7
K-LC5	25	60	80	34	✓	✓		5	50		25 × 25 × 7
K-LC5_V2	25	60	80	34		✓		5	50		25 × 25 × 7
K-LC5_V3	25	60	80	34	✓	✓		3.3	50		26 × 25 × 7
K-LC6	35	80	80	12	✓	✓		5	50		66 × 25 × 7
K-LC6_V2	35	80	80	12	✓	✓	✓	5	50		66 × 25 × 7
K-MC4	40	100	30	12	✓	✓✓	✓	5	140 / 5		78 × 78 × 7
K-MC1	60	150	25	12	✓	✓	✓	5	70 / 7		65 × 65 × 7
K-MC1_LP	60	150	25	12		✓	✓	3.3 … 5	8		65 × 65 × 7
K-MC3	70	180	25	7	✓	✓	✓	5	70 / 7		105 × 85 × 7
K-MD2	100	200	30	21	✓	✓✓✓		12	550	✓	120 × 72 × 17
K-HC1	400	1000	25	12		✓	✓	15 … 30	220		110 × 77 × 21

(1) - values with simple comparator detector, (2) ✓ - 2 Channels, ✓✓ - 4 Channels, ✓✓✓ - 6 Channels

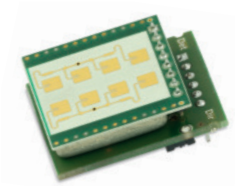
Above are indicative values only and cannot be guaranteed. Range depends on many parameters like size of object, direction of movement and data processing method.

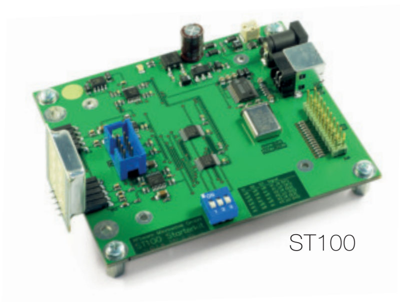
ST100 Starter kit, ST200 evaluation system and RSP1/K-LD2 evaluation kit

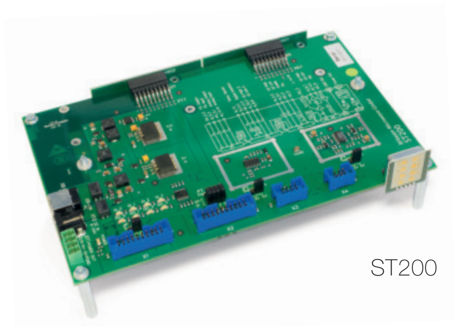
These kits allow to learn radar basics and evaluating radar technology for your specific application. STxxx kits can save a lot of initial time and money in order to get first radar experience. While ST100 and ST200 allow signal analysis in more detail, RSP1 and K-LD2 Evaluation Kits are oriented on practical implementation of movement sensors.

Scope of delivery

- **ST100 Starter kit** is including board, K-LC1a, USB cable, signalViewer software
- **ST200 high performance evaluation system** is including board, K-LC1, K-LC2, K-MC1, USB cable, signal explorer software
- **RSP1 evaluation kit** is including board, K-LC1a, K-LC2, K-LC3, K-LC5, K-LC6, USB-cable, RSP_Scope and RSP_Terminal software
- **K-LD2 evaluation kit** is including board, K-LD2, USB-cable, powerful control panel software & documentation on USB-stick


K-LD2 EVAL


ST100


ST200

PURPOSE	ST100	ST200	RSP1 EVAL / K-LD2 EVAL	COMMENTS
ST100 Starter kit vs. ST200 evaluation system vs RSP1/K-LD2 Evaluation kit				
Learning Doppler basics	✓	✓	✓	
Exploring Doppler sensors	✓	✓	✓	
Developing movement sensors	✓	✓	✓	
Analyzing Doppler frequency spectra	✓	✓	✓	
Working with complex FFT and I/Q sensors	✓	✓	✓	Important for separating multiple objects, suppressing interferences etc.
Recording and playback of Doppler signals	✓	✓		
Analog output of recorded Doppler signals	✓			Very helpful for analyzing real world signals in the laboratory
Exploring FSK ranging		✓		Ranging of moving objects
Exploring FMCW ranging		✓		Ranging of moving and stationary objects
Exploring monopulse principle		✓		Detect direction angle of moving objects
Suppression of false triggering			✓	

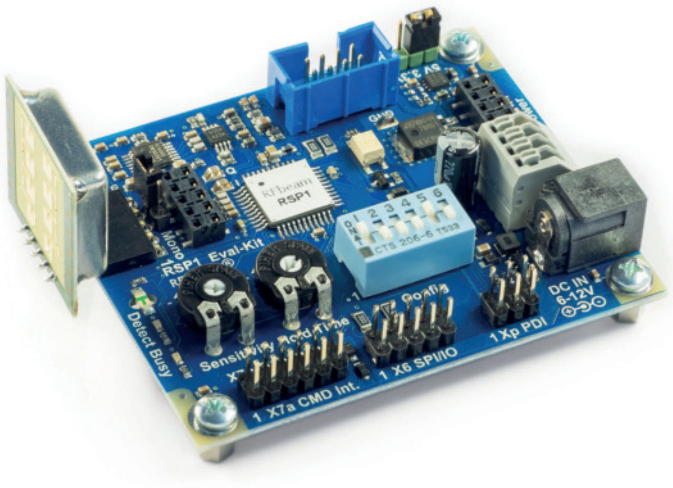
3.3 RADAR DOPPLER SIGNAL PROCESSOR RSP1 **RFbeam**

Radar signal processing chip RSP1

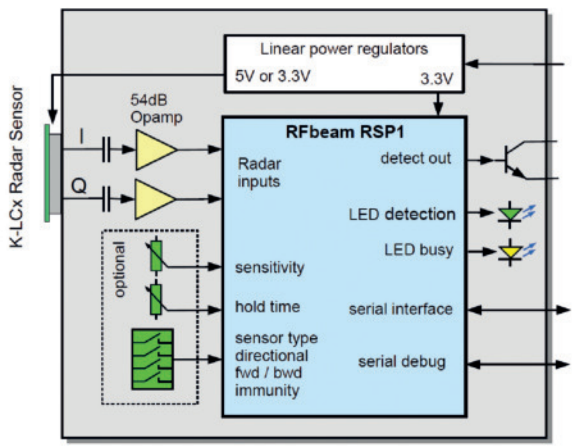
RSP1 is a new microcontroller, which is designed for a smart evaluation of output signals of radar transceivers operating in the Doppler-mode. Speed and presence of moving objects will be detected.

Features

- Universal Doppler radar signal processor
- Complete I/Q radar sensor interface
- Double detection distance compared to traditional solutions
- Object speed and direction detection
- Complex FFT based signal processing
- Efficient adaptive interference suppression
- Inherent object speed detection up to 200 km/h
- Stand-alone or hosted operation
- Serial interfaces to host processor
- Reference design and evaluation board available



Evaluation board for RSP1



RSP1 Typical Application

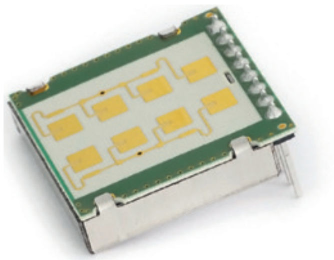
Stand-alone application circuitry

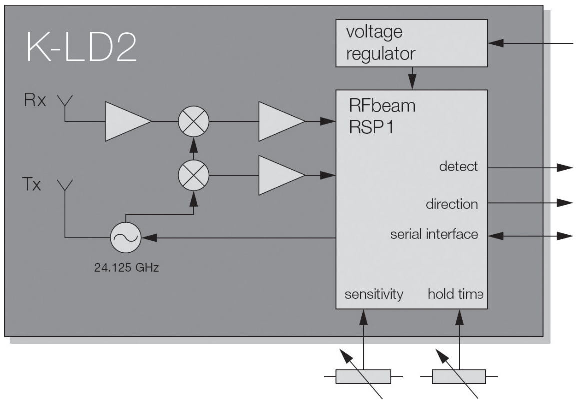
Key Data

- 12 bit ADC
- Differential analog inputs for I and Q signals
- Internal programmable gain amplifier
- Sampling rates from 1280 Hz ... 22.5 kHz
- Efficient 256 pt complex FFT
- Logarithmic detection algorithms
- Adaptive noise and interference analysis and canceling algorithms
- Serial command and debug/streaming interfaces
- Highly configurable by serial interface and/or digital and analog inputs
- Application settings can be down- and uploaded from chip
- Sophisticated serial outputs like peak magnitude, frequency and sign, noise level and many more

The K-LD2 is an easy to use 2 × 4 patch Doppler module with an asymmetrical beam for low cost short distance applications. This transceiver includes a RFbeam RSP1 signal processor and all necessary circuitry. It outputs a detection signal and also the direction of the movement. Important parameters can be adjusted with external potentiometers. Object speed can be measured using the integrated serial connection.

There is no need to write own signal processing algorithms or handle small and noisy signals. This module contains everything what is necessary to build a simple but reliable movement detector. An extremely slim construction with a thickness of 6 mm depth gives you maximum flexibility in your equipment design. A powerful starter kit with signal visualization on the PC is available.





Applications

- General movement detection applications
- Door opener
- Indoor and outdoor lighting control applications
- Object speed measurement systems
- Industrial sensors

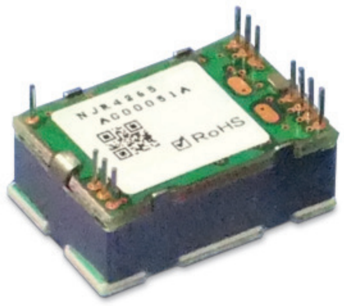
Features

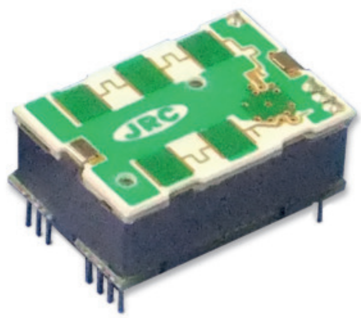
- 24 GHz miniature I/Q transceiver
- Integrated FFT signal processing with digital output
- Low cost design
- Digital outputs for detection and direction
- Sensitivity and hold time can be set using analog inputs
- Additional configuration with serial input possible
- 2 × 4 patch antenna with 80 °/ 34 ° beam aperture
- 25 × 25 mm² surface, thickness < 6.5 mm

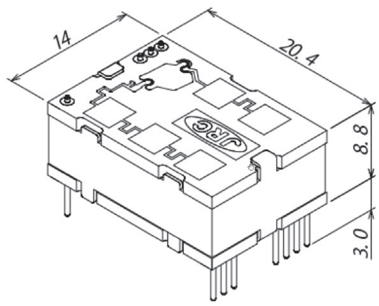
PARAMETER	CONDITIONS / NOTES	SYMBOL	MIN	TYP	MAX	UNIT
OPERATING CONDITIONS						
Supply voltage		V_{CC}	3.15		6.0	V
Supply current		I_{CC}		55		mA
Operating temperature		T_{op}	-20		+85	°C
Storage temperature		T_{st}	-20		+105	°C
SIGNAL PROCESSING						
Velocity processing				256 point FFT		
Sample rate		f_{sample}	1.28		22.5	kHz
Speed range	Depending on sampling frequency	r_{speed}	0		255	km/h
Response time	Depending on sampling frequency	t_{detect}		100		ms

3.5 MOTION SENSOR NJR4265R

Intelligent K-Band Doppler module







NJR4265R is an intelligent motion sensor that is designed for the sensing of short distance low speed moving objects like pedestrians etc. The steady sensing of a moving object is realized by embedded software. The sensor is suitable for the built-in use of the sensing function to various equipments since all functions are integrated in a small package. The NJR4265R can easily be controled from PC/ MCU by UART interface. Furthermore, stand alone operation is also possible.

Features

- Motion sensor based on 24 GHz Microwave Doppler effect
- Antenna, RF circuit, IF amp, MCU and voltage regulator are integrated in a small package (14 × 20.4 × 8.8 mm)
- Signal processing software for the steady sensing
- Enhancing signal from movement object and decreasing random noises
- Decreasing mutual interference between sensors
- Identification of moving direction (approaching and leaving)
- Low voltage operation and low power consumption
- In compliance with EC directive (CE Marking) and FCC certification

Applications

- Energy saving equipment (lighting equipment, air conditioner etc.)
- Room access control system equipment
- Human detection sensor for various devices

Sensing performance

- Speed range of target: 0.25 ... 1 m/s
- Max. distance in the front: 10 m
- Detection angle: ±35°

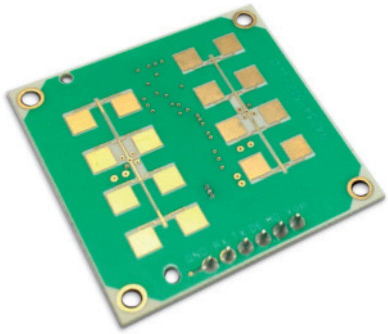
Environmental characteristics

- Operating temp. range: -20°C ... +60°C
- Storage temp. range: -40°C ... +80°C
- Humidity: 0-95% at +30°C

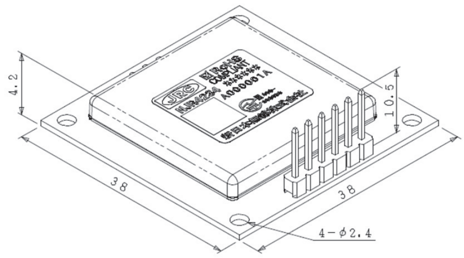
PART NUMBER	FREQUENCY	REGION
Product line-up		
NJR4265RJ1C1	24.05 ... 24.25 GHz	Japan
NJR4265RF1C1	24.05 ... 24.25 GHz	EU except specific regions
NJR4265RF2C1 (1)	24.15 ... 24.25 GHz	All of EU regions
NJR4265RF3C1	24.075 ... 24.175 GHz	United States

(1) - preferential model

3.6 DISTANCE MEASUREMENT SENSOR NJR4234B



Front view



Intelligent K-Band middle distance measurement sensor module for moving objects

NJR4234B is a sensor module that measures the distance of stationary and moving objects such as a pedestrian up to 30 m ahead. It incorporates a 24 GHz band microwave circuit, antenna and signal processing circuit in a low profile package of 38 mm x 38 mm x 4.2 mm. As a sensor capable of distance measurement using microwave, it detects moving objects by innovative proprietary signal processing and contains the function to calculate and output the distance to the objects in indoor and outdoor environments.

Furthermore, it has the unique algorithm to prevent radio interference, and to use multiple sensors in the same location. It can be used as a sensor front end with built-in primary signal processing for distance measurement. Due to the easy connection to other equipment via the UART interface, it can be used in a wide range of applications.

Features

- 24 Ghz microwave distance measurement sensor for moving objects
- Antenna, microwave RF circuit, base-band IF circuit, MCU and also signal processing are integrated in low-profile package (38 mm x 38 mm x 4.2 mm)
- Low-power-consumption
- High sensitivity mobile object detection (patented technology)
- Distance measurement signal processing
- Automatic calibration and gain control
- Radio interference prevention
- UART interface and digital CMOS output

Applications

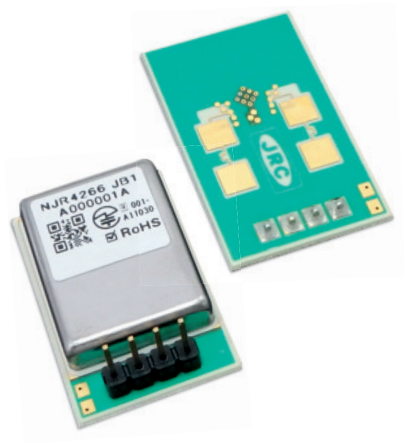
- Various equipment controlled by moving objects detection and distance measurement
- Security equipment
- Traffic control system
- Industrial drones
- Parking management system

Product Line-up

PART NUMBER	CENTER FREQUENCY	REGION	MOVING OBJECT	STATIONARY
NJR4234BVF1C1	24.05 ... 24.25 GHz	Japan [MIC Techn. Conf. ARIB STD-T73]	✓	
NJR4234BVF2C1 (1)	24.15 ... 24.25 GHz	All of EU regions [RED 2014/53/EU]	✓	
NJR4234BVF3C1	24.075 ... 24.175 GHz	United States [FCC Part 15.245]	✓	
NJR4234BWF1C1	24.05 ... 24.25 GHz	Japan [MIC Techn. Conf. ARIB STD-T73]	✓	✓
NJR4234BWF2C1 (1)	24.15 ... 24.25 GHz	All of EU regions [RED 2014/53/EU]	✓	✓
NJR4234BWF3C1	24.075 ... 24.175 GHz	United States [FCC Part 15.245]	✓	✓

(1) - preferential model

3.7 DOPPLER SENSOR MODULE SERIES NJR4266



Intelligent low speed K-band motion sensor for short distance

NJR4266 is an intelligent human motion sensor module series that can detect objects moving at low speed like a pedestrian in a short distance range (approx. 7 to 14 m). It incorporates a 24 GHz band microwave circuit, antenna, signal processing circuit and MCU in a low profile package of only 17.2 mm x 27.3 mm x 5.1 mm. Signal processing technology greatly reduces false detection ofo environmental noise and achieves stable detection results.

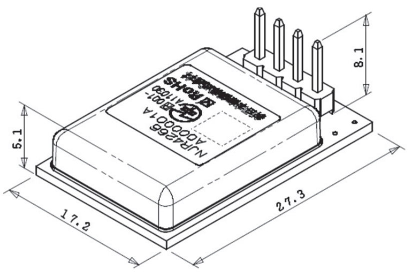
It also reduces power consumption by sensitivity setting. The NJR4266 series is available in multiple antenna versions so that the users can select the ideal detection angle best suitable for their specific application. Moreover, the user can select between UART and stand alone version (digital output / analog range setting) as interface type.

Features

- Motion sensor based on 24 Ghz microwave Doppler effect
- Antenna, microwave RF circuit, IF amplifier, MCU and voltage regulator are integrated in low-profile package (17.2 mm x 27.3 mm x 5.1 mm)
- Low power consumption (intermittent mode 1.9 mA min@3.3 V)
- Sleep mode for power reduction
- Decreasing mutual interference between sensors
- Available in 4 antenna versions to select the optimum detection angle
- Selectable between UART interface or digital output / analog sensitivity setting version
- UART interface version offers identification of direction (approaching and leaving) for moving objects

Applications

- Various control equipment by human sensing
- Lighting sensors
- Safety and Security equipment
- Energy saving management
- Entrance and exit management



Product Line-up

PART NUMBER	CENTER FREQUENCY	REGION
NJR4266Jxx	24.05 ... 24.25 GHz	Japan [MIC Techn. Conf. ARIB STD-T73]
NJR42366F2xx	24.15 ... 24.25 GHz	All of EU regions [RED 2014/53/EU (CE Marking)]
NJR4266F3xx	24.075 ... 24.175 GHz	United States [FCC Part 15.245]

Ordering information

PART NUMBER	ANTENNA PATCH ARRAY	DETECTION RANGE	DETECTION ANGLE	INTERFACE
NJR4266F2C1	TX/RX: 4 x 1	15 m	76°/ 32°	C1: UART
NJR4266F2C2	TX/RX: 4 x 1	15 m	76°/ 32°	C2: Analog Threshold / CMOS Output

Note: As 1x1 type, 4x1 type and 2x2 type are being developed, design values are listed for detection angle and detection distance.