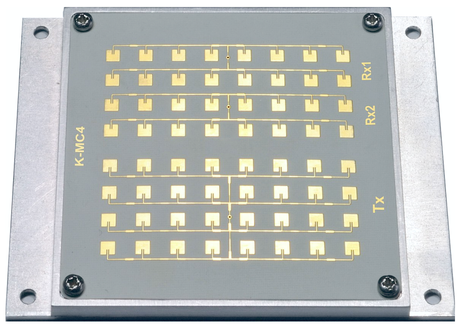
K-MC4 MONOPULSE RADAR TRANSCEIVER

Datasheet

Features

- 24 GHz short range monopulse transceiver
- Dual receiver +/- 15° angle coverage
- Beam aperture 30°/ 12° @ -3dB
- 180MHz sweep FM input
- High sensitivity, integrated RF/IF amplifier
- Buffered I/Q IF outputs for both channels
- Temperature compensated oscillator
- RSW Rapid Sleep Wakeup for power saving
- Extremely compact: $78x98x7mm^3$ construction



Applications

- Ranging, distance and direction finding measurements
- Traffic supervision and counting
- Object speed measurement systems
- Indµstrial sensors

Description

K-MC4 is a Doppler Transceiver with an asymmetrical beam and two receiver antennas. This configuration allows measuring the angle of moving objects. This technique is often simply called “Monopulse Radar”, but in fact it is a “Phase-Comparison Monopulse” technique.
Target deviation of +/-15° from main axis results in a phase deviation of +/- 100° at the IF outputs I1/I2 or Q1/Q2 respectively.

The unique "RSW" *R*apid *S*leep *W*akeup function with <5µs wakeup time makes this module ideal for battery operated equipment. Typical duty cycle in RWS mode may be < 1% with full movement detection capability by sampling the IF signals.
An extremely slim construction with only 6mm depth gives you maximum flexibility in your equipment design.
A powerful evaluation kit ST200 is available.

Blockdiagram

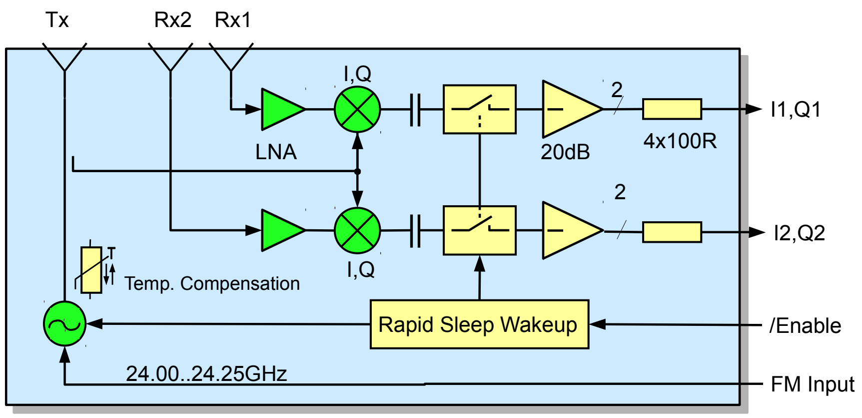


Fig. 1: K-MC4 Blockdiagram

Characteristics

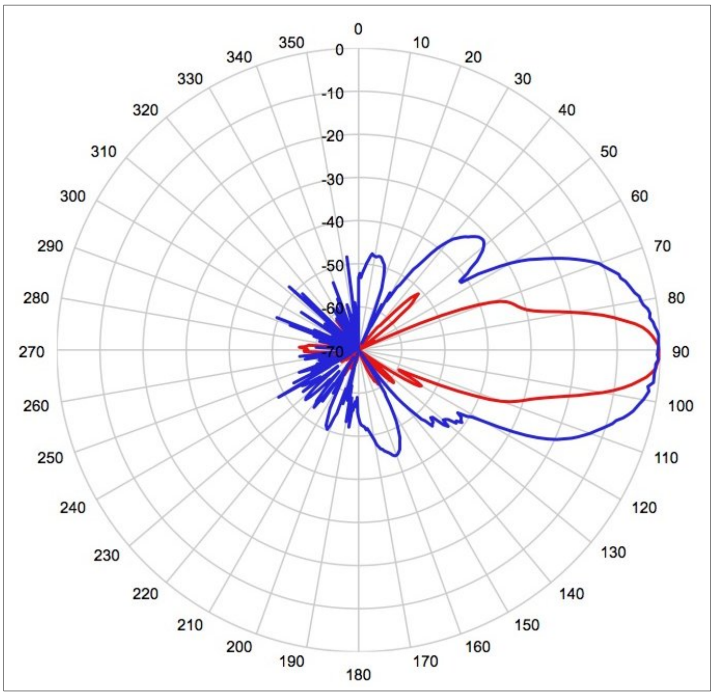
Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Unit
Operating conditions						
Supply voltage		V_{cc}	4.75	5.00	5.25	V
Supply current	Module enabled (Pin 1 = V_{IL})	I_{cc}		180		mA
	Module RSW mode (Pin 1 = V_{IH})			5	7	mA
VCO input voltage		U_{vco}	1		10	V
VCO pin resistance	Internal pullup to 5V	R_{vco}		10K		Ω
Operating temperature		T_{op}	-20		+80	°C
Storage temperature		T_{st}	-20		+80	°C
Power down/Enable						
Module power down	Input tied high with pullup 100k	V_{IH}	V_{cc}-0.7		V_{cc}+ 0.3	V
Module enable		V_{IL}	-0.2		2	V
Minimum enable time	RF- and IF-part fully functional	t_{on}	5			µs
Minimum duty cycle	Signal amplitude degradation < 3dB	t_{off}	0.25			%
Transmitter						
Transmitter frequency	U_{VCO}= 5V, T_{amb}=-20°C .. +80°C	f_{TX}	24.050	24.150	24.250	GHz
Frequency drift vs temp.	V_{cc}=5.0V, -20°C .. +80°C	Δf_{TX}		-0.1		MHz/°C
Frequency tuning range (VCO)		Δf_{vco}		180		MHz
VCO sensitivity		S_{vco}		18		MHz/V
VCO Modulation Bandwidth	Δf=10MHz	B_{VCO}		31		MHz
Output power	EIRP	P_{TX}	+16	+18	+20	dBm
Output power deviation	Full VCO tuning range	ΔP_{TX}			+/- 2	dB
Spurious emission	According to ETSI 300 440	P_{spur}			-30	dBm
Receiver						
Antenna gain	F_{TX}=24.125GHz	G_{Ant}		13.0		dBi
LNA gain	F_{RX}=24.125GHz	G_{LNA}		16		dB
Mixer Conversion loss	f_{IF} =500Hz	D_{mixer}		-12.5		dB
Receiver sensitivity	f_{IF} =500Hz, B=1kHz, S/N=6dB	P_{RX}		-116		dBm
Overall sensitivity	f_{IF} =500Hz, B=1kHz, S/N=6dB	D_{system}		-134		dBc
IF output						
IF output impedance		R_{IF_AC}		100		Ω
IF Amplifier gain		G_{IF_AC}		20		dB
I/Q amplitude balance	f_{IF} =500Hz, U_{IF}=100mV$_{pp}$	ΔU_{IF1}		3		dB
I/Q phase shift	f_{IF} =500Hz, U_{IF}=100mV$_{pp}$	φ_1	70	90	110	°
Amplitude balance Rx1 / Rx2	f_{IF} =500Hz, U_{IF}=100mV$_{pp}$, Object in front	ΔU_{IF2}		3		dB
Phase balance Rx1 / Rx2	f_{IF} =500Hz, U_{IF}=100mV$_{pp}$, Object in front	φ_2		+/- 5		°
Monopulse resolution	Phase Rx1 / Rx2 divided by object angle [1)]	k		6.7		-
IF frequency range	-3dB Bandwidth	f_{IF_AC}	15		300k	Hz
IF noise voltage	f_{IF} =500Hz	$U_{IFnoise}$		1.0		µV/√Hz
	f_{IF} =500Hz	$U_{IFnoise}$		-120		dBV/Hz
IF output offset voltage	V_{cc}=5.0V	U_{os}	2.2	2.5	2.8	V
Supply rejection	Rejection supply pins to IF outputs, 1kHz	D_{supply}		10		dB

Note 1) Refer to chapter Object Angle Phase Conditions

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Unit
Antenna						
TX vertical -3dB beamwidth	E-Plane	W_φ		12		°
TX horizontal -3dB beamwidth	H-Plane	W_θ		30		°
RX vertical-3dB beamwidth	E-Plane	W_φ		12		°
RX horizontal -3dB beamwidth	H-Plane	W_θ		40		°
Horiz. sidelobe suppression		D_φ		-20		dB
Vert. sidelobe suppression		D_θ		-20		dB
Rx1, Rx2 mechanical distance		d_{Rx}		13.7		mm
Body						
Outline Dimensions	Connector left unconnected			98*78*7		mm^3
Weight				90		g
Connector	Module side: AMP X-338069-8			8		Pins

Antenna System Diagram

This diagram shows module sensitivity (output voltage) in both azimuth and elevation directions. It incorporates the transmitter and one receiver antenna characteristic.



Azimuth 30° , Elevation 12°
At IF output voltage -6dB
(corresponds to -3dB Tx power)

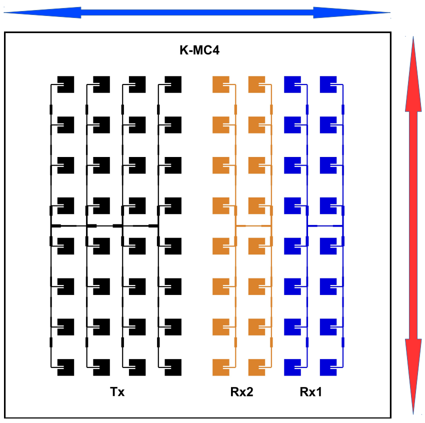


Fig. 2: Antenna system diagram

Object Angle Phase Conditions

A moving object generates Doppler Signals on both I and Q outputs.
Phase relations between Ix an Qx indicate forward or backwards movements.
Objects approaching the sensor generate 90° shift between Ix and Qx outputs.
Objects moving away from the sensor generate -90° shift between Ix and Qx outputs.

Phase relations between I1 an I2 or Q1 and Q2 indicate the object's deviation α from the 90° axis . Please note the position of the antennas Rx1 and Rx2 in Fig. 3.

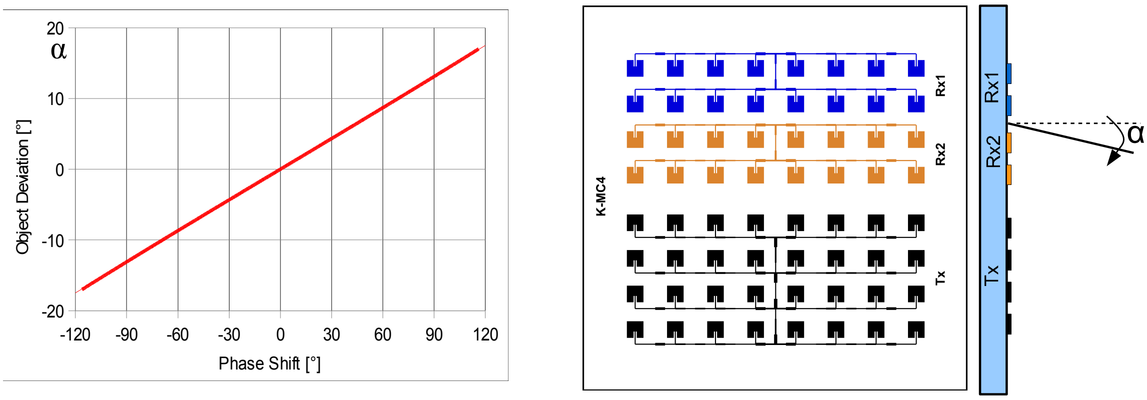


Fig. 3: IF Signal phase shift vs object angle

FM Characteristics

Frequency modulation allows FSK (Frequency Shift Keying) and FMCW (Frequency Modulation Continuous Wave) techniques for ranging applications.
For optimal FMCW results, the VCO characteristic should be linearized by the driving software.

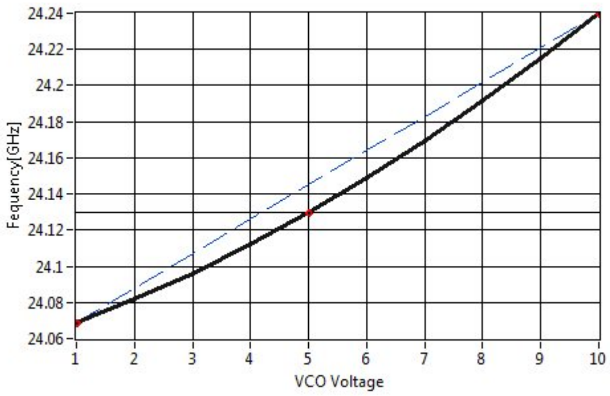


Fig. 4: Typical frequency vs. VCO voltage

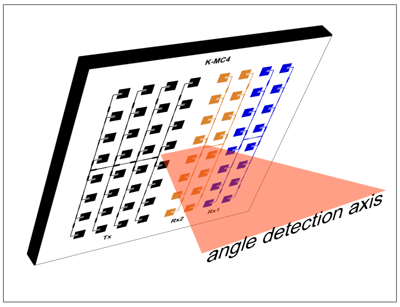
Pin Configuration

Pin	Description	Typical Value
1	/Enable	GND: module active
2	VCC	5V supply
3	GND	0V supply
4	Q1: Rx1 IF output	Q Output from Rx1
5	I1: Rx1 IF output	I Output from Rx1
6	VCO in	5V = f_0 (Range 0 ..10V)
7	Q2: Rx2 IF output	Q output from Rx2
8	I2: Rx2 IF output	I output from Rx2

Application Notes

Using Monopulse Phase Comparison Features

Using multiple antennas allows discrimination of the angle of moving objects. K-MC4 uses two receiver antennas Rx1 and Rx2.



On the right half, there are the two receiver antennas shown in different colors. The angle detection happens in the horizontal plane as shown in the picture.
The antenna layout results in a horizontal -6dB (IF voltage) beam width of 30° according to Fig. 2.
The usable angle detection will be approx +/- 13°.
Please note, that the vertical beam width is narrower (12°) because of the geometry of the antenna.

Fig. 5: Angle detection direction vs. antenna arrangement

A more detailed explanation of the effects by using two receiver channel are shown in the figure below.

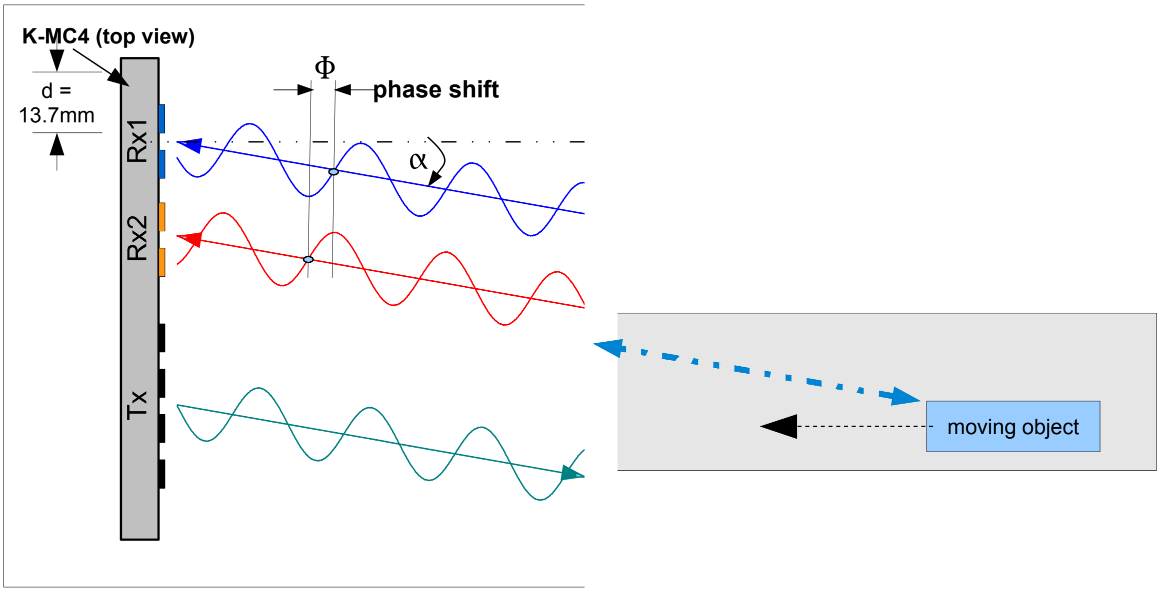


Fig. 6: Antenna Rx1 reveives a delayed reflection

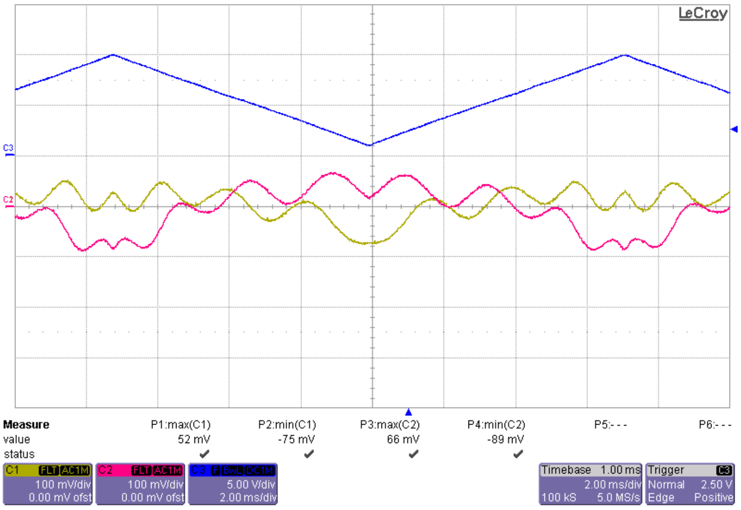
The phase shift of the received Doppler carrier waves appears between the outputs I1 and I2 or Q1 and Q2.

Object's angle in ° can be can be calculated as $\alpha = \frac{\phi}{k}$ $\quad \alpha = objects\,angle$, $\phi = phase\ shift\ Ix - Qx$, $k = 6.7$

The sign of α changes depending on the moving direction of the object (forward or backward).

Using VCO and IF Outputs

The IF amplifier provides two outputs per channel according to Fig. 1. These outputs are designed for different requirements in processing radar signals. Both I (imaginary) and Q (real) mixer signals are available. The I and Q signals are phase shifted by +90° or -90°, depending on the moving direction of objects in range. I1 and I2 (and Q1 and Q2) signals are phase shifted by the object deviation from the normal axis (refer to chapter Fig. 3).
FMCW generates an output signal even without an object in range because of the finite isolation between transmitter and receiver path. This effect is called self-mixing and leads to a DC signal that depends on the carrier frequency.



Example showing a single target:
Triangle VCO Amplitude: 8Vpp
Triangle period T_M = 14ms.
Modulation depth f_M = 160MHz
IF output freq. f_b = 450Hz

I_AC and Q_AC outputs show a low frequency caused by local carrier feedthrough.
The superposed higher frequency f_b is often called beat frequency, caused by a target at a distance of about 3m.

Fig. 7: Ix and Qx Output FMCW signals with triangle VCO and df = 80MHz

Distance calculation

$$\boxed{R = \frac{c_0}{2} \cdot \frac{f_b}{f_M} \cdot \frac{T_M}{2}}$$ = 3m approx

For legend refer to Fig. 7
R *Range, distance to target*
c_0 *Speed of light (3 * 10^8 m/s)*

Please contact RFbeam Microwave GmbH for more informations on FMCW and also on FSK applications

Ix and Qx IF Outputs

These outputs provide amplified low noise signals generated by doppler effects or FMCW. They directly can drive ADC input stages of microprocessors or DSPs. Even with 10Bit of resolution only, sensitive and relatively long range Doppler detections are possible. The outputs cover a frequency range of 15Hz ... 300kHz.
12Bit ADConverters are recommended for higher sensitivity to get optimal resolution for filtering and signal processing.

Rapid Sleep Wakeup (RSW)

RFbeam's unique rapid sleep wakeup feature allows power savings of more than 90% during 'silent' periods. The module may be used in a relaxed sampling mode as long as no movements are detected. RSW also helps saving power, if the full IF bandwidth is not needed.
In battery operated equipment such as traffic control, RSW may significantly lower battery and equipment volume and cost.

RSW Principle

K-MC4 contains a high speed variant of RSW without internal S&H device. RSW combines switching of the RF oscillator and an isolation of the following IF amplifier (please refer to Fig. 1: K-MC4 Blockdiagram). During sleep mode (pin /ENABLE = high), only the amplifiers stay supplied to hold the output center voltage.
IF output signals are active, as soon as /Enable is low, otherwise IF outputs fall back to their DC level which is Vcc/2.

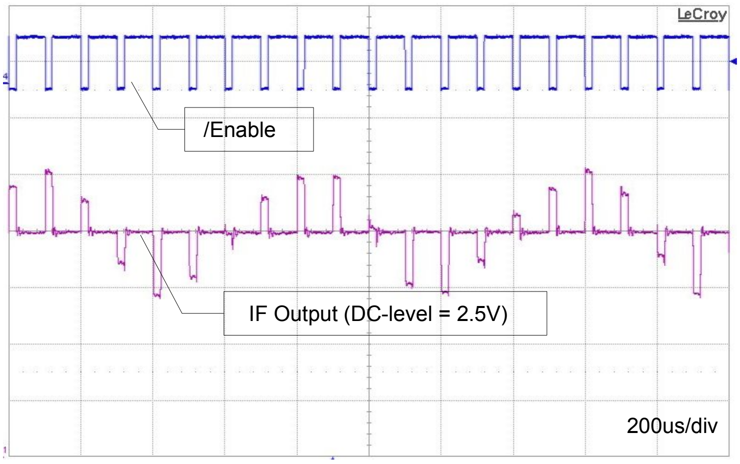
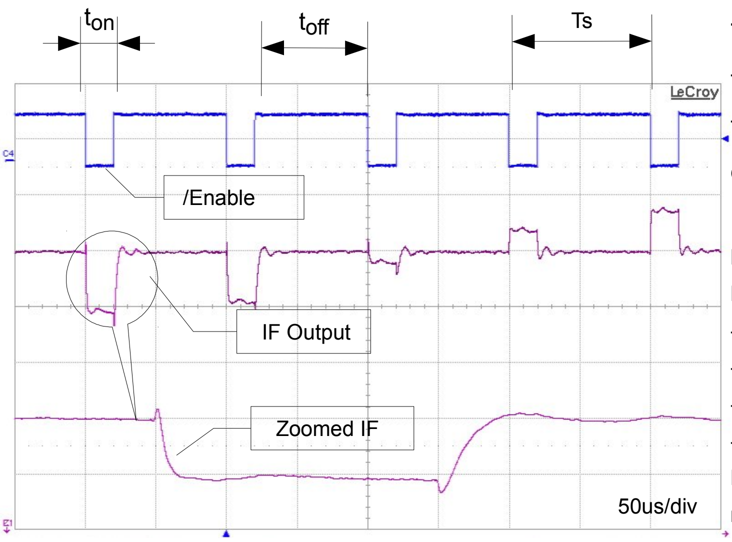


Fig. 8: Sampled Doppler signal (1.3kHz) at IF I or Q outputs



$T_s = t_{on} + t_{off}$

t_{on} min = 5µs

t_{OFF} max = 2ms

duty cycle d = 100* t_{on} / T_s > 0.25%

Example for calculationg power saving:

Max object speed to detect = 200km/h

-> $f_{doppler}$ = 200km/h * 44Hz = 8.8kHz

-> f_s = 20kHz to meet Nyquist criteria

-> T_s = 1/f_s = 50us

-> d = 100% * 5µs/50us = 10%

Note: With undersampling during silent periods, much more power saving is possible

Fig. 9: Detailed RSW sampling behaviour

Sampling Requirements

Using RSW requires sampling of the IF signals during the active enable time. Normally, AD conversion and asserting /Enable signal on K-MC4 must be synchronized.
If the ADC contains a sample-and-hold (S&H) device, sampling command can be fired at the end of the /Enable signal. Enable time t_{on} must be > 5µs or > setup time of the S&H, whatever value is higher.
If the ADC does not contain a S&H input stage, conversion command should be issued at the very beginning of the enable period. Enable time t_{on} must be > 5µs or > 1/bandwidth of the ADC, whatever value is higher.

Sensitivity and Maximum Range

The values indicated here are intended to give you a 'feeling' of the attainable detection range with this module. It is not possible to define an exact RCS (radar cross section) value of real objects because reflectivity depends on many parameters. The RCS variations however influence the maximum range only by $\sqrt[4]{\sigma}$.

Maximum range for Doppler movement depends mainly on:

- Module sensitivity	S:	-134dBc (@1kHz IF Bandwidth)
- Carrier frequency	f_0:	24.125GHz
- Radar cross section RCS ("reflectivity") of the object	σ[1)]:	1m² approx. for a moving person >50m² for a moving car

note [1)] RCS indications are very inaccurate and may vary by factors of 10 and more.

The famous "Radar Equation" may be reduced for our K-band module to the following relation:

$$r = 0.0167 \cdot 10^{\frac{-s}{40}} \cdot \sqrt[4]{\sigma}$$

Using this formula, you get an indicative detection range of
- > 37 meters for a moving person
- > 93 meters for a moving car

Please note, that range values also highly depend on the performance of signal processing, environment conditions (i.e. rain, fog), hoµsing of the module and other factors.
With K-MC3, you can achieve a maximum range of more than 500m when µsing high resolution AD-converters and selective FFT algorithms.

Integrators Information

Installation Instruction

Mechanical enclosure

It is possible to hide the sensor behind a so called radome (short for radar dome) to protect it from environmental influences or to simply integrate it in the case of the end product. A radar sensor can see trough different types of plastic and glass of any colour as long as it is not metallized. This allows for a very flexible design of the housing as long as the rules below are observed.

- Cover must not be metallic.
- No plastic coating with colors containing metallic or carbon particles.
- Distance between cover and front of Radar sensor >= 6.2mm
- Best cover material is Polycarbonat or ABS
- Best cover thickness is 3-4mm
- Vibrations of the Radar antenna relatively to the cover should be avoided, because this generates signals that can trigger the output
- The cover material can act as a lens and focus or disperse the transmitted waves. Use a constant material thickness within the area used for transmission to minimize the effect of the radome to the radiated antenna pattern.

Note
Detailed information about the calculation and thickness for different cover materials can be found in the application note “AN-03-Radome”.

United States (FCC) and Canada (ISED)

This module has been granted modular approval for fixed and/or mobile applications. The modular approval allows the end user to integrate the module into a finished product without obtaining subsequent and separate FCC/ISED approvals for intentional radiation, provided no changes or modifications are made to the module circuitry. Changes or modifications could void the user's authority to operate the equipment. The end user must comply with all of the instructions provided by the Grantee, which indicate installation and/or operating conditions necessary for compliance. The finished product is required to comply with all applicable FCC/ISED equipment authorizations regulations, requirements and equipment functions not associated with the transmitter module portion.

Note
Modification to this product will void the users' authority to operate this equipment.

Warning
The OEM integrator is responsible for the final compliance of the end product with this integrated modular approved transmitter module. This includes measurements with the RF module integrated and activated as defined in KDB 996369 and if applicable appropriate equipment authorizations as defined in §15.101.

Labelling and user information requirements

If the label of the module is not visible from the outside of the end product, it must include the following texts on the label of the host product:

FCC: Contains FCC ID: 2ASYV-K-MC4
ISED: Contains IC: 24358-KMC4

In addition to marking the product with the appropriate ID's, the end product shall bear the following statement in a conspicuous location on the label or alternatively in the user manual:

> This device complies with Part 15 of the FCC Rules and with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.
>
> Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

RF Exposure

This module is approved for installation into fixed and/or mobile host platforms and must not be co-located or operating in conjunction with any other antenna or transmitter except in accordance with FCC/ISED multi-transmitter guidelines. End users must be provided with transmitter operating conditions for satisfying RF Exposure compliance.

Europe (CE-RED)

This module is a Radio Equipment Directive assessed radio module that is CE complaint and have been manufactured and tested with the intention of being integrated into a final product.

According to the RED every final product that includes a radio module is also a radio product which falls under the scope of the RED. This means that OEM and host manufacturers are ultimately responsible for the compliance of the host and the module. The final product must be reassessed against all of the essential requirements of the RED before it can be placed on the EU market. This includes reassessing the module for compliance against the following RED articles:

- Article 3.1(a): Health and safety
- Article 3.1(b): Electromagnetic compatibility (EMC)
- Article 3.2: Efficient use of radio spectrum (RF)

The RED knows different conformity assessment procedures to show compliance against the essential requirements (See RED Guide, chapter 2.6b). As long as the radio module can show compliance to Article 3.2 by the use of a harmonized standard, which is listed in the official journal of the EU (OJEU), it is not necessary to do an EU type examination for the final radio product by a notified body. In this case it is possible to demonstrate conformity according to the essential requirements of the RED by using Module A (Annex II of the RED), which allows to show conformity by internal production control.

Note
As long as a harmonized standard listed in the OJEU can be used to demonstrate conformity in accordance with Article 3.2 of the RED, it is possible to carry out the CE certification in self-declaration without the involvement of a notified body.

The K-MC4 shows compliance against the Article 3.2 by the use of the standard EN 300 440 which is a harmonized standard listed in the OJEU, what gives the possibility to show conformity by internal production control.

An OEM integrator can show compliance to article 3.1(a) and 3.1(b) for the final product by doing internal or external tests and following the Module A (Annex II of the RED) assessment procedure. To show compliance against article 3.2 it is possible to reuse the assessment of the K-MC4 as long as it is the only radio module in the final product or if the integrator can guarantee that only one radio module is operating at the same time. Test reports of the K-MC4 are available on request.

Note
The ETSI guide EG 203 367 provides detailed guidance on the application of harmonized standards to multi-radio and combined equipment to demonstrate conformity.

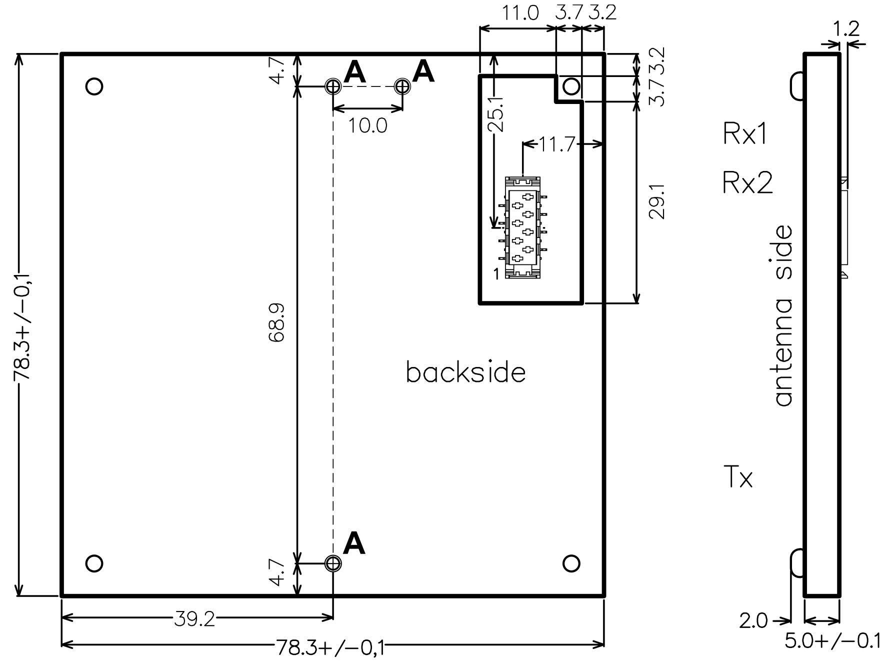
RF Exposure Information (MPE)

This device has been tested and meets applicable limits for Radio Frequency (RF) exposure. A detailed calculation to show compliance to the RED Article 3.1(a) is available on request.

Simplified DoC Statement

Hereby, RFbeam Microwave GmbH declares that the radio equipment type K-MC4 is in compliance with Directive 2014/53/EU. The declaration of conformity may be consulted at www.rfbeam.ch.

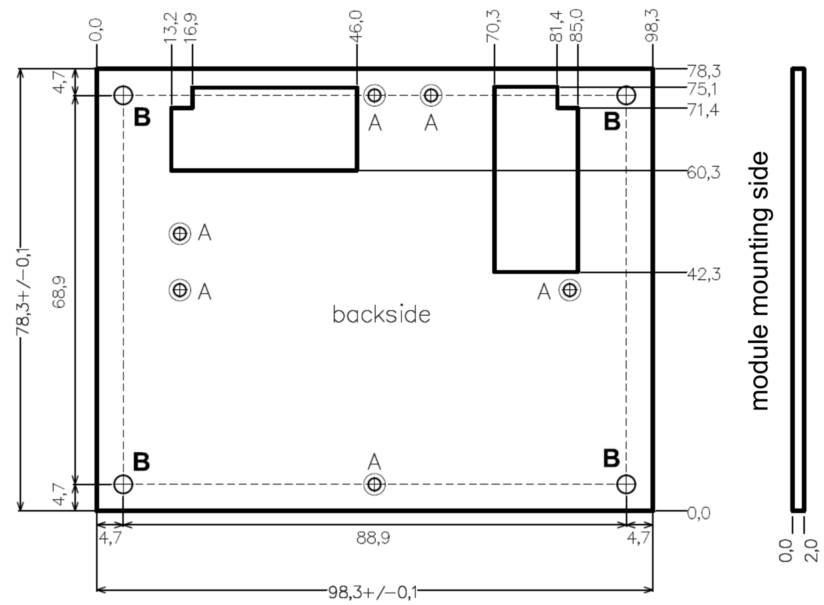
Outline Dimensions



All Dimensions in mm
All values given are typical unless otherwise specified.
A 3x M2 thread for module mounting

Fig. 10: Module dimensions

Module may be mounted on an optional mounting plate in 0° or 90° position:



A 6x bore hole 2.2mm with countersink for mounting K–MC4
B 4x mounting bore hole 3.2mm

Fig. 11: Mounting plate

Ordering Information

Module Part #: K-MC4 Transceiver
(includes Mounting Plate Type1)

Datasheet Revision History

Version	Date	Changes
1.0	2010-10-29	initial release
1.1	2011-04-18	Corrected chapter Sensitivity and Maximum Range to S = -134dBc
1.2	2011-05-10	Changed the drawing of the case
1.3	2011-05-26	Case dimensions corrected on page 1, features
2.0	2011-11-15	Chapter Using VCO and IF Outputs adapted to new Hardware starting with Lot# L1120
2.1	2012-01-17	Gain corrected to 20dB in block diagram
2.2	2015-09-23	Typing Error VCO 12V corrected to 10V in chapter Pin Configuration
2.3	2020-03-05	Added chapter Integrators Information, changed Layout