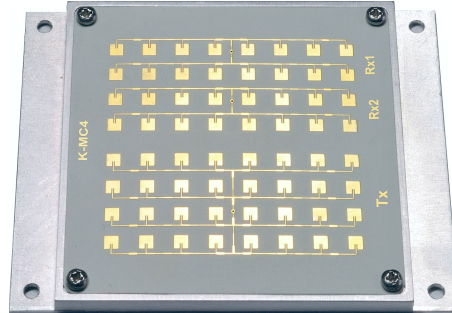


K-MC4 MONOPULSE RADAR TRANSCEIVER

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: 78x98x7mm³ construction



Applications

- Ranging, distance and direction finding measurements
- Traffic supervision and counting
- Object speed measurement systems
- Industrial 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" Rapid Sleep Wakeup 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

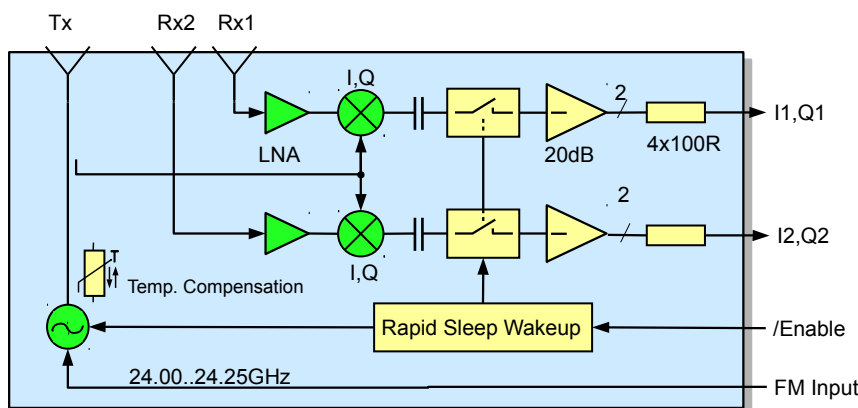


Fig. 1: K-MC4 Blockdiagram

K-MC4 MONOPULSE RADAR TRANSCEIVER

Datasheet

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} | | 140 | | 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 | $^{\circ}\text{C}$ |
| Storage temperature | | T_{st} | -20 | | +80 | $^{\circ}\text{C}$ |
| 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 | $U_{VCO}=5\text{V}$, $T_{amb}=-20^{\circ}\text{C} \dots +80^{\circ}\text{C}$ | f_{TX} | 24.050 | 24.150 | 24.250 | GHz |
| Frequency drift vs temp. | $V_{CC}=5.0\text{V}$, $-20^{\circ}\text{C} \dots +80^{\circ}\text{C}$ | Δf_{TX} | | -0.1 | | MHz/ $^{\circ}\text{C}$ |
| Frequency tuning range (VCO) | | Δf_{VCO} | | 180 | | MHz |
| VCO sensitivity | | S_{VCO} | | 18 | | MHz/V |
| VCO Modulation Bandwidth | $\Delta f=10\text{MHz}$ | 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 | $F_{TX}=24.125\text{GHz}$ | G_{Ant} | | 13.0 | | dBi |
| LNA gain | $F_{RX}=24.125\text{GHz}$ | G_{LNA} | | 16 | | dB |
| Mixer Conversion loss | $f_{IF}=500\text{Hz}$ | D_{mixer} | | -12.5 | | dB |
| Receiver sensitivity | $f_{IF}=500\text{Hz}$, $B=1\text{kHz}$, $S/N=6\text{dB}$ | P_{RX} | | -116 | | dBm |
| Overall sensitivity | $f_{IF}=500\text{Hz}$, $B=1\text{kHz}$, $S/N=6\text{dB}$ | 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 | $f_{IF}=500\text{Hz}$, $U_{IF}=100\text{mV}_{pp}$ | ΔU_{IF1} | | 3 | | dB |
| I/Q phase shift | $f_{IF}=500\text{Hz}$, $U_{IF}=100\text{mV}_{pp}$ | φ_1 | 70 | 90 | 110 | $^{\circ}$ |
| Amplitude balance Rx1 / Rx2 | $f_{IF}=500\text{Hz}$, $U_{IF}=100\text{mV}_{pp}$, Object in front | ΔU_{IF2} | | 3 | | dB |
| Phase balance Rx1 / Rx2 | $f_{IF}=500\text{Hz}$, $U_{IF}=100\text{mV}_{pp}$, Object in front | φ_2 | | +/- 5 | | $^{\circ}$ |
| 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 | $f_{IF}=500\text{Hz}$ | $U_{IFnoise}$ | | 1.0 | | $\mu\text{V}/\sqrt{\text{Hz}}$ |
| | $f_{IF}=500\text{Hz}$ | $U_{IFnoise}$ | | -120 | | dBV/Hz |
| IF output offset voltage | $V_{CC}=5.0\text{V}$ | 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

K-MC4 MONOPULSE RADAR TRANSCEIVER

Datasheet

| Parameter | Conditions / Notes | Symbol | Min | Typ | Max | Unit |
|------------------------------|-----------------------------|--------------|-----|---------|-----|-----------------|
| Antenna | | | | | | |
| TX vertical -3dB beamwidth | E-Plane | W_{θ} | | 12 | | ° |
| TX horizontal -3dB beamwidth | H-Plane | W_{ϕ} | | 30 | | ° |
| RX vertical-3dB beamwidth | E-Plane | W_{θ} | | 12 | | ° |
| RX horizontal -3dB beamwidth | H-Plane | W_{ϕ} | | 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.

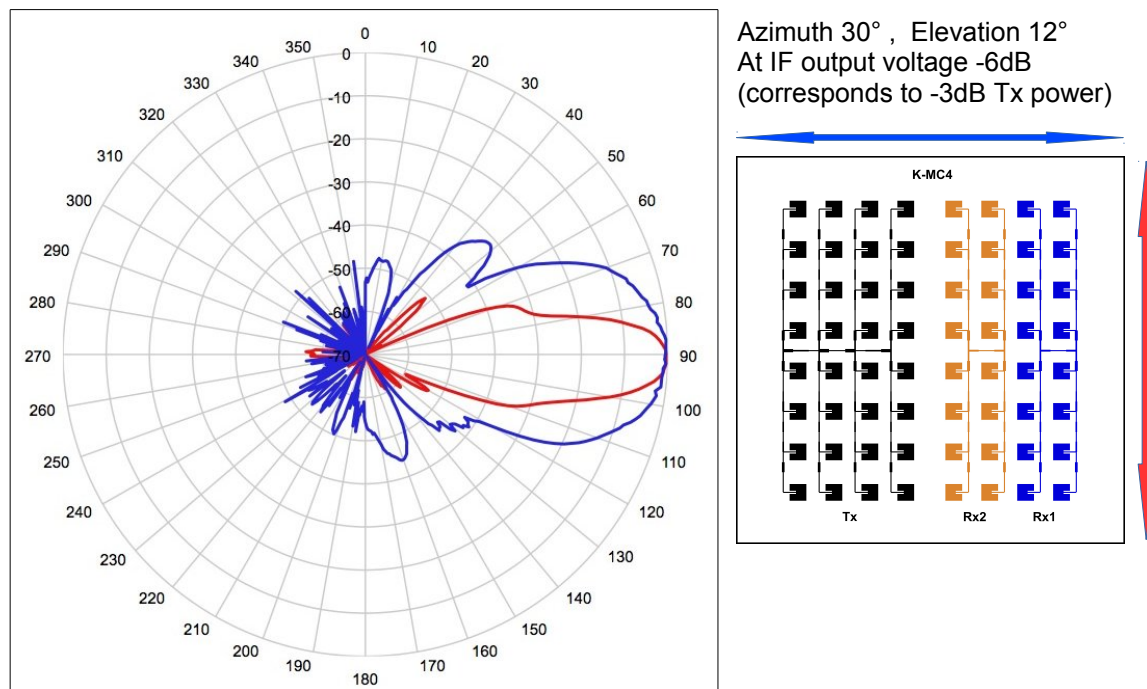


Fig. 2: Antenna system diagram

Object Angle Phase Conditions

A moving object generates Doppler Signals on both I and Q outputs.

Phase relations between Ix and 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 and 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.

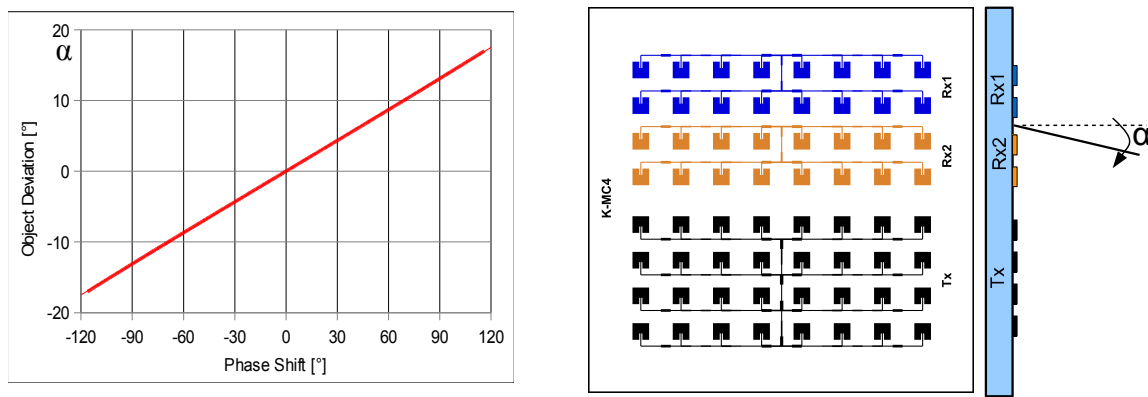


Fig. 3: IF Signal phase shift vs object angle

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.

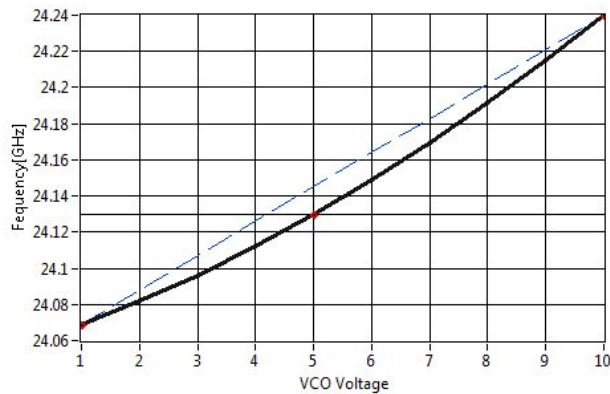


Fig. 4: Typical frequency vs. VCO voltage

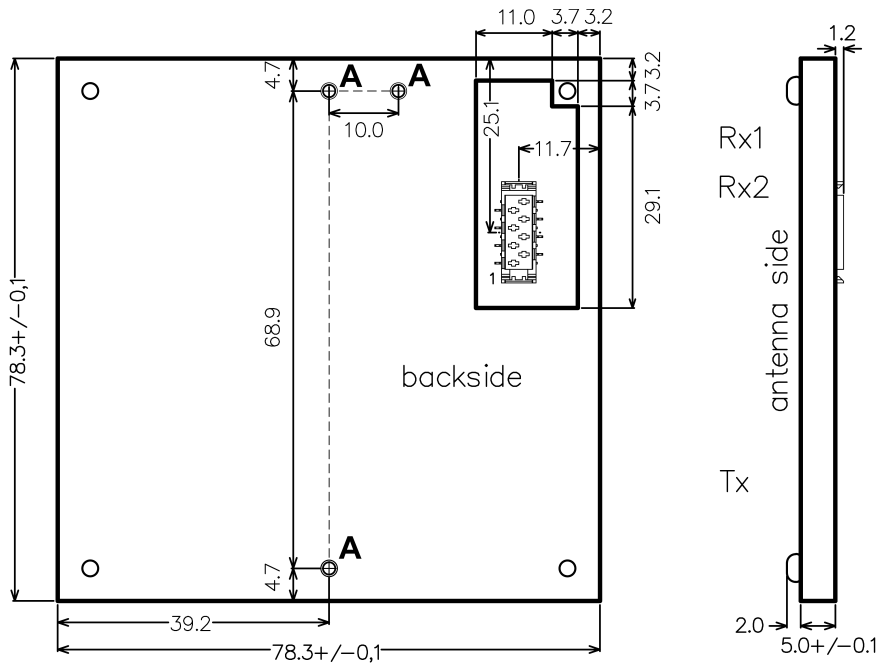
Pin Configuration

| 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 |

Ordering Information

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

Outline Dimensions



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

Fig. 5: Module dimensions

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

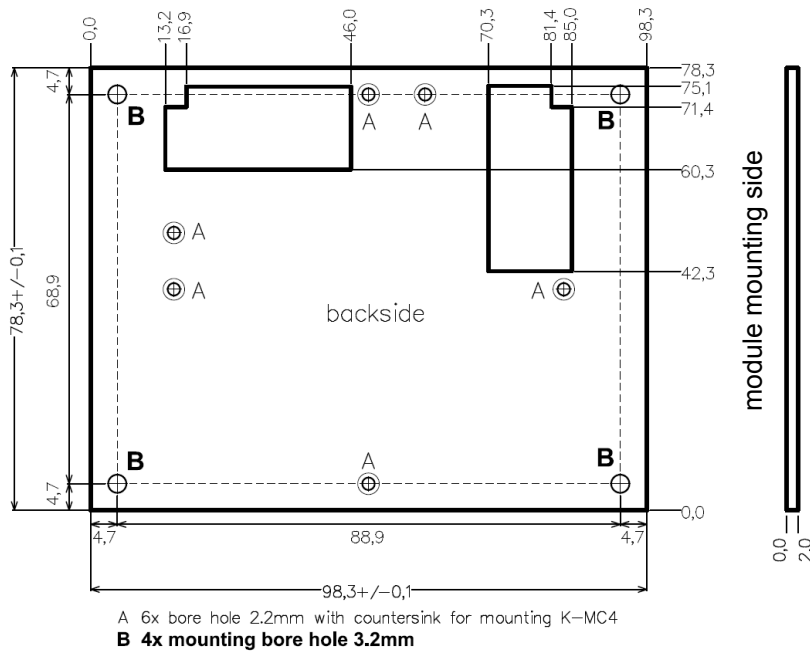
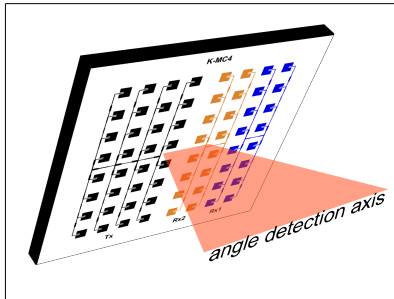


Fig. 6: Mounting plate

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. 7: Angle detection direction vs. antenna arrangement

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

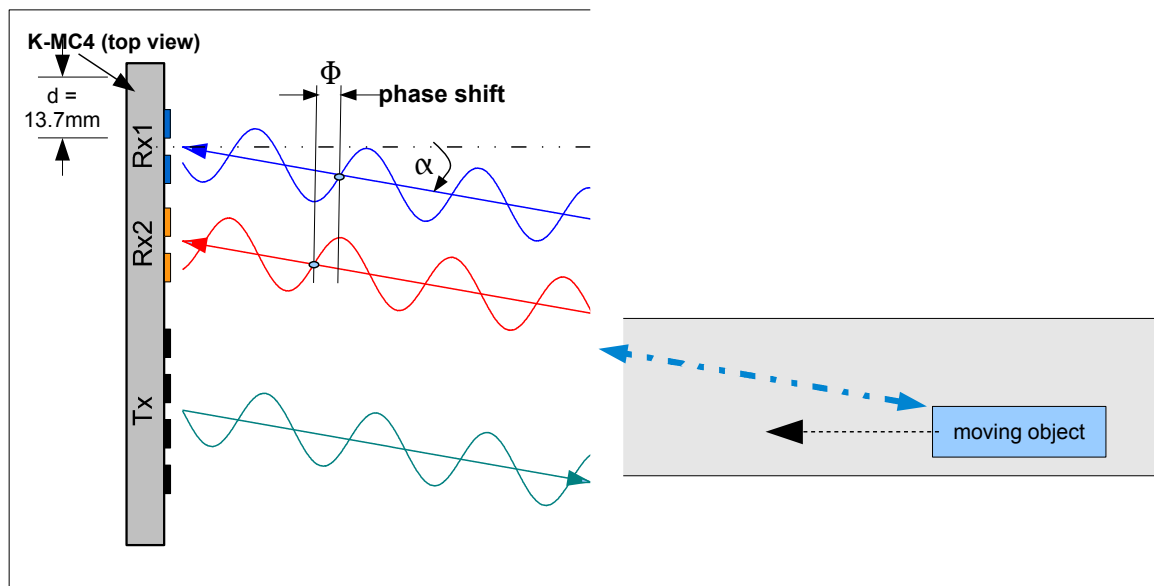


Fig. 8: Antenna Rx1 receives a delayed reflection

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

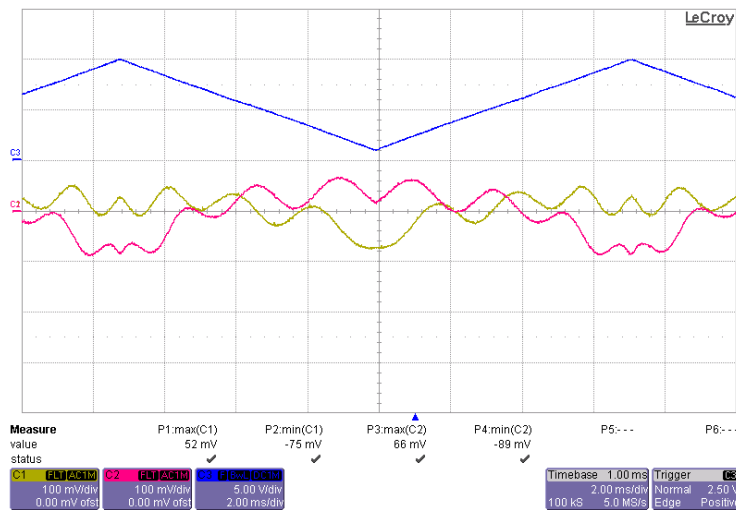
Object's angle in ° can be calculated as $\alpha = \frac{\Phi}{k}$
 $\alpha = \text{objects angle}$
 $\Phi = \text{phase shift } I_x - Q_x$
 $k = 6.7$

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 $+90^\circ$ 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 $T_M = 14\text{ms}$.

Modulation depth $f_M = 160\text{MHz}$

IF output freq. $f_b = 450\text{Hz}$

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. 9: Ix and Qx Output FMCW signals with triangle VCO and $df = 80\text{MHz}$

Distance calculation

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

For legend refer to Fig. 9

R Range, distance to target

c_0 Speed of light ($3 \cdot 10^8 \text{ m/s}$)

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 $V_{cc}/2$.

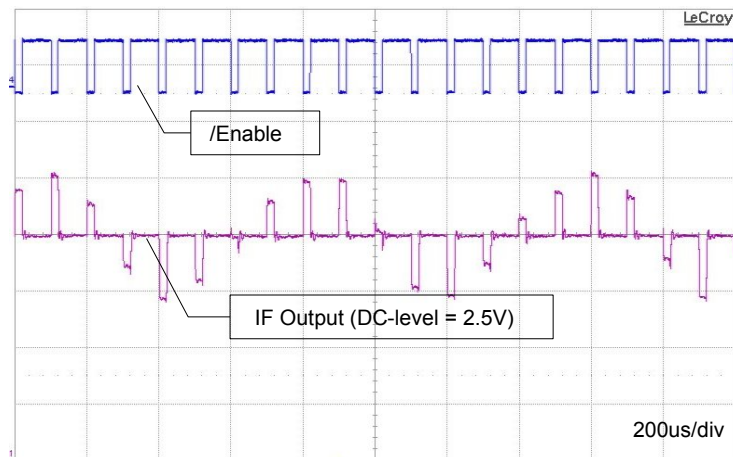


Fig. 10: Sampled Doppler signal (1.3kHz) at IF I or Q outputs

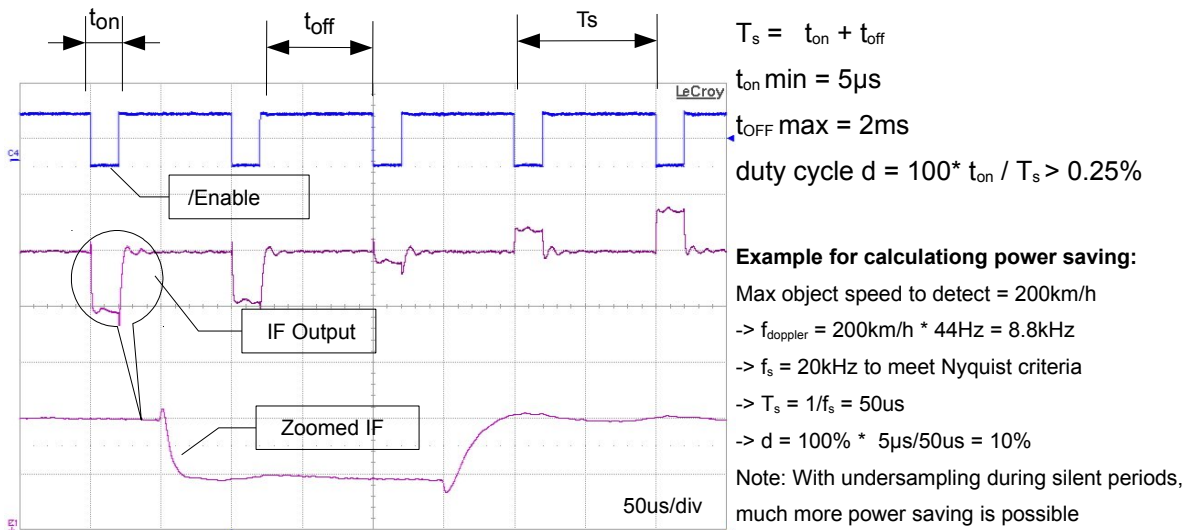


Fig. 11: Detailed RSW sampling behaviour

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 $> 5\mu s$ 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 $> 5\mu s$ or $> 1/\text{bandwidth}$ 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 | $\sigma^{1)}$: | 1m ² approx. for a moving person >50m ² 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), housing of the module and other factors.

With K-MC3, you can achieve a maximum range of more than 500m when using high resolution AD-converters and selective FFT algorithms.

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 | 2018-11-02 | |

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