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Abstract

RFbeam's K-XC1 Hardware is a demonstration system for a continuous wave (CW) Radar system for measuring distances to moving and stationary objects with a high resolution. Basically there exist different possibilities to measure distances with Radar:

Frequency Modulated Continuous Wave (FMCW)

Here the frequency of a RF carrier is linearly modulated. Stationary and moving objects can be detected, since they now generate a low frequency signal on the IF outputs depending on their distance. This algorithm can e.g. be implemented in our K-MC1 modules. To have a good resolution, a high modulation bandwidth is necessary. When respecting the 250MHz bandwidth allowed for a 24GHz system, a resolution of 0.6 meters can be achieved. Higher resolution is possible when also the phase is involved, but in this case close objects can cancel out each other.

Frequency Shift Keying (FSK)

The RF frequency is switched between two discrete frequencies, which are close together (spacing e.g. 1MHz at 24GHz). For both RF frequencies the resulting Doppler signal on the IF output is reconstructed by a sample and hold (S&H) circuit. A moving object generates a Doppler signal for both frequencies. The distance information is available in the phase between these two Doppler signals. This principle only works for moving objects. The resolution is better compared to FMCW, but a high effort has to be taken to distinguish the distances of several concurrently present objects. This algorithm can also be implemented with a K-MC1 module.

Pulse Radar

This system transmits a very short RF pulse and measures the time it takes until the pulse was reflected by the object to be measured and returns to the Radars receiver antenna. The shorter the pulse the better the resolution of the system. To separate two objects with a distance of 10cm, a maximum pulse length of 300ps is allowed. The pulse repetition rate defines the maximum distance that can be measured. This system is used in airborne radar. The drawback is the high pulse RF power needed due to the low duty cycle.

The K-XC1 works similar to a Pulse Radar, but uses pulse compression technology to enlarge the transmitted pulse to a continuous wave signal. So it is possible to work with low power and still having a reasonable range coverage. This is called a Pseudo-Noise (PN) radar.

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Principle of Operation

Pseudo-Noise (PN) radar is a CW-radar using very wideband pseudo-random codes, e.g. m-sequences, to stimulate the test scenario. The transmitted signal is periodic and hence deterministic. On the receiver side the original can be reconstructed by the use of a correlator.

The following block diagram shows the structure of a K-XC1:
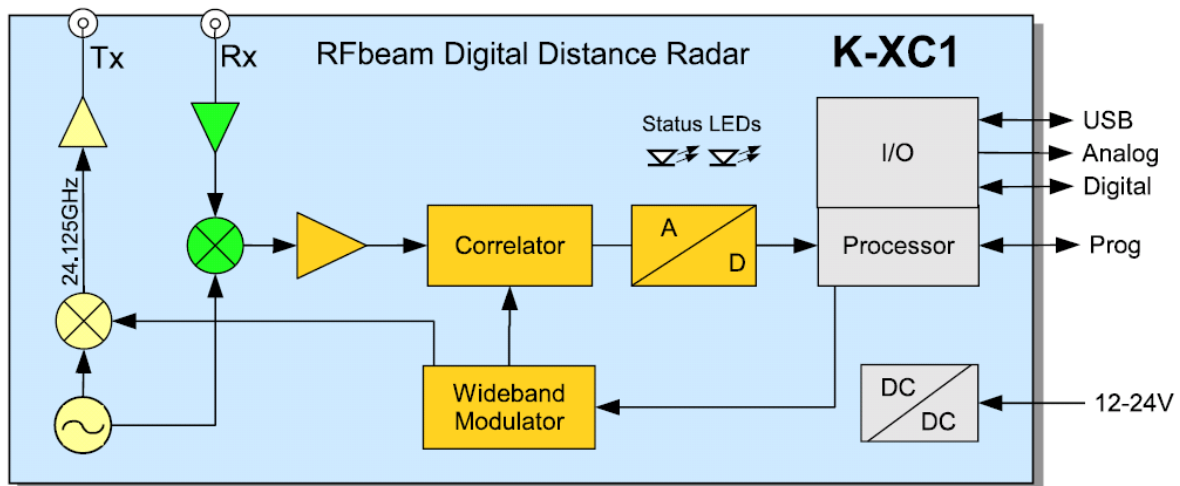
A microwave source generates the carrier frequency of 24.125GHz. This signal is BPSK-modulated by a PN code which is created in the 'Wideband Modulator'. The bandwidth of this PN-sequence can be digitally adjusted between 1GHz and 4GHz. The output of the BPSK-modulator now has a bandwidth of up to 8GHz and is further amplified before it is fed to a TX-connector (2.92mm RF connector). Here you can connect a broadband antenna, e.g. a horn-antenna.

The received signal which K-XC1 receives on the RX-connector is amplified by a low-noise amplifier (LNA) and downconverted by a first mixer. This IF signal now has a bandwidth of up to 4GHz and is correlated with the same PN-sequence generated by the Wideband Modulator. The resulting signal from the Correlator is A/D-converted and further processed by a CPU. This CPU calculates a time-domain signal which looks very similar to the output of a conventional Pulse Radar and outputs it at the Analog Output port. The K-XC1 demonstration system is also offered with a digital output, where the same information is output in a digital format instead of the analog stream.

A built-in USB port can be used to configure the operating conditions of the K-XC1 radar. All setups can be stored in a non-volatile memory, so the system can also be used without a PC.

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Quick Setup

For commissioning the K-XC1 follow these steps:

- **Connect an antenna to the RX- and TX-port**
  You can use the supplied horn-antennas or also an own one. Please make sure the antenna is able to radiate a 24GHz +/- 4GHz carrier. So normally Patch-Antennas can't be used. The larger the antenna, the smaller is the beam and the larger is the reach of this system. The supplied horn-antennas have an opening angle of 40x30° and can detect persons in a distance of up to 10-15 meters

- **Connect an oscilloscope to the analog output**
  The analog output can be found on the 6-pin connector on one side of the K-XC1 system. Attach the supplied cable and connect your oscilloscope to Pin 5 (signal) and Pin 6 (ground). All other pins on this connector are for the (optional) digital output and should be left unconnected.
  Adjust the oscilloscope to 500mV/Div vertical and 200us/Div horizontal. Set the trigger to leading edge at approx. 200mV. Use DC-coupling.

- **Connect the power supply**
  K-XC1 uses a voltage between 12 .. 24VDC. You can use the supplied wall plug transformer or an own power supply. Current consumption is around 300mA @ 24V DC.

- **Optionally connect a PC to the USB port**
  To adjust the setting, a PC can be connected. Windows will recognize a new hardware and install a virtual COM port VCP. If windows is asking for a device driver, it can be downloaded from the FTDI homepage: http://www.ftdichip.com/Drivers/VCP.htm. After the driver was installed, check the COM port number with Windows' device manager. To connect to K-XC1 you have to start a terminal program (e.g. Hyperterminal) and use the COM port number found in the device manager. Use the following communication settings: Baudrate = 115200, 1 Stopbit, 8 Databit, No Parity, No Handshake. After pressing the <ENTER> key you should see a configuration menu on your screen.
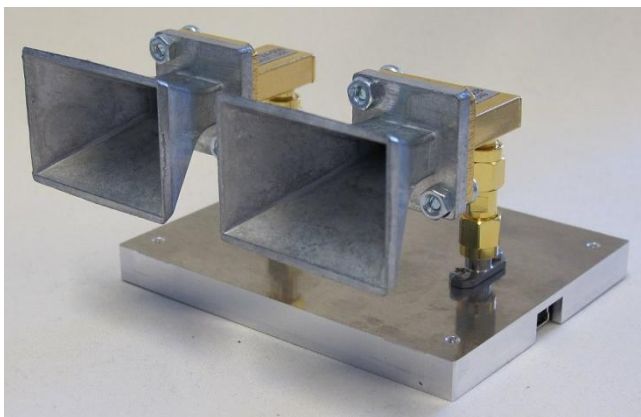
K-XC1 with 2 mounted horn-antennas

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On your oscilloscope you should see a picture similar to this one:
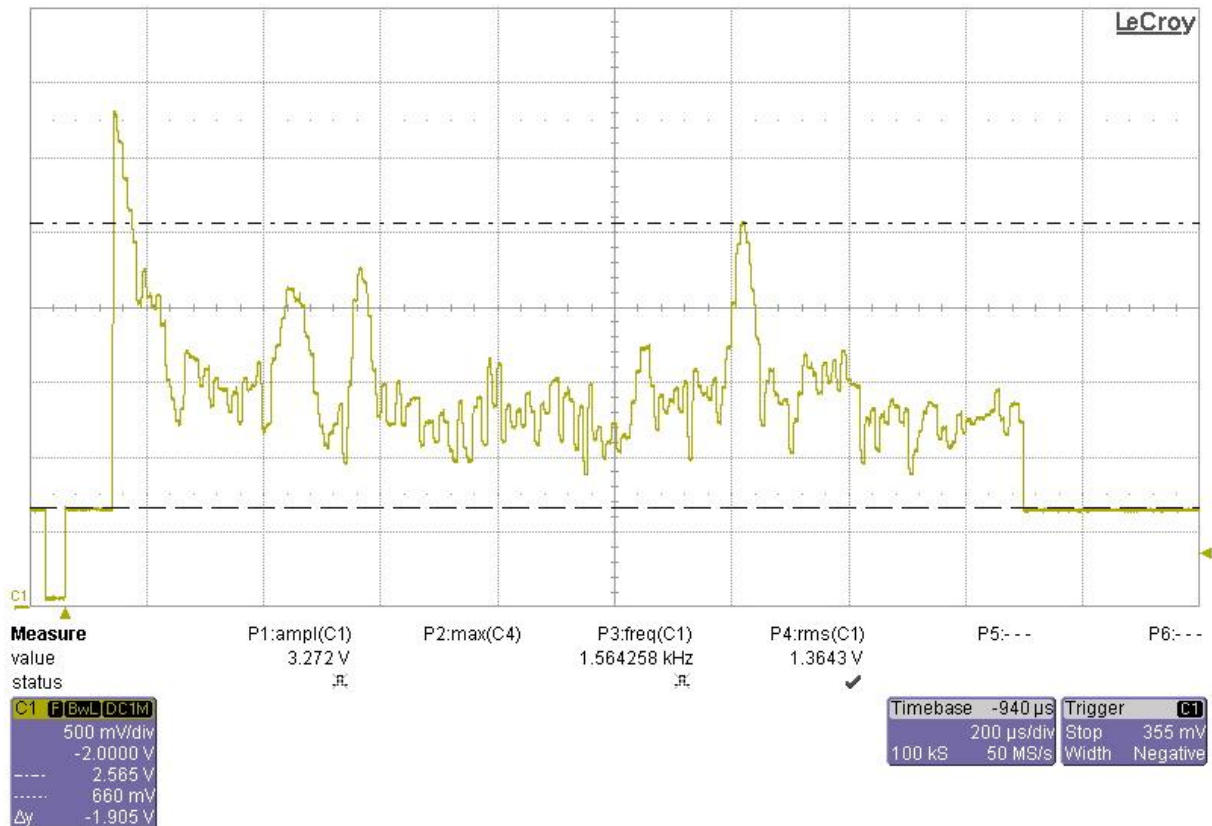
On the left side you see a negative pulse from 600mV to (nearly) zero. This is the pulse used for triggering. Directly after the pulse the measurement starts. In this picture the first 10 points are blanked so we have a 'zero' for approx. 80us. Depending on the used bitrate each distance has the following length in the time-signal:

4GBit/s:	Length: 8.192us	Resolution: 3.75cm	max. Distance: 9.5m
3GBit/s:	Length: 10.912us	Resolution: 5cm	max. Distance: 12.7m
2GBit/s:	Length: 16.384us	Resolution: 7.5cm	max. Distance: 19m
1GBit/s:	Length: 32.768us	Resolution: 15cm	max. Distance: 38m

For this picture we used 4GBit/s, so this 'blanking' has a length of 37.5cm and removes local echos very close to the antenna. On the horizontal axis we now see the distance between the antenna and the object(s), on the vertical axis we see the reflectivity. The closer the object and the higher the RCS of this object, the higher is the peak. In the picture we see e.g. a peak 1.16ms after the leading edge of the trigger. This pulse was created by a wall in a distance of (1.16ms / 8.192us * 3.75cm) 5.31 meter. K-XC1 measures and displays the first 256 distance steps. Larger distances could be implemented upon request. In this picture we have also 'blanked' every pulse > 200 (what is 7.5m) this is the reason for the 'zero' after 1.64ms. The noisefloor of this system is at approx. 1300mV, what corresponds to -91dBm. In this logarithmic display, we have a vertical resolution of approx. 40mV/dB.

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Characteristics

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Unit
Operating conditions						
Supply voltage		V_{cc}	12	24	26	V
Supply current	V_{cc} = 24V	I_{cc}		300		mA
Operating temperature		T_{op}	-20		+60	°C
Storage temperature		T_{st}	-20		+80	°C
Transmitter						
Carrier frequency	T_{amb}=-20°C .. +60°C	f_{TX}	24.000	24.125	24.250	GHz
Output power	Measured on SMA connector	P_{TX}	-6	-2	+2	dBm
Spectral width	Measured on SMA connector	f_{full}	20		28	GHz
Spectral density	Outside of ISM band, BW=100kHz	P_s			-30	dBm
Frequency drift vs temperature	V_{cc}=24.0V, -20°C .. +60°C [Note 2]	Δf_{TX}		-0.3		MHz/°C
Spurious emission	According to ETSI 300 440	P_{spur}		-30		dBm
Receiver						
Antenna Gain	Supplied horn antenna	G_{Ant}		17		dBi
Receiver sensitivity		P_{RX1}		-91		dBm
Overall sensitivity		D_{system}		-106		dBc
IF output						
IF resistance	Analog output	R_{IF}		100		Ω
IF frequency range	-3dB Bandwidth, IF load = 1kΩ	f_{IF}	0		300	kHz
IF output offset voltage	No objects in range, logarithmic output	U_{IF}		1300		mV

Configuration via USB

Several setting of K-XC1 can be adjusted using a PC running a terminal software and a VCP (virtual COM port) driver. After pressing <ENTER> on your terminal software, a screen similar to this one will appear:

```
RFbeam K-XC1  V0.40
===================

[1] Modulation      PN        [0=None,1=Pulse,2=Square,3=PN]
[2] Bitrate         4GBit/s   [1..4GBit/s]
[3] DAC Output      Log       [0=None,1=Distance,2=I,3=Q,4=Mag,5=Log,6=Dig]
[4] ADC Delay       2         [0..9]
[5] Mean            10        [01..99]
[6] Start Range     020       [000..255]
[7] End Range       255       [000..255]
[8] Learn                     [0=delete, 1=learn]
[9] Store to EEPROM
[a] Range extend    0         [0..3]
[b] Option Data     192       [000..255]

-->
```

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To change any of the above parameter, you can type the number corresponding to the parameter (e.g. ‚1' for changing the modulation) followed by the value you want set (e.g. ‚3' to set ‚PN') and press <ENTER>.

Example:

23<ENTER>   Sets the bitrate to 3GBit/s
13<ENTER>   Carrier is modulated with a PN sequence

Here is a description of the meaning of these parameters:

Modulation
The modulation type used by the Wideband Modulator can be adjusted. The only meaningful setting is 'PN':

- **None**
  The carrier is not modulated, only a unmodulated CW carrier at 24.125GHz is radiated
- **Pulse**
  The system emits short pulses instead of a PN sequence. This results in a heavily decreased sensitivity
- **Square**
  The carrier is modulated by a square wave. This is used for tests only
- **PN**
  The carrier is modulated by a PN sequence.

Bitrate
Defines the bandwidth of the transmitted PN sequence. This also affects the resolution and the maximal distance which can be measured:

- **4GBit/s**
  Resolution: 3.75cm, max. Distance: 9.5m
- **3GBit/s**
  Resolution: 5cm, max. Distance: 12.7m
- **2GBit/s**
  Resolution: 7.5cm, max. Distance: 19m
- **1GBit/s**
  Resolution: 15cm, max. Distance: 38m

Other resolution and max. Distances can be implemented upon request.

DAC output
The K-XC1 will output the calculated result in analog form. This setting defines which signal / information is available on this output:

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- **None**
  K-XC1 does not generate any output signal
- **Distance**
  The position of the 1st peak is converted into an analog output voltage
- **I-Channel**
  Internal signal, can be used to calculate doppler speed of a moving object or to increase the resolution by using phase information
- **Q-Channel**
  Internal signal, can be used to calculate doppler speed of a moving object or to increase the resolution by using phase information
- **Magnitude**
  Amplitude of the reflected signal (linear)
- **Logarithmic Magnitude**
  Amplitude of the reflected signal (logarithmic)
- **Digital**
  Beginning from Software-Version V0.20 it is also possible to output the data in digital format (see chapter 'Digital Output Stream'). This mode can be selected her. When the digital output is selected, the analog output is disabled.

ADC Delay
This setting allows to define the sampling point of the internal AD-converter. Adjusting this setting will reduce the noise, but will lower the update rate. Default setting: 2

Mean
K-XC1 will do an averaging of several distance information before an output signal is calculated. This factor defines how much averaging is used. A larger number will reduce the noise, but will lower the update rate, Default setting: 10

Start Range
This value is used to blank the first n measurements directly after the trigger position. This can be used to remove the local crosstalk inside the device or to compensate for RF cables between the unit and the antennas. Default value: 10

End Range
K-XC1 always measure 256 distance points behind the trigger (upon request this number can also be increased). If in your application you are not interested to see the full distance range, it can be narrowed by this parameter. If the measurement range is narrowed, unused distance points are blanked. The update rate of the system is unchanged!

Learn
This function can be used to 'learn' a given situation. After that command the output shows the difference between the actual measurement and the learned value. Makes only sense, if the output format is set to 'Magnitude'. A learned value can also be removed, in this case K-XC1 returns to its normal operating method.

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Store to EEPROM

The actual parameters will be stored to the internal memory (except learned values, which are **not** stored). When the power is switched off and on, these parameters will immediately be loaded and used.

Range extend

This function allows it to measure targets also in a bigger distance. The K-XC1 module still outputs 256 distance information points, but these points are calculated of several distances. If you set Range extend to 1 always 2 measured points are converted into 1 displayed point what extends the measurement range by a factor of 2:

0   Standard mode. Each measured point corresponds to the displayed point
1   Extend by 2: 2 measured points are combined to 1 displayed point
2   Extend by 4: 4 measured points are combined to 1 displayed point
3   Extend by 8: 8 measured points are combined to 1 displayed point

It is not recommended to use this function (set a value different of 0) without a high-gain antenna.

Option Data

The K-XC1 module has several internal settings which can be activated or deactivated by this value. Option Data is a bit-coded 8bit value, where currently 2 bits are used:

Bit 7: Control Speed of digital output (0=115'200 Bit/s, 1=921'600 Bit/s)
Bit 6: Data Stream Content (0=Include Logarithmic Magnitude, 1=Only I/Q is sent)

To activate both functions, this value has to be set to $2^7+2^6=192$

Digital Output of Datastream

Software version V0.20 and higher also support a digital output. This can be selected in the main menu. When activated, the analog output is disabled and instead of this the digital representation of measured values is presented on the output connector:

Pin 4: Digital signal output, serial format, 3.3V levels
Pin 6: Ground

The signal voltages are 3.3V, so to connect a PC the use of a level-shifter or a USB-converter is necessary. Possible devices are available from FTDI: http://www.ftdichip.com/Products/Cables/USBTTLSerial.htm.

On this port the following data are permanently sent:

- **I-Data**
  256 Points with a resolution of 16Bits (4 MSB bits are always '0')

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- **Q-Data**
  256 Points with a resolution of 16 Bits (4 MSB bits are always '0')
- **Logarithmic Magnitude**
  256 Points with a resolution of 16 Bits
  This value is only sent, when Option Bit 6 is cleared (see above)

These data are sent with 115'200Bit/s or 921'600Bit/s (depending on the option byte), without any handshake with 8 Bit Data, 1 Stopbit and no parity. Each frame consists of 1544 Bytes and takes 134ms for transmission (1032 Bytes and 11ms with both option bytes set). There is no gap between the frames. Each frame has the same structure:

SYNC	A sequence of 8 Bytes used to synchronize the frame. The sequence is: 0x24, 0x02, 0xa2, 0xe1, 0x5a, 0xd6, 0x19, 0x73
I-Data	512 Bytes containing 256 Points of I-Data. For each point 2 Bytes are sent, High-Byte is sent first, followed by the Low-Byte. So the sequence is: - I-Data[0] High - I-Data[0] Low - I-Data[1] High - I-Data[1] Low - ... Beginning with SW-Version 0.40, the offset value is compensated. K-XC1 still transfers unsigned values, so a constant offset of 2048 is added to each value
Q-Data	512 Bytes containing 256 Points of Q-Data. Structure is the same as for I-Data
LogMag-Data	512 Bytes containing 256 Points of Logarithmic Magnitude. Values are sent as unsigned shorts with a resolution of 16 Bits. Structure is the same as above This value is only sent, when option bit 6 is cleared

Datasheet Revision History

Version: 0.1
Date: September 10th
Changes: Initial Release
Version: 0.2
Date: December 14th, 2011
Changes: Description for digital output added
Version: 0.4
Date: September 10th 2012
Changes: Range extend and Option byte added