Features



- Universal Doppler Radar signal processor
- Complete I/Q Radar sensor interface
- Complex FFT based signal processing
- Double detection distance compared to traditional solutions
- Object speed and direction detection up to 250km/h
- Efficient adaptive interference suppression
- Stand-alone or hosted operation
- Evaluation Kit available

1 Applications

- Movement detectors
- Lighting control systems
- Security applications
- Object speed detection

2 Description

2.1 Application Example

RSP1 contains all Doppler signal processing.
Up to now, development of Doppler Radar signal processing has been a time consuming matter and needed experience in analog and digital electronics.
With RSP1, typical applications need minimal external components. Configuration can be made by switches and potentiometers or fully digital via serial interface.

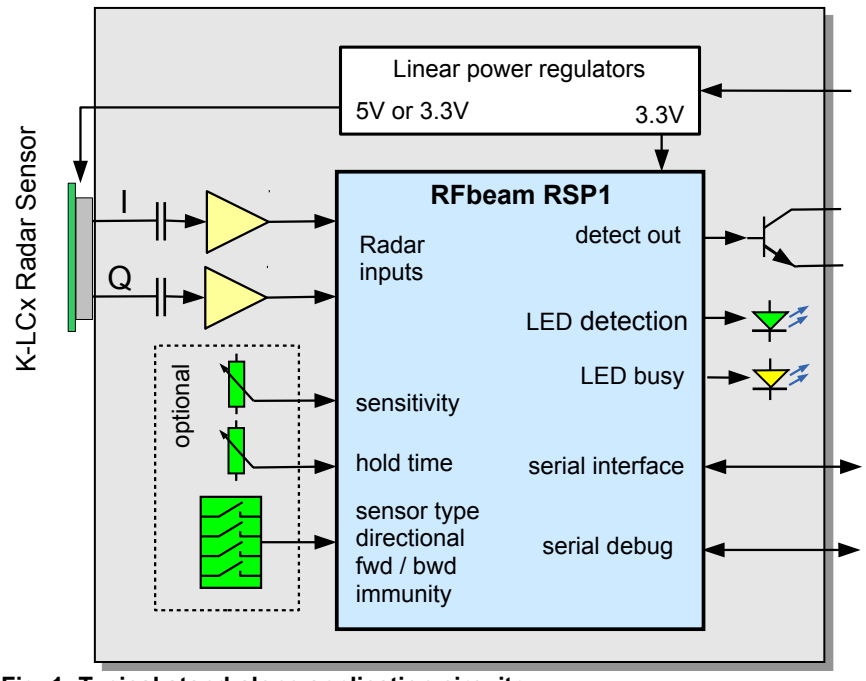


Fig. 1: Typical stand-alone application circuitry

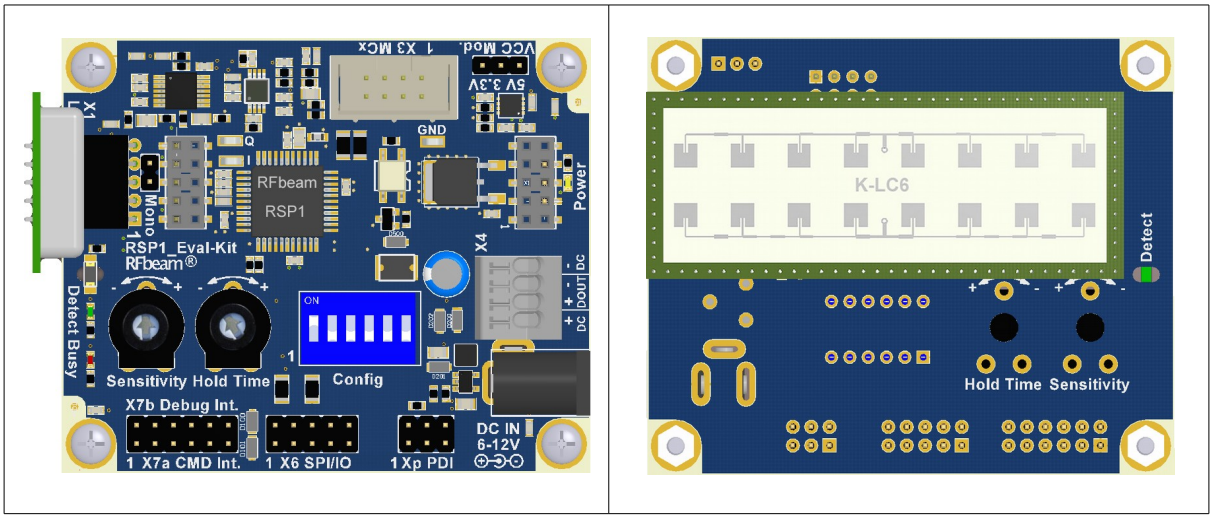
2.2 RSPx Family

RSP1 is the first member of RFbeam Radar signal processors.
The RSPx family helps users concentrating on their application know-how instead of investing time and money in raw signal processing.
RSP1 contains all signal processing for Doppler Radar. It covers slow movement detectors as well as speed estimators up 250km/h.
It can be used as stand alone processor or as a co-processor in higher complexity systems.
User has only to add an input amplifier and digital output drivers and gets a high performance detection system.
Evaluation and development is supported by the **RSP1 Evaluation Kit** reference design.

2.3 Key Data

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

2.4 RSP1 Evaluation Kit



RSP1_Eval-Kit; Left: K-LC2 sensor on front connector; Right: Backside equipped with K-LC6 sensor

With RSP1 Evaluation Kit, you may explore most features of RSP1 working with different RFbeam sensors. 5 different sensors are included in the kit.
Using a RSP_Terminal you have access to more than 30 parameters. Explore FFT, noise and other signals with the RFbeam SerialScope PC Software, that.also makes part of the kit.
All schematics, PCB layout and BOM are included as a reference.

3 Sensor Configurations

RSP1 Chip may be used with one or two sensors. Sensors can not be used in parallel, but as alternative sensor connected to the Alt_RADAR inputs. Inputs can be selected by parameter ***S01***.

Channels	Sensor examples	Comments
1 ("mono")	K-LC1a, K-LC3	Lowest cost. Mostly used for indoor applications
2 ("stereo")	K-LC2, K-LC5, K-LC6, K-MC1	Directional detection, excellent interference suppression

Table 1: Sensor Configurations

3.1 Single channel vs Dual channel (I/Q) processing

RSP1 can be operated with dual channel ("stereo") I/Q sensors as well as with one channel ("mono") sensors (see Table 1: Sensor Configurations).

Feature	Dual channel	Single channel
Directional detection (receeding / approaching)	x	
Interferenc suppressin (fluorescence lights, vibrations and others)	x	
Noise suppression (better sensitivity)	x	
Lower cost		x

Table 2: Dual channel versus single channel comparison

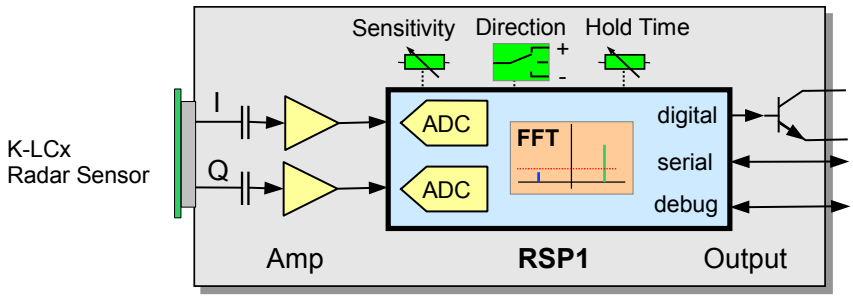


Fig. 2: Typical dual channel architecture

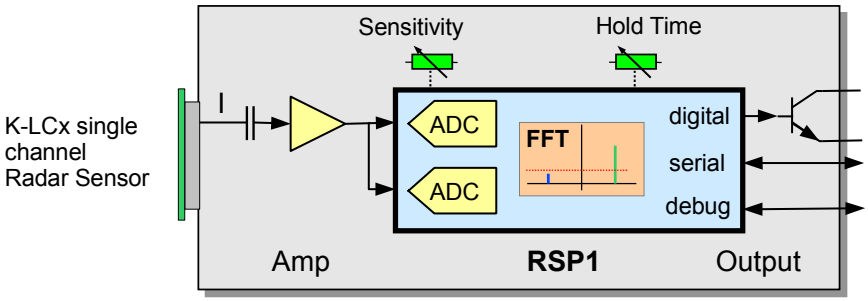


Fig. 3: Typical single channel architecture

4 RSP1 Architecture

4.1 Data Acquisition

An internal, programmable differential amplifier allows gains from 1 to 16.
RSP1 works with 2 12Bit ADCs, sampling rate is selectable between 1'200Hz up to 22.5kHz in 10 steps.
This corresponds to maximum speeds from 13km/h to 250km/h.

4.2 Data Processing

Processing is based on a complex FFT and on an adaptive noise threshold. Many parameters allow adjusting and optimizing the performance for many different applications.

Advantages of FFT

FFT stands for Fast Fourier Transform, that allows signal processing in the frequency domain (see details on http://en.wikipedia.org/wiki/Fft).
Processing of the Quadrature Doppler signals is performed by a complex FFT. Using FFT results in much better performance than using simple comparator designs or time domain processing.

The RSP1 FFT implementation leads to sophisticated movement and speed detectors:

- Better S/N (21dB with 256pt FFT) → 2 to 3 times larger detection range
- Inherent object speed detection
- Reliable distiction between approaching / receding objects
- Efficient interference suppression through complex FFT (fluorescent light, rain, vibrations …)
- Narrowband filtering of known interference frequencies
- Selective and adaptive noise threshold capability

RSP1 Hardware Architecture

The processor architecture allows data acquisition and processing in parallel. Only a few external components are needed thanks to the high integration level including EEPROM and precision clock generator.

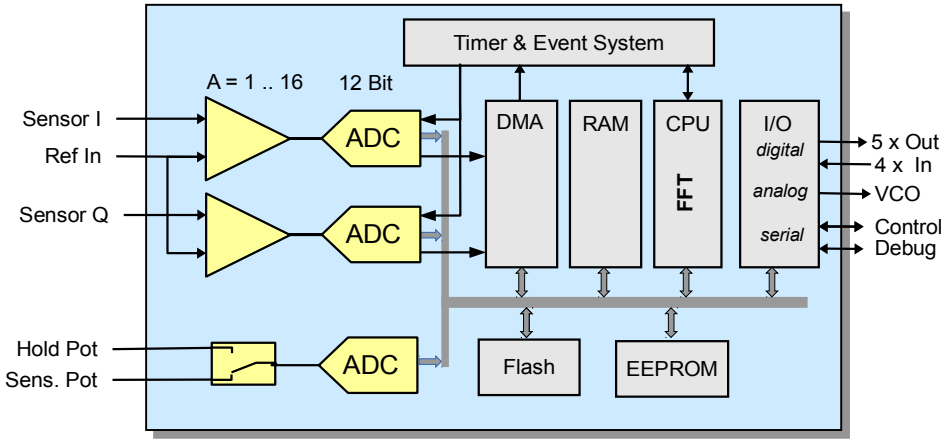


Fig. 4: RSP1 simplified block diagram

5 Performance data

5.1 Overview

RSP1 is working at an internal clock frequency of 32MHz.
Radar I and Q signals pass a programmable gain amplifier (A=1 to 16). A 12Bit differential ADC running at a 500kHz clock converts the amplified signals. I and Q channels are acquired quasi parallel with a time shift of 2us.
Complex 256pt fixpoint FFT runs in parallel to the data aqcuisition. Time signal passes a Hanning window and is then processed by the FFT.
Acquisition is interrupted only by a 300us windowing calculation time. All other signal processing is performed in parallel to the data acquisition.

5.2 Internal Timing

Sampling timing depends on setting of parameter S03 (sampling rate). This results in following FFT resolutions and measuring speed ranges:

Parameter ***S03*** (hex)	fs (sampling freq.)	df (resolution)	max. speed	remark
01 … 08	S03 value * 1280Hz	5Hz to 40Hz	4.5km/h to 116km/h	allows direct readout of frequency
09	11.254kHz	44Hz (1km/h)	127km/h	allows direct readout of speed in km/h
0A	22.528kHz	88Hz (2km/h)	255km/h	allows direct readout of half speed

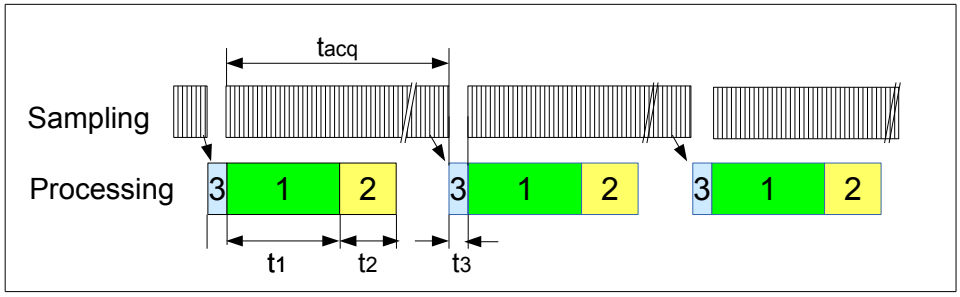


Fig. 5: Acquiring and processing executes in parallel. A small gap (t3) occurs during windowing

t_{acq} *= 256 * 1/fs = 11.4ms … 200ms (with fs = 22.5kHz … 1280kHz)*
t_1 *= 7.7ms FFT*
t_2 *= 2ms Logarithmic result conversion*
t_3 *= 0.3ms Hanning window calculation*

ADC Sampling of both channels is performed quasi-parallel with a maximum time shift of 2us max.

5.3 Response time

Response time on parameter requests on sampling rate *fs* (parameter S03):
t_{Rmin} *= 11.4ms * A03 value (S03 = 0A)*
t_{Rmax} *= 200ms * A03 value (S03 = 01)*

Update time on result parameters and digital outputs depend on sampling rate *fs* (parameter S03), on and immunity value (parameter A03) and on FFT avaraging (parameter S02).
t_{UPDmin} *= 11.4ms * A03 value (S03 = 0A, S02 = 00) or 22.8ms * A03 value (S02 = 01)*
t_{UPDmax} *= 200ms * A03 value (S03 = 01, S02 = 00) or 400ms * A03 value (S02 = 01)*

See also chapter 8.4 Sampling Rate and Frequency Resolution

5.4 Internal signal representation

RSP1 computes the complex amplitude spectrum of the input I/Q signals.

Analog conversion is performed with 12Bit resolution. In order to get better accuracy in fixpoint calculations, ADC result is left shifted by 4 bits resulting in a value range from -32'768 … 32'767.

All internal processing and signal parameter settings are based on logarithmic FFT results. This allows optimal handling of small signals and fits well to the Radar signal vs. object distance behaviour.

Parameters returning levels such as *$R02, $L00, $D00* return logarithmic scaled results

Step	Processing stage	Value range	Remark
1	Input signal (Radar Common input = 1.65V)	3.3Vpp (A=1) .. 206mVpp (A=16)	resolution 806µV/bit @A=1
2	Internal amplification	A = 1, 2, 4, 8, 16	Parameter S09
3	AD conversion 12 bit signed	-2048 … + 2047	2 channels in parallel
4	Internal representation * 16	-32768 … + 32767	used to enhance FFT accuracy
5	16/32 bit fix point FFT with Hamming window	magnitude 0 … 23'168	
6	log conversion in fixpoint form x.yy	log10 as integer: **0 … 437**	corresponds to 0 … 4.37

Table 3: Internal processing stages

Value	Range / conversion	Remark
Input voltage at Radar input	1.65Vp = 1.17Vrms	Gain A = 1; parameter **S09= 0**
Input voltage at Radar input	193mVp = 72.9mVrms	Gain A = 16; parameter **S09 = 4**
Maximal internal signal level	437	logarithmic magnitude level * 100
Internal signal level relation to dB	dB ≙ value / 5	
Internal FFT magnitude at 1Vrms input	[dBVrms] = value - 86	430 / 5 = 86
Max. input frequency	640Hz .. 11.25kHz	sampling rate / 2 (see parameter S03)
Frequency resolution	sampling rate / 256	5Hz ... 88Hz
Speed resolution	0.1km/h ... 2km/h	corresponds to 5Hz to 88Hz

Table 4: Useful signal level conversions

6 Detection Algorithm

Detection algorithms are based on the complex FFT (Fast Fourier Transform) of the I and Q analog signal inputs.FFT output logarithmic in order to get good signal processing conditions for both large and small signals.
FFT represents in fact many narrowband filters that reduce noise amplitude. RSP1 uses 256 point FFT resulting in 128 bins (filters) for each forward and backward movements.
This kind of detection results in a much better sensitivity than simple comparator solutions.
Approximative gain in S/N ratio by using a 256pt FFT is 10 * log(128) = 21dB. In reality, more than double detection range can be reached compared to comparator solution.

Signals and processing behaviour may be explored by the RFbeam tool RSP1_Scope, connected at the serial debug port (see 7.5 Serial Debug Interface)

6.1 Adaptive noise detection

The advanced noise detection technique leads to the outstanding sensitivity of the RSP1 solution. Noise is measured separately for each frequency represented by the FFT results. Two stages in noise measurement exist:

1. After power-on, an initial noise curve is built by measuring the mean of each FFT frequency bin. Number of means (measuring time) can be selected by Parameter ***S04.***

2. Adaptive mean is continuously built during operation. Adaptation time constant ca nbe selected by Parameter ***S0C***

If using I/Q stereo sensors (like K-LC2, K-LC5 etc.), noise cancellation is very efficient, because movement Doppler signals can be efficiently distinguished from noise signals.

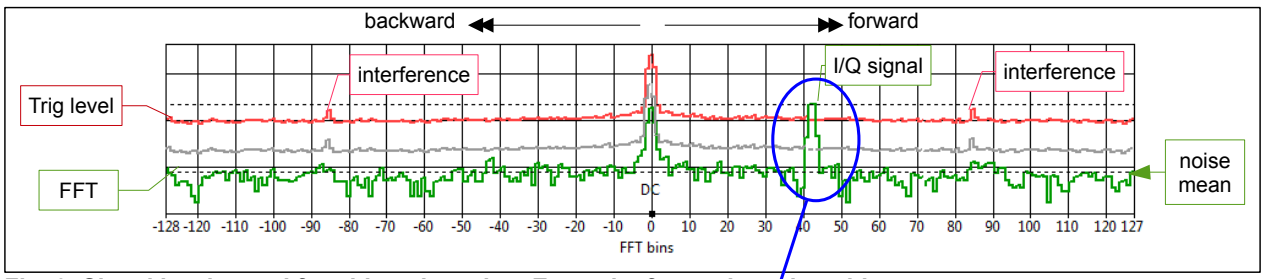
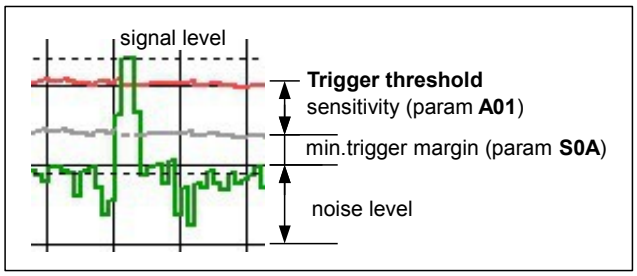


Fig. 6: Signal levels used for object detection. Example: forward moving object

Trigger level results from the sum of adaptive noise threshold (Grey plot) and the sensitivity selected by parameter ***A02***.

Signal in the center is the DC offset caused by the amplifier and ADC converter.



Noise and small signals looks very strong in logarithmic form of the FFT magnitude. Remember that a signal difference of 1mVrms to 2mVrms produces same logarithmic magnitude difference as a difference from 500mVrms to 1Vrms.

6.2 I/Q Signal Processing

RSP1 supports I/Q processing by using complex FFT. I/Q Doppler signals are phase shifted by + 90° or -90°. Those signals appear either in the real(right) plane or in the imaginary (left) plane of the FFT output. Signal in the center is the DC offset caused by the amplifier and ADC converter and can be ignored. (see Fig. 8).

Main advantages of using I/Q sensors compared to single channel sensors:

- Forward / Backward movement differentiation
- Efficient interference suppression
- Vibration suppression

Even if directional detection is not required, I/Q processing allows significantly better immunity suppression.

Doppler I and Q signals in Time domain at RSP1 Radar inputs:

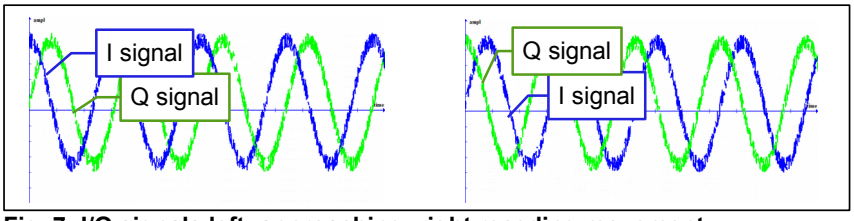


Fig. 7: I/Q signals left: approaching; right receding movement

Doppler signals in Frequency domain, processed by RSP1:

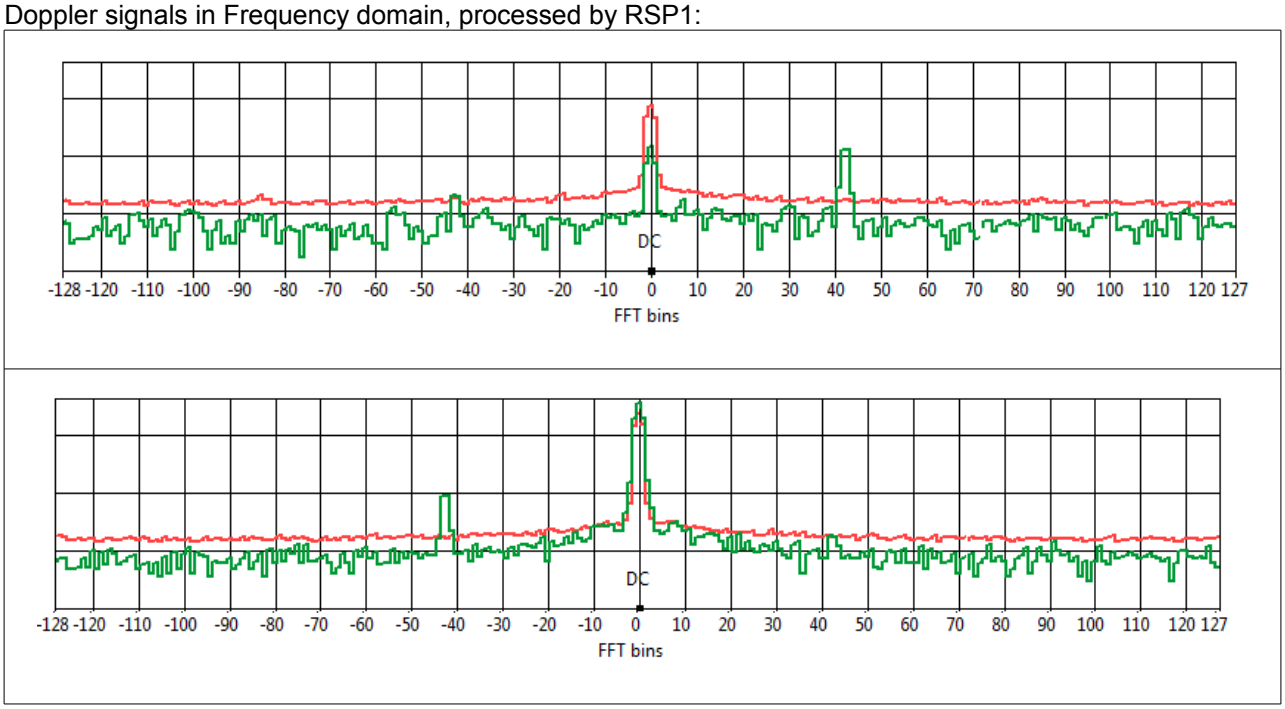


Fig. 8: FFT magnitude of forward moving and backward moving objects

Single channel sensors produce same signal on left and right plane of the complex FFT.

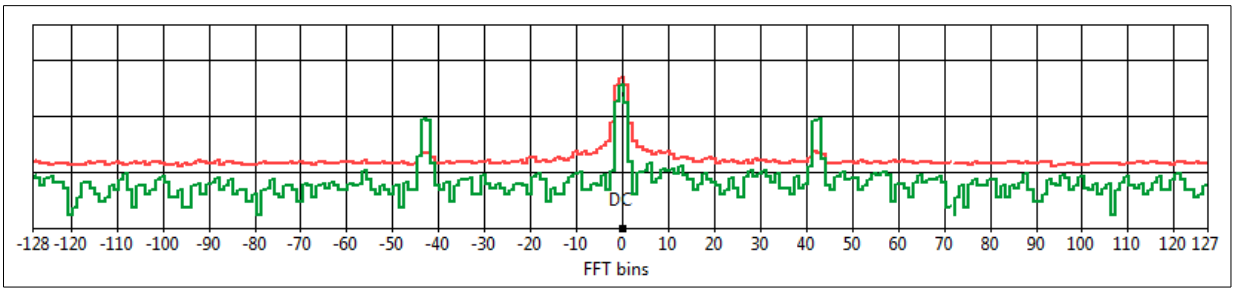


Fig. 9: Single channel signal appears symmetrically in the left and right half

6.3 Interference Filter

Typical interferences appear symmetrically on the left and right plane in the FFT output. Typical noise source are electronic ballasts and fluorescent lights.
Therefore those interference signals may easily be distinguished from I/Q Doppler signals produced by stereo sensor modules:
RSP1 adapts threshold (red line) for noise, but not for real I/Q Doppler signals. See also chapter 6.1 Adaptive noise detection

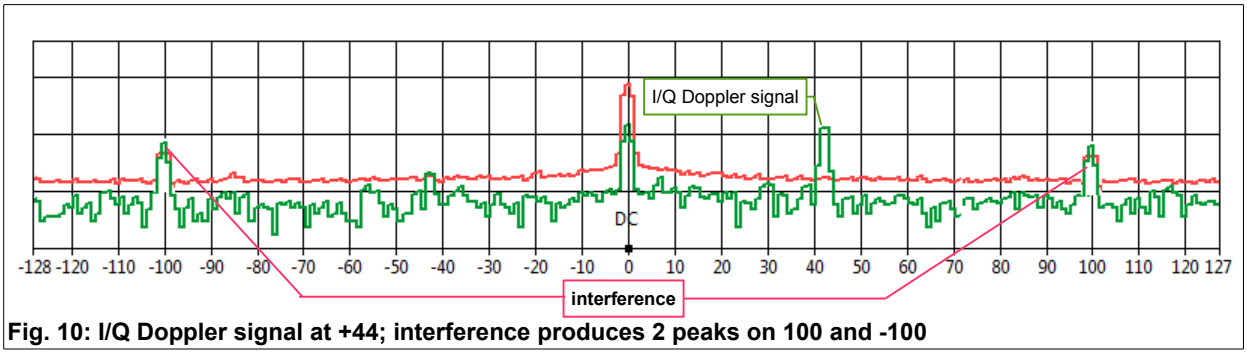


Fig. 10: I/Q Doppler signal at +44; interference produces 2 peaks on 100 and -100

Interferences like in Fig. 10 look different from I/Q Doppler signals caused by movement.
With single channel modules, Doppler signals (Fig. 9) look similar to interferences.

6.4 Random Noise Filter

RSP1 offers different mechanisms in order to suppress influence of stochastic noise:
Random noise produces stochastically distributed peaks in the FFT output and can be reduced by averaging. FFT averaging can be enabled by parameter ***S02.***
Noise peaks exceeding trigger threshold are counted and must exceed a counter threshold adjusted by parameter ***A03***.

6.5 Selective FFT Filter

Up to 8 single frequencies may be suppressed by means of array parameters X20 to X27.
Each value represents an FFT bin, that will be masked out from triggering.
Example:
Mask out frequencies 100Hz and 1kHz at sampling rate 2560Hz (Param ***S02*** = 02).
Set parameter X20=000A and param X21=03E8. For more details see chapter FFT Filter

7 Interfaces

RSP1 provides different interfaces for configuration and control signals. RSP1 can be used as a stand-alone processor or in conjunction with a host controller.

- Command interface: Standard UART interface for parameter settings with 38'400Baud.
- Debug Interface: High speed UART interface for debug purposes with 460'800Baud (Parameter ***S06***).
  This interface acts also as bootloader interface for software updates.
- Digital I/O: Control signals for status LED, digital outputs and optional SPI interface.

7.1 Analog I/O

Please refer to chapter 14 Sample Schematics for details of analog signal handling.
Range of RADAR input signals depend on the internal gain setting by parameter ***S09:***
S09 = 0: range 3.3Vpp; ***S09 = 4:*** 200mVpp.

Pin	Function	Remark
AVcc	Power supply for chip analog section	Decouple well: see Fig. 14
RADAR_AREF	ADC reference voltage	Vcc/2 (1.65V), connect to RADAR_COMMON
RADAR_COMMON	Input reference voltage	Vcc/2 /1.65V) decoupling see Fig. 14
RADAR_I1	Radar in-phase signal (I)	Signal referenced to RADAR_COMMON
RADAR_Q1	Radar in-phase signal (Q)	Signal referenced to RADAR_COMMON
ALT_RADAR_I1	Alternative Radar I input	selected by parameter ***S01***
ALT_RADAR_Q1	Alternative Radar I input	selected by parameter ***S01***
ALT_RADAR_COMMON	Input reference voltage	connect to RADAR_COMMON
HOLD_POT	Optional hold time setting	Range 0 to Vcc/2. Function must be enabled by param. ***S07***
SENS_POT	Optional sensitivity setting	Range 0 to Vcc/2. Function must be enabled by param. ***S06***

7.2 Digital I/O

All digital inputs have internal pull-down resistors and are high active.
Secondary pin functions (IDx) are reserved for future versions.

7.2.1 Mode settings



- Input SETTING_MODE must be tied to Vcc in order to activate the setting inputs.
- Setting inputs are sampled at power ON only
- Settings can be over-written by sending similar software parameter commands

Pin	Function, if high (3.3V)	Remark
SENSOR_MONO	1 channel sensor connected	e.g. K-LC1a, K-LC3
DIR_MONO	no directional processing	detect both movement directions with I/Q sensors also
DIR_BACKWARD	detect receding movements only	DIR_MONO input must be low / left open
IMMUNITY	set extended interference immunity	
SETTING_MODE	enable setting inputs	if low or left open, setting inputs have no effect

7.2.2 Control Outputs

Digital outputs are high active push-pull circuits with typically 10mA driving power.

Pin	Function, if high (3.3V)	Remark
LED_BUSY	RSP is busy and is not detecting	Active during power-on learning
LED_DETECT	Active, as long as movement is detected	including hold time
DETECT_OUT	same signal as LED_DETECT	use for driving external hardware output
LOW_BANDWIDTH	set according to parameter ***S08***	optional use for external amp bandwidth limitation
CMD_TX_ENABLE	*reserved for future RS-485 expansion*	*active during serial transmission*
CMD_TX	Command interface UART Tx	see chapter 7.3 Host Command Interface
CMD_RX	Command interface UART Rx	see chapter 7.3 Host Command Interface
DETECT_SIGNAL	same signal as DETECT_OUT	optional use for digital signaling to host device

7.3 Host Command Interface

This is a 3.3V asynchronous UART interface:
Pins: Input: CMD_RX, output CMD_TX
Physical data: 38'400Baud, 8 databit, 1 stopbit, no parity, no handshake
Protocol: Client-Server protocol. RSP1 acts as server. See 8 Software Parameter Settings

This interface is supported by the RSP_Terminal tool.

7.4 SPI / IO Interface

This interface is reserved for future versions of RSP1.

7.5 Serial Debug Interface

Debug interface provides highspeed parameter access as well as streaming output of I and Q signals and FFT results signals over a serial UART interface.
This is a 3.3V asynchronous UART interface:

Pins:	Input: DEBUG_RX, output DEBUG TX
Physical data:	460'800Baud (parameter ***S0B***), 8 databit, 1 stopbit, no parity, no handshake.
Protocols:	- Streaming protocol, supported by RSP_Scope tool. (see chapters below)
	- Client-server protocol supported by RSP_Scope and RSP_Terminal tool
	- Bootloader protocol. Proprietary, for use with RSP_PROG tool

7.5.1 Cyclic Signal Streaming

Cyclic signal streaming is a continuous data stream with no host intervention except start and stop.
This mode is initiated by commands ***D0001*** and ***D0002*** the **Host Command Interface** .
RSP1 then outputs cyclic binary data frames on **Debug Interface.**
Cyclic output stops at command ***D000*.**

Protocol Item	Binary data items on line DEBUG_TX		Format	Comment
Sync Header	0x24, 0x02, 0xa2, 0xe1, 0x5a, 0xd6, 0x19		7 Bytes	
Mode Byte	0x7a or 0x7f		1 Byte	***D00x1 or D00x2***
1024 or 2048 bytes for "Scope" display	**FFT spectrum**	bin -128 bin -127 ….. bin 127	High, Low Byte	Data Byte 0, 1 **Note 1)** . . Data Byte 254, 255
	Threshold	bin -128 bin -127 ….. bin 127	High, Low Byte	Data Byte 256, 257 **Note 1)** . . Data Byte 510, 511
	I signal	sample 0 sample 1 …. sample 255	High, Low Byte	Data Byte 512, 767 **Note 2)** Data Bytes 766, 767
	Q signal	sample 0 sample 1 …. sample 255	High, Low Byte	Data Bytes 768, 769 **Note 2)** Data Bytes 1022, 1023
2 data bytes strongest object speeds	Forward frequency peak index 0 to 127		1 Byte	0: no peak, >0 speed
	Backward frequency peak index 0 to 127		1 Byte	0: no peak, >0 speed

Table 5: Debug cyclic and single shot protocol

Note 1): FFT and Threshold values are unsigned integers, ranging from 0 to 437. These are logarithmic magnitude values from 0 to 43.7. --> 0 ... 4.37. See chapter 5.4 Internal signal representation for more details on conversions.

Note 2): Present only at commands ***D0002 and D012.***
Streamed I/Q signals are for display and debug purposes because signals may not be continuous.
I/Q Signals come as 16 bit signed interger format (2th complement) and left shifted by 4 bits.
Example: sent 0x0120 must be interpreted: 0x012 (i.e. divide received value by 16).

7.5.2 Single Shot Signal Streaming (recommended)

Single shot streaming is a client server protocol.
This mode is initiated by commands ***D0011*** and ***D0012*** at the Debug **or** Host Command Interface.
RSP1 then outputs one binary data frame on Debug Interface.
Data frame is the same as in the cyclic protocol described before.

8 Software Parameter Settings

Parameters may be set by the command interface. It works at 38.4kBaud, 1 stop bit and no parity.

8.1 Parameter Storage

All parameters except real-time and debug parameters are permanently stored into the processor-internal EEPROM.

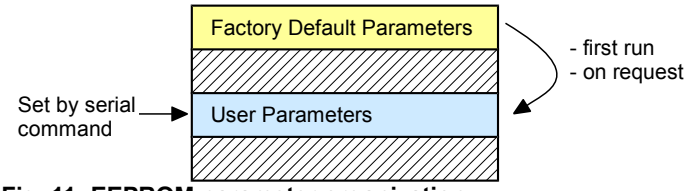


Fig. 11: EEPROM parameter organization

Parameters are divided into classes:

Parameter Type	Par. Class	EEPROM	Purpose
Application parameters	A	Yes	End-User specific settings in final application
System parameters	S	Yes	Application specific parameters
Array parameters	X	Yes	Application specific tables
Real time read parameters	R	No	Real-Time information on processing state
Real time write parameters	W	No	Real-Time commands
Debug parameters	D	No	Debug behavior control

Table 6: Setting parameter types and classes

8.2 Parameter Format

Parameter changes (except class W and D) will be directly stored into the EEPROM user space.
Parameters are set by a serial UART interface and may be set by a host CPU or by an ASCII terminal:

Physical format: 38.4KBaud, 8 bit data, 1 stop-bit, no parity ("8n1")
Format: Request with prefix $; answers come with @ prefix
<CR> represents Enter key (0x0D hex)

$	aa	P	nn	vv	<CR>	Example request	RSP response	Comment
Prefix	Optional Node ID	Parameter class	Number(Hex)	Value (Hex)	"Enter"	$A02<CR> $A0207<CR>	@A0209<CR><LF> @A0207<CR><LF>	Actual value request Set new value

Table 7: Setting parameter format (Node ID is reserved for future RSP1 derivatives)

8.2.1 Error messages (RSP response)

@E01: value out of limits
@E02: parameter number does not exist
@E03: parameter class does not exist
@E04: writing to EEPROM error
@E05: command format error
@E06: UART communication error

8.3 Parameter List

8.3.1 8 Bit Parameters

All values are in hexadecimal notation! Except values marked with *. *Column "R": needs reset*

Param. [1)]	default	min	max	Function	Description	R
Class A	(EEPROM)			**Application Parameters**	End-User specific settings in final application	
A00	*00*	*00*	*00*	*reserved*	*reserved for future use*	
A01	01	00	09	hold time	9: maximum hold time of detection output	
A02	09	00	09	sensitivity	9: maximum detection sensitivity	
A03	03	00	09	immunity	9: maximum immunity against interference	
A04	*00*	*00*	*00*	*reserved*	*reserved for future use*	
A05	00	00	02	direction	0: approaching; 1: receding; 2: both	
A06 *V1.8*	00	00	7F	low frequency (=speed) limit	0: inactive; >0: Low limit (unit = FFT bin: see chapter 8.4)	
A07 *V1.8*	00	00	7F	high frequency (=speed) limit	0: inactive; >0: High limit (unit = FFT bin: see chapter 8.4)	
A08 … A0F	*00*	*00*	*00*	*reserved*	*reserved for future use*	
Class S	(EEPROM)			**System Parameters**	Application specific parameters	
S00	00	00	01	sensor type	0: stereo I/Q sensor; 1: mono sensor (1 channel)	x
S01	00	00	01	Use alternate analog port	1: ADC input on pin 2 and 3 instead of pin 44 and pin 1	x
S02	01	00	01	FFT average	1: averaging on	
S03	02	01	0A	sampling rate	rate = value*1280Hz. except 9: 11.264kHz; A: 22.53kHz	x
S04	10	01	40	start up learn	noise learn cycles after reset	x
S05	01	01	02	active sensors	*reserved*	x
S06	01	00	01	sensitivity pot	1: use potentiometer for sensitivity setting	x
S07	01	00	01	hold time pot	1: use potentiometer for hold time setting	x
S08	01	00	01	bandwidth	1: low bandwidth (digital output used for external filter)	
S09	04	00	03	ADC gain	gain = 2^n: 0 -->1; 1-->2; 2-->4; 3-->8; 4-->16	x
S0A	38	20	50	minimum trigger margin	minimum margin between noise and max. sensitivity	x
S0B	00	00	00	baudrate serial debug port	0:460800; 1:115200; 2: 38400	x
S0C *V1.8*	00	00	FF	threshold adapt. speed	00:max. depending on sampling rate; >0: n*500ms / dB	
S0D … S1F	00	00	00	reserved	*reserved for future use*	
Class R	(immediate)			**Real-Time Read Params**	Read only parameters	
R00	-	00	01	detection active?	1: detection output active (includes hold time)	
R01	-	00	FF	detection speed	>0 peak position (FFT bin #)	
R02		0	FF	noise level mean	arithmetic mean over all FFT bins	
R03	-	00	02	operation state?	start up; learn; run	
R04	-	00	FF	software version	major.minor version (x.0 are preliminary versions)	
R10	*	--	--	software version string	Full software version and date string. Max 40 characters	
R11	*	--	--	result string	SpeedFW, SpeedBW, MagFW, MagBW<CR>	
R20	*	--	--	get EEPROM hex string	Full 512 EEPROM bytes in Intel hex format	

1) Vx.y Parameter added in Firmware Version Vx.y

Param.	default	min	max	Function	Description	R
Class W	(immediate)			**Real Time Write Params**	Volatile write parameters	
W00	-	00	01	force detection output	1: set digital detection output; 0: normal output operation	
W01	**-**	**-**	**-**	reset processor	software reset. value has no effect	
W02	-	-	-	load default parameters	load default values for all parameters	
W03	*00*	*00*	*01*	*reserved for future use*	*1: power saving and output disable.*	
W04	-	-	-	dump EEPROM content	get all permanent parameters	
W0B	-	-	-	enter bootloader	switches to bootloader on serial debug port	
Class L	LOOP			**Continuous Output**	Streaming comma separated results	
L00	-	00	01	Decimal output stream Peak positions, Peak values	SpeedFW, SpeedBW, MagFW; MagBW<CR> (DECIMAL) Start:$L00 or $L0001; Stop: $L0000 or other parameter	
Class D	DEBUG			**Debug stream**	Control serial data stream loop **at debug interface only**	
D00	-	00	02	Cyclic FFT on DEBUG int.	1: 2 ch. (FFT + Threshold); 2: 4 ch: additional I and Q	
D00	-	11	12	One shot FFT on DEBUG int.	11: 2 ch. (FFT + Threshold); 12: 4 ch: additional I and Q	

Table 8: 8 Bit parameters overview

8.3.2 16 Bit Array Parameters

Purpose: Values indirectly accessed by simple 8 bit parameters.

These parameters represent arrays that are addressed by 8Bit parameters or by signal processing. Values may be adapted and are application specific.

All values are in hexadecimal notation!

Param.	default	min	max	Function	Description	R
Class X	(EEPROM)			**Array parameters**	16bit hexadecimal table values for indirect parameters	
X00...X09	*)	0000	FFFF	Output hold time	hold time table in 100ms, addressed by parameter A01	x
X10....X19	*)	0000	00FF	Trigger level	sensitivity table, addressed by parameter A02	x
X20...X27	0	0	007F	Narrow band FFT filter	masks out single FFT bins from trigger criteria	x

*) see tables below

Table 9: Array parameter Xnn overview

Output Hold Time Table

Values from this tables are addressed by parameter A01 (Hold Time).

Default values:

Param A01 value	0	1	2	3	4	5	6	7	8	9
X00...X09 HEX	0002	0005	000A	0014	0032	0064	00C8	0190	0320	0640
→ Seconds	0.2	0.5	1	2	5	10	20	40	80	160

Table 10: Array parameter X0n hold time

Trigger Level Table (Sensitivity)

Values from this tables are addressed by parameter A02 (Sensitivity)

Default Values:

Param A02 value	0	1	2	3	4	5	6	7	8	9
X10...X19 HEX	00DC	00BE	00A0	008C	0078	0064	003C	0028	0014	0000
Decimal	220	190	160	140	120	100	60	40	20	0

Table 11: Array Parameter X1n trigger level

FFT Filter

Up to 8 different, individual frequencies may be filtered by setting values according to the FFT frequency resolution (called *df*).
Filtered frequency = Parameter X * *df;*
See chapter 8.4 Sampling Rate and Frequency Resolution for more details.

Parameter	X20	X21	X22	X23	X24	X25	X26	X27
Value (HEX)	0001	000A	0	0	0	0	0	0
Filter frequency @ S03 = 2	10Hz	100Hz	--	--	--	--	--	--

Table 12: Array parameter X2n filter

8.3.3 Application Parameters

Application parameters are typically accessible be the end-user. Values range from 1 ..9 i(n order to become accessible by simple one digit entry. Exception: frequency filters A06 and A07.
More detailed description.

A01	Hold Time	Sets retriggerable output hold time. Value is is a pointer to the array parameters X00 to X09. See Table 10
A02	Sensitivity	Sets trigger threshold. Value is a pointer to the array parameters X10 to X19. See Table 11. Used to set an approximate maximum detection range.
A03	Immunity	Sets the number of consecutive internal triggers until the detection output will be set. This parameter therefore influences the output reaction time. See also chapter 5.3 Response time
A04	reserved	
A05	direction	Defines which moving direction shall be detected. This value has only effect for I/Q sensors.
A06 A07	frequency limits	These values build very selective frequency(=object speed) range filters. Values represent FFT bins from 1 to 127 (0x7F) in hexadecimal notation. Filters apply for both forward and backward directions. Example: ***Set output only for cars exceeding 53km/h***. *(with sampling rate set to 11.264kHz (parameter **S03=09**):* *Minimum frequency (speed)* ***A06=35*** *(hex) correspondig to 53 (decimal)* *Maximum frequency* ***A07=00*** *(no limit)*

8.4 Sampling Rate and Frequency Resolution

FFT frequency resolution:
Frequency resolution *df* depends on sampling rate *fs* and on FFT size *FFT_N*.
FFT_N = 256 (for RSP1); *fs* = depends on parameter S03; *df = fs / FFT_N.*

Example:
Parameter S03 = 2 -> sampling rate = 2*1280Hz = 2560Hz --> df = 2560Hz / 256 = 10Hz
We want also filter out very slow movements at 10Hz and
100Hz interference, typically caused by fluorescent lights in 50Hz mains.

Parameter ***S03***	sample rate Hz	resolution Hz	max. frequency Hz	resolution km/h	max speed km/h	update time ms [1)]
01	1'280	5	640	0.11	14.5	200
02	2'560	10	1'280	0.23	29.1	100
03	3'840	15	1920	0.34	43.6	67
04	5'120	20	2"560	0.45	58.2	50
05	6'400	25	3'200	0.57	72.7	40
06	7'680	30	3'840	0.68	87.3	33
07	8'960	35	4'480	0.80	101.8	29
08	10'240	40	5'120	0.91	116.4	25
09	11'264	44	5'632	1.00	128.0	23
0A	22'530	88	11'265	2.00	256.0	12

Note 1): response time on host interface. Digital output depends also on params $A03 and $S02

Tabelle 13: Sampling rate - resolution - speed

9 Bootloader

RSP1 processor contains a fix programmed bootloader featuring:

- Storing, programming and copying parameter settings (EEPROM)
- RSP1 Firmware updating
- Access via the Serial Debug Interface

A PC program RSP_Prog Software comes with the RSP1_Eval-Kit.
Refer to RSP1_Eval-Kit_User Manual.pdf



DO NOT TRY TO ERASE or program RSP1 processor with any different programming tool.
Bootloader will be lost and RSP updating will no longer be possible.
RFbeam will not recover erased chips.

10 RSP1 Memory Organization

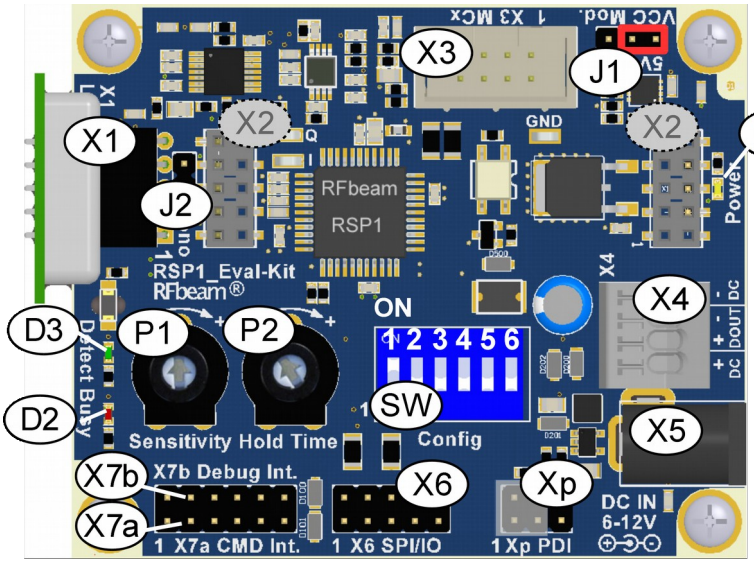
Storage item	Storage location	Purpose	Programmable by	
			RSP_Prog	Serial interfaces
User Parameters	EEPROM	Initially a copy of default parameters. Changable by ***$S*** and ***$X*** parameters	YES	YES
Default parameters	EEPROM	Factory default values	YES	NO
Firmware	Flash	RSP1 functionality	YES	NO
Bootloader	Flash	Used for programming flash and default parameters	NO	NO

11 Related Support Tools

For more details, please refer to the RSP_Eval-Kit User Manual.

11.1 RSP_Eval-Kit

This evaluation kit demonstrates applications of RSP1 with a large number of K-LCx sensor devices.
It is fully documented including schematics and PCB layout.



Indicators	
D1	Power LED
D2	Busy LED (start-up)
D3	Detection LED
Connectors	
X1	K-LCx sensor connector
X2	***Backside*** K-LCx connector
X3	K-MCx sensor connector
X4	Digital output connector
X5	DC Supply input 6 .. 12V
X6	Digital I/O (SPI in preparation)
X7a	Serial Command (**RSP_Terminal**)
X7b	Serial Debug (**RSP_Scope**)
Xp	Reserved / Reset
Settings	
P1	Sensitivity pot
P2	Hold time pot
SW	Mode switch
J1	Sensor supply volage
J2	Optional for mono sensor

Fig. 12: RSP1 Evaluation Kit

Evaluation kit contains the following software tools:

11.1.1 RSP_Terminal Software

This Windows software allows exploring and setting RSP1 parameters via the serial "Host command Interface".

11.1.2 RSP_Scope Software

This Windows software is a virtual oscilloscope for viewing internal FFT signals, thresholds, I/Q time domain signals.
It also allows setting parameters and exploring graphically their function.

11.1.3 RSP_Prog Software

This Windows software allows RSP parameter exchange with a PC.
It also includes an RSP1 chip software update utility.

12 Electrical Data

12.1 Power Supply

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
Digital supply voltage digital		Vcc	3.0	3.3	3.5	V
Analog supply voltage		AVcc	3.0	3.3	Vcc + 05.	V
Digital supply current		I_{Vcc}		12	15	mA
Analog supply current		A_{IVcc}		3		mA

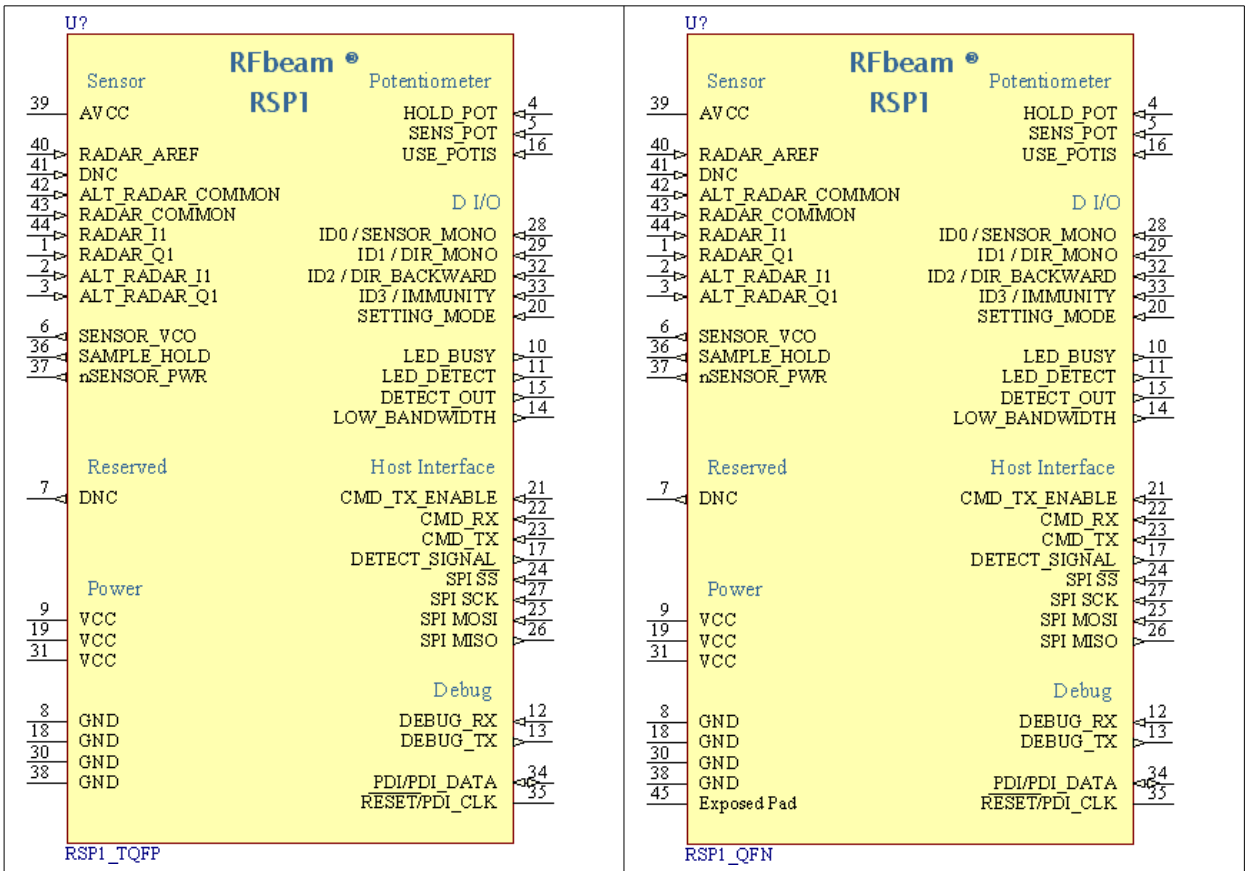
12.2 Analog I/O

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
ADC Resolution				12		bit
Sampling rate	adjustable by parameter S03		1.280		22.528	kHz
Reference input voltage range			1.6	1.65	1.7	V
Reference input resistance			10			MΩ
Radar Input type			--	differential	--	--
Radar input sensitivity	Gain = 1, V_{REF} = 1.65V	A_1		860		µV/bit
Radar input sensitivity	Gain = 16, V_{REF} = 1.65V	A_{16}		54		µV/bit
Radar Input impedance				4		kΩ
Radar Input capacitance					10	pF
Potentiometer input impedance				100k		kΩ
Potentiometer input range	V_{REF} = 1.65V		0		V_{REF}	V

12.3 Digital I/O

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
Input voltage high		V_{IH}	2		V_{CC} + 0.3V	V
Input voltage low		V_{IL}	-0.3		0.8	V
Input currents		$I_{IH,}$			140	µA
Output current		I_{OH}, I_{OL}	-20		20	mA
Output voltage high	I_{OH} = -8mA	V_{OH}	2.6	2.9		V
Output voltage low	I_{OL} = 10mA	V_{OL}		0.4	0.76	V

13 Pin Configuration



Standard RSP1 package: 44 pin TQFP	On request: 45 pin QFN package

Fig. 13: RSP1 Pin Configuration: left TQFP case, right QFN case

14 Sample Schematics

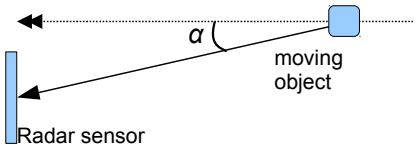
For complete schematics, please refer to the RSP1_Eval-Kit user manual.

14.1 Amplifiers

14.1.1 Sensor Outputs

A moving object in range of a Radar sensor (often called “transceiver “) generates a low frequency output signal. Frequency depends on the object speed. Amplitude depends on distance, reflectivity and size of the object. Doppler frequency f_d is proportional to the object speed v:

$$f_d = v \cdot \frac{44\text{Hz}}{km/h} \cdot \cos\alpha$$ or $$f_d = v \cdot \frac{158\text{Hz}}{m/s} \cdot \cos\alpha$$ with



Note that the angle of the moving object reduces Doppler frequency.

Radar sensor signals have low frequency outputs called 'IF' outputs.
Most sensors of the K-LCx family do not have an integrated amplifier. This makes these devices universal and low cost. Different applications need different amplification and frequency response.
Sensor output amplitude can range from less than 100nV to some mV .

14.1.2 Amplifier Structures

The following example schematics show 2 channel (I/Q) solutions with one- and two stage amplifiers.
Dual channel configurations need I/Q (sometimes called "stereo" sensors) like K-LC2, K-LC5, K-LC6 etc.

Dual channel configurations are state-of-the-art solutions with much better noise and interference suppression than single channel solutions. Furthermore, dual channel allows distinguishing approaching and receding objects.
Please refer also to Table 4: Useful signal level conversions.

Single channel solutions need less components and can be used with low cost sensors like K-LC1 or K-LC3.

If only 1 channel is required, only amp of channel 'I' is is needed, but RSP1 inputs 'RADAR_I1' and 'RADAR_Q1' must be connected together.

RSP1 provides an internal programmable gain amplifier with gains from 1 to 32 (0dB to 30dB).
Gain is set by parameter 'S09'. Default setting is 32.

$$A_{total} = A_{intern} \cdot A_{extern}$$ - > in our examples

$$A_{total} = 16 \cdot 500 = 8'000 \text{ or } 24\text{dB} + 54\text{dB} = 78\text{dB}$$

Maximum detection range is a function of the signal/noise (S/N) ratio at the RSP1 input.
Higher gain does not automatically mean higher detection range.
For more details on optimal amplification refer to the RSP1_Eval-Kit manual.

Dual amp stage structures allow higher external gains, higher bandwidth and lower gain.
If high speed detection at maximum range is required, dual amp stage is the right choice.

14.1.3 Single Amp, 2 Channels

Example for speed ranges from 0.1km/h up to 180km/h. This configuration needs the RSP1 internal gain stage with A = 16 (24dB)

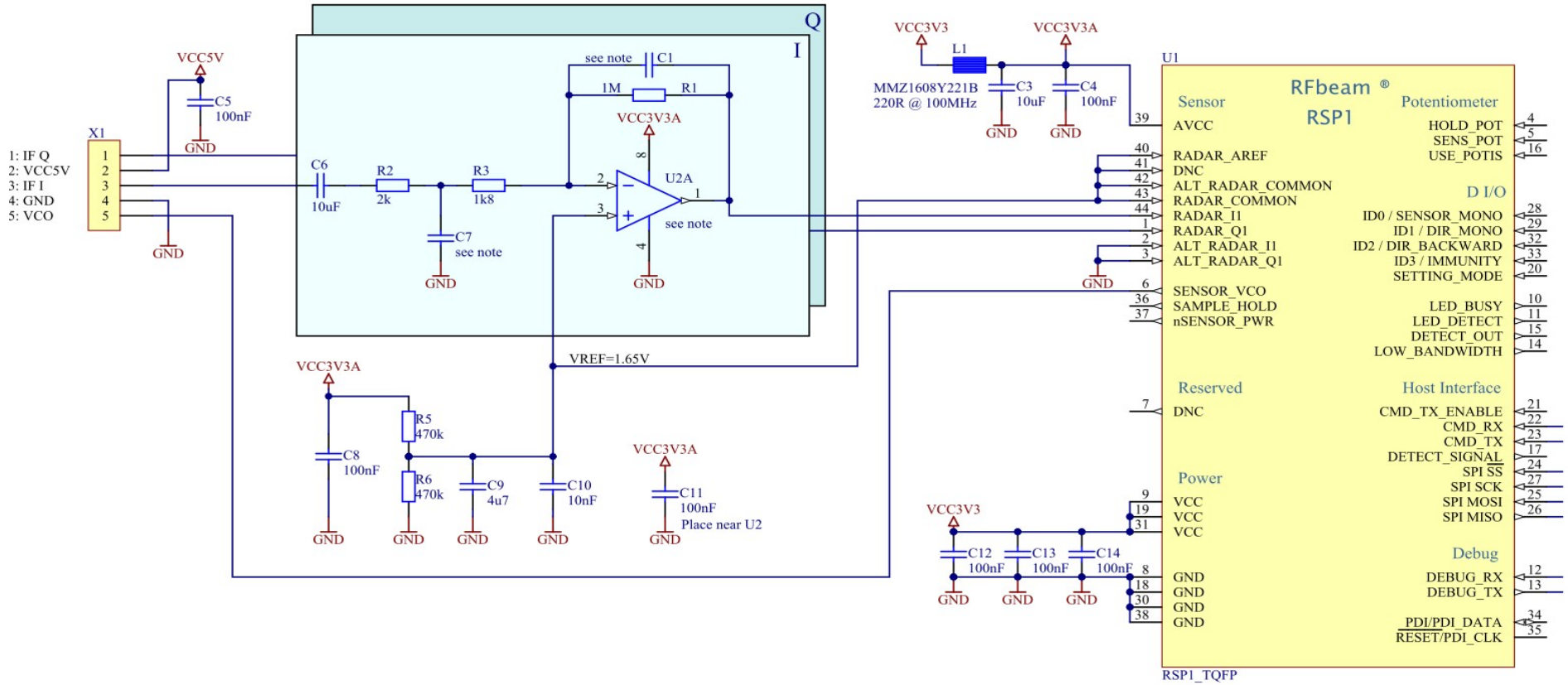


Fig. 14: Single Amp example for K-LCx sensors. Channel Q circuit is equivalent to channel I

Bandwidth (-3dB)	C1 *)	C7 *)	Op-Amp Type	Amp Gain
5Hz … 1kHz	15nF	120nF	LMV772	54dB (A = 500)
5Hz … 8kHz	15pF	15nF	LMP7716	54dB (A = 500)

*) For Q channel, same capacitor values

14.1.4 Dual Amp, 2 Channels

Example for speed ranges from 0.1km/h up to 250km/h. This configuration results in better S/N ratio and higher bandwidth than Single Amp solution

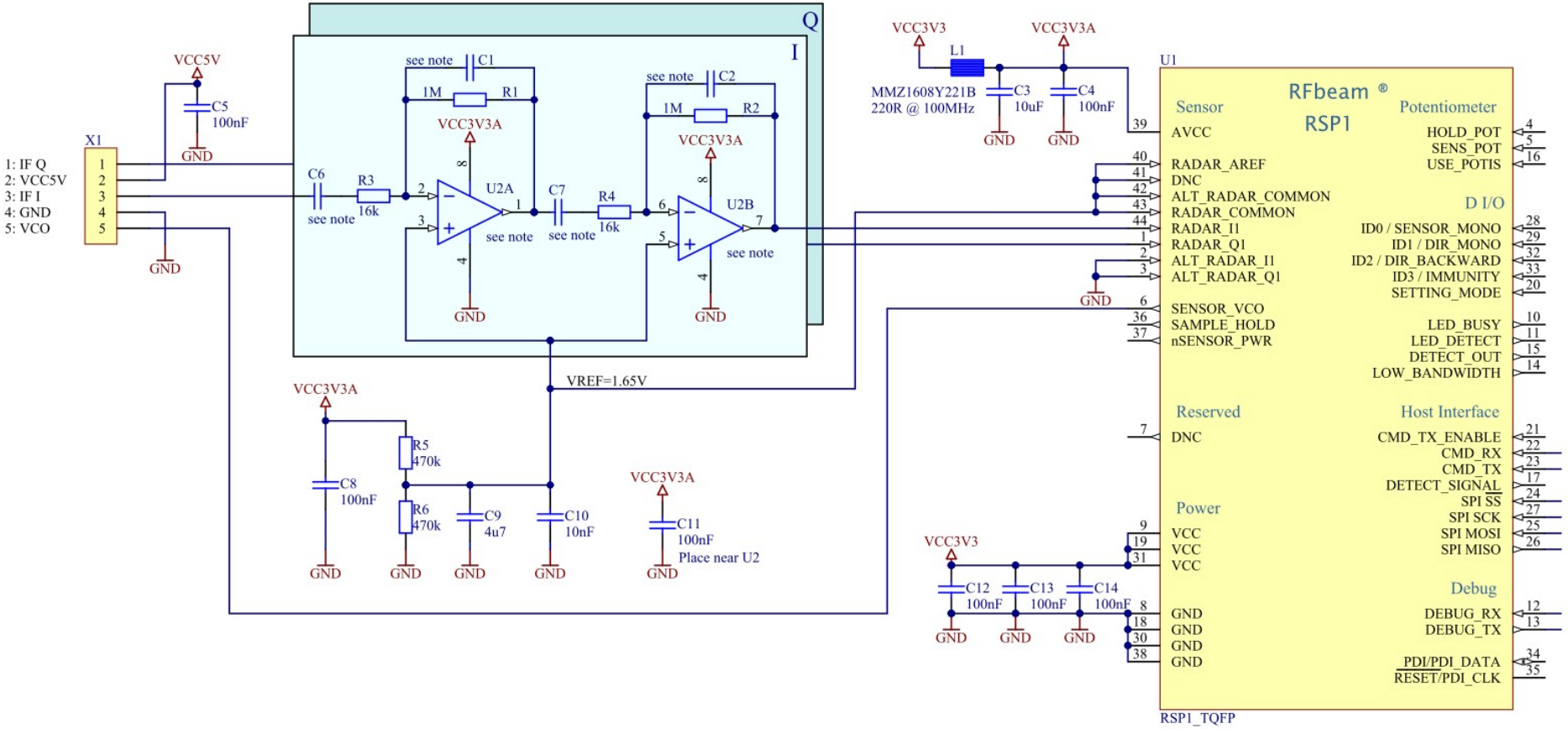


Fig. 15: Dual Amp example for K-LCx sensors. Channel Q circuit is equivalent to channel I.

Bandwidth	Speed range	C6, C7	C1, C2	Op-Amp	Amp Gain	Typical Application
5Hz … 500Hz	3cm/s 3m/s	2.2uF	15nF	LMV774	72dB (A = 15'800)	Person detection
400Hz … 12kHz	0.9 .. 270 km/h	33nF	10pF	LMP7716	72dB (A = 15'800)	Car speed or detection

For Q channel, same component values apply

14.2 Control Input Output

Please note: digital I/O are all 3.3V types.

14.2.1 Peripheral IO

All inputs are tied by a pull down resistor to ground.
All outputs switch to Vcc 3.3V.

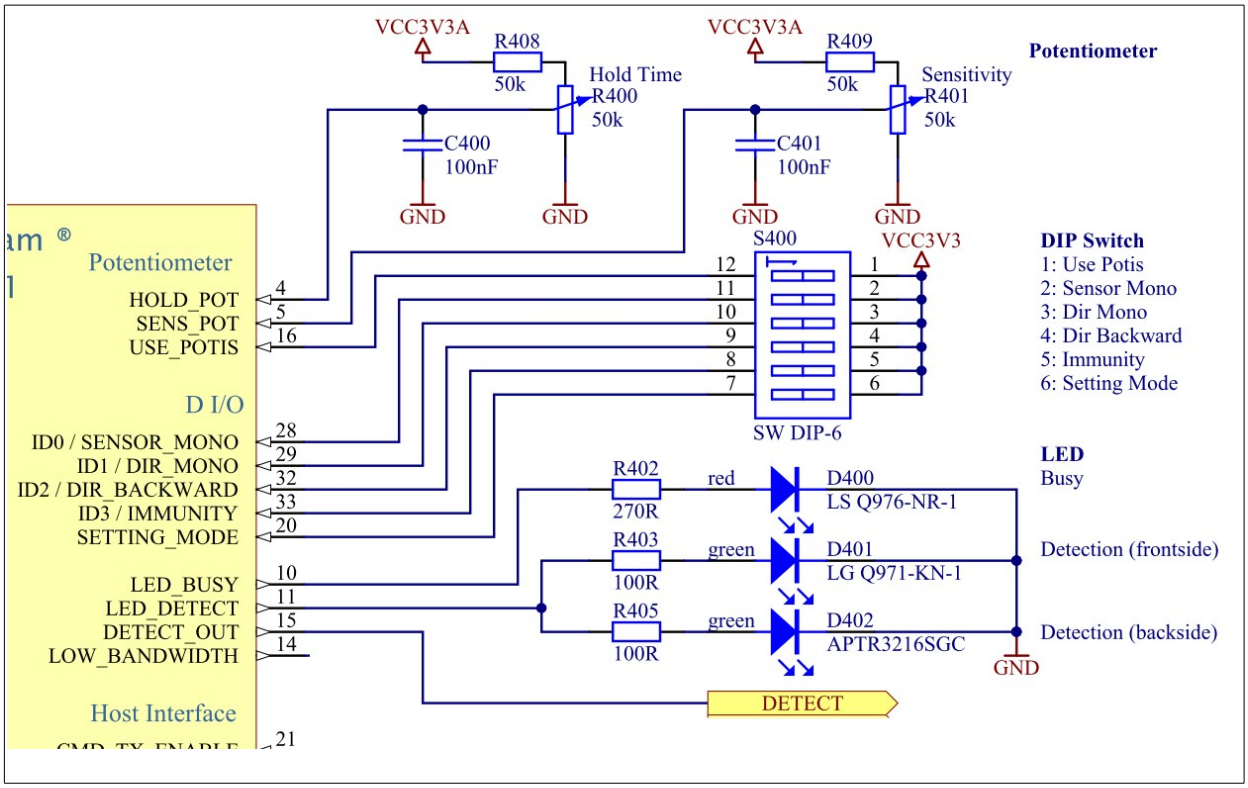


Fig. 16: Stand alone configuration, control elements

Isolated output is preferable in order to prevent ground loops and noise injection.

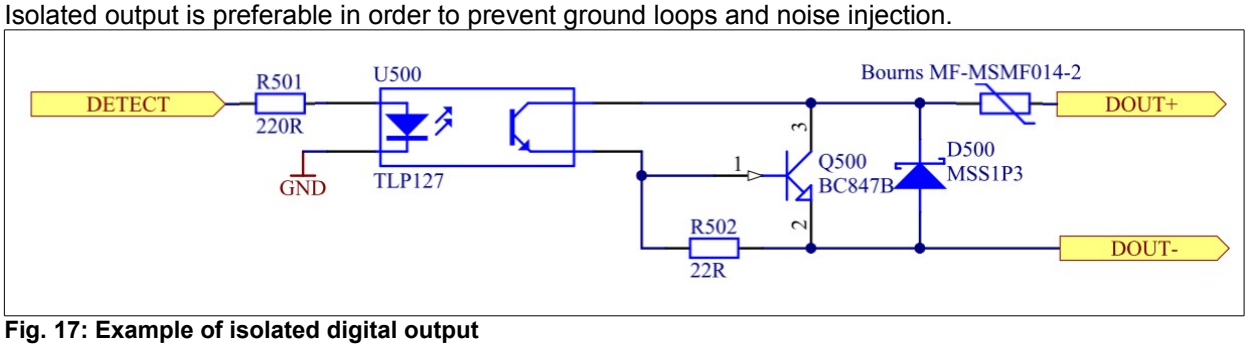


Fig. 17: Example of isolated digital output

15 Ordering Information

RSP1 processor in 44-pin TQFP case	RSP1-TQFP
RSP1 processor in 45-Pin QFN case	RSP1-QFN (on request for high volume production)
RSP1 evaluation Kit	RSP1_Eval-Kit

16 Revision History

Version 0.1	Mai 10, 2014	Preliminary release
Version 0.2	August 13, 2014	Preliminary release 2
Version 0.3	Sept 18, 2014	Preliminary release 3
Version 0.4	Nov 04, 2014	Preliminary release 4, valid from software version V1.7
Version 1.0	Feb 26, 2015	Valid from RSP1 firmware V1.8
Version 1.1	Dec 11, 2015	Component table for schematic Fig. 15 corrected Debug protocol description corrected in Table 5

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