

IQRF SPI

Technical guide

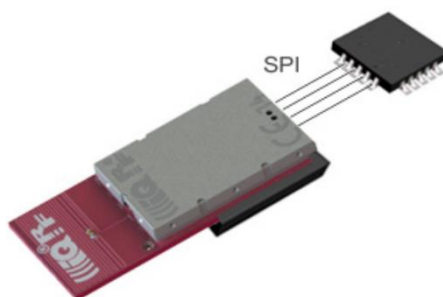
For TR-7xD

For IQRF OS v4.02, v4.03D, and v4.04D



This document describes **SPI** implementation in IQRF TR transceivers. It is primarily intended for **application engineers** implementing one's own **SPI masters** connected to TR transceivers. E.g., it enables to write a one's own PC control program with features similar to ones used in [IQRF IDE](#).

For other readers just the chapters [IQRF SPI purpose](#) and [SPI in TR transceivers](#) may be useful.



1 IQRF SPI purpose

SPI serves as an essential wired serial communication for IQRF platform.

It can be used for:

- General communication with TR transceiver
- **Handling** the application contents of the **memories** inside the TR ([TR configuration](#), application program, plug-ins, and data in Flash and both EEPROM memories). Primarily, the contents can be **uploaded** into TR, but can also be **read** from TR, except application program which is allowed to be **verified** only, and plug-ins which are allowed neither to be read nor verified.

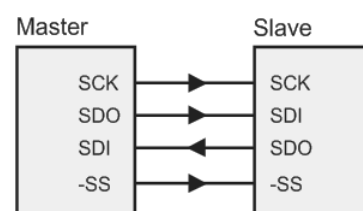
For short, all such handling TR memories in [programming mode](#) is called **TR Upload** throughout this document.

2 SPI general overview

SPI™ (Serial Peripheral Interface, introduced by Motorola) is a standard serial four wire synchronous data bus that can operate in full duplex. Devices communicate in Master/Slave mode with a single master initiating data frames. Multiple Slave devices are allowed with individual Slave select lines.

The SPI bus specifies four logic signals:

SPI signal	Function	Implementation at TR	
		TR pin	Direction
SCK	Serial Clock	C6 / Q6	Issued by Master
SDI	Serial Data In	C7 / Q7	To TR
SDO	Serial Data Out	C8 / Q8	From TR
-SS	Slave Select	C5 / Q9	Issued by Master



The SPI bus with a single Slave.

2.1 SPI at TR transceivers

The MCU inside the TR is equipped with generic **HW module** for serial communication (MSSP), among others implementing SPI Master/Slave.

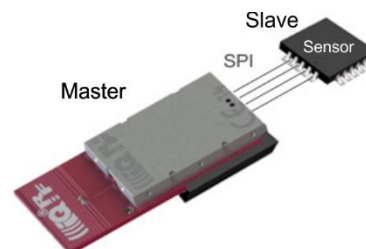
Note: Since SPI shares HW resources (dedicated pins and the MSSP module), it is not possible to use them for I²C or UART when SPI is used. However, if necessary, such as serial communications can alternatively be implemented in SW (without MSSP and using different pins), thus without the limitation above.

SPI at TR can work in Master or Slave mode as follows:

Master

One (or more) SPI slave device(s) (such as sensors or memories) can directly be connected to TR transceiver. However, SPI Master mode is **not supported by IQRF OS** and the communication must be implemented in other layers:

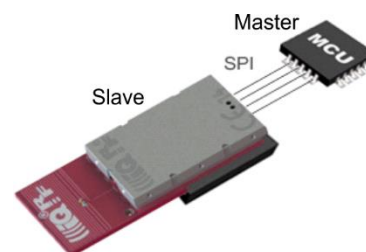
- **Under DPA:** Example [UserPeripheral-SPImaster](#) implements SPI Master as one of common user DPA peripherals. See *IQRF DPA Framework Technical guide [3]*, chapter [UserPeripheral-SPImaster](#).
- **Under IQRF OS:** `SPI_MASTER` is available as one of IQRF Advanced examples in C. See *IQRF Startup package [4]*, folder *Examples/IQRF_OS/Advanced_examples*.



Slave

On the contrary, SPI Slave mode gains massive **support from IQRF OS**:

- IQRF OS supports TR transceiver working as SPI slave, full or half duplex. Simplifiedly speaking, SPI slave implemented in IQRF observes the SPI standard, but with the only exception: Due to the highest priority of RF communication in OS foreground, the minimal space between individual SPI bytes must be longer than the standard one. See chapter [Timing](#).
- SPI is implemented as a [state machine](#) and runs in **OS background**.
- `bufferCOM` is a buffer dedicated to SPI communication. It enables an easy data exchange between the Master and the Slave.
- OS provides the set of powerful SPI **functions**: `enableSPI()`, `disableSPI()`, `startSPI(x)`, `restartSPI()`, `stopSPI()` and `getStatusSPI()`. See *IQRF OS Reference guide [2]*, chapter [SPI](#).
- OS implements a very simple proprietary **protocol** above the basic layer described in chapters [Data transfer](#) and [Timing](#). Refer to chapters [SPI status](#), [Packet structure](#), [SPI in practice](#) and [Examples](#).
- OS supports a set of **commands** (to be sent via this protocol) implementing [Upload](#) TR memories in **programming mode**. See chapters [Programming mode](#) and [TR upload](#).



Implementation possibilities:

- **Under DPA:** There are two ways absolutely different on principle:
 - **DPA Peripheral** is intended to exchange data between the TR and a peripheral (in this case via SPI). Refer to *IQRF DPA Framework Technical guide [3]*, chapter [Peripherals](#).
 - **DPA Interface** is intended to control the TR in wireless Mesh network from a higher system (in this case via SPI). It is a channel communicating via the DPA protocol (transferring [DPA messages](#) containing so called DPA foursome and optional data). The DPA protocol corresponds to the [DM](#) and [DS](#) bytes of IQRF SPI protocol, see chapter [Packet structure](#). Refer to *IQRF DPA Framework Technical guide [3]*, chapter [Interfaces](#). DPA Interface is typically used at network Coordinator. However, using at network Nodes is also possible.
- **Under IQRF OS:** Example [External SPI Master \[8\]](#) shows the implementation of the Master in C language. It is also included in the *IQRF Startup package [4]*, folder *Examples/Miscellaneous*.

[IQRF SDK](#) provides ready-to-use [libraries](#) for SPI Master implemented in an MCU under Linux (e.g. for Raspberry Pi) or without an operation system at all (e.g. for Arduino).

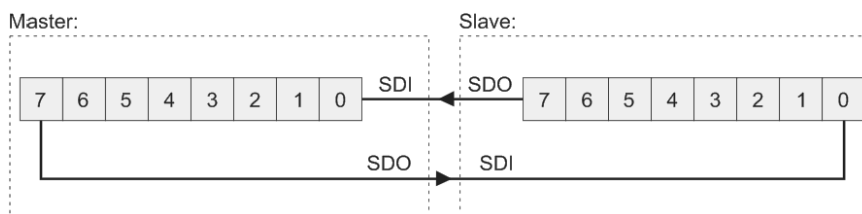
The rest of this document refers to SPI Slave implemented in IQRF OS.

3 SPI communication

3.1 Data transfer

SPI communication is fully synchronous without any timeouts. It is packet oriented and works in OS background. Packets consist of selectable number of bytes. IQRF SPI allows packets up to 64 B.

Each data byte is transferred using two internal shift registers to form a circular buffer, MSb first. After the registers have been shifted (rotated 8 bits to the left), the Master and Slave have swapped their register values.



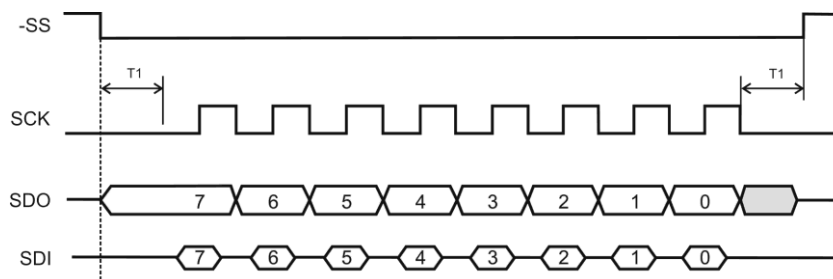
If the Slave is configured to receive data, the received byte is copied to the `bufferCOM` then. More bytes can be transferred by this repeated process in single packet and stored starting from `bufferCOM[0]`.

The TR module operates according the following Slave specification:

Slave select	Active low
Idle clock polarity	Low
Clock edge	Output data from TR on rising SCK edge

3.2 Timing (from the Slave point of view)

To start the communication, the Master pulls the Slave select low. Then the Master must wait for at least the T1 period before starting to issue clock cycles. During each SPI clock cycle, a duplex data bit can be transferred to complete a full duplex byte transmission in 8 clocks.



Then the Master must wait for at least the T2 period before sending the next byte.



SCK	SPI clock	250 kHz	Max.
T1	-SS to SCK (falling edge), SCK (falling edge) to -SS	5 μ s	Min.
T2	Delay between bytes	30 μ s	For non-networking RF communication
		150 μ s	For networking RF communication

The **delay between bytes** (T2) is very important parameter for IQRF SPI communication. Due to RF communication and possible peripheral processes running in background (e.g. writing to EEPROM), proper value depends on the application. RF communication has higher priority than SPI (RF interrupts should be served first), is time-demanding (depending on RF duty cycle) and runs in OS foreground. That is why RF RX has the strongest impact to SPI throughput. Additionally, it may strongly depend even on RF noise. All IQRF standard USB devices ([CK-USB-04A](#), [GW-USB-06](#), ...) use T2=150 μ s.

After transferring the last byte, -SS must still be kept low at least the T1 period (after the last SCK falling edge).

For detailed information about SPI implementation in the MCU see MCU datasheet [5], chapter *MSSP module*.

3.3 SPI status

IQRF SPI is implemented as a [state machine](#). Thus, TR stays always in one of given states and can be polled for this state at any time:

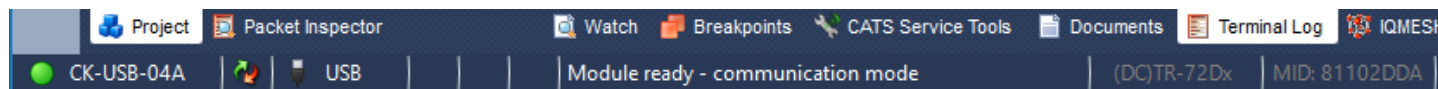
at the Slave using the `getStatusSPI()` function. See the *IQRF OS Reference guide* [2].

at the Master using the `SPI_CHECK` command sent to the Slave. For answers see the table below (SPI status).

After the `SPI_CHECK` command sent from the Master to the Slave via SPI the following answer can be returned:

Hex value	SPI status (SPISTAT)
00 or FF	SPI not active (HW error, SPI disabled by the <code>disableSPI()</code> command etc.). The default state is 00.
07	SPI suspended (stopped by the <code>stopSPI()</code> command)
3F	SPI not ready (buffer full, last CRCM O.K.). Data in <code>bufferCOM</code> is protected against overwriting by next transmission from the Master. <code>startSPI(0)</code> can be used at the Slave to enable continuing the transmission.
3E	SPI not ready (buffer full, last CRCM error). <code>startSPI(0)</code> can be used to recover.
40 to 79	<p>SPI data ready to be read from the Slave</p> <p>For 0x41 to 0x7F: Data length = this SPI status value - 0x40</p> <p>For 0x40: Data length = 64</p> <p>Examples:</p> <p>After <code>startSPI(10)</code> the TR returns status 0x4A until SPI transfer starts. It means that 10 B data is ready in <code>bufferCOM</code> to be sent from the Slave.</p> <p>After <code>startSPI(41)</code> the TR returns status 0x69.</p> <p>After <code>startSPI(64)</code> the TR returns status 0x40.</p>
80	SPI ready – Communication mode
81	SPI ready – Programming mode
82	SPI ready – Debugging mode

The SPI status of TR is indicated by the IQRF IDE when used with related IQRF development tools (e.g. [CK-USB-04A](#)):



3.4 Packet structure

Two types of SPI packets are defined: `SPI_CHECK` and `SPI_CMD`.

SPI_CHECK: The Master checks the SPI status of TR:

Master:	SPI_CHECK
Slave:	SPISTAT

SPI_CMD: The Master reads/writes a packet from/to TR:

Master:	SPI_CMD	PTYPE	DM1	DM2	...	DM _{SPIDLEN}	CRCM
Slave:	SPISTAT	SPISTAT	DS1	DS2	...	DS _{SPIDLEN}	CRCS

Where:

- `SPI_CHECK` 0x00 SPI check. Available anytime.
- `SPI_CMD` 0xF0 Data read / write (exchanged between the Master and `bufferCOM` at the Slave). Available in all SPI ready modes. See [Example 1](#) and [Example 3](#).
- 0xFA The same as 0xF0. Intended for DPA. Available in Communication mode only. For DPA data read use 0xF0, see above.
- 0xF5 Get TR Module Info. Available in Communication mode only.
 - For IQRF OS v4.02D:
16 B must be specified to be returned. 8 B Module Info (LSB first) and 8 B dummy data is returned.
 - For IQRF OS v4.03D or higher:
16 B or 32 B must be specified to be returned.
 - If 16 B is specified, the 8 B Module Info (LSB first) and 8 B dummy data is returned.
 - If 32 B is specified, the 8 B Module Info (LSB first), 8 B dummy data and 16 B IBK (Individual Bonding Key) is returned.

For Module Info format, refer to the [IQRF OS Reference guide \[2\]](#), function `moduleInfo()` and [Example 2](#).
- 0xF3 Write data to EEPROM. Write other TR configuration parameters. Available in Programming mode only. See [TR memories handling](#).
- 0xF2 Read data from EEPROM. Read other TR configuration parameters. Available in Programming mode only.
- 0xF6 Write data to EEPROM or Flash. Read data from EEPROM. Write TR configuration. Available in Programming mode only.
- 0xFC Verify data in Flash. Read TR configuration. Available in Programming mode only.
- 0xF9 Upload from proprietary secured .IQRF file provided by IQRF producer. Available in Programming mode only.

SPISTAT SPI status (see the [table](#) above)

PTYPE:

b7	b6	b5	b4	b3	b2	b1	b0
CTYPE		SPIDLEN					

SPIDLEN SPI packet data length (from 1 to 64)

CTYPE Communication type (regarding data transfer directions)

b7 = 1: `bufferCOM` changed (DM → DS or DM ↔ DS)

b7 = 0: `bufferCOM` unchanged (DS → DM)

Typical applications often use just unidirectional transmissions ($DM \rightarrow DS$ and $DS \rightarrow DM$) but in fact, physical communication is always full duplex:

- $DM \leftrightarrow DS$: The Master sends useful data (to `bufferCOM`) and the Slave sends useful data (from `bufferCOM`).
- $DM \rightarrow DS$: The Master sends useful data (to `bufferCOM`).
The Slave sends dummy data (currently meaningless data from `bufferCOM`) which should be ignored by the Master.
- $DS \rightarrow DM$: The Master sends dummy data (e.g. zeroes, see example below) just to generate clocks.
The Slave sends useful data (from `bufferCOM`) and ignores incoming data (ignoring is arranged by OS).

DM Data from the Master

DS Data from the Slave

CRCM $SPI_CMD \text{ xor } PTYPE \text{ xor } DM1 \text{ xor } DM2 \dots \text{ xor } DM_{SPIDLEN} \text{ xor } 0x5F$

CRCM must be calculated and sent by the Master. OS automatically verifies received CRCM and:

- Returns `0x3F` (O.K.) or `0x3E` (Error) to the Master as an answer to the `SPI_CHECK` command.
- Updates the `SPICRCok` flag for the Slave after the `getStatusSPI()`.

CRCS $PTYPE \text{ xor } DS1 \text{ xor } DS2 \dots \text{ xor } DS_{SPIDLEN} \text{ xor } 0x5F$

CRCS is automatically calculated and included to outgoing packet by OS and should be verified by the Master.

Tip: IQRF IDE [SPI Test](#) provides a powerful tool for SPI communication testing, including CRC calculation and checking.

3.5 SPI in practice

All SPI communication is under the Master's control. The Slave can not initiate the communication at all. It can only offer one's own state to the Master including a possible request to send data or to refuse the transfer when it is not convenient for the Slave. Therefore, the Master should watch the state of the Slave continuously and response in corresponding way (respect the Slave requirements, read offered data, calculate `CRCM` and check `CRCS`, verify successful reception by the Slave, repeat unsuccessful transfers etc.)

The Master should periodically send `SPI_CHECK` to get TR status. A good practice for the Master is to send `SPI_CHECK` every 10 ms. (This is a period used e.g. by IQRF IDE.)

If the Slave requests to send data, the Master should generate the "reading" packet for it. If omitted, the Slave still stays in the state `0x40` to `0x7F` and can be changed e.g. by `startSPI(x)`.

If the Master needs to send data, it should check first whether the Slave is ready to receive, especially whether has processed previous data correctly (so that the Slave is in the communication mode again, without reporting an error). If omitted, the SPI packet will be lost and the `bufferCOM` will not be overwritten. To refuse SPI transfer by the Slave for some reason required by the application, the `stopSPI()` function is intended. If the Slave is not ready (SPI is stopped or disabled by the Slave or the `bufferCOM` is full), it is useless to send packets by the Master.

Stopped SPI communication can also be restarted by `startSPI(x)` to continue. Thus, current packet can be completed later on.

Useful data can be exchanged at the same time (full duplex) but it is not usual in typical applications.

The Slave should also take into consideration its own state which can be checked by `getStatusSPI()`. Return value and output flags are optimized for user application requirements that is why they differ from the SPI status format sent to the Master.

If a communication error occurs during reading the `bufferCOM`, the reading can immediately be repeated. The data still remains valid in the `bufferCOM` (unless it is overwritten by the user application). See [Example 3](#).

If the `CRCM/CRCS` check is not sufficient for given application, for further security increase, the user should include one's own additional verification in user data.

See *IQRF OS User's guide* [6], *IQRF OS Reference guide* [2], Application examples included in the *IQRF Startup package* [4], folder *Examples*, and www.iqrf.org.

3.6 Examples

Configuration:

TR-7xDx transceiver plugged in [CK-USB-04A](#)

The E07-SPI example uploaded in TR. See *IQRF Startup package* [4], folder *Examples/IQRF_OS/Basic_examples*.

The IQRF IDE with *SPI Test* running on PC which CK is connected to.

Values "From Master" should be typed into the *Data to send* field and values "From Slave" can be watched in the *Terminal Log* window.

3.6.1 Example 1

Sending data between Master and Slave

```

From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS – TR is in communication mode
.
. // Master periodically sends SPI_CHECK to get TR status
.

From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS – TR stays in communication mode

From Master: F0.81.69.47.00 // Now the Master requires to send data "i"
// F0 81: SPI_CMD (PTYPE = 81: DM → DS, SPIDLEN = 1)
// 69: "i" in ASCII
// 47: CRCM (F0 xor 81 xor 69 xor 5F)
// 00: SPI_CHECK added to get SPI_STATUS: CRCM OK or Error

From Slave: 80.80.30.EE.3F // 5 B answer for 5 B issued by Master
// 80 80: 2 x SPI_STATUS – TR is in communication mode
// 30: dummy – current (undefined) content of bufferCOM
// EE: checksum (81 xor 30 xor 5F)
// 3F: SPI_STATUS: CRCM is OK

From Master: 00 // SPI_CHECK
From Slave: 4A // SPI_STATUS – TR offers 10 B in bufferCOM

From Master: F0.0A.00.00.00.00.00.00.00.00.00.00.A5.00
// F0 0A: SPI_CMD (PTYPE = 0A: DS → DM, SPIDLEN = 10)
// 10 x 00: dummy (to generate master clock only)
// A5: checksum (F0 xor 0A xor 00 ... xor 00 xor 5F)
// 00: SPI_CHECK

From Slave: 4A.4A.30.31.32.33.34.35.36.37.38.39.54.3F
// 4A 4A: 2 x SPI status (ready to sent 10 B)
// 30 ... 39: data from bufferCOM (10 B)
// 54: checksum (0A xor 30 ... xor 39 xor 5F)
// 3F: SPI_STATUS: CRCM is OK

From Master: 00 // SPI_CHECK
From Slave: 00 // SPI_STATUS – TR is in communication mode

.
. // Master periodically sends SPI_CHECK to get TR status
.

```

3.6.2 Example 2

Reading Module Info from TR via SPI

```
From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS - TR is in communication mode

From Master: F5.10.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.BA.00
// F5: command get Module Info
// 10: PTYPE - read 16 B
// 16 x 00: dummy
// BA: CRCM
// 00: SPI_CHECK added to get SPI_STATUS (CRCM OK or Error)

From Slave: 80.80.74.E5.10.81.43.24.C2.08.00.00.00.00.00.00.00.00.E2.3F
// 80 80: 2 x SPI_STATUS - TR is in communication mode
// 74.E5.10.81: Module ID = 8110E574 (LSB first)
// 43: IQRF OS version 4.03D
// 24: TR type = TR-72D, FCC not certified, MCU type = PIC16LF1938
// C2.08: IQRF OS build 0x08C2 (LSB first)
// Next 8 B are not defined
// E2: CRCS
// 3F: SPI_STATUS: CRCM is OK

From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS - TR is in communication mode
```

Reading Module Info including IBK from TR via SPI (for IQRF OS v4.03D)

```
From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS - TR is in communication mode

From Master: F5.20.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.00.8A.00
// F5: command get Module Info
// 20: PTYPE - read 32 B
// 32 x 00: dummy
// 8A: CRCM
// 00: SPI_CHECK added to get SPI_STATUS (CRCM OK or Error)

From Slave: 80.80.74.E5.10.81.43.24.C2.08.00.00.00.00.00.00.00.00.40.FE.11.19.48.1D.8D.E1.3F.04.98.04.1E.81.24.09.48.3F
// 80 80: 2 x SPI_STATUS - TR is in communication mode
// 74.E5.10.81: Module ID = 8110E574 (LSB first)
// 43: IQRF OS version 4.03D
// 24: TR type = TR-72D, FCC not certified, MCU type = PIC16LF1938
// C2.08: IQRF OS build 0x08C2 (LSB first)
// Next 8 B are not defined
// 40.FE.11.19.48.1D.8D.E1.3F.04.98.04.1E.81.24.09:
// IBK = 40FE1119481D8DE13F0498041E812409
// 48: CRCS
// 3F: SPI_STATUS: CRCM is OK

From Master: 00 // SPI_CHECK
From Slave: 80 // SPI_STATUS - TR is in communication mode
```

3.6.3 Example 3

Repeated reading after communication failure

```

From Master: 00      // SPI_CHECK
From Slave:  80      // SPI_STATUS - TR is in communication mode

From Master: F0.81.69.47.00 // Write "i" (0x69 in ASCII)
From Slave:  80.80.30.EE.3F // See Example 1

From Master: 00      // SPI_CHECK
From Slave:  4A      // SPI_STATUS - TR offers 10 B in bufferCOM

From Master: F0.0A.00.00.00.00.00.00.00.00.00.00.A4.00
                // Reading with error in CRCM (A4 instead of A5)
From Slave:  4A.4A.30.31.32.33.34.35.36.37.38.39.54.3E
                // Trailing 3E indicates wrong CRCM
...
                // Send SPI_CHECK until TR is in communication mode again

From Master: 00      // SPI_CHECK
From Slave:  80      // SPI_STATUS - TR is in communication mode

From Master: F0.0A.00.00.00.00.00.00.00.00.00.00.A5.00
                // Repeated reading with correct CRCM (It is not needed to
                // write "i" again. Data remains valid in bufferCOM)
From Slave:  80.80.30.31.32.33.34.35.36.37.38.39.54.3F
                // Trailing 3F indicates correct CRCM

From Master: 00      // SPI_CHECK
From Slave:  80      // SPI_STATUS - TR is in communication mode

```

4 TR Upload

TR **Upload** (sometimes called TR **Programming** as well) means writing a user application or configuration into TR transceiver. Similar approaches can also be applied for reading or verification of uploaded data.

The term **Upload** is simplifiedly used for handling contents of **all TR memories** in **programming mode** throughout this document.

For short, the EEPROM inside MCU is called **EEPROM**, while the on-board serial EEPROM is called **EEPROM** throughout this document.

4.1 TR non-volatile memories

Flash memory Upload

Writing into Flash is only possible in individual independent data blocks with fixed **16 words** length. However, the Flash memory cells must be precleared before writing. **Preclearing** is performed automatically but in blocks with fixed **32 words** length. See chapter [Write data to Flash](#) for significant details how to keep precleared areas under control.

EEPROM Upload

Writing as well as reading is possible in data blocks with up to 32 B (thus even single byte by single byte). See chapter [EEPROM](#).

EEPROM Upload

Writing is possible in data blocks with fixed length 32 B. Reading is possible in data blocks with up to 32 B. See chapter [EEPROM](#).

Tip: To arrange placing a data into EEPROM or EEPROM in source code, the `#pragma cdata[VirtualAddress]` directive for C compiler is intended. The difference between these both is in values of virtual addresses, see the `__EESTART` and `__EEESTART` constants in `IQRF-memory.h` header file and example E04-EEPROM in *IQRF Startup package* [4].

For memory types, refer to the *IQRF OS User's guide*, chapter *Memories*. Depending on memory type and purpose, data to be uploaded can be stored in **files** with the following extensions:

- **.HEX**

Standard Intel HEX format `INHX8M` generated by the C compiler. For the description, refer to *CC5X C compiler User's guide* (included in IQRF IDE) or *IQRF DPA Framework Technical guide*, chapter [Custom DPA Handler Code at .hex File](#).

Caution: Addresses in .HEX file are multiplied by two.

- **.IQRF**

A proprietary encrypted text format to upload IQRF OS or DPA plug-ins.

- **.TRCFNG**

A proprietary binary format to store and subsequently upload [TR configuration](#). Individual parameters are encoded as follows:

Byte[0] – Byte[31]	See <i>IQRF DPA Framework Technical guide</i> [3], chapter DPA configuration .
Byte[32]	RFPGM parameters. See Setup RFPGM and <i>IQRF OS Reference guide</i> [2], function <code>setupRFPGM(x)</code> .
Byte[33]	RF band. See Select RF band , parameter <code>DM3</code> .

Access key and *User key* are not exported/imported due to security.

See IQRF IDE Help, chapter [TR configuration window](#) how to create the .TRCFNG file from IQRF IDE.

For TR memories handling, three types of **addresses** are used:

Physical

The **actual** address in given memory (from 0 to the memory size).

Virtual

To enable storing data of various memories in a single **.HEX** file (typically created by C compiler), individual memory areas are mapped into a single virtual space. Starting virtual addresses for individual spaces are defined in the `IQRF-memory.h` header file, see *IQRF Startup package* [4], folder *Development/include/IQRF_OS*. E.g., `__EEESTART` means the beginning of the EEPROM virtual space.

Index

Addresses used to access **EEPROM** in 32 B blocks (from 0 to total number of blocks).

TR-7xD transceiver memories and accessible ranges (in hexadecimal):

Memory type		Accessible range			Size	Purpose	File	Access
		Physical	Virtual	Index				
Flash	Standard	3A00 - 3FFF	3A00 - 3FFF	–	1536 words	Application program or	.HEX	W V
	Extended	2C00 - 37BF	2C00 - 37BF	–	3008 words	DPA plug-in	.IQRF	W –
						and (optionally) Custom DPA handler.	.HEX	W V
						Optionally also OS plug-ins	.IQRF	W –
Configuration	37C0 - 37DF	37C0 - 37DF	–	32 words	TR (OS and DPA) configuration	.TRCFNG	W R *	
EEPROM	Standard	0000 - 009F	F000 - F09F	–	160 B	Application data	.HEX	W R
		00A0 - 00BF	F0A0 - F0BF	–	32 B	Application Info		
	Configuration	00C0 - 00DF	F0C0 - F0DF	–	32 B	TR (OS and DPA) configuration	.TRCFNG	W R *
EEPROM		0000 - 3FFF	0200 - 41FF	0 - 1FF	16 KB	Application data	.HEX	W
			0400 - 43FF					R

Legend:

W	Writable	R	Readable	V	Verifiable	–	Not readable, not verifiable
---	----------	---	----------	---	------------	---	------------------------------

* Access to configuration areas are allowed by [appointed methods](#) only. Addresses dedicated to configuration (in red) are mentioned in this table just for information where the restricted locations are placed. *Access password* and *User key* are not readable.

Other parts of these memories (beyond the ranges specified in the table) are dedicated to IQRF OS or DPA and not allowed to be accessed via the SPI Upload.

4.1.1 Memory mapping overview

Virtual address (in .HEX)	Flash					EEPROM	EEPROM				
	Physical address	Standard	Extended	Configuration	OS	Physical address	Write		Read		
							Physical address	Index address	Physical address	Index address	
0000	0000				0000						
.	.				.						
0200						Addressable by #pragma	0000	000			
.											
0400									0000	400	
.											
09FF								07FF	03F		
0A00							Not addressable by #pragma	0800	040	0600	430
.	.										
					2BFF						
.	.		2C00								
.	.		.								
.	.		37BF								
.	.			37C0							
.	.			.							
.	.			37DF							
.	.				37E0						
.	.				.						
.	.				39FF						
.	.	3A00									
.	.	.									
3FFF	3FFF	3FFF									
4000							3E00	1F0	3C00	5E0	
.											
41FF							3FFF	1FF			
.											
43FF									3FFF	5FF	
4400	Unused										
.											
FFFF											
F000						00					
.						.					
F0FF						FF					

4.2 Programming mode

Upload and all other handling TR memories are available when TR is in [programming](#) mode, either wired (**PGM**) or wireless (**RFPGM**).

The Upload procedure should be performed as follows:

1. Reset TR transceiver

- Set all SPI interface pins at the Master to low levels.
- Switch TR power supply Off
- Wait 300 ms
- Switch TR power supply On
- Set the idle levels to SPI interface pins at the Master, see the [Slave specification](#).

2. Activate the programming mode

Copy the level on the SDO pin to the SDI pin for the first 400 ms after the TR is switched on. TR transceiver generates a determinate data sequence on the SDO pin. If this sequence is copied to the SDI pin, TR is switched to the programming mode (PGM - wired upload via SPI) and the OS jumps to the PGM bootloader. The PGM mode is indicated by short red LED flashing every 2 s.

Such copying can be implemented by SW e.g. as follows:

```
while (is_delay_400ms)
{
    if (SDO_level) SDI_level = 1;
    else          SDI_level = 0;
}
```

3. Wait until TR transceiver is in programming mode

Repeat polling for the TR state ([SPI_CHECK](#)). If TR starts to respond with 0x81 the programming mode is initiated.

4. Perform required operations

Perform TR upload and/or other required tasks according to chapter [TR memories handling](#).

5. Terminate the programming mode

After sending the last packet according to point 4 above, it is necessary to wait for end of SPI cycle by polling the TR state ([SPI_CHECK](#)). If TR transceiver starts to respond with 0x81, reset the TR transceiver according to the point 1 above and the newly uploaded application will start.

4.3 TR memories handling

Of course, all `SPI_CMD` packets introduced in this chapter must comply with the specification described in chapter [Packet structure](#). Thus, packets sent from the Master should also contain `PTYPE` and `CRCM` which are not mentioned below for simplicity.

Caution: All addresses in `.HEX` files generated by CC5X compiler are multiplied by two.

Therefore, when handling with memories according to all the commands described below, all addresses read from a `.HEX` file must be divided by two first.

All HEX addresses mentioned below mean the resulting addresses (thus divided by two already). See the *Example* in chapter [Write data to EEPROM](#).

Individual memory types (see below) can be uploaded in any order, with the only exception: if the `.IQRF` file as well as the *Access password* and/or *User key* are to be uploaded, the `.IQRF` file must be uploaded sooner.

Tip: Upload the *Access password* and *User key* as the last one(s).

4.3.1 EEPROM

Virtual EEPROM addresses (0xF000 to 0xF0FF) are used in `.HEX` files but physical addresses (0x00 to 0xFF) are used in Upload commands.

Write data to EEPROM

Writing into EEPROM inside the MCU is possible in individual independent data blocks with up to 32 B.

Write data to EEPROM

`SPI_CMD = 0xF3`

`DM1 = Address in EEPROM (0 – 255)`

`DM2 = Number of data bytes to be written (1 – 32). Addresses must be in allowed range ($DM1 + DM2 \leq 256$).`

`DM3 to DMx = Data to be written ($x = 2 + DM2$)`

Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).

Read data from EEPROM

Reading from EEPROM inside the MCU is possible in individual independent data blocks with up to 32 B.

Store data block from EEPROM into `bufferCOM[0-31]`. Complete 32 B block is always stored.

`SPI_CMD = 0xF2`

`DM1 = Address in EEPROM (0 – 255)`

`DM2 = 0 (Must be cleared. Reserved for future use.)`

Repeat SPI state checking until (`SPI_CHECK = 0x60`). Then 32 B data is ready in `bufferCOM` to be sent.

Read the data from `bufferCOM`

`SPI_CMD = 0xF0`

`DM1 = Number of bytes to be transferred (1 to 32)`

`DM2 to DMx = 0x00 (dummy), $x = 1 + DM1$`

`DS1 to DSDM1` contains data read from EEPROM

Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).

4.3.2 EEPROM

Write data to EEPROM

Writing into EEPROM (serial) is possible in individual independent data blocks with fixed length 32 B.

Write data to EEPROM

SPI_CMD = 0x**F6**

DM1 = Index address in EEPROM, lower byte

DM2 = Index address in EEPROM, upper byte

- Index address must be in allowed range 0x0000 to 0x1FFF.
- Index addresses access individual 32 B blocks. E.g., index 0x0000 addresses EEPROM from physical address 0x0000 to 0x001F, 0x0001 from 0x0020 to 0x003F, ..., 0x01FF from 0x3FE0 to 0x3FFF.
- CC5X compiler generates virtual addresses from physical addresses in EEPROM by adding the offset 0x0200. Address 0x0200 in HEX file corresponds to physical address 0x0000 in EEPROM etc.
- Thus, $\text{index address} = (\text{HEX address} - 0x0200) \text{ div } 0x20$.
- Example:
 - A record in .HEX file: :10044000100011001200...
 - HEX address = 0x0440 div 2 = 0x0220
 - Index address = (HEX address – offset 0x0200) div 0x20 = (0x0220 – 0x0200) div 0x20 = 1
 - DM1 = 0x01, DM2 = 0x00
 - This addresses the block from 0x0020 to 0x003F.

DM3 to DM34 = Data to be written (always 32 B)

Repeat SPI state checking until the operation is completed (SPI_CHECK = 0x81). Then it is possible to continue (send a next SPI packet).

Read data from EEPROM

Reading from EEPROM (serial) is possible in individual independent data blocks with up to 32 B.

Store data block from EEPROM into bufferCOM[0-31]. Complete 32 B block is always stored.

SPI_CMD = 0x**F6**

DM1 = Index address in EEPROM, lower byte

DM2 = Index address in EEPROM, upper byte

- Index address must be in allowed range 0x0400 to 0x5FFF.
- Index addresses access individual 32 B blocks. E.g., index 0x0400 addresses EEPROM from physical address 0x0000 to 0x001F, 0x0401 from 0x0020 to 0x003F, ..., 0x05FF from 0x3FE0 to 0x3FFF.
- Thus, $\text{index address} = (\text{EEPROM address} \text{ div } 0x20) + 0x0400$.

Repeat SPI state checking until (SPI_CHECK = 0x60). Then 32 B data is ready in bufferCOM to be sent.

Read data from bufferCOM

SPI_CMD = 0x**F0**

DM1 = Number of bytes to be transferred (1 – 32)

DM2 to DMx = 0x00 (dummy), x = 1+DM1

DS1 to DSDM1 contains data read from EEPROM

Repeat SPI state checking until the operation is completed (SPI_CHECK = 0x81). Then it is possible to continue (send a next SPI packet).

4.3.3 Flash memory

Write data to Flash

Writing into Flash is only possible in individual independent data blocks with fixed length **16 words** (16 machine instructions), starting from addresses modulo 16 (0x3A00, 0x3A10, 0x3A20, ...), each word by two 8 b DM_x values, LSB first. However, the Flash memory cells must be precleared before writing. **Preclearing** is only possible in blocks with fixed length **32 words** (32 machine instructions), starting from virtual addresses modulo 32 (0x3A00, 0x3A20, ...). It is performed at given block automatically whenever writing into Flash is requested. **All 'unused' positions** (without meaningful values requested by the application) **throughout the entire precleared block** of 32 words must be filled with **0xFF 0x34** values.

Tip: To place a code at a specific location in Flash, the `#pragma origin ADDRESS` directive for C compiler is intended.

- Write data to Flash:
 - `SPI_CMD = 0xF6`
 - `DM1` = Virtual address in Flash, lower byte
 - `DM2` = Virtual address in Flash, upper byte.
 - The address must be modulo 16:
 - For Standard Flash 0x3A00, 0x3A10, ..., 0x3FF0
 - For Extended Flash 0x2C00, 0x2C10, ..., 0x37B0
 - `DM3` to `DM34` = Data (32 B, 16 instructions)
- Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).

Verify data in Flash

Verification is based on reading the individual words from the Flash but with XORed lower and upper bytes of each word. It is possible in individual independent data blocks with up to 32 words (32 machine instructions). Thus, one verification cycle spans up to two Flash writing cycles.

- Store data block from Flash into `bufferCOM[0-31]`. Complete 32 B block is always stored.
 - `SPI_CMD = 0xFC`
 - `DM1` = Virtual address in Flash, lower byte
 - `DM2` = Virtual address in Flash, upper byte
 - The address must be modulo 32:
 - For Standard Flash 0x3A00, 0x3A20, ..., 0x3FE0
 - For Extended Flash 0x2C00, 0x2C20, ..., 0x37A0
- Repeat SPI state checking until (`SPI_CHECK = 0x60`). Then 32 B data is ready in `bufferCOM` to be sent.
- Read data from `bufferCOM`
 - `SPI_CMD = 0xF0`
 - `DM1` = Number of bytes to be transferred (1 – 32)
 - `DM2` to `DMx` = 0x00 (dummy), $x = 1+DM1$

`DS1` to `DSDM1` contains XORed data words read out from the Flash.

```
word.low8[address] XOR word.high8[address], word.low8[address+1] XOR word.high8[address+1], ...
... XOR word.low8[address+31] XOR word.high8[address+31]
```

- Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).

Write IQRF plug-in to Flash

IQRF OS plug-in can be uploaded into Flash memory by sending the raw data from given `.IQRF` file. It uses a line-oriented text format. Lines initiated with the '#' character must be ignored. All other lines are intended as data to be uploaded as it is (without any changes). Every line corresponds to one SPI packet. Every two subsequent characters represent one DM_x data byte in hexadecimal. Number of bytes in a line may vary up to 32.

- Write plug-in data to Flash
 - `SPI_CMD = 0xF9`
 - `DM1` to `DMx` = Data from the line of the `.IQRF` file
- Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).
- Repeat this two steps line by line until all lines are uploaded.

More plug-ins can be uploaded in a single TR at the same time in this way.

4.3.4 TR configuration

TR configuration means an obligatory predefined basic TR setup to be uploaded into EEPROM and Flash. It is restored after every TR power on or reset and can be changed (except of the RF band switching) during application executing.

TR configuration consists of **OS**, **DPA** and **Security** parts.

DPA part should be uploaded even when DPA approach is not used. However, in this case only the RF channels (specified in DPA TR configuration bytes 0x11 and 0x12, see *IQRF DPA Framework Technical guide* [3], chapter *DPA configuration*) are read from it, but other parameters (e.g. RF output power) must be selected in application program.

TR configuration can be created, modified, uploaded into TR and read from TR interactively in IQRF IDE. It is also possible to export/import the configuration to/from a **.TRCNFG** file. See [IQRF IDE Help](#) for details.

Caution: The method described in this chapter is the only way to upload/download TR configuration and must strictly be observed. Direct access to memory areas dedicated to the configuration by the procedures intended for general access to Flash or EEPROM (described above) are not possible.

Write OS part of TR configuration

Select RF band

```
SPI_CMD = 0xF3
DM1 = 0xC0
DM2 = 0x01

DM3 = 0x00      868 MHz
           0x01  916 MHz
           0x02  433 MHz
```

Note: RF band must be set properly even if it is the only possibility, e.g. for 433 MHz transceivers or TR-7xDA-IL (not supporting RF band switching).

Setup RFPGM

```
SPI_CMD = 0xF3
DM1 = 0xC1
DM2 = 0x01
DM3 = x
```

For meaning see *IQRF OS Reference guide* [2], function `setupRFPGM(x)`.

Read OS part of TR configuration

- Read other TR configuration parameters into `bufferCOM[0-31]`. Complete 32 B block is always stored.

```
SPI_CMD = 0xF2
DM1 = 0xC0
DM2 = 0
```

- Repeat SPI state checking until (`SPI_CHECK = 0x60`). Then 32 B data is ready in `bufferCOM` to be sent.

- Reading the data from `bufferCOM`

```
SPI_CMD = 0xF0
DM1 = 0x20      32 B to be transferred
DM2 to DM33 = 0x00  Dummy
```

DS1 to DS32	TR configuration data
DS1	RF Band
DS2	RFPGM setup
DS3-32	Reserved

- Repeat SPI state checking until the operation is completed (`SPI_CHECK = 0x81`). Then it is possible to continue (send a next SPI packet).

Write DPA part of TR configuration

DPA part of TR configuration (32 B) can be uploaded into TR using the write procedure repeated two times (to send two SPI packets, each containing 16 B data) as follows:

- Write lower 16 B of TR configuration to Flash:
SPI_CMD = 0x**F6**
DM1 = 0xC0 (virtual address of TR configuration origin in Flash, lower byte)
DM2 = 0x37 (virtual address of TR configuration origin in Flash, upper byte)
DM3 to DM34 = Data (32 B) to be written. It must be in format 0x34dd, where dd is TR configuration byte.
 - For meaning of individual dd[i] values (i = 0 to 31), refer to *IQRF DPA Framework Technical guide [3]*, chapter *TR configuration*. Reserved items (not defined at current DPA version) must be cleared (dd[i] = 0).
 - TR configuration address 0x00 corresponds to virtual address 0x37C0 in Flash memory etc.
 - dd[0] = dd[1] XOR dd[2] XOR ... XOR dd[31] XOR 0x5F is a checksum of TR configuration array. Refer to *IQRF DPA Framework Technical guide [3]*, chapter *Write TR Configuration*.
- Repeat SPI state checking until the operation is completed (SPI_CHECK = 0x81).
- Write upper 16 B of TR configuration to Flash:
SPI_CMD = 0x**F6**
DM1 = 0xD0 (virtual address of upper half of TR configuration in Flash, lower byte)
DM2 = 0x37 (virtual address of upper half of TR configuration in Flash, upper byte)
DM3 to DM34 = Data (32 B) to be written. It must be in format 0x34dd, see above.
 - dd[30] is dedicated to configuration version which is used by IQRF IDE for checks but not defined within *IQRF DPA Framework*. E.g. value 0x03 represents DPA v3.0.
- Repeat SPI state checking until the operation is completed (SPI_CHECK = 0x81). Then it is possible to continue (send a next SPI packet).

Read DPA part of TR configuration

DPA part of configuration can be read from TR in one SPI packet containing a 32 B data block using the following read procedure. Thus, one reading cycle spans up to both TR configuration writing cycles.

- Read TR configuration from Flash into bufferCOM[0-31]. Complete 32 B block is always stored.
SPI_CMD = 0x**FC**
DM1 = 0xC0 (virtual address of TR configuration origin in Flash, lower byte)
DM2 = 0x37 (virtual address of TR configuration origin in Flash, upper byte)
 - TR configuration address 0x00 corresponds to virtual address 0x37C0 in Flash memory etc.
- Repeat SPI state checking until (SPI_CHECK = 0x60). Then 32 B data is ready in bufferCOM to be sent.
- Read data from bufferCOM
SPI_CMD = 0x**F0**
DM1 = 32 Number of bytes to be transferred
DM2 to DM33 = 0x00 Dummy
- DS1 to DS32 contains XORed data read from the words at the TR configuration area:
DS[x] = TR_configuration_word.low8[x] XOR TR_configuration_word.high8[x], (x = 1 - 32).
Factual configuration byte should be extracted from this as follows: dd[x] = DSx xor 0x34.
For meaning of individual values Refer to *IQRF DPA Framework Technical guide [3]*, chapter *Write TR Configuration*.
- Repeat SPI state checking until the operation is completed (SPI_CHECK = 0x81). Then it is possible to continue (send a next SPI packet).

Write Security part of TR configuration

Specify Access password

SPI_CMD = 0x**F3**
DM1 = 0xD0
DM2 = 0x10
DM3 to DM18 = password[0-15] See *IQRF OS Reference guide [2]*, function *setAccessPassword*.

Specify User key

SPI_CMD = 0x**F3**
DM1 = 0xD1
DM2 = 0x10
DM3-DM18 = key[0-15] See *IQRF OS Reference guide [2]*, function *setUserKey*.

4.3.5 Upload commands overview

		Standard	Extended	Configuration	OS	EE	EEE	(DM2) / DM1
Flash	Write application Blocks 16 words	F6		–	–	–	–	3A00 - 3FFF
			F6	–	–	–	–	2C00 - 37BF
	Verify application Blocks up to 32 words	FC + F0		–	–	–	–	3A00 - 3FFF
			FC + F0	–	–	–	–	2C00 - 37BF
Plug-in	Write	F9	F9	F9	F9	–	–	–
Configuration	Write OS	–	–	F3	–	F3	–	01C0, 01C1
	Read OS	–	–	F2 + F0	–	F2 + F0	–	00C0
	Write DPA	–	–	2 x F6	–	F6	–	37C0, 37D0
	Read DPA	–	–	FC + F0	–	FC + F0	–	37C0
	Write Security	–	–	F3	–	F3	–	10D0
EE	Write	–	–	–	–	F3	–	00 - FF
	Read	Blocks up to 32 B	–	–	–	F2 + F0	–	00 - FF
EEE	Write	Blocks 32 B	–	–	–	–	F6	000 - 1FF
	Read	Blocks up to 32 B	–	–	–	–	F6	400 - 5FF

5 Migration notes

5.1 Migration from IQRF OS v4.2xD to v4.03D

Features	OS v4.02D	OS v4.03D
IBK readable via command <i>Get TR module info</i>	IBK not implemented	Yes

5.2 Migration from IQRF OS v3.0xD or v4.00D to v4.02D

Features	OS v3.0xD	OS v4.02D
TR upload	Not publicly documented	Publicly documented
TR configuration upload	Not supported	Supported

5.3 Migration from IQRF OS v3.0xD or v4.00D to v4.01D

Do not use **OS v4.01D** at all due to a serious bug in RFPGM (wireless upload).

5.4 Migration from TR-5xD to TR-7xD

Features	TR-5xD	TR-7xD
–SS to SCK (falling edge), SCK (falling edge) to –SS (period T1)	T1 = 10 μ s	T1 = 5 μ s
Min. delay between bytes (period T2)	T2 = from 100 μ s to 700 μ s	T2 = 30 μ s (non-networking RF)
		T2 = 150 μ s (networking RF)
Slave select deactivating between bytes (period T3 *)	Necessary (T3 = min. 20 μ s)	Not necessary (T3 = 0)

See chapter [Timing](#).

* Refer to the *IQRF SPI Technical guide for TR-5xD* [7].

6 Documentation and information

- 1 [IQRF CDC Technical guide](#) – Specification of CDC implementation in IQRF transceivers
- 2 [IQRF OS Reference guide](#) – Description of OS functions and macros
- 3 [IQRF DPA Framework Technical guide](#) – DPA description
- 4 [IQRF Startup package](#) – Complete SW bundle to start with IQRF
- 5 [MCU datasheet](#) – For MCU inside the TR
- 6 [IQRF OS User's guide](#) – Description of IQRF OS
- 7 [SPI Technical guide for TR-5xD](#) – Specification of SPI implementation in TR-5xD transceivers
- 8 [SPI Master](#) for communication with the TR

If you need a help or more information, contact [IQRF support](#).

7 Document revision

- | | |
|--------|---|
| 200904 | Links revised. Document valid also for IQRF OS v4.04D. |
| 200526 | Link to example <i>SPI Master</i> added. Information about IQRF SDK added in chapter <i>SPI at TR transceivers / Slave</i> added. Direct links to external on-line documents added. HWP configuration renamed to (DPA part of) TR configuration. A bug in addresses of RF channels fixed in chapter <i>TR configuration</i> . |
| 191209 | Chapter Activate the programming mode revised. |
| 181018 | Updated for IQRF OS v4.03D. IBK is readable via command <i>Get TR module info</i> . References to the HEX format description added into chapter Upload / download TR memory. |
| 180319 | Chapter <i>TR Upload</i> revised and extended, 3 tables with mapping of memories added. |
| 171018 | Introductory section in chapter <i>TR memories handling</i> extended, a <i>Tip</i> added. |
| 171009 | <i>Caution</i> added to chapter <i>TR memories handling</i> . Example added to chapter <i>Write data to EEPROM</i> . A typo bug in the <code>.TRCNFG</code> file name fixed. |
| 170823 | Updated for IQRF OS v4.02D. |
| 170810 | For TR-7xD and IQRF OS v4.01 or higher. TR Upload added. |
| 160715 | A bug (N_{max}) in the table on page 4 fixed. |
| 151106 | Min. delay between SPI bytes changed for networking RF communication. |
| 150608 | First release for (DC)TR-7xD |

8 Sales and Service

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