# SMK-900 SERIES INTEGRATION GUIDE

PORTIA Module

Revision 4

# CONTENTS

# Introduction

SMK900 transceivers provide for highly-reliable, long-range, and low power mesh networking radio applications. They use frequency hopping spread spectrum (FHSS) technology to ensure resistance to multipath fading and robustness, as well as for compliance with 900 MHz unlicensed band regulations in Canada and the US. The SMK900 supports a CTS-enabled serial port interface with data rates ranging from 1.2 to 230.4 kbps, with two possible modes of operation (transparent ASCII and protocol-formatted). For easy integration, error correction and buffering is all accomplished within the mesh controller module. A Virtual Machine is also available so that the user can leverage the module peripherals of the radio processor to perform operation such as signal processing and remote control devices. The module accepts multiple sleep synchronization clock sources: internal crystal, internal RC, or with an external I2C-line sleep controller for optimal sleep management. Key features include:

- Multipath fading resistance, with more than 51 frequency channels, 902.7 to 927.4 MHz
- Receiver protected by low-loss SAW filter for excellent receiver sensitivity and interference rejection
- Support for high-speed mesh networking applications
- Maximum range in free space exceeds 10 km (antenna height dependent)
- Typical range in forested areas between 250 and 500 m
- Transparent ASCII serial data mode for easiest integration available
- Advanced protocol-formated serial data mode available for maximum flexibility
- Accessibility to multiple analog and digital I/O via Virtual Machine
- Serial baud rates between 1.2 and 230.4 kbps
- AES 128 bits encryption available
- Module configuration stored in non-volatile memory
- Local and Over-the-air configuration for the radio
- Virtual Machine locally and remotely programmable at whim
- VM engine bytecode can be locally or remotely accessed/modified at whim via IDE

# System

## SMK900 System Overview

A SMK900 radio can be configured to operate in two main modes: *gateway* or *node*. A *gateway* controls a whole mesh network and functions as the main coordinator *node*, and its usual primary function is to bridge a *host* such as a PC, tablet, or internet *gateway*, with the rest of the mesh network. A *node* is a transceiver that acts as a repeater inside of the mesh network. The primary function of a *node* is to allow communication between an external devices and the *gateway*, or to serve as a bridge between analog and/or digital inputs/outputs such as for sensor arrays.

It is possible to configure any *node* so that it filters messages by MAC address, or configure it so that it acts like a *sniffer* relaying all messages transiting through the mesh network to the client circuitry via serial port.

## Mesh Network Systems

The topology used by a SMK900 radio is that of a broadcast-only mesh network, with sleep-wake synchronization handled by the *gateway*. This mean that any SMK900 radio transmission sends a *broadcast* to the whole mesh network. There are no provisions for pure *unicast* messaging, and such needs are usually handled by integrator using a higher-level protocol sitting on top of the SMK900 protocol. The maximum of broadcast transmission of the same messages over the mesh network depend on the number of *hops* allowed.

Multiple independent mesh networks may coexist in the same physical space by configuring *nodes* with differing FHSS channels, different network IDs and/or different encryption patterns. Each of those mesh networks have to be controlled by its own *gateway*. The bridging between *gateways* is handled by the integrator.

### Frequency Hopping implications

The SMK900 uses the FHSS approach in order to ensure that co-located networks using different FHSS hopping tables (a.k.a *channels*) can coexist with graceful degradation of network performance as the number of conflicting networks overlapping increases. This however comes with the price that any *node* needs a certain time delay (called "*seek time*") in order to connect itself to its desired network (this delay can range between seconds to minutes, depending on the sleep interval between wake cycles for said network. For instance, at a sleep interval of 1 second, the seek time is of the order of 30 seconds to 1 minute, and this seek time increases linearly with said sleep interval.

## Specifications

| | |
|---|---|
| Absolute maximum ratings | |
| Supply voltage | -0.5 to 6.5V |
| All input/output pins | -0.5 to 3.3V |
| Specification | Descriptions |
| Operating Temperature | -20 to 70 ◎C guaranteed for max up count<br>-40 to 85 ◎C guaranteed for half up count |
| Storage Temperature | -40 to 85 ◎C |
| Power requirement | |
| Supply voltage | 3.3 to 5.5V |
| Transmit Current | 130 mA peak |
| Receive Current | 20 mA |
| Idle | 30 uA |
| Transceiver | |
| Urban / Indoor / NLOS* | 100 to 500m |
| Outdoor / LOS** | 10Km+ |
| Transmit Power | Low: 50mW High 100mW |
| RF Data Rate | 50 Kbits |
| Number Of Channel | 5 |
| Frequency band | 902 to 928 MHz |
| Receiver Sensitivity | -110 dBm |
| Antenna Connector | U.FL |
| Antenna Gain Maximum | 3 dBi |
| Max Hop Count | 31 |
| Encryption OTA | AES 128 bits |
| Virtual Machine | |
| Memory | 16 KBytes |

* NLOS: None Line Of Sight
** LOS: Line Of Sight

## Broadcast Frame

In order to ensure synchronization of every nodes within a given network, the *gateway* always initiates a broadcast beacon periodically, which encompasses a broadcast parameters. This is the primary construct within which all nodes communicate. In particular, there is Time-Division Multiple Access (TDMA) slotting mechanism that specify unique slots, called broadcast phases, for outbound communication from a *gateway* to *nodes*, and inbound communication from a *node* back to a *gateway*.

### Dynamic parameters

There is 6 parameters inside the broadcast beacon. They will be referred to in this integration guide by the moniker: *dynamic parameters*, or, in short, *DYN*. Configuration of those parameters usually take the form of a sequence of 6 bytes, with 1 byte per parameter, as follows:

DYN <= {$B_O$, $B_I$, $N_H$, $N_R$, R, D}

For each *broadcast frame*, the periodic delay between broadcast as well as its length being determined by:

$\boldsymbol{B_O}$: number of *gateway* to *node* messages per broadcast (also called *broadcast out phase count*),

$\boldsymbol{B_I}$: number of *node* to *gateway* messages (also called *broadcast in phase count*),

$\boldsymbol{N_H}$: the maximum number of *hops* for the network
(i.e. maximum number of time a message can be relayed from *node* to *node*),

$\boldsymbol{N_R}$: number of random-access specialized hop slots (called *redux*),

***R***: specialized slotting mechanism enabled

***D***: inverted sleep-wake duty cycle ratio *D* (min. value is 1),

The broadcast time can be then calculated as:

$T_{BCAST}$[msec] = 10 * ( $N_H$*($B_O + B_I$) + $N_R$*$R$ )

The interval between each broadcast is:

$T_{INTERVAL}$[msec] = $T_{BCAST}$ * $D$

For the vast majority of applications, the default settings, where $B_O = B_I = 1$ and $R = 0$, are applicable, in which case the timing equations simplify to:

$T_{BCAST}$[msec] = 20 * $N_H$
$T_{INTERVAL}$[msec] = $T_{BCAST}$ * $D$

Allowable values for each of those are, with default values in (**boldface**):

| | |
|---|---|
| $B_O$: | [(**1**), 2, 3, 4] |
| $B_I$: | [(**1**), 2, 3, 4] |
| $N_H$: | [1, 2, ... ,4, (**5**), 6, ... , 31] |
| $N_R$: | [(**1**)] |
| R: | [(**0**), 1] |
| D: | [1, 2, 5, (**10**), 20, 40, 80] |

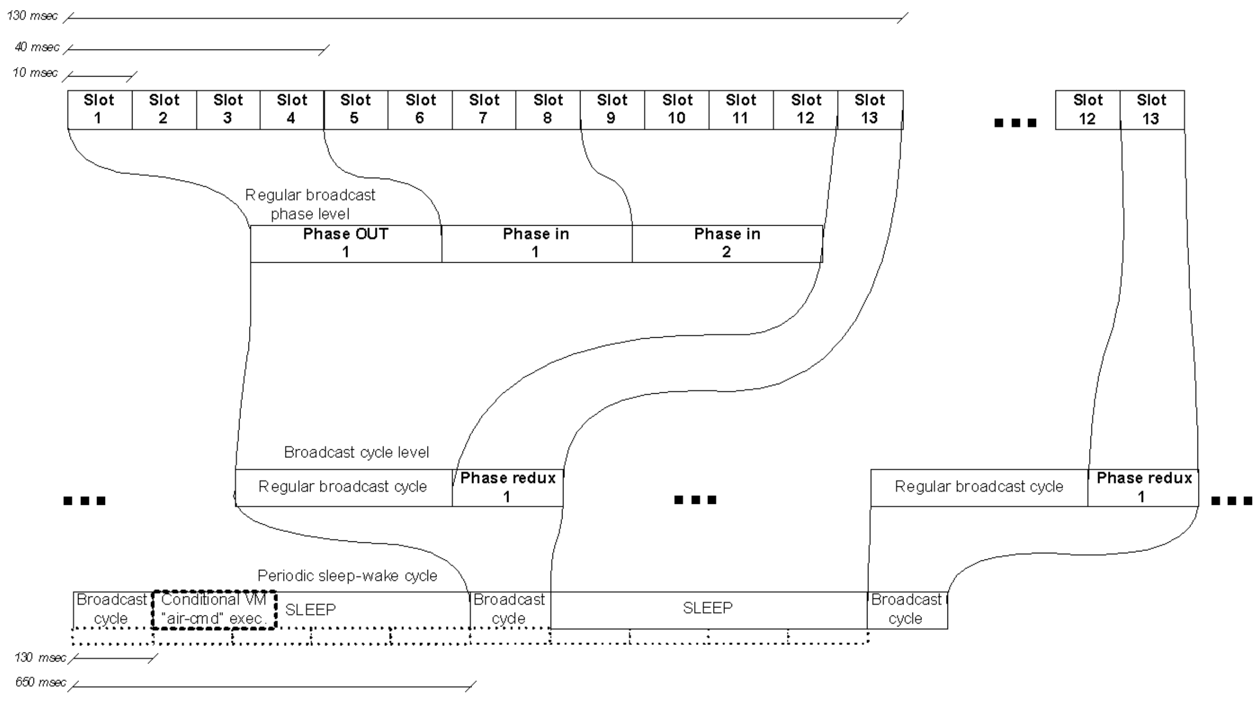
Note that D is defined as $T_{INTERVAL}$ / $T_{BCAST}$, and is thus the inverse of what is commonly defined as the network *duty-cycle*, which is defined as follows:

*duty cycle*[%] = 100% / D

Note that there are no parameters controlling any acknowledgement/retry cycles in case a message from one *node* to another fails to pass through. It is assumed that the onus of managing packet delivery failure occurrences fall upon the shoulder of the higher-level protocol as implemented by the integrator. The easiest way to do so, say for a mesh network with standard round-robin sensor polling, is simply to detect reply failure at the host side connected to the *gateway*, and retry polling for a number of times, before flagging a failure to user in the case a maximum number of retries has been hit. Note, however, that there is an internal CRC-based mechanism for controlling packet integrity, so any packet received can be assumed for the majority of applications as containing valid and uncorrupted information.

### Broadcast Frame Structure

The following schematic shows the typical structure of periodic network broadcast cycles, for the following configuration DYN = {1, 2, 4, 1, 1, 5}:



## SMK900 Addressing and Network Segregation

Each module has a unique factory-configured 3-byte address, called the MAC address. In the standard protocol-based serial data mode, this MAC address can be used to specify to which destination a message is intended, although this is not a necessary part of the protocol due to the fact that every message is treated as a broadcast to all *nodes*. The MAC address 0x000000 is treated as an *invalid* address. There is no broadcast address, in contrast with regular IEEE802.15.4 schemes (where a broadcast address is typically the highest possible address for a given number of bytes encoding said address). Note that in transparent serial data mode, MAC addresses are not used, and in this case the system behaves as a transparent point-to-multipoint system.

Every *node* also has a configurable network ID, called *NWKID*, between 0 and 7, which can be used to segregate multiple networks hopping on the same FHSS channel in order to reduce the impact of interference. Every *node* can also be encrypted using an unique network key, which not only secures a given mesh network, but also allows for more segregation between coexisting networks within the same physical space.

The primary means for network segregation is of course the selection of the FHSS channel via a configuration variable named *HOPTABLEID*. The current implementation allows for values between 0 and 5 (i.e. 6 different hop tables).

### Transparent and Protocol-formatted Mode

A SMK900 based network can be configured to use either the *transparent* or the *protocol-formatted* mode for the serial port interface.

#### Transparent

The *transparent* mode allows for basic, unsynchronized integration which emulate a simple point-to-multipoint serial link between a *gateway* and its *nodes*. In this case, the message is assumed to be of standard ASCII format, with the special ASCII terminator characters 0x13 (Carry) or 0x10 (Line Feed) are used as markers to trigger the end of a message stream, and thus to trigger transmission over radio waves.

#### Protocol-formatted

Protocol-formatted messages also referred to as  Application Programing Interface (API) are discussed in the following sections. rotocol-formatted messages usea start-of-message marker, followed by message length, message information type (or *command byte*), an optional string of MAC addresses, and finally, the payload.

## Virtual machine

### Description

SMK900 radios feature an embedded Virtual Machine (VM) allowing Over-The-Air (OTA) firmware updates. This allows application-specific user scripting to control the internal modules of the SMK900 radio and ease interfacing with external devices. The main processor controls and manages wireless mesh operations and  executes VM user scripts.

TheVirtual Machine is available when the serial protocol is configured to  protocol-formatted  mode (not to transparent mode). An IDE is available for Virtual Machine development, which includes basic compiler, disassembler,  *node* configuration and VM upload/erase functions as well as direct node serial connection and OTA firmware node upload with a gateway.

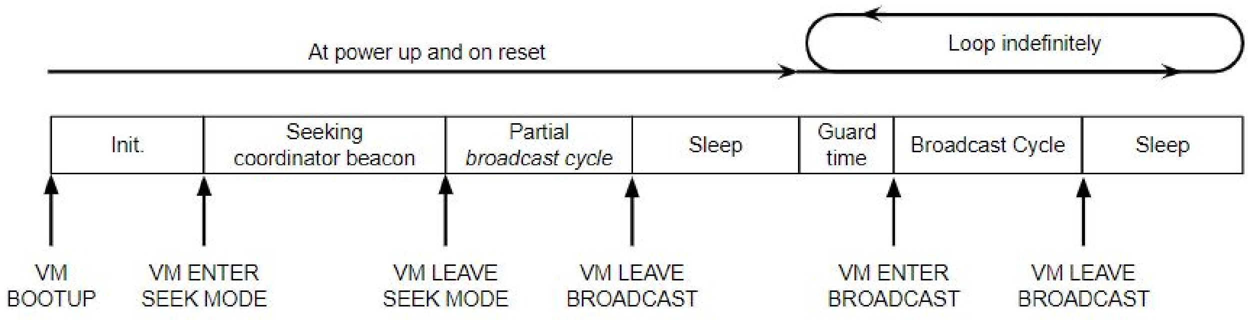
### Virtual Machine Triggers

Virtual Machine script execution is managed by the mesh network process. This is to ensure mesh operation priority over the Virtual Machine. VM execution is triggered by various events, which are defined in the table below.

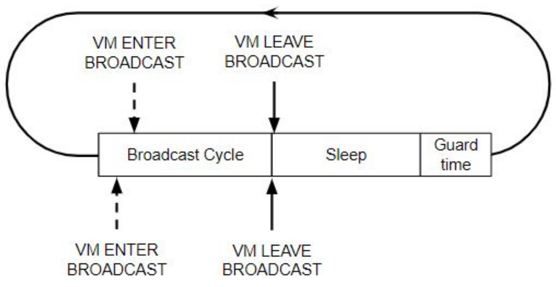
| Trigger | Description |
|---|---|
| Bootup | Bootup system initialization |
| Enter Seek Mode | The transceiver is attempting communication with the *gateway* over the mesh network. |
| Leave Seek Mode | The transceiver has established a link to the mesh network. |
| Enter Broadcast | The transceiver  wakes up to enter the broadcasting cycle |
| Leave Broadcast | Broadcasting cycle has ended and the transceiver is ready to enter sleep mode. |
| Serial Event | A message from a local serial device has been received by the transceiver. Note: The local serial device must read CTS low before sending. |
| Air command | An execute air command message has been received. Typically, air command is used to control or read modules connected to the radio. |

The available triggers in the mesh network cycle are shown in the figures below.

## Mesh network triggers



## External triggers



# Hardware

The SMK900 module provides multiple application interfaces: a primary communication serial port (CTS enabled), a dedicated I2C port (Master mode only), and 13 generic digital I/O. The latter can be reconfigured to ADC (2x), to DAC (2x) or to PWM hardware signalling or clock generation (2x). The SMK900 transceiver can also use advanced peripherals such as hardware timers and event capture/compare within custom bytecode executed by its VM engine.

## Serial Port

The host processor is tied to the SMK900 module over a full-duplex UART interface serial port with CTS pin hardware control. aud rate is configurable from 1.2 to 230.4 kbps, with non standard baud rates also achievable (between the aforementioned boundaries). The serial port is configured for standard 8-bit data with no parity and 1 stop bit.

Baudrate configuration is done on the *uart_bsel* register (register offset 0x06) This register can be split into: *BSEL* = *uart_bsel*[0..11], and *BSCALE* = *uart_bsel*[12...15]. where *BSCALE* is a 4-bit signed integer, ranging from -7 (0b1001) to +7 (0b0111). For positive values of *BSCALE*, the baud rate is prescaled by $2^{BSCALE}$. or negative values the baud rate will use fractional counting, which increases resolution.

The formulae for calculating the effective baud rate $f_{BAUD}$:

| Conditions | Baud Rate (in baud or Hz) | BSEL Value |
|---|---|---|
| $BSCALE \geq 0$ <br> $f_{BAUD} \leq 1MHz$ | $f_{BAUD} = \frac{1\times10^6}{2^{BSCALE} \bullet (BSEL+1)}$ | $BSEL = \frac{1\times10^6}{2^{BSCALE} \bullet f_{BAUD}} - 1$ |
| $BSCALE < 0$ <br> $f_{BAUD} \leq 1MHz$ | $f_{BAUD} = \frac{1\times10^6}{(2^{BSCALE} \bullet BSEL)+1}$ | $BSEL = \frac{1}{2^{BSCALE}}\left(\frac{1\times10^6}{f_{BAUD}} - 1\right)$ |

Thus, here is a list of standard baud rates and their corresponding suggested configuration values:

| Baud Rate (baud) | *BSEL* | *BSCALE* | *uart_bsel* |
|---|---|---|---|
| 2400 | 831 (0x33F) | -1 (0b1111) | 0xF33F |
| 4800 | 829 (0x33D) | -2 (0b1110) | 0xE33D |
| 9600 | 825 (0x339) | -3 (0b1101) | 0xD339 |
| 19200 | 817 (0x331) | -4 (0b1100) | 0xC331 |
| 38400 | 801 (0x321) | -5 (0b1011) | 0xB321 |
| 57600 | 1047 (0x417) | -6 (0b1010) | 0xA417 |
| 115200 | 983 (0x3D7) | -7 (0b1001) | 0x93D7 |
| 125000 | 7 (0x007) | 0 (0b0000) | 0x0007 |
| 230400 | 428 (0x1AC) | -7 (0b1001) | 0x91AC |

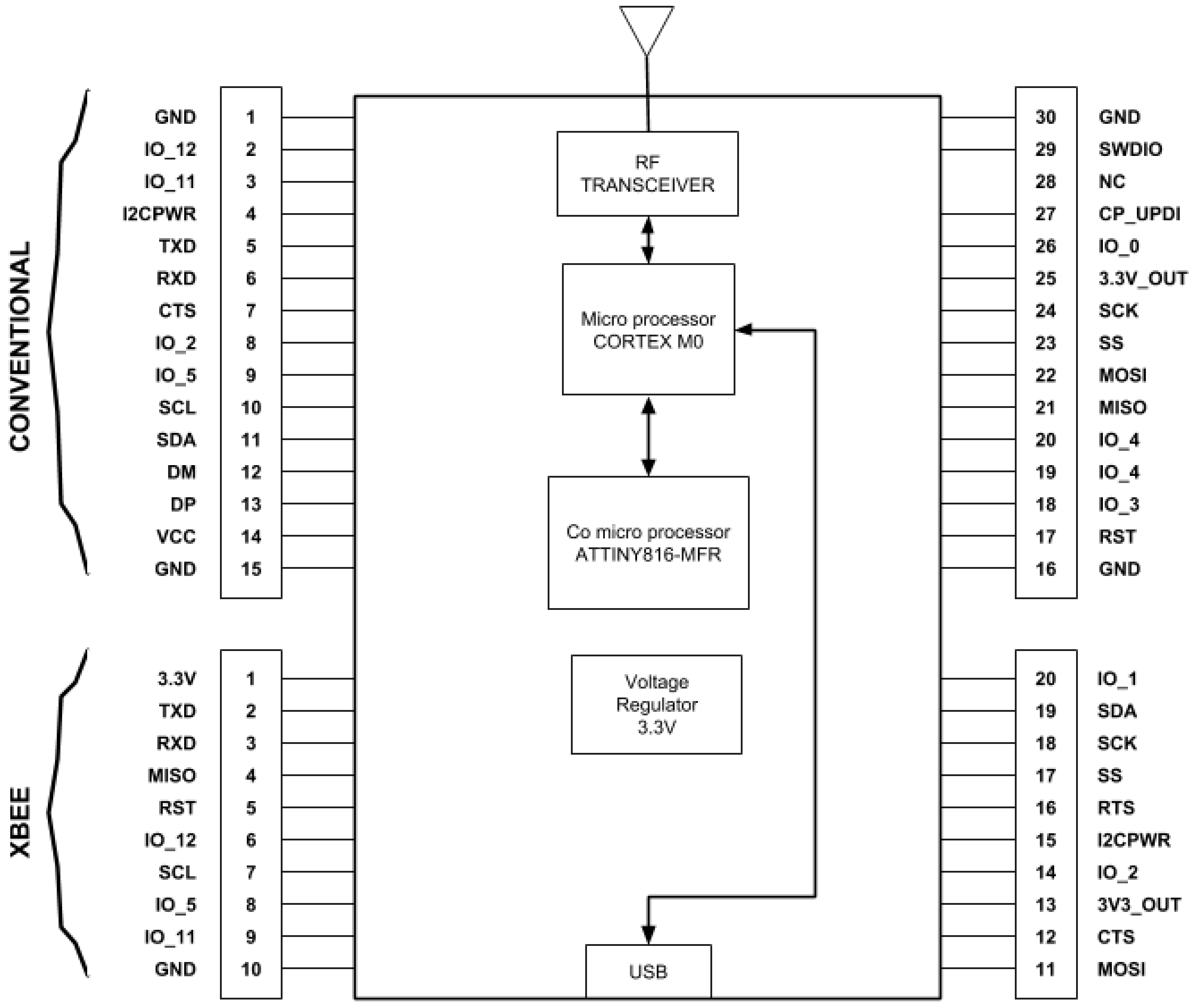
## Module Pin Out

Electrical connections to the SMK900 are made through the I/O pads and through the I/O pins (depending on whether it is the SMT castellated or the through-hole version). The hardware I/O functions are detailed in the table below (note that the MCU alias is useful only when using advanced VM programming using accessible native MCU functionalities, and only the mutable generic I/O pins are available for such purposes, and are denoted by the principal name IO_x, where x is the generic pin number as used in VM programming):

| PIN TH | PIN XB | PIN SMD | NAME | ALIAS | I/O | DESCRIPTION |
|---|---|---|---|---|---|---|
| 1 | 10 | 1,13, 28 | GND | - | - | Power supply and signal ground. Connect to the host ground. |
| 2 | 6 | 9 | IO_12 | TX_LED | O (I) | Transmit LED pin. This pin activates only when a radio transmission is active. |
| 3 | 9 | 12 | IO_11 | BCAST_ LED | O (I) | Broadcast LED pin. This pin activates/deactivates itself in order to mark the beginning and the end of a broadcast cycle. |
| 4 | 15 | | I2C_PWR | - | O | I2C Power pin. Can be configured by changing the powerBusMode byte in the I2C configuration register. Allows to turn on/off an I2C peripheral connected to the module on demand when required (usually when a VM execution is running after a broadcast cycle). |
| 5 | 2 | 5 | TXD | - | O | Serial data output from the radio. |
| 6 | 3 | 6 | RXD | - | I | Serial data input to the radio. |
| 7 | 12 | 15 | /CTS | - | O | Host serial port CTS pin. When the line goes high, the host must stop sending data. |
| 8 | 14 | | IO_2 | RTS | I (O) | Generic I/O. |
| 9 | 8 | 11 | IO_5 | DAC0 | I (O) | Generic I/O. Alternately, hardware DAC channel 0. |
| 10 | 7 | 10 | I2C_SCL | - | O | I2C Master SCL clock pin. This pin should be pulled via resistor to a 3.3V high line (possibly the 3.3V_OUT pin). |
| 11 | 19 | 22 | I2C_SDA | - | I/O | I2C Master SDA data pin. This pin should be pulled via resistor to a 3.3V high line (possibly the 3.3V_OUT pin). |
| 12 | 20 | 23 | IO_1 | - | I (O) | Generic I/O. |
| 13 | | | IO_6 | DAC1 | I (O) | Generic I/O. Alternately, hardware DAC channel 1. |
| 14 | | | VCC | - | I | Power supply input, +3.3 to +5.5 Vdc. |
| 15 | 10 | 1,13,28 | GND | - | - | Power supply and signal ground. Connect to the host ground. |
| 16 | 10 | 1,13,28 | GND | - | - | Power supply and signal ground. Connect to the host ground. |
| 17 | 5 | 8 | /RESET | - | I | Active low module hardware reset. |
| 18 | | | IO_3 | ADC0 | I (O) | Generic I/O. Alternately, hardware ADC channel 0. |
| 19 | | | IO_4 | ADC1 | I (O) | Generic I/O. Alternately, hardware ADC channel 1. |

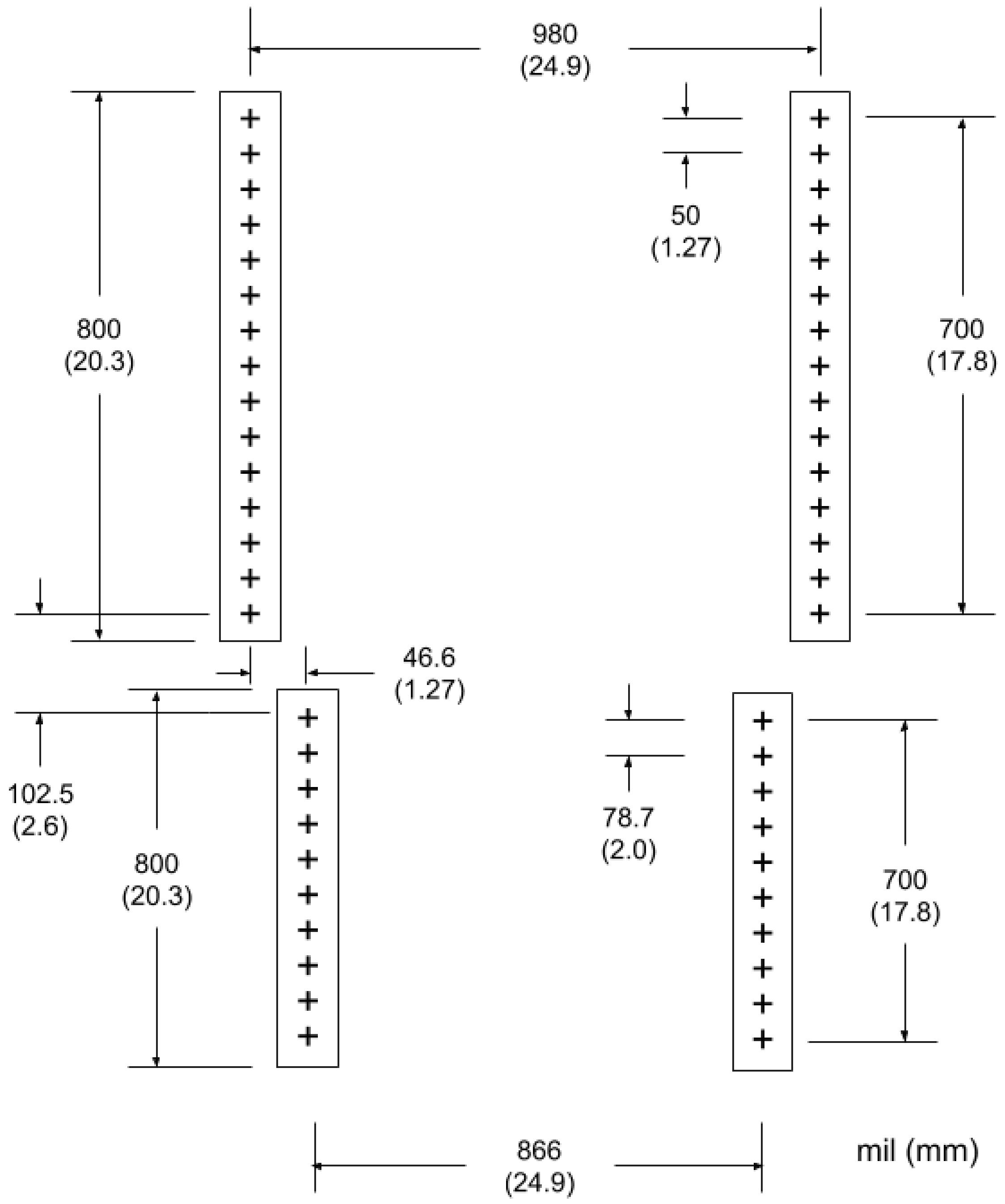
| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | 4 | 7 | IO_9 | MISO | I (O) | Generic I/O. Alternately, hardware SPI Master In Slave Out pin, or OC1A Timer C wave out Channel A. |
| 21 | | 14 | IO_8 | MOSI | I (O) | Generic I/O. Alternately, hardware SPI Master Out Slave In pin, or OC1B Timer C wave out Channel B. |
| 22 | 17 | 20 | IO_7 | /SS | I (O) | Generic I/O. Alternately, hardware SPI enable pin. |
| 23 | 18 | | IO_10 | SCK, MIRROR | I (O) | Generic I/O. Alternately, hardware SPI port clock, or MCU event mirror output pin. |
| 24 | 1, 13 | 4,16 | 3.3V | - | O | Stable, low-power 3.3V output. Use with low-power devices only (<10 mA average power consumption, <20 mA peak consumption). |
| 25 | | 24 | IO_0 | ADC_EXT _ REF | | Generic I/O. Alternately, ADC external reference voltage pin. The voltage at this pin can be used by the ADCs as a reference for ratiometric measurements. |
| 26 | | | RSVD | - | | |
| 27 | | | RSVD | - | | Reserved pin. Leave unconnected. |
| 28 | 10 | 1,13,28 | GND | - | | Connect to the host circuit board ground plane. |
| 29 | | | RSVD | - | | Reserved pin. Leave unconnected. |
| 30 | 10 | 1,13,28 | GND | - | | Connect to the host circuit board ground plane. |
| | | 2 | DM | - | I/O | USB negative wire (white) |
| | | 3 | DP | - | I/O | USB positive wire (green) |

## Through holes pinout

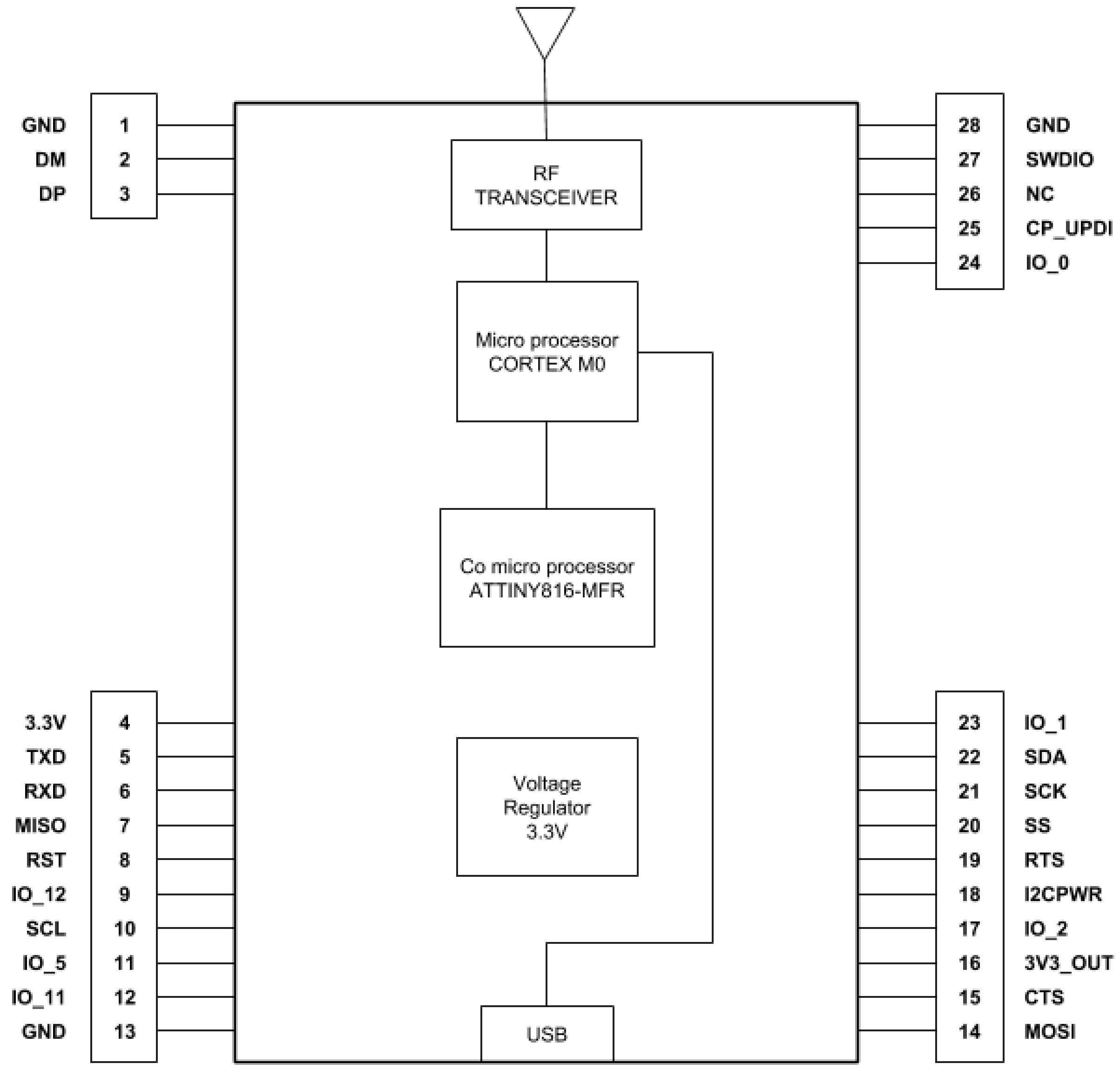


PORTA SCHEMATIC BLOCK DIAGRAM THROUGH HOLES

## Through Holes Mounting



## Surface mount pinout



PORTA SCHEMATIC BLOCK DIAGRAM CASTELLATION

## Power Supply and Input Voltages

SMK900 radio modules can operate from an unregulated DC input in the range of 3.3 to 5.5 V with a maximum ripple of 5% over the temperature range of -40 to 85 °C. Applying AC, reverse DC, or a DC voltage outside the range given above can cause damage and/or create a fire and safety hazard. Further, care must be taken so logic inputs applied to the radio stay within the voltage range of 0 to 3.3 V. Signals applied to the analog inputs must be in the range of 0 to ADC_EXT_REF (Pad/Pin 25) if the reference is used as such, else the range of 0 to VCC shall be used. Applying a voltage to a logic or analog input outside of its operating range can damage the SMK900 module.

## ESD and Transient Protection

The SMK900 circuit boards are electrostatic discharge (ESD) sensitive. ESD precautions must be observed when handling and installing these components. Installations must be protected from electrical transients on the power supply and I/O lines. This is especially important in outdoor installations, and/or where connections are made to sensors with long leads. Inadequate transient protection can result in damage and/or create a fire and safety hazard.

In the case where low power consumption is desired, dedicated logic level converters, or equivalent FET circuitry can be used to achieve such specifications.

## Antenna Connector

The antenna connector is a U.FL type male connector which can either be mated to a PCB host board or directly to an antenna using the appropriate adapter. Impedance of all components from the connector up to the antenna part has to be 50 Ohms.

## Additional I2C Functions

the following I2C commands are available for execution from a custom user VM script(see section 5 for more details):

| Name | Type | Description | Master command byte stream | Expected slave answer byte stream |
|---|---|---|---|---|
| Read configuration | Read | Read in the following order: voltage (1 byte), RF channel (1 byte), I2C address (1 byte), expected reference voltage (2 bytes, Little-Endian byte ordering). Voltage is the input VCC voltage of the external sleep controller, using the internal chip FVR voltage reference. Precision expected of this voltage measurement is ±0.15 V, and is thus usually sufficient to evaluate battery pack status if standard alkaline batteries are used. The raw voltage value sent VRAW is in increments of 0.05V, and is an unsigned 8-bit integer. In other terms, V[Volt] = VRAW * 0.05. The expected reference voltage REFVOLT is the actual reference voltage of the internal FVR used for ADC measurements, which defaults to 2048 mV (value stored in 16-bit as a mV value). In the case where there is a discrepancy in the voltage assessment of VCC by the external sleep controller $V_{ext}$ and a calibrated measurement in laboratory $V_{lab}$, then the REFVOLT should be corrected in the following manner: REFVOLT <= REFVOLT * $V_{lab}$ / $V_{ext}$. | [(ADDR * 2)+1] | [VOLTAGE, RF channel, ADDR, REF voltage LS byte, REF voltage MS byte] |

| | | | | |
|---|---|---|---|---|
| Change I2C address | Write | Write a new I2C address to the external sleep controller. Note that changes are effective without having to reboot the external sleep controller chip, less than 100 msec after the I2C command is sent on the I2C bus. | [ADDR * 2, 0x28, new I2C ADDR] | N/A |
| Change reference voltage | Write | Change the reference voltage used for calibrating the voltage measurements. Change is valid and enforced < 100 msec. after end of I2C command. | [ADDR * 2, 0x11, new REF voltage LS byte, new REF voltage MS byte] | N/A |
| Change RF channel | Write | Change the generic RF channel value via I2C. Change is valid and enforced < 100 msec. after end of I2C command. | [ADDR * 2, 0x18, new RF channel value] | N/A |

Note that all byte streams are notated as a sequence of bytes in brackets [], and that ADDR is the current I2C address of the external sleep controller chip when the command is issued from the I2C master side.

## Example VM User Script using I2C Functions

Here is a VM example for a simple *node* that (1) at boot-up, queries the external sleep controller for the RF channel variable, and configures the transceiver *NwkId* and *HopTable* configuration registers accordingly (see section 7.3 for details about configuration registers); (2) when receiving an air command from a *gateway*, it queries the external sleep controller voltage, and sends this back as the *gateway* answer, in conjunction with the last known received packet RSSI value.

```
#include "SMK900.evi"
//Note that SMK900.evi include code listing is appended as an annex of this document.
//This include defines transceiver-specific constants as well as available special-purpose
//transceiver functions. See section 8.2.1 for details.

#define RFCHANNEL_MAX_RETRIES_COUNT_STD (20)
#define SLEEPCTRL_I2C_ADDR_AND_0X7F_SHIFTL_1_OR_I2CMASTER_READMODE_gc (0x91)

function exec_bootup(){
        local rfChannel;
        local retryCount;

        local nwkid;
        local hoptableid;
        local i;
        retryCount=0;

        //Hardcode a delay of 100usec * 1000 * 60 = 6 seconds
        for(i=0;i<60;i++){
           Delay(1000);
        }

        while(retryCount<RFCHANNEL_MAX_RETRIES_COUNT_STD){
           if(I2C_Start( SLEEPCTRL_I2C_ADDR_AND_0X7F_SHIFTL_1_OR_I2CMASTER_READMODE_gc ) ){
                   //Sleep controller answered NAK
                   I2C_Stop();
                   retryCount++;
                   Delay(5000);//delay 500 msec before retrying
           }
           else{
                   //Sleep controller answered ACK
                   I2C_ReadAck(); //1st byte is voltage. We discard
                   rfChannel = I2C_ReadNak();    //2nd byte is RF channel
                   I2C_Stop();

                   //Define NwkId and HopTable register values according to read RF channel value
                   //stored in external sleep controller
                   nwkid = rfChannel % NWK_COUNT;
                   hoptableid = HOPTABLE_50K_START + (rfChannel % HOPTABLE_50K_COUNT);

                   //REGISTER_xxx are VM-accessible mesh controller configuration parameters
                   GetRegisterRAMBUF(8, REGISTER_NWKID);
                   GetRegisterRAMBUF(9, REGISTER_HOPTABLE);
                   if( (nwkid!=GetBuffer_U8(8)) || (hoptableid!=GetBuffer_U8(9)) ){
                           SetBuffer(8,nwkid,1);
                           SetBuffer(9,hoptableid,1);
                           SetRegisterRAMBUF(8, REGISTER_NWKID);
                           SetRegisterRAMBUF(9, REGISTER_HOPTABLE);

                           TransferConfigEEPROM();
                           //force reset by letting watchdog expire (the mesh controller
                           //has a safety watchdog that runs at all times, and set by default at 8 sec)
                           while(1){}
                   }

                   break;
           }
        }
}

//Custom VM function executed when end node mesh controller receives an "air cmd", which is
//a command from coordinator node to execute a VM function over the air
function exec_aircmd(){
        local V;

        //time to read external sleep controller voltage using I2C bus
        if(I2C_Start( SLEEPCTRL_I2C_ADDR_AND_0X7F_SHIFTL_1_OR_I2CMASTER_READMODE_gc ) ){ //failure
           V=0;
        }
        else{
           V = I2C_ReadNak();
        }
        I2C_Stop();

        SetBuffer(0,GetRSSI(),1); //set first answer byte as the RSSI of the last known good packet received
        SetBuffer(1,V,1); //set 2nd answer byte as voltage fetched via I2C bus
        Send(2);
}

//Common entry point for all VM executions: the subfunction to b executed is selected according to trigger
//type via GetExecType().
function main()
{
        local execType;

        execType = GetExecType();
        if(execType==MESHEXECTYPE_BOOTUP_bm){
          exec_bootup();
        }
        else if(execType==MESHEXECTYPE_AIRCMD_bm){
          exec_aircmd();
        }
}
```

## Protocol-formatted Messages

### Protocol Formats

SMK900 module can work in one of two serial data modes - transparent or protocol. Transparent mode requires no data formatting, but cannot leverage the embedded *node* addressing schemes, nor can access configuration and VM upload/erase/check/execute functions. Thus, transparent mode is adapted mainly for simple drop-in serial wire replacement for point-to-multipoint applications.

Thus, a *gateway* that needs to send messages to a specific *node*, or a *node* replying to said *gateway*, must use protocol formatting if any advanced functionality other than simple ASCII message broadcast is needed, such as access to sensor I/O commands, configuration commands and replies, event monitoring, etc. All protocol-formatted messages have a common header as shown in Figure :

| 0 | 1 | 2 | 3 | 4... |
|---|---|---|---|---|
| SOP | Length (LSByte) | Length (MSByte) | PktType | Variable number of arguments ... |

The scale above is in bytes.

The *Start-of-Packet* (SOP) character, 0xFB, is used to mark the beginning of a protocol-formatted message and to assure synchronization in the event of a glitch on the serial port at startup.

This is followed by two length bytes, in Little-Endian ordering (lowest-significant byte first). This 16-bit value corresponds to the length of the *remainder* of the message following the length bytes themselves, i.e. the length of the entire message - 3.

The Packet Type (PktType) byte specifies the type of message. It is a bitfield-oriented specifier, decoded as follows:

| Bit(s) | Meaning |
|---|---|
| 7 | Address send back request bit |
| 6 | Reserved for future use |
| 5 | Event - this bit is set to indicate an event message |
| 4 | Reply - this bit is set to indicate a message is a reply |
| 3..0 | Type - these bits indicate the message type |

### Message

Messages generated on the serial interface by the user are referred to as *host* messages, and have a PktType reply bit (4) cleared. Messages generated on the serial interface by the radio are referred to as *reply* or *event* messages, and have either bit 4 (replies) or bit 5 (event) of the PktType byte set. For most commands, there is a corresponding reply message, which is either an acknowledgement message.

Errors are usually flagged using event messages. Messages received by the radio and relayed back to user, such as *node* reply messages, are flagged as event messages as well. Note that for all quantities encoded using multi-byte, the byte ordering is Little-Endian, except for text strings. Little-Endian byte order places the lowest order byte in the left-most byte of the argument and the highest order byte in the right-most byte of the argument.

A command sent from the host to a module locally via serial port in order to initiate an action locally, or to read/write to the module locally, is the default type of message. However, there is also another type of message, which are called *air command wrapped messages*. Those are typically akin to local destination messages, but wrapped around a meta-message, which, combined with a destination MAC address, allows to execute said command at a remote transceiver *node* location with said MAC address as if that command was locally executed at this remote *node* location. Thus, it is possible to use the same command set (encapsulated within those meta-messages, called *air command wrappers*) to change the configuration and act on remote *nodes* in a straightforward manner. It is also possible to send *air command wrapped messages* to multiple MAC addresses (up to 4), if multi-phase mode is used (only possible when the number of *broadcast in phases* $B_I > 1$).

## Message Format Details

### Summary of message types

| Com-mand | Reply | Event | Type | Direction | AirCmd. Wrapped, no MAC | AirCmd. Wrapped, w/ MAC | Gateway cmd. | Node cmd. |
|---|---|---|---|---|---|---|---|---|
| 0x00 | - | - | EnterProtocolMode | from Host | - | - | X | X |
| - | 0x10 | - | EnterProtocolModeReply | from Radio | - | - | X | X |
| 0x01 | - | - | ExitProtocolMode | from Host | - | - | X | X |
| 0x02 | - | - | DeviceReset | from Host | 0x02 | 0x82 | X | X |
| - | 0x12 | - | DeviceResetReply | from Radio | - | - | X | X |
| 0x05 | - | - | TXLongData | from Host | - | - | X | X |
| 0x07 | - | - | TXReduxData | from Host | - | - |  | X |
| - | - | 0x26 | RXDataPacket | from Radio | - | - | X | X |
| - | - | 0x28 | RXReduxDataPacket | from Radio | - | - | X |  |
| - | - | 0x29 | RXBcastInSniffedDataPacket | from Radio | - | - |  | X |
| - | - | 0x2A | BcastUART2TrxBufferDone | from Radio | - | - | X | X |
| - | - | 0x2B | RXBcastInSnifferAirDataPacket | from Radio | - | - |  | X |
| - | - | 0x2C | RXBcastOutSnifferAirCmd | from Radio | - | - |  | X |
| 0x0A | - | - | DynConfig | from Host | - | - | X |  |
| - | 0x1A | - | DynConfigReply | from Radio | - | - | X |  |
| 0x03 | - | - | GetRegister | from Host | 0x03 | 0x83 | X | X |
| - | 0x13 | - | GetRegisterReply | from Radio | 0x13 | 0x93 | X | X |
| 0x04 | - | - | SetRegister | from Host | 0x04 | 0x84 | X | X |
| - | 0x14 | - | SetRegisterReply | from Radio | 0x14 | 0x94 | X | X |
| 0x0B | - | - | TransferConfig | from Host | 0x0B | 0x8B | X | X |
| - | 0x1B | - | TransferConfigReply | from Radio | 0x1B | 0x9B | X | X |
| 0x0C | - | - | TXAirCmdWrapper | from Host | - | - | X |  |
| - | - | 0x2D | RXAirCmdWrapper | from Radio | - | - | X |  |
| 0x0D | - | - | VMFlash | from Host | 0x0D | 0x8D |  | X |
| - | 0x1D | - | VMFlashReply | from Radio | 0x1D | 0x9D |  | X |
| 0x0E | - | - | VMExecute | from Host | 0x0E | 0x8E | X | X |
| - | 0x1E | - | VMExecuteReply | from Radio | 0x1E | 0x9E | X | X |
| - | - | 0x27 | Announce/Error | from Radio | 0x27 | 0xA7 | X | X |

### EnterProtocolMode

This command is used to enter protocol formatted mode from transparent serial mode via a special keyword (transceiver will reply with an *EnterProtocolModeReply* message).

| **EnterProtocolMode (special keyword command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x08 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 - 0x10 | Keyword | 0x44 0x4E 0x54 0x43 0x46 0x47 0x00 0x00 = Keyword string |

## EnterProtocolModeReply

This reply is the expected reply from transceiver module to the corresponding command *EnterProtocolMode*.

| **EnterProtocolModeReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x10 = EnterProtocolModeReply |

## DeviceReset

This resets the transceiver module (for local UART commands only, the transceiver will reply with a *DeviceResetReply* message). This command can be wrapped as an *air command*.

| **DeviceReset (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x02 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x02 = DeviceReset |
| 0x04 | Reset Type | 0x00 = Normal reset |

## DeviceResetReply

This is the reply message (only for local UART commands) after the transceiver receives a *DeviceReset* command. An equivalent *air command* reply wrapped accordingly can be sent out from a *node* back to its *gateway* if the latter sent an *air command* with *DeviceReset* as the wrapped command.

| **DeviceResetReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x12 = DeviceResetReply |

## TxLongData

Basic data send in command mode, that can span multiple consecutive broadcast phases. Note that no reply is tied to this command. In the case where the transmitter is a *gateway*, then all *nodes* directly or indirectly connected to that *gateway* via the mesh network that properly receives the broadcasted packet will send a corresponding *RxDataPacket* reply to their own hosts. In the case where the transmitter is a *node*, then only the *gateway* will send a corresponding *RxDataPacket* reply at reception of packet. If another *node* needs to monitor that signal, then the proper *sniffer* configuration register flags (RAM bank register *sniffFlagsMask*, flag *BROADCASTIN_bm*) must be written (see section 7.3), in which case the corresponding *sniffed* receive replies to host will be in the form of *RXBcastInSniffedDataPacket*.

| **TxLongData (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x05 = TxLongData |
| 0x04 | Start Broadcast Phase | 0x00-0x03 = Start Broadcast Phase (range is in practice limited to B-1, where B is the number of Broadcast Out Phases if sender is a *gateway*, or the number of Broadcast In Phases if sender is a *node* |

| | | |
|---|---|---|
| 0x05 - … | Payload | Up to 20*B bytes of data at 50kbit/sec, 72*B bytes of data at 100kbit/sec, where B is the number of Broadcast Out Phases if sender is a *gateway*, or the number of Broadcast In Phases if sender is a *node* |

## TxReduxData

Special data send using the broadcast cycle *redux* phase. This command is only available for *nodes* (*redux* phase utilization is forbidden by *gateway*), and only if the *dynamic configuration* of the network has the redux phase enabled (see section 2.2 for more details). Note that no reply is tied to this command.

**TxReduxData (command)**

| Byte offset | Field | Description |
|---|---|---|
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x07 = TxReduxData |
| 0x04 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

## RxDataPacket

Event message from transceiver to its host when it received a regular packet sent via *TxLongData*. Note that this packet type is also used as a special Broadcast End Marker, in which case the packet byte stream is hard-coded to the following: [0xFB 0x03 0x00 0x26 0xFF 0x00], a marker that is sent at the end of every broadcast cycle, before any *air command* is processed (and only if configuration register in RAM bank *enableNotificationFlagsMask*, flag *CLOSEBROADCAST_bm*, is set; see section 7.3 for details).

**RxDataPacket (event)**

| Byte offset | Field | Description |
|---|---|---|
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x26 = RxDataPacket |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID; 0xFF = Broadcast End Marker (special case) |
| 0x05 | RSSI | 0x00-0xFF = Received packet strength (for regular received packet); this value is forced to 0x00 if Broadcast Phase ID is 0xFF (Broadcast End Marker) |
| 0x06 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

## RxReduxDataPacket

Event message from transceiver to host when it receives a packet in the broadcast cycle *redux* phase. This is only available if the current *dynamic configuration* of the network allows a *redux* phase.

**RxReduxDataPacket (event)**

| Byte offset | Field | Description |
|---|---|---|
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x28 = RxReduxDataPacket |
| 0x04 | RSSI | 0x00-0xFF = Received packet strength |
| 0x05 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

## RXBcastInSniffedDataPacket

Event message from a *node* (exclusively) transceiver to host, when it receives a *sniffed* packet transmitted from another *node* towards the network *gateway* via command *TxLongData*. This message is only sent to transceiver host if the proper transceiver configuration register flag is set (RAM bank register *sniffFlagsMask*, flag *BROADCASTIN_bm*, see section 7.3).

| **RXBcastInSniffedDataPacket (event)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x29 = RXBcastInSniffedDataPacket |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID |
| 0x05 | RSSI | 0x00-0xFF = Received packet strength |
| 0x06 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

### BcastUART2TrxBufferDone

Event message sent from transceiver to host after the UART transmit buffer is cleared and its corresponding data is transferred in RF packet buffers, ready to be transmitted out. This marker is always sent at the beginning of a broadcast, even if the UART transmit buffer is clear (only if configuration register in RAM bank *enableNotificationFlagsMask*, flag *ENDUARTTRANSFERTOTXBUFFER_bm*, is set; see section 7.3 for details).

| **BcastUART2TrxBufferDone (event)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x2A = BcastUART2TrxBufferDone |

### RXBcastInSnifferAirDataPacket

Event message from a *node* (exclusively) transceiver to host, when it receives a *sniffed* packet transmitted from another *node* towards the network *gateway* which contains an *air command* reply of any kind (i.e. an *air command* reply sent back by a *node* after having received an *air command* sent by a *gateway*, the latter having sent it via command *TXAirCmdWrapper*). This message is only sent to transceiver host if the proper transceiver configuration register flag is set (RAM bank register *sniffFlagsMask*, flag *BROADCASTIN_bm*, see section 7.3). Also note that the entirety of the raw wrapped *air command* answer, including the sender *node* address bytes (if applicable), can be found within the payload of this message.

| **RXBcastInSnifferAirDataPacket (event)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x2B = RXBcastInSnifferAirDataPacket |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID |
| 0x05 | RSSI | 0x00-0xFF = Received packet strength |
| 0x06 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

### RXBcastOutSnifferAirCmd

Event message from a *node* (exclusively) transceiver to host, when it receives a *sniffed* packet transmitted from a *gateway* towards another *node* which contains an *air command* of any kind (sent via *TXAirCmdWrapper*). This message is only sent to transceiver host if the proper transceiver configuration register flag is set (RAM bank register *sniffFlagsMask*, flag *BROADCASTOUT_AIR_bm*, see section 7.3). Also note that the entirety of the raw wrapped *air command*, including the requested *node* address bytes (if applicable, and possibly for multiple *nodes*), can be found within the payload of this message. Note that a supplementary parameter (Phase In Count) is provided in this message in order for the recipient to know how many MAC addresses are in said *air command*, which directly correlates with the current number of Broadcast In Phases of the network (parameter $B_I$, see section 2.2).

Note that although is in effect theoretically possible for a *node* to extrapolate this information by retrieving the network *dynamic configuration* parameters, in order to get parameter $B_I$ instead on relying on the Phase In Count parameter of this event message, it is not a recommended practice. Indeed, it would be possible for a network to dynamically change its current *dynamic configuration* after the sniffed message arrives, but before the request for fetching the *dynamic configuration* is sent (by reading RAM bank register *dyn*; see section 7.3), thereby creating the low-level equivalent of a "concurrency atomicity problem". Thus, the Phase In Count parameter is provided to user in order to ensure atomicity when reading the current Broadcast In Phase count within the *dynamic configuration* parameters of the mesh network.

| **RXBcastOutSnifferAirCmd (event)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x2C = RXBcastOutSnifferAirCmd |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID |
| 0x05 | RSSI | 0x00-0xFF = Received packet strength |
| 0x06 | Phase In Count | 0x01-0x04 = Number of Broadcast In Phases at sniffed message reception |
| 0x07 - … | Payload | Up to 20 bytes of data at 50kbit/sec, 72 bytes of data at 100kbit/sec |

## DynConfig

This is the main command for changing the dynamic configuration of a network, and can only be sent to a transceiver set as a *gateway*. After this command is sent, a reply will acknowledge the change request immediately if said request is valid (via a *DynConfigReply* message), and those changes will be applied to the *gateway* mesh configuration at the beginning of the next broadcast cycle (see section 2.2 for details about broadcast cycles, and for details about the DYN parameters), or will return an error event message if the set of DYN parameters is deemed invalid. Note that the new set of DYN parameters are then subsequently flooded to the whole of the mesh network via a *gateway* broadcast out packet.

| **DynConfig (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x07 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x0A = DynConfig |
| 0x04 | Phase Out Count | 0x01-0x04 = Number of Broadcast Out Phases |
| 0x05 | Phase In Count | 0x01-0x04 = Number of Broadcast In Phases |
| 0x06 | NumSeq | 0x01-0x1F = Number of sequence slots (repeater hop count for mesh network) |
| 0x07 | NumSeqRedux | 0x01 = Numer of sequence slots for redux phase (for the current firmware version, only 1 value is supported) |
| 0x08 | ReduxEnableFlag | 0x00-0x01 = Redux phase enable flag |
| 0x09 | DutyCycleDiv | 0x01, 0x02, 0x05, 0x0A, 0x014, 0x28, 0x50 = Duty Cycle inverted |

## DynConfigReply

This is the reply message corresponding to *gateway* command *DynConfig*, and is sent from *gateway* transceiver back to its host if the requested DYN configuration changes are deemed valid.

| **DynConfigReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |

| | | |
|---|---|---|
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x1A = DynConfigReply |

## GetRegister

This is a configuration parameter register read command, in a certain register bank, and with a given offset (see section 7.3 for specific configuration register details). Note that the correct expected register size has to be provided as an argument, as the transceiver will use this to verify validity of the *GetRegister* command (in case of an invalid size, it will return an error event message). This command can be wrapped as an *air command*.

| **GetRegister (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x04 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x03 = GetRegister |
| 0x04 | Register Type | 0x00=RAMBUF, 0x01=RAM, 0x02=EEPROM (configuration register bank selector) |
| 0x05 | Register Offset | 0x00-0x14 = Configuration register offset in register bank |
| 0x06 | Register Size | 0x01-0x08 = Requested configuration register size |

## GetRegisterReply

This is the reply corresponding to *GetRegister* command. An equivalent *air command* reply wrapped accordingly can be sent out from a *node* back to its *gateway* if the latter sent an *air command* with *GetRegister* as the wrapped command.

| **GetRegisterReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | (0x04 + N) 0x00 = Number of bytes in message following this byte (Little-Endian), where N is the Register Size parameter (see below) |
| 0x03 | Packet Type | 0x13 = GetRegisterReply |
| 0x04 | Register Type | 0x00=RAMBUF, 0x01=RAM, 0x02=EEPROM (configuration register bank selector) |
| 0x05 | Register Offset | 0x00-0x14 = Configuration register offset in register bank |
| 0x06 | Register Size | 0x01-0x08 = Returned configuration register size (N) |
| 0x07 - … | Register content | From 1 to 8 bytes of data (byte count is N): this is the content of register being read, with variables or structures being stored in a Little-Endian manner |

## SetRegister

This is a configuration parameter register write command, in a certain register bank, and with a given offset (see section 7.3 for specific configuration register details; note that some registers are read-only). The correct expected register size has to be provided as an argument, as the transceiver will use this to verify validity of the *SetRegister* command (in case of an invalid size, it will return an error event message). This command can be wrapped as an *air command*.

| **SetRegister (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | (0x04 + N) 0x00 = Number of bytes in message following this byte (Little-Endian), where N is the Register Size parameter (see below) |

| | | |
|---|---|---|
| 0x03 | Packet Type | 0x04 = SetRegister |
| 0x04 | Register Type | 0x00=RAMBUF (direct register writes disallowed for RAM and EEPROM banks) |
| 0x05 | Register Offset | 0x00-0x14 = Configuration register offset in register bank |
| 0x06 | Register Size | 0x01-0x08 = Configuration register size (N) of register to be written |
| 0x07 - … | Register content | From 1 to 8 bytes of data (byte count is N): this is the content of register being modified, with variables or structures being stored in a Little-Endian manner |

### SetRegisterReply

This is the reply corresponding to *SetRegister* command. An equivalent *air command* reply wrapped accordingly can be sent out from a *node* back to its *gateway* if the latter sent an *air command* with *SetRegister* as the wrapped command.

| **SetRegisterReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x14 = SetRegisterReply |

### TransferConfig

This is a command for transferring content from one register bank to another bank (see section 7.3 for the definition of register banks), or to reset *node* to factory settings. Note that a factory reset might set the *node* address to another address than its current address, in which case the *node* address should be changed to its desired value immediately after a factory reset operation (either via local *SetRegister* UART command writing new values in RAMBUF bank register *addressBuf* as defined in section 7.3, followed by a *TransferConfig* command for RAMBUF to EEPROM, followed by a device reset, or via the equivalent VM execution commands, which are defined in section 5). This command can be wrapped as an *air command*.

| **TransferConfig (command)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x02 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x0B = TransferConfig |
| 0x04 | Transfer Type | 0x00 = RAM->TMP, 0x01 = TMP->RAM, 0x02 = TMP->EEPROM, 0x03 = RESET TO FACTORY DEFAULTS |

### TransferConfigReply

This is the reply corresponding to *TransferConfig* command. An equivalent *air command* reply wrapped accordingly can be sent out from a *node* back to its *gateway* if the latter sent an *air command* with *TransferConfig* as the wrapped command.

| **TransferConfigReply (reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x01 0x00 = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x1B = TransferConfigReply |

### TXAirCmdWrapper

This command is used to wrap a local serial device command, so that it can be rerouted from a *gateway* to a given set of *nodes*, and executed there. This is useful when one needs to send a command to a *node*, without local access to its serial communication bus, in which case the command can be packaged within a *TXAirCmdWrapper* command, then sent via serial communication bus to a *gateway* transceiver controlling the network which is connected to the *node* in question. Said *gateway* then reroutes that command to the desired destination *node(s)* via the mesh network. The *node(s)* then read that command, as if it received it via its own local serial communication bus, except for the fact that all *air commands* are read by the *node(s)* only after a broadcast cycle ended, just before they go into sleep mode (if sleep mode is enabled for any particular *node*).

Any *node* which executes any command is usually expected to generate a reply. Because an *air command* is received via the mesh network, the corresponding reply is not transmitted over the serial bus to a host locally connected to that *node*, but is instead transmitted over the mesh network back to the *gateway*, which then proceeds to wrap the reply received in a *RXAirCmdWrapper* message. That wrapped reply message is then sent out to the host connected to that *gateway* transceiver.

Therefore, this command is only available for transceivers configured as *gateways*. If a *node* wants to *sniff* those special *air command* packets sent out from a *gateway*, then it needs to use the event marker *RXBcastOutSnifferAirCmd* (with proper concomitant configuration register flag set).

For a diagram detailing the whole flow of information and processing events related to it for *air commands* and the corresponding *air replies*, see section 7.2.23.

| **TXAirCmdWrapper (command wrapping another command for remoting)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x0C = TXAirCmdWrapper |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID |
| 0x05 | Wrapped Packet Type | IF using MULTI-PHASE mode:<br>0x0F = multiphase mode<br>ELSE:<br>0x?? (not 0x0F) = any single command packet type byte for any command compatible with *air command* wrapping |
| 0x06 - (0x06+N-1) | Destination MAC Address List | IF using MULTI-PHASE mode:<br>N = M*$B_I$ bytes, which is the concatenated series of M MAC address bytes for each *node* being queried (total number of *nodes* queried is $B_I$, i.e. corresponds to the Broadcast In Phase count of the network)<br>ELSE:<br>N = M bytes, which are the M MAC address bytes for the single *node* being queried |
| (0x06+N) - … | Wrapped Partial Payload | IF using MULTI-PHASE mode:<br>Wrapped command message, with Start-of-Packet & Length word removed<br>ELSE:<br>Wrapped command message, with Start-of-Packet & Length word & Packet Type byte of that command removed |

### RXAirCmdWrapper

This event message is a wrapper message for any replies from a *node* transmitted back to the *gateway* of a given mesh network (instead of being transmitted to a host locally connected to that *node* via serial communication bus), and thus is the corresponding message to *TXAirCmdWrapper* (see section 7.2.22 for details).

This reply message is only applicable for transceivers configured as *gateways*. If a *node* needs to sniff another *node* answer to an *air command* previously sent by *gateway*, then that *node* needs to use the event marker *RXBcastInSnifferAirDataPacket* (with proper concomitant configuration register flag set).

| **RXAirCmdWrapper (event wrapping remote reply)** | | |
|---|---|---|
| **Byte offset** | **Field** | **Description** |
| 0x00 | Start-of-Packet | 0xFB = Indicates start of protocol formatted message |
| 0x01 - 0x02 | Length | 0x?? 0x?? = Number of bytes in message following this byte (Little-Endian) |
| 0x03 | Packet Type | 0x2D = RXAirCmdWrapper |
| 0x04 | Broadcast Phase ID | 0x00-0x03 = Received packet Broadcast Phase ID |
| 0x05 | RSSI | 0x00-0xFF = Received packet strength |
| 0x06 | Wrapped Packet Type | IF Packet Type byte of corresponding *air command* has its bit 7 set (i.e. if bit-masking that byte with 0x80 yields a non-zero result), then:<br>0x??, which is the reply Packet Type byte matching said *air command*, with its bit 7 set also<br>ELSE:<br>0x??, which is the regular reply Packet Type byte matching said *air command* |
| 0x07 - (0x07+N-1) | Node MAC Address | IF Packet Type byte of corresponding *air command* has its bit 7 set (i.e. if bit-masking that byte with 0x80 yields a non-zero result), then:<br>N = M bytes, which are the M MAC address bytes for the *node* answering said *air command*<br>ELSE:<br>N = 0 bytes |
| (0x07+N) - … | Wrapped Partial Payload | Wrapped message, with Start-of-Packet & Length word & Wrapped Packet Type byte of that wrapped reply message removed |

## Configuration Registers

There are three configuration parameter banks: the TMP bank (also called RAMBUF), RAM bank, and EEPROM bank. The EEPROM allows a configuration that must stick through radio module reset or power-down to be stored in non-volatile memory. The RAM bank is copied from the EEPROM bank at boot-up, and is the main bank used by the mesh controller itself for its operations within its mesh network.

To control the mesh configuration registers, the SMK900 must be in protocol-formated mode. All three banks can be read via *GetRegister* command. Write operations (SetRegister) are only allowed to the TMP bank, and only to those registers. The proper procedure to change mesh configuration register, containing critical parameters such as the NwkID or the HopTable are changed, is as follows:

1. Set registers in TMP bank to the desired value (using *SetRegister* command);
2. Transfer TMP bank to EEPROM bank (using *TransferConfig* command);
3. Reset the module to activate the changes into RAM bank (using *DeviceReset* command).

Here is a table summarizing the configuration parameter registers available to the user:

## Register table

| Register offset | Size (bytes) | Read-Only Flag | Register name | Sub-register name | Sub-register location (bit offset) | Sub-register range | Default value | Description |
|---|---|---|---|---|---|---|---|---|
| 0x00 | 8 | | addressBuf | - | - | | N/A | MAC address buffer |
| 0x01 | 1 | | addressBufLen | - | - | | 3 | MAC address buffer length |
| 0x02 | 6 | X | dyn | BO | 0 | 1..4 | 1 | Dynamic configuration, Broadcast Out Phase Count |
| | | | | BI | 8 | 1..4 | 1 | Dynamic configuration, Broadcast In Phase Count |
| | | | | NH | 16 | 2..31 | 5 | Dynamic configuration, Number of Hops |
| | | | | NR | 24 | 1 | 1 | Dynamic configuration, Number of Hops for Redux Phase |
| | | | | R | 32 | 0..1 | 0 | Dynamic configuration, Redux Enable Flag |
| | | | | D | 40 | 1, 2, 5, 10, 20, 40, 80 | 10 | Dynamic configuration, Inverted Duty Cycle |
| 0x03 | 1 | | nwkId | - | - | 0..7 | 0 | Network ID |
| 0x04 | 1 | | hopTable | - | - | 0..5 | 0 | FHSS Hop Table selection |
| 0x05 | 1 | | power | - | - | 0..1 | 1 | Power selection (0=LO, 1=HI) |
| 0x06 | 2 | | uart_bsel | - | - | 1..65535 | 0x93D7 | UART baudrate selector. See Serial Interface section for more details. |
| 0x07 | 1 | | nodeType | - | - | 0..1 | 1 | Node Type (0=GATEWAY 1=NODE) |
| 0x08 | 1 | | sleepMode | - | - | 0..2 | 2 | Sleep mode (0=IDLE, 1=RC, 2=EXTERNAL) |
| 0x09 | 1 | | extSlpCtrlI2CAddress | - | - | 0..127 | 0x48 | Ext Slp Ctrl I2C address |
| 0x0A | 2 | X | extSlpCorrectionFactor | - | - | 0..65535 | N/A | Correction Factor (current value) |
| 0x0B | 1 | | presetRF | - | - | 0..1 | 0 | Preset RF configuration set (0=PRESET1_50K(default), 1=PRESET2_100K) |
| 0x0C | 8 | | cryptoData_qWord0 | - | - | 0..2^64-1 | 0 | Data encryption key, first 8 bytes, Little Endian |
| 0x0D | 8 | | cryptoData_qWord1 | - | - | 0..2^64-1 | 0 | Data encryption key, last 8 bytes, Little Endian |
| 0x0E | 7 | | i2c | delayClockLen | 0 | 0..65535 | 16 | I2C delay for clock generation. The I2C max clock speed is: MaxSpeed[MHz] = 1 / ( 2 + 0.5*(delayClockLen) ). Thus, a value of 16 yields a 100KHz max speed, and a value of 96 yields a 20KHz max speed. Use lower clock values when using higher value resistor pull-ups or when the capacitance charge on the I2C pins is higher than usual. |
| | | | | srcPort | 16 | 0 | 0 | I2C source port (hard-coded to the I2C pins assigned to module, for the current firmware revision) |
| | | | | pullupEnabledFlag | 24 | 0..1 | 1 | I2C internal weak pull-up on I2C pins (0 = disabled, 1 = enabled) |
| | | | | powerBusMode | 32 | 0..3 | 1 | I2C Power Bus mode. Values possible are: 0 = DISABLED (hi-impedance), 1 = NORMAL (pin state toggling between hi-impedance and VCC connection depending on VM execution and I2C commands - on if I2C command executed, and togglable via VM commands), 2 = ALWAYSOFF (pin connected to ground), 3 = ALWAYSON (pin connected to VCC) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | powerBus_powerUp Delay_msec | 40 | 0..65535 | 0 | I2C additional power-up delay for stabilization purpose (if needed) |
| 0x0F | 1 | | meshExecActiveFlag | SERIAL_bm | 0 | 0..1 | 1 | VM Execution Trigger Enable Flag On Serial Cmd Receive Event |
| | | | | AIRCMD_bm | 1 | 0..1 | 1 | VM Execution Trigger Enable Flag On Air-Cmd Receive Event |
| | | | | BOOTUP_bm | 2 | 0..1 | 1 | VM Execution Trigger Enable Flag On Boot-Up Event |
| | | | | ENTER SEEKMODE_bm | 3 | 0..1 | 0 | VM Execution Trigger Enable Flag On Enter Seek Mode Event |
| | | | | LEAVE SEEKMODE_bm | 4 | 0..1 | 0 | VM Execution Trigger Enable Flag On Leave Seek Mode Event |
| | | | | ENTER BROADCAST_bm | 5 | 0..1 | 0 | VM Execution Trigger Enable Flag On Enter Broadcast Event |
| | | | | LEAVE BROADCAST_bm | 6 | 0..1 | 0 | VM Execution Trigger Enable Flag On Leave Broadcast Event |
| | | | | ENABLEVM FLASHOP_bm | 7 | 0..1 | 1 | Enable VM Flash Operations Flag |
| 0x10 | 1 | | sniffFlagsMask | BROADCASTIN_bm | 0 | 0..1 | 0 | Enable *node* sniffing of broadcast in phase messages from other *nodes* to *gateway* |
| | | | | BROADCASTOUT_AIR_bm | 1 | 0..1 | 0 | Enable *node* sniffing of broadcast out air commands to specific MAC addresses that do not match address of said sniffer *node* |
| 0x11 | 1 | | enableNotificationFlagsMask | CLOSE BROADCAST_bm | 0 | 0..1 | 0 | Enable broadcast end close event message report (via special RxDataPacket event message with Broadcast phase ID = 0xFF) |
| | | | | ENDUART TRANSFERTO TXBUFFER_bm | 1 | 0..1 | 0 | Enable uart transfer to TX buffer event message report (via BcastUART2TrxBufferDone event message) |
| 0x12 | 8 | | gpStorage_qWord0 | - | - | 0..2^64-1 | 0 | General purpose storage buffer, bytes [0,7] |
| 0x13 | 8 | | gpStorage_qWord1 | - | - | 0..2^64-1 | 0 | General purpose storage buffer, bytes [8,15] |
| 0x14 | 8 | | gpStorage_qWord2 | - | - | 0..2^64-1 | 0 | General purpose storage buffer, bytes [16,23] |

## Registers Description

### addressBuf

holds the address bytes for the transceiver. This buffer is always defined as having 8 bytes, and the address is held in a Little-Endian format. The number of bytes used to form the effective address is defined in subsequent register *addressBufLen* (register offset 0x01) from the left. For example an *addressBuf* = [0x08 0x15 0x02 0x04 0x00 0x00 0x00 0x00] with *addressBufLen* = 3 will yield a 3-byte MAC address of 2.21.8 (if one uses a 4-byte MAC convention, this can also be written as 0.2.21.8).

### addressBufLen

holds the effective number of address bytes, as described above.

### dyn

holds the dynamic configuration of the transceiver. This is the set of 6 parameters that determine the configuration of the broadcast cycles and sleep intervals of a given mesh network, as described in dynamic parameters section. This register is read-only, because only a transceiver configured as a *gateway* is allowed to change the dynamic configuration of the whole network it is attached to (and this is not done via asynchronous writing to the *dyn* register in the RAM bank directly, but is rather accomplished using a special command, which schedules a change action of the *dyn* parameters in the RAM bank in such a way that the change becomes effective at the beginning of the next broadcast cycle).

### nwkID

holds the network ID of the network that the transceiver is allowed to receive and transmit to. This is used as a basic packet filter in such a way that any network using the same frequency hop sequence than the transceiver, but with a different configured network ID, will be effectively invisible to said transceiver. Range of valid *nwkID* is from 0 to 7 (i.e. 8 different possible values). A given network access key can be uniquely configured using a given set of 4 configuration registers: *nwkID*, *hopTable*, *cryptoData_qWord0*, and *cryptoData_qWord1*.

## hopTable

holds the current hop sequence of the network intended to be connected to the transceiver. This variable ranges from 0 to 5 (i.e. 6 different possible values). Combined with *nwkID*, *cryptoData_qWord0* and *cryptoData_qWord1*, this defines a unique network access key. Note that if one discounts the use of encryption keys, then it would be possible to combine *hopTable* and *nwkID* in such a way that the combined number becomes an extended "channel number". For instance, one could define an arbitrary configuration variable CHANNEL with the following mapping: *hopTable* = CHANNEL % 6 + HOPTABLE_OFFSET, and *nwkID* = CHANNEL % 8 + NWKID_OFFSET, where HOPTABLE_OFFSET and NWKID_OFFSET are arbitrarily chosen numbers. This would extend the maximum number of channels to effective

## power

holds two different power presets, one at high power (1 = HI: 158mW) and the other at low power (0 = LO: 40mW).

## uart_bsel

baud rate selector register for the main UART communication bus. See section 3.0 for details on how to configure this register.

## nodeType

defines the type of transceiver, which can either be a *gateway* (*nodeType* = 0) or an individual node of the mesh (*nodeType* = 1).

## sleepMode

selects the active sleep clock in use with the transceiver. Idle mode (*sleepMode* = 0) is a setting where only the internal fast clock of the mesh controller is employed as the main sleep time base. WARNING: this setting is the highest power consumption mode, and is mainly suitable for transceivers wired on the electrical grid in some way, with high power availability off-grid. Examples include typically transceivers configured as *gateways*. RC mode (*sleepMode* = 1) is a setting where a lower power RC clock is used as the main sleep clock... This mode uses the higher-speed clock in order to recalibrate the RC clock operation from broadcast cycle to broadcast cycle, in order to compensate for clock frequency variation due to environmental changes such as temperature. Note that even with this compensation in place, it is not suggested to use this sleep mode for sleep intervals between broadcast cycles higher than 2 seconds. Finally, external sleep controller mode (*sleepMode* = 2) allows the use of a dedicated Smartrek external sleep controller chip in I2C slave mode in order to retro-fit ultra-low power consumption capabilities for longer sleep period of times (> 2 seconds, up to about 20 seconds). This chip is to be connected to the main transceiver using the transceiver I2C lines. Pull-up resistor values suggested for that I2C bus is 2 kOhms or less, and powered with an input voltage between 3.3 and 5.5 V. See section 6.3 for more details on how to integrate the external sleep controller chip.

## extSlpCtrlI2CAddress

external sleep controller I2C address, if external sleep controller is selected as the main *sleepMode* mode of operation. Default factory-configured I2C address is 0x48 (note that the external sleep controller itself can have its own internal address changed via I2C command (see section 6.3 for more details).

### extSlpCorrectionFactor

this is a read-only register indicating the current correction factor compensating for the external sleep controller crystal drift (see section 6.3 for more details).

### presetRF

this is the current RF parameter preset for the transceiver (default value is *presetRF* = 0) and corresponds to a RF bitrate of 50 kbit/sec. Currently, it is the only suggested preset, and for this preset, the data payload of every packet is limited to 20 bytes. For the *presetRF* = 1 set of parameters, it is a (beta-stage) preset for 100 kbit/sec mode of operation with a somewhat larger maximum data payload size (72 bytes).

### cryptoData_qWord0

AES-128 16-byte key least significant 8 bytes (Little-Endian). This register, combined with its counterpart *cryptoData_qWord1*, *nwkId* and *hopTable*, constitutes the set of registers for a given network access key.

### cryptoData_qWord1

AES-128 16-byte key most significant 8 bytes (Little-Endian). This register, combined with its counterpart *cryptoData_qWord0*, *nwkId* and *hopTable*, constitutes the set of registers for a given network access key.

### i2c

register set for I2C bus configuration parameters. The following sub-registers are defined:

- *delayClockLen* - I2C maximum clock speed parameter, which defines the minimum duration of an I2C bit in the following fashion: *MaxSpeed[MHz] = 1 / ( 2 + 0.5*(delayClockLen) );*
- *srcPort* - I2C port selector (must be set to 0 in the current firmware revision);
- *pullupEnabledFlag* - enables or disables the internal resistor pull-ups for I2C port (those are very weak >10kOhm pull-ups, and will not satisfy the I2C rise-time specifications by default);
- *powerBusMode* - selects the operation mode for I2C Power Pin (module pin #4, see section 6.1). Values possible are: 0 = DISABLED (hi-impedance), 1 = NORMAL (pin state toggling between hi-impedance and VCC connection depending on VM execution and I2C commands - on if I2C command executed, and togglable via VM commands), 2 = ALWAYSOFF (pin connected to ground), 3 = ALWAYSON (pin connected to VCC). Note about NORMAL mode: every time the I2C bus is used in order for the mesh controller to interact with an external sleep controller, the I2C Power Pin will be connected to VCC temporarily, then shut down and set to high impedance when that transaction is done. For user-customized control of this pin, see section 5 for details;
- *powerBus_powerUpDelay_msec* - delay automatically applied after the I2C Power Pin (module pin #4, see section 6.1) is auto-connected to VCC, in milliseconds, for hardware stabilization purposes.

### meshExecActiveFlag

bit-mask register in order to set up event trigger points that are to activate a VM user-made program. All bit flags are considered enabled when their binary value is 1, and disabled when their binary value is 0. The bit-mask constants corresponding to each trigger point as defined in section 5 are:

| Constant name | Bit positio n | Bit-mask value | Description |
|---|---|---|---|
| SERIAL_bm | 0 | 0x01 | Activate virtual machine when a serial command for VM Exec has been received locally (see section 5 for details) via the UART communication bus. In this case, the VM command is executed on the spot when the serial command is received. Note that if the VM is executed during an active broadcast cycle, the virtual machine engine will always yield to the mesh protocol controller software when the latter needs to execute timing-critical operations for synchronizing the transceiver with its mesh network, as for any local serial commands (see section 3.0 for details). |
| AIRCMD_bm | 1 | 0x02 | Activate virtual machine in a *node* when an air command for VM Exec (i.e. command wrapped with an Air Cmd. Wrapper) from a *gateway* has been received via a *gateway* broadcast out phase (see section 5 for details). In this case, the VM execution command is executed at the end of the broadcast cycle in which the air command was received, like any other air command requests. Note that LEAVEBROADCAST_bm event marker will be activated before said VM will be executed, if that event marker is enabled. |
| BOOTUP_bm | 2 | 0x04 | Activate virtual machine when the main boot sequence and configuration initialization of the transceiver finished executing. |
| ENTERSEEKMODE_bm | 3 | 0x08 | Activate virtual machine when a *node* goes into seek mode (i.e. searches for an existing mesh network to latch itself onto). |
| LEAVESEEKMODE_bm | 4 | 0x10 | Activate virtual machine when a *node* leaves seek mode (i.e. just found an existing mesh network to latch itself onto). |
| ENTERBROADCAST_bm | 5 | 0x20 | Activate virtual machine when a transceiver (*gateway* or *node*) starts a broadcast cycle (i.e. leaves sleep/idle state in between broadcast cycles). |
| LEAVEBROADCAST_bm | 6 | 0x40 | Activate virtual machine when a transceiver (*gateway* or *node*) broadcast cycle just ended (i.e. about to go to sleep). Note that this event, if enabled, will be always triggered before any pending VM execution request via air command (see above, AIRCMD_bm) will be executed. |
| ENABLEVMFLASHOP_bm | 7 | 0x80 | Enable VM flash operations. This needs to be enabled for VM programming operations to be available, and thus acts as a safety lock flag. |

## sniffFlagsMask

flags which, when activated, enable sniffing of some types of packets, either from a *gateway* to another *node*, or vice versa. The concept of sniffing is only relevant when using UART command mode, because transparent mode acts as a dumb point-to-multipoint serial link between all the transceivers. Moreover, this mode is only relevant for air commands when considering packets outgoing from a *gateway* to *nodes*, because only this mode uses automatic packet filtering at the destination transceiver site using the requested MAC address given by the *gateway*. Indeed, all regular long packet transmissions out in command mode are considered as being whole network broadcasts, and are received by default by all *node* transceivers in the mesh network. Here is a description table of the relevant flags:

| Constant name | Bit position | Bit-mask value | Description |
|---|---|---|---|
| BROADCASTIN_bm | 0 | 0x01 | Enable *node* sniffing of broadcast in phase messages from other *nodes* to *gateway*. All broadcast in that was sent in command mode by another *node*, be it an air command or a regular packet transmission, will be read by the sniffing transceiver when this mode is activated. |
| BROADCASTOUT_AIR_bm | 1 | 0x02 | Enable *node* sniffing of broadcast out air commands to specific MAC addresses that do not match address of said sniffer *node*. Note that this mode only applies for air commands sent from a *gateway* out. |

## enableNotificationFlagsMask

flags enabling special notification UART messages for some useful events. Here is a description table of the relevant flags:

| Constant name | Bit pos-iti on | Bit-ma sk value | Description |
|---|---|---|---|
| CLOSEBROADCAST_bm | 0 | 0x01 | Enable broadcast end close event message report (via special RxDataPacket event message with Broadcast phase ID = 0xFF). If this is activated, the following raw UART message will be sent from transceiver to the host in order to mark the end of a broadcast (this always occur before any air command is processed, as explained in section 5): [0xFB 0x03 0x00 0x26 0xFF 0x00] |
| ENDUARTTRANSFERTOTXBUFFER_bm | 1 | 0x02 | Enable UART transfer to TX buffer event message report (via BcastUART2TrxBufferDone event message). This marker will be sent from transceiver to the host in order to mark a transfer from internal UART buffer of a message to the main RF packet buffers, in which case a new UART message can now be queued in the UART buffer. This event occurs at the very beginning of every broadcast cycle, and is triggered even if no UART message is pending (in that case, the byte transfer count internally to the transceiver is zero, but the transfer event still occurs) The raw UART message sent to host for this event marker is: [0xFB 0x01 0x00 0x2A] |

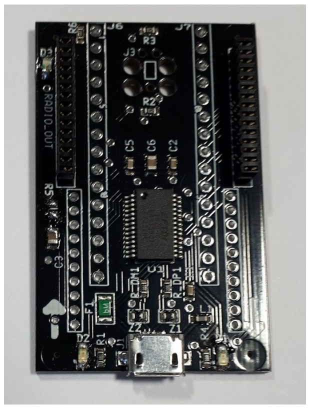
## gpStorage_qWordx

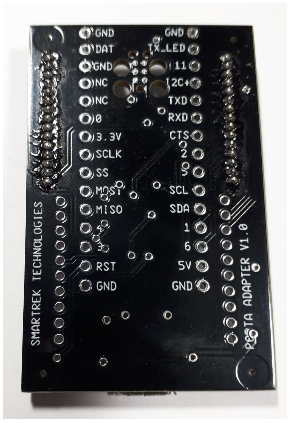
*gpStorage_qWord0*, *gpStorage_qWord1*, *gpStorage_qWord2* - 8 byte sized general purpose registers, that are usually employed as general storage space for a VM user program so that variables can be carried over from a given VM execution instance to the next (see section 5 for more details). Moreover, because those registers exist in both RAMBUF, RAM and EEPROM banks, the latter (EEPROM) can be used as non-volatile general purpose storage space for a given VM user program.

## Developer Kit

### Portia Adapter Board

The Portia Adapter Board is provided in the development kit in order to connect a Portia SMK900 radio module to a USB serial device such as a PC or laptop This is especially useful, when developing, to monitor the mesh network, to generate/modify/upload a Virtual Machine firmware. Additionally, the adapter board features a breadboard footprint compatible dual inline package (DIP). Note that two 15 positions male headers with 100 mil spacing have to be soldered .





### Arduino-compatible Shield

The Arduino-compatible Shield can be used for fast prototyping by leveraging the extensive Arduino library

## SMK900 Certifications Information

Smartrek Technologie module
FCC ID: 2AP8V-SMK900
IC: 24079-SMK900

### United State (FCC)

**Note:** This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

**FCC Antenna Gain Restriction and MPE Statement:**
The SMK900 radio has been designed to operate with any dipole antenna of up to 3 dBi of gain. The antenna used for this transmitter must be installed to provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

**IMPORTANT:** The SMK900 Module has been certified by the FCC for use with other products without any further certification (as per FCC section 2.1091). Modifications not expressly approved by Smartrek Technologies could void the user's authority to operate the equipment.

**IMPORTANT:** OEMs must test final product to comply with unintentional radiators (FCC section 15.107 and 15.109) before declaring compliance of their final product to Part 15 of the FCC rules.

**IMPORTANT:** The RF module has been certified for remote and base radio applications. If the module will be used for portable applications, please take note of the following instructions the device must undergo SAR testing.

**OEM labeling requirements:** As an Original Equipment Manufacturer (OEM) you must ensure that FCC labeling requirements are met. You must include a clearly visible label on the outside of the final product enclosure that displays the following content:

**Contains FCC ID: 2AP8V-SMK900**
The enclosed device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (i. ) this device may not cause harmful interference and (ii. ) this device must accept any interference received, including interference that may cause undesired operation.

**Remarque :** Cet équipement a été testé et déclaré conforme aux limites d'un appareil numérique de classe B, conformément à la partie 15 des règlements de la FCC. Ces limites sont conçues pour fournir une protection raisonnable contre les interférences nuisibles dans une installation résidentielle. Cet équipement génère, utilise et peut émettre de l'énergie radiofréquence et, s'il n'est pas installé et utilisé conformément aux instructions, peut causer des interférences nuisibles aux communications radio. Cependant, il n'y a aucune garantie que des interférences ne se produiront pas dans une installation particulière. Si cet équipement cause des interférences nuisibles à la réception de la radio ou de la télévision, ce qui peut être déterminé en éteignant et en rallumant l'équipement, l'utilisateur peut tenter de corriger ces interférences par une ou plusieurs des mesures suivantes :

- Réorienter ou déplacer l'antenne de réception.
- Augmenter la distance entre l'équipement et le récepteur.
-Brancher l'équipement dans une prise de courant sur un circuit différent de celui auquel le récepteur est branché.
- Consulter le revendeur ou un technicien radio/TV expérimenté pour obtenir de l'aide.

**Restriction de gain d'antenne FCC et déclaration MPE :**
La radio SMK900 a été conçue pour fonctionner avec n'importe quelle antenne dipôle jusqu'à 3 dBi de gain. L'antenne utilisée pour cet émetteur doit être installée à une distance de séparation d'au moins 20 cm de toutes les personnes et ne doit pas être placée ou utilisée conjointement avec une autre antenne ou un autre émetteur.

**IMPORTANT :** Le module SMK900 a été certifié par la FCC pour une utilisation avec d'autres produits sans autre certification (selon la section 2.1091 de la FCC). Toute modification non expressément approuvée par Smartrek Technologies pourrait annuler le droit de l'utilisateur d'utiliser l'équipement.

**IMPORTANT :** Les OEM doivent tester le produit final pour se conformer aux radiateurs non intentionnels (articles 15.107 et 15.109 de la FCC) avant de déclarer la conformité de leur produit final à la partie 15 des règles de la FCC.

**IMPORTANT :** Le module RF a été certifié pour les applications radio de base et à distance. Si le module doit être utilisé pour des applications portables, veuillez prendre note des instructions suivantes, l'appareil doit subir un test SAR.

**Exigences d'étiquetage OEM :** En tant que fabricant d'équipement d'origine (OEM), vous devez vous assurer que les exigences d'étiquetage de la FCC sont respectées. Vous devez inclure une étiquette clairement visible à l'extérieur de l'enveloppe du produit final qui affiche le contenu suivant :

**Contient l'ID FCC : 2AP8V-SMK900**
L'appareil fourni est conforme à la partie 15 des règlements de la FCC. L'exploitation est assujettie à aux deux conditions : (i.) cet appareil ne doit pas causer d'interférences nuisibles et (ii.) cet appareil doit
doit accepter toute interférence reçue, y compris des interférences susceptibles de provoquer un fonctionnement non désiré.

## ISED (Innovation, Science and Economic Development Canada)

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

### Labeling requirements

Similarly to FCC, labeling requirements for Industry Canada must be clearly visible label on the outside of the final product enclosure  and must display the following text.

**Contains IC: 24079-SMK900**

The integrator is responsible for its product to comply with IC ICES-003 & FCC Part 15, Sub. B Unintentional Radiators. ICES-003 is the same as FCC Part 15 Sub. B and Industry Canada accepts FCC test report or CISPR 22 test report for compliance with ICES-003.

# ANNEXE

## Virtual Machine IDE

### SMK900.evi include file

Here is the code listing for the required include file with all constant and function defines that allows access to transceiver-specific functions:

```
//hop table specs
#define HOPTABLE_50K_START 0
#define HOPTABLE_50K_COUNT 6

//nwk max count
#define NWK_COUNT 8

//MeshExecType
#define MESHEXECTYPE_SERIAL_bm 0x01
#define MESHEXECTYPE_AIRCMD_bm 0x02
#define MESHEXECTYPE_BOOTUP_bm 0x04
#define MESHEXECTYPE_ENTERSEEKMODE_bm 0x08
#define MESHEXECTYPE_LEAVESEEKMODE_bm 0x10
#define MESHEXECTYPE_ENTERBROADCAST_bm 0x20
#define MESHEXECTYPE_LEAVEBROADCAST_bm  0x40
#define MESHEXECTYPE_ENABLEVMFLASHOP_bm 0x80

#define MESHI2CPOWERBUSMODE_DISABLED 0
#define MESHI2CPOWERBUSMODE_NORMAL 1
#define MESHI2CPOWERBUSMODE_ALWAYSOFF 2
#define MESHI2CPOWERBUSMODE_ALWAYSON 3

#define I2CMASTER_READMODE_bm 0x01

#define REGISTER_GPSTORAGE_COUNT 3
#define REGISTER_ADDRESS 0x00
#define REGISTER_ADDRESSLEN 0x01
#define REGISTER_DYN 0x02
#define REGISTER_NWKID 0x03
#define REGISTER_HOPTABLE 0x04
#define REGISTER_POWER 0x05
#define REGISTER_UARTBSEL 0x06
#define REGISTER_NODETYPE 0x07
#define REGISTER_SLEEPMODE 0x08
#define REGISTER_EXTSLEEPI2CADDRESS 0x09
#define REGISTER_EXTSLEEPCORRECTIONFACTOR 0x0A
#define REGISTER_PRESETRF 0x0B
#define REGISTER_CRYPTODATA_KEY_0 0x0C
#define REGISTER_CRYPTODATA_KEY_1 0x0D
#define REGISTER_I2C 0x0E
#define REGISTEROFFSET_I2C_DELAYCLOCKLEN 0
#define REGISTEROFFSET_I2C_SRCPORT 2
#define REGISTEROFFSET_I2C_PULLUPENABLEDFLAG 3
#define REGISTEROFFSET_I2C_POWERBUSENABLED 4
#define REGISTEROFFSET_I2C_POWERBUS_POWERUPDELAY_MSEC 5
#define REGISTER_MESHEXECACTIVEFLAG 0x0F
#define REGISTER_SNIFFBROADCASTINENABLEDFLAG 0x10
#define REGISTER_ENABLENOTIFICATIONFLAGSMASK 0x11
#define REGISTER_GPSTORAGE_0 0x12
#define REGISTER_GPSTORAGE_1 0x13
#define REGISTER_GPSTORAGE_2 0x14

#define GetBuffer_S8(r) $uf0(0x20, r)
#define GetBuffer_U8(r) $uf0(0x21, r)
#define GetBuffer_16(r) $uf0(0x22, r)
#define InvBuffer_S32(r) $uf0(0x25, r)
#define AddBuffer_32(r1,r2) $uf0(0x43, r1, r2)
#define MulBuffer_S32(r1,r2) $uf0(0x45, r1, r2)
#define DivBuffer_S32(r1,r2) $uf0(0x46, r1, r2)
#define CompBuffer_S32(r1,r2) $uf0(0x47, r1, r2)
#define GetRegisterRAMBUF(r,regOffset) $uf0(0x50, r, regOffset)
#define GetRegisterRAM(r,regOffset) $uf0(0x51, r, regOffset)
#define GetRegisterEEPROM(r,regOffset) $uf0(0x52, r, regOffset)
#define SetRegisterRAMBUF(r,regOffset) $uf0(0x54, r, regOffset)
#define ShiftLeftBuffer_U32(r,shLeft) $uf0(0x57, r, shLeft)
#define CopyBuffer(r1,r2,len) $uf0(0x60, r1, r2, len)
#define SetBuffer(r,val,len) $uf0(0x70, r, val, len)
#define GetAirBuf(r,i,len) $uf0(0x74, r, i, len)
#define GetTxBuf(r,i,len) $uf0(0x75, r, i, len)

#define GetAirBufCount() GetAirBuf(0,0,0)
#define GetTxBufCount() GetTxBuf(0,0,0)
```

```
#define GetExecType() $uf1(0x00)
#define GetRSSI() $uf1(0x01)
#define TransferConfigRAMBUF() $uf1(0x08)
#define TransferConfigRAM() $uf1(0x09)
#define TransferConfigEEPROM() $uf1(0x0A)
#define ResetFactoryDefaults() $uf1(0x0B)
#define Send(count) $uf1(0x20, count)
#define Delay(delay) $uf1(0x24, delay)
#define SetPinMirror(type) $uf1(0x28, type)

#define I2CPowerBus_Activate() $uf2(0x00)
#define I2CPowerBus_Deactivate() $uf2(0x01)
#define I2C_Stop() $uf2(0x04)
#define I2C_ReadAck() $uf2(0x05)
#define I2C_ReadNak() $uf2(0x06)
#define I2C_Start(addr_rw) $uf2(0x20, addr_rw)
#define I2C_Write(val) $uf2(0x21, val)

#define GetPinIn(pinID) $uf3(pinID)
#define GetPinDir(pinID) $uf3(pinID+0x10)
#define SetPinOut(pinID, val) $uf3(pinID, val)
#define SetPinDir(pinID, dir) $uf3(pinID+0x10, dir)

#define GetPerReg(reg) $uf4(reg)
#define SetPerReg(reg, val) $uf4(reg, val)

#define GetSignatureRow(memOffset) $uf5(memOffset)

//here are the IO mapping to real XMEGA pins. Note that XMEGA PA1 reserved for I2CPowerBus, Mesh PA2/PA3 are
//reserved for I2C. PA5 is reserved to CTS. All those are potentially system critical,
//so access is NOT granted to them.
//-IO PIN---+---XMEGA PIN --+----EQV OEM DNT NAME---+---------- DNT-MESH Special function name
//                    |                                       |                             |
//     0              |         PA0                           |                             ADC_EXT_RC          |         ADC_EXT
//     1              |         PA4                           |                             GPIO3               |
//     2              |         PA6                           |                             RTS                           |         RTS
//     3              |         PA7                           |                             ADC0                |         ADC0
//     4              |         PB0                           |                             ADC1                |         ADC1
//     5              |         PB2                           |                             DAC0                |         DAC0
//     6              |         PB3                           |                             DAC1                |         DAC1
//     7              |         PC4                           |                             SS                            |
       (SPI_SS), OC1A (TIMER TCC1 wave out ch A)
//     8              |         PC5                           |                             MOSI                |         SPI_MOSI,    OC1B
       (TIMER TCC1 wave out ch B)
//     9              |         PC6                           |                             MISO                |         SPI_MISO
//     10             |         PC7                           |                             SCLK                |         SPI_SCLK,   MIRROR
       PIN
//     11             |         PD2                           |                             DCD                           |         DCD
       (Broadcast phase indicator)
//     12             |         PD3                           |                             ACT                           |         ACT  (TX
       LED, this is non critical, thus can be changed)

#define _PA0 0
#define _PA4 1
#define _PA6 2
#define _PA7 3
#define _PB0 4
#define _PB2 5
#define _PB3 6
#define _PC4 7
#define _PC5 8
#define _PC6 9
#define _PC7 10
#define _PD2 11
#define _PD3 12

//PERIPHERIAL REGISTER TABLE
#define _EVSYS_CH0MUX 0x0000
#define _EVSYS_CH1MUX 0x0100

#define _EVSYS_CH0CTRL 0x0001
#define _EVSYS_CH1CTRL 0x0101

#define _PORTA_PIN0CTRL 0x0002

#define _PORTA_PIN4CTRL 0x0003

#define _PORTA_PIN6CTRL 0x0004
#define _PORTA_PIN7CTRL 0x0104

#define _PORTB_PIN0CTRL 0x0005

#define _PORTB_PIN2CTRL 0x0006
#define _PORTB_PIN3CTRL 0x0106

#define _PORTC_PIN4CTRL 0x0007
#define _PORTC_PIN5CTRL 0x0107
#define _PORTC_PIN6CTRL 0x0207
#define _PORTC_PIN7CTRL 0x0307

#define _PORTD_PIN2CTRL 0x0008
```

```
#define _PORTD_PIN3CTRL 0x0108

#define _DACB_CTRLA 0x0009
#define _DACB_CTRLB 0x0109
#define _DACB_CTRLC 0x0209
#define _DACB_EVCTRL 0x0309
#define _DACB_TIMCTRL 0x0409
#define _DACB_STATUS 0x0509

#define _DACB_GAINCAL 0x000A
#define _DACB_OFFSETCAL 0x010A

#define _DACB_CH0DATAL 0x000B
#define _DACB_CH0DATAH 0x010B
#define _DACB_CH1DATAL 0x020B
#define _DACB_CH1DATAH 0x030B

#define _ADCA_CTRLA 0x000C
#define _ADCA_CTRLB 0x010C
#define _ADCA_REFCTRL 0x020C
#define _ADCA_EVCTRL 0x030C
#define _ADCA_PRESCALER 0x040C

#define _ADCA_INTFLAGS 0x000D

#define _ADCA_CALL 0x000E
#define _ADCA_CALH 0x010E

#define _ADCA_CMPL 0x000F
#define _ADCA_CMPH 0x010F

#define _ADCA_CH0_CTRL 0x0010
#define _ADCA_CH0_MUXCTRL 0x0110

#define _ADCA_CH0_INTFLAGS 0x0011
#define _ADCA_CH0_RESL 0x0111
#define _ADCA_CH0_RESH 0x0211

#define _ADCA_CH1_CTRL 0x0012
#define _ADCA_CH1_MUXCTRL 0x0112

#define _ADCA_CH1_INTFLAGS 0x0013
#define _ADCA_CH1_RESL 0x0113
#define _ADCA_CH1_RESH 0x0213

#define _SPIC_CTRL 0x0014

#define _SPIC_STATUS 0x0015
#define _SPIC_DATA 0x0115

#define _TCC1_CTRLA 0x0016
#define _TCC1_CTRLB 0x0116
#define _TCC1_CTRLC 0x0216
#define _TCC1_CTRLD 0x0316
#define _TCC1_CTRLE 0x0416

#define _TCC1_CTRLFCLR 0x0017
#define _TCC1_CTRLFSET 0x0117
#define _TCC1_CTRLGCLR 0x0217
#define _TCC1_CTRLGSET 0x0317
#define _TCC1_INTFLAGS 0x0417

#define _TCC1_CNTL 0x0018
#define _TCC1_CNTH 0x0118

#define _TCC1_PERL 0x0019
#define _TCC1_PERH 0x0119
#define _TCC1_CCAL 0x0219
#define _TCC1_CCAH 0x0319
#define _TCC1_CCBL 0x0419
#define _TCC1_CCBH 0x0519

#define _TCC1_PERBUFL 0x001A
#define _TCC1_PERBUFH 0x011A
#define _TCC1_CCABUFL 0x021A
#define _TCC1_CCABUFH 0x031A
#define _TCC1_CCBBUFL 0x041A
#define _TCC1_CCBBUFH 0x051A

//the following not available for module_Mesh_V2 (only for V3 onwards)
#define _ACA_AC0CTRL 0x001B
#define _ACA_AC1CTRL 0x011B
#define _ACA_AC0MUXCTRL 0x021B
#define _ACA_AC1MUXCTRL 0x031B
#define _ACA_CTRLA 0x041B
#define _ACA_CTRLB 0x051B
#define _ACA_WINCTRL 0x061B
#define _ACA_STATUS 0x071B
```