RFD MultiComm Firmware User Manual

RF Design Pty Ltd
7/1 Stockwell Place
Archerfield, QLD 4108 Australia
rfdesign.com.au

Contents

1 Key Features 4
2 Overview 5
2.1 Compatibility 5
2.1.1 Hardware 5
2.1.2 Firmware 6
2.1.3 Regional Variants 6
2.2 LED functions 6
2.2.1 Green LED 6
2.2.2 Red LED 6
2.3 Serial Ports 6
2.4 Encryption 7
2.5 Network Topologies 7
2.5.1 Point-to-Point 7
2.5.2 Multi-modem network 10
2.6 Listen Only Nodes 13
2.7 Relay Nodes (Data Forwarding) 13
2.8 GPIO Pin Functions 13
3 Configuring modem settings 14
3.1 RFD Tools GUI 14
3.2 AT Commands 14
3.3 RTI commands 15
3.4 Errors 15
4 S Parameter Definitions 16
4.1 S parameter settings table: 16
4.2 S parameter definitions and purposes: 17
4.2.1 Miscellaneous settings: 17
4.2.2 Network Layer Settings: 17
4.2.3 Encryption Settings: 20
4.2.4 Serial Port Configuration: 20
4.2.5 Link and RF Parameters: 22
4.2.6 GPIO Pin Settings: 25
4.2.7 RC Parameters 27
5 Example Modem Configurations 29
5.1 Point-to-Point 29
5.1.1 Modem linking 29
5.1.2 Remote Control Signal Passthrough 30
5.2 Listen Only Nodes 30
5.3 Networks 30
5.3.1 Single Network 30
5.3.2 Multiple Subnetworks 31
5.3.3 Forwarding with local data 33
5.3.4 Forwarding No Local Data 35
6 Loading firmware 37
6.1 Programming with RFD modem tools 37
7 Pinout 41
7.1 x series modems 41

7.2 ux series modems 43
8 Performance Characteristics 46
8.1 Thermal Management 47
8.2 RSSI Report 47
9 Useful Links 49
10 Glossary 50
11 Revision History 52

1 Key Features

- Support for point-to-point, one to many and mesh network topologies
- Per node bandwidth allocation
- PPM and SBus signal passthrough in point-to-point operation
- Multi–hop data forwarding
- Raw, MAVLink and SAS data packet support
- Addressable GPIO pin state mirroring
- Antenna diversity
- Enhanced hardware accelerated AES encryption
- Selectable data rates

2 Overview

2.1 Compatibility

2.1.1 Hardware

The firmware can be used to form pair/networks of x and ux series modems or mixtures of both types.

The RFD MultiComm firmware **is only compatible with V2 hardware**. This means that it can be installed only on 868x2, 868ux2, 900x2 and 900ux2 models of RFD modems.

The x series modems currently have two major hardware revisions. These can be identified by the text on the PCB between the antenna ports, illustrated in figure 1. This will read '9X' for V1 type hardware and '9X2' for V2 type hardware.

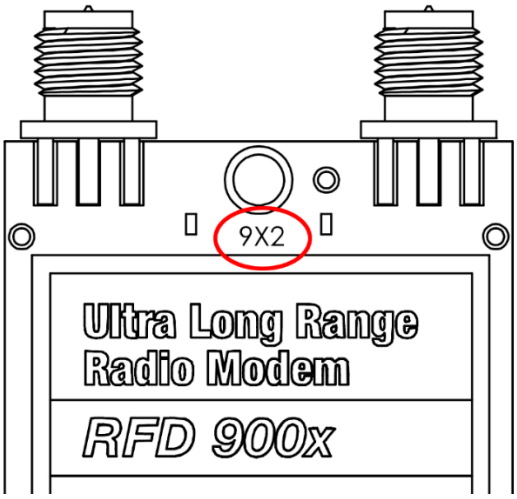

Figure 1: RFD x series modem hardware revision label

The ux series modems currently have two major hardware revisions. These can be identified by the text on the PCB between the antenna ports, illustrated in figure 2. This will read V1.# for V1 type hardware and V2.# V2 type hardware, where # can be any number and is indicative of a minor revision.

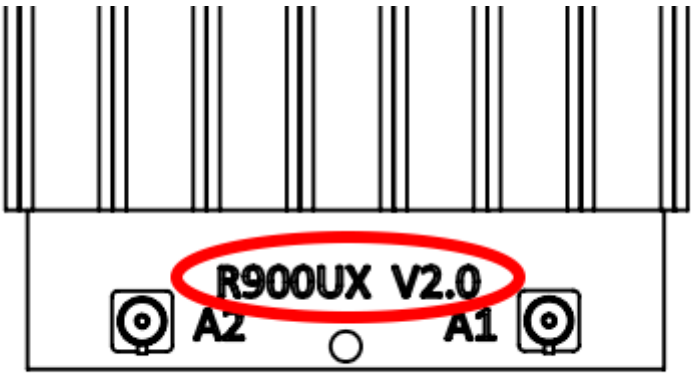

Figure 2: ux series modem hardware version label

2.1.2 Firmware

MultiComm firmware is not interoperable with any other existing firmware types. All modems in a pair/network need to have MultiComm firmware installed.

> Note compatibility is only guaranteed and tested between modems operating the same firmware version. Backward and forward compatibility of firmware is not assured.

2.1.3 Regional Variants

Whilst the firmware compatible with most of the the various region variants of the 900x2, 900ux2, 868x2 and 868ux2 hardware models the exact parameter options available, e.g. min/max frequency, may be restricted, in line with regulatory requirements. These restrictions, if any, may affect or limit network performance, the number of nodes that can practically be supported and/or be incompatible with the exact setting presented in the examples outlined.

> Only the region locked versions of the modems are represented to be compliant in their respective regions. Interoperable configuration does not convey regional compliance for an unlocked modem.

> Note this firmware's network modes other than point-to-point may be unsuitable for, or have limited functionality with, 868x/ux and region locked versions thereof.

> Note 868x-EU and 868ux-EU modems will currently only support operations in low power mode.

> Note that network mode settings are not tested on or endorsed for use with EU region locked modem.

2.2 LED functions

2.2.1 Green LED

This LED indicates the modem link status:

- A solid green indicates that the link has been established.
- A master unit flashing approximately every two seconds indicates that the unit is unlinked.
- A node unit flashing approximately every second indicates that the unit is unlinked.
- A node unit flashing approximately every half second indicates that the unit is linking/unlinking to/from the network.
- A unit flashing for one second and off for three seconds indicates that the firmware has been installed on an unsupported modem.

2.2.2 Red LED

This LED indicates data and link control packets received:

- A flash indicates an RF data packet received by the modem.
- A solid red indicates that the modem has entered bootloader mode.

2.3 Serial Ports

There are two serial ports available on each modem:

- Both support hardware flow control.
- Baud rates are set independently.

The S#RXROUTE parameters direct the serial port data to be output on a specified port on the receiving modem. Additionally, the data can be echoed to the second serial port of the local modem.

By default, only serial port 1 is configured and flow control is disabled, i.e. only TX and RX pins are active. The default settings of this port are:
Baud – 57600
Data Bits – 8
Parity Bits – 0
Stop Bits – 1

2.4 Encryption

The firmware supports hardware accelerated AES encryption with key lengths of 128 or 256 bits. To send and receive valid data all nodes need to have the same encryption level and key. All payload data is encrypted including RC passthrough signals.

Note despite being a hardware accelerated process there can be a small latency associated with the encryption and decryption process.

The encryption key (K) should be a string of 32 comma-separated values each with a maximum value of 255 and a final trailing comma. This represents the 256 bits of the maximum key length.

Note even when only 128-bit encryption is used the full 256-bit key is required when setting this parameter.

For example, the default key is:
6,61,235,16,21,202,113,190,43,115,174,240,133,125,119,129,31,53,44,7,59,97,8,215,45,152,16,163,9,20,223,244,

To enable encryption the following settings should be set:

Setting	AT Command
ENCRYPTLV=1 (128-bit key), or 2 (256-bit key)	ATS20=1 or 2
ENCRYPTKEY=K	ATS48=K

2.5 Network Topologies

2.5.1 Point-to-Point

This operating mode is designed to function in a manner similar to the traditional RFD modem SiK firmware. Modem pairs operate as a wireless half duplex serial link.

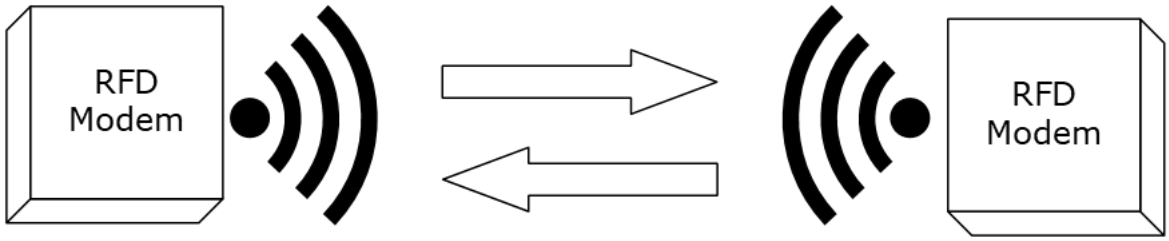

Figure 3: Point-to-point modem diagram

A common use case for such a configuration is to provide a long range link between a Ground Control Station (GCS) and a Remotely Operated Vehicle (ROV), for example a fixed wing drone.

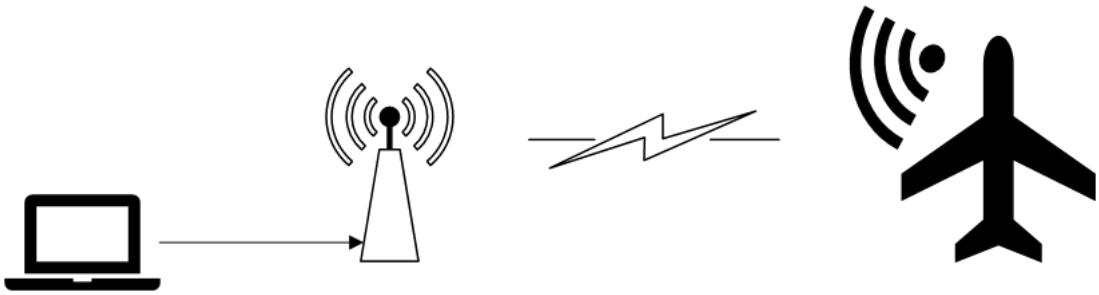

Figure 4: Illustration of modem use case for drone control

Point-to-point linking can be configured in an automatic or fixed master mode.

Point-to-point operations depend on the configuration of the key parameters:

- P2PAUTO
- SLOTIDS
- NODEID
- SLOTS

Note by default, the MultiComm firmware is configured for point-to-point operation and automatic master mode is enabled. As supplied, the radios will attempt to establish a link in this mode on boot.

The total size of a slot, in terms of bytes of data is related to the settings of the TOTALUS and BITRATE parameters. Slot BYTES~=TOTALUS*BITRATE/8000

Note the radio will not allow for configurations that result in a slot size smaller than approximately 300bytes or larger than approximately 1000 bytes. If incompatible settings are made the modem will automatically reconfigure to minimum suitable TOTALUS on reboot.

Note that the network practical throughput is not the same as the theoretical maximum, as represented by the BITRATE parameter, and will vary based on parameter settings and network configurations.

2.5.1.1 Point-to-Point Modem Linking

Point-to-point modems can be further configured for automatic or fixed master mode.

In automatic master mode a modem will self-configure as a master node if it detects no other master modems on boot. As such, the first modem to boot will generally take on the role of master in the network.

Note that if a modem is configured for remote control signal input, then it will configure as the master and a modem configured for remote control signal output will configure as a slave regardless of turn on time

In fixed master mode one modem is configured to take the role of master node. This configuration will generally allow for faster modem pairing as there is not waiting period for master self-configuration to occur.

2.5.1.2 Point-to-point with Remote Control (RC) Passthrough

The modem will pass SBUS or PPM remote control (RC) signals in addition to the serial data.

RC operations depend on the configuration of the key parameters:

- PIN1TYPE
- PRI
- TOTALUS
- RCDEFS or AT&R (Failsafe modes only)

The RC signals supported include PPM and various SBUS formats.

- PPM
- SBUS:
  - SBUS 1 and 2 signal formats are supported
  - Modes for 10 or 18 total channels with 2 digital channels
- Failsafe and no-failsafe stream modes
- Support for conversion of input type to different output type e.g. PPM input to SBUS output

Note that all SBUS signals are one way. There is no support for SBUS 2 two way signals with RFD modems.

Note that in no-failsafe mode the output signal will cease if valid input signals or modem RF link is lost.

Note the RC signal is sent to/from modem pin 15 with 3.3V logic level. Ensure that any connected devices are compatible with this signal level

Note that for proper operation of the RC signal, the modem ground also needs to be connected to the signal ground of any connected device. Pin 16 is the nearest ground pin on the modem header.

Note if enabling RC passthrough the input modem should be assigned PRI=3 and the TOTALUS should be set to give the minimum acceptable slot size. This will ensure minimal latency for control signals.

Note due to the inclusion of the RC signal and the associated modifications to the link settings, effective throughput for serial data will be somewhat reduced compared to point-to-point configurations without RC signals.

2.5.2 Multi-modem network

In this operating mode the system is designed to function in a manner similar to the RFD modem Multipoint firmware. There are several multi-modem configurations that can be configured. Groups of modems may operate in links, either between individual nodes, or as a broadcast message to all nodes in Line of Sight (LoS).

Multi-modem operations depend on the configuration of the key parameters:

- P2PAUTO
- SLOTS
- SLOTIDS
- NODEID
- BITRATE
- TOTALUS
- NETWORKS
- DESTID

Note it is the responsibility of the user to confirm the compatibility of this firmware with the local regulations of their Area of Operations (AoO) and operate accordingly.

The total slot size, in terms of bytes of data, is related to the settings of the TOTALUS and BITRATE parameters. Slot BYTES~=TOTALUS*BITRATE/8000

Note that the network practical throughput is not the same as the theoretical maximum as represented by the BITRATE parameter and will vary based on parameter settings and network configurations.

Note the radio will not allow for configurations that result in an slot size smaller than approximately 300bytes or larger than approximately 1000 bytes. If incompatible settings are made the modem will automatically reconfigure to minimum suitable TOTALUS on reboot.

The highest NODEID available in any a single network is 62.

Using the DESTID parameter each node in a network can be configured to broadcast messages to all other nodes in range, (DESTID set to 63), or to address messages only to a single specific node in the network leading to a couple of different possible network configurations.

2.5.2.1 Single Network One to Many and Mesh

In single network configuration the system may operate in a one-to-many mode where a single broadcasting nodes sends data to all other LoS nodes, but no data is sent back to the broadcasting node. Illustrated in figure 5.

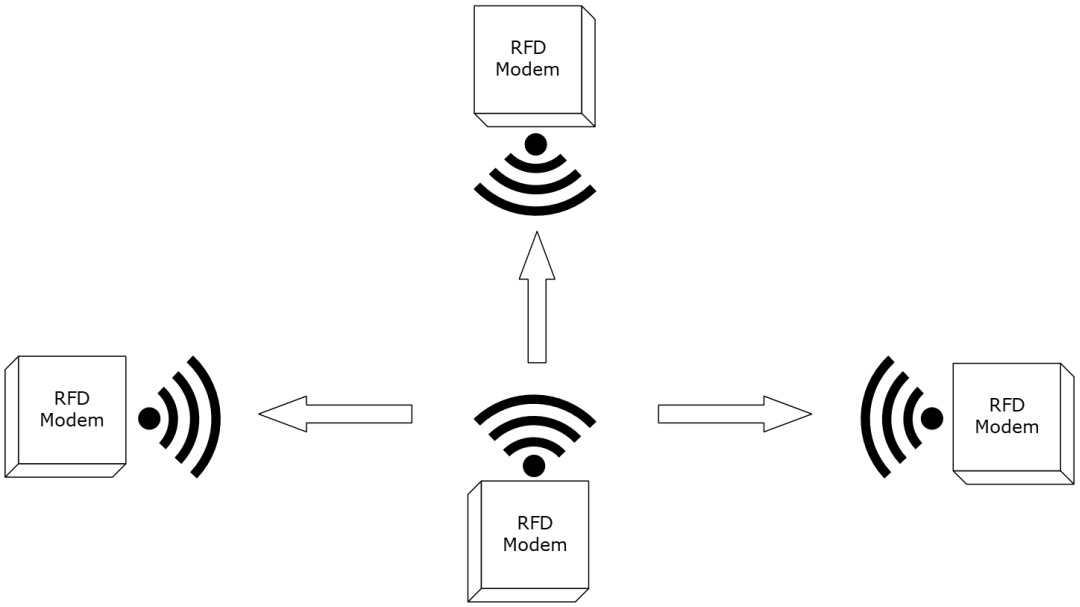

Figure 5:One-to-many network topology

Alternatively, the network may be configured such that any node can send data to all other nodes or to any specific node in the network, see an example in figure 6.

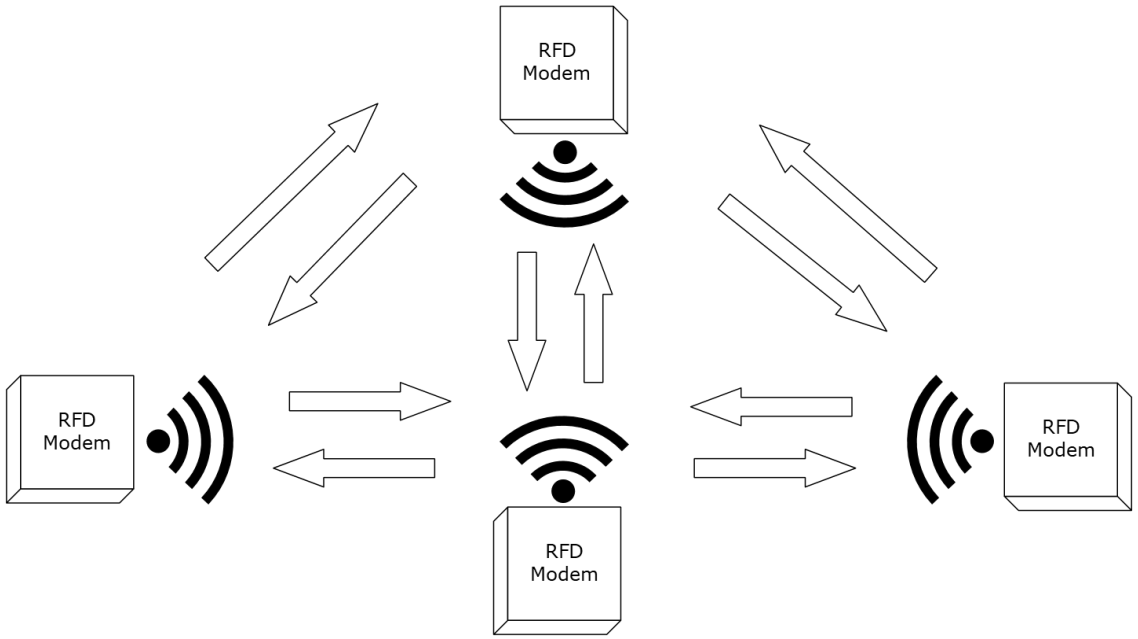

Figure 6: Mesh network topology

2.5.2.2 Multiple Network One to Many and Mesh

In cases where single node throughput requirements mean more nodes cannot practically be added to a network, and setting up other distinct networks poses a risk of RF interference,

extra subnetworks can be configured and grouped together in the same RF band under a single master node.

The nodes in each subnetwork can be configured in any way required, one to many, or as a mesh.

The throughput of the individual nodes in each subnetwork will depend on the BITRATE and the number of nodes in the same SUBNETID and the number of slots assigned to any node.

Note that each subnetwork must have the same number of SLOTS though the number of nodes and the way in which these are assigned may vary.

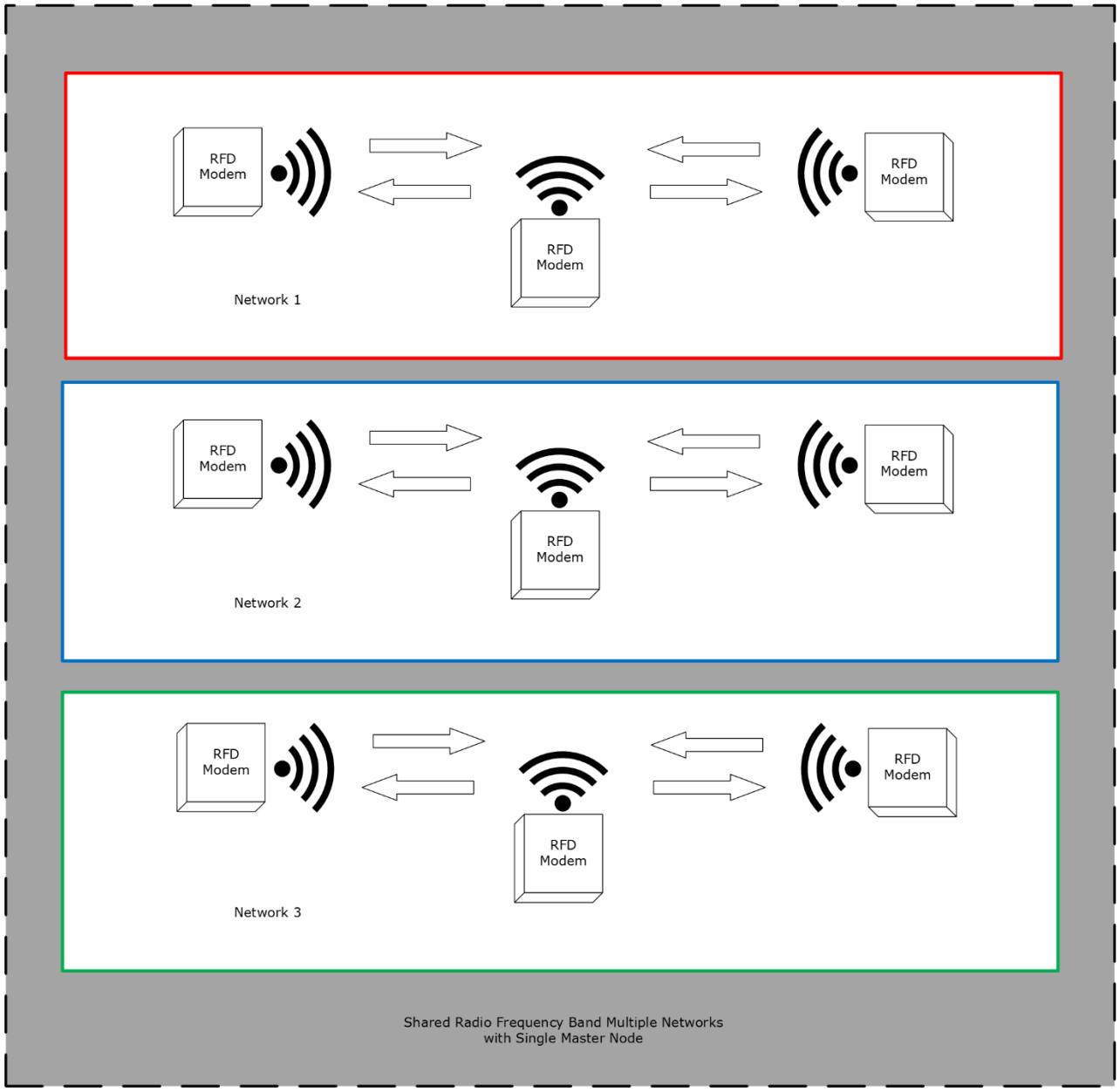

Figure 7: Multiple network topology

Note that radio packets can only move between nodes within the same subnetwork.

2.5.2.3 Master Node

This node will coordinate the transmit cycles of the network to avoid self-interference within the network.

The master node is NODEID 0 of NETID 0. The master's SLOTIDS must include slot 1.

The Master node must be on for the network to operate.

Unlike the previous Multipoint firmware LoS with the master for all nodes is no longer required as nodes can be synchronised from relayed messages.

2.6 Listen Only Nodes

Listen only nodes will only receive data and can only be added to networks with a fixed master configuration.

These nodes will receive broadcast data from the other nodes in the network.

2.7 Relay Nodes (Data Forwarding)

Nodes in the network can be configured to forward messages between nodes that do not have line of sight.

Relay nodes can additionally transmit local data from the modem serial ports.

It is possible to cascade relay nodes to increase the ultimate range of the network. This will however increase the latency of messages with each required hop.

Note that relay nodes may require extra slot assignments to provide enough bandwidth to satisfy the requirements of the relayed messages.

2.8 GPIO Pin Functions

Pins can be assigned various functions including:

- UART functions
- Pin mirror
- External reset
- LED state
- RC signal in/out

These provide various ancillary functions in addition to the modem serial data link.

Note the behaviour and/or function of the GPIO pins may be modified or limited based on whether the firmware is operating in point-to-point or network modes.

Note that not all functions are assignable to all GPIO pins.

3 Configuring modem settings

3.1 RFD Tools GUI

The RFDTools version 4.0.18 and above support configuring the settings for modems with MultiComm firmware.

3.2 AT Commands

The AT command mode can be entered by sending a +++ command, in a serial terminal connected to the radio at the correct baud rate.

If successful, an *OK* prompt will be displayed on the screen and the modem will stop displaying incoming data from the remote modem, if any.

In command mode, you can use the AT commands to manage the local modem settings.

AT Command	Description
ATI	Shows the firmware version, country code and hardware revision
ATI1	Shows the firmware version number
ATI2	Shows the board type code
ATI3	Shows board frequency code
ATI4	Shows board version
ATI5	Shows user settable EEPROM parameters and their values (not all values maybe shown due to limitations in the UART buffer)
ATI5:x:y	A subset of the ATI5 command. It displays only the specified parameters in the range x to y inclusive. Example usage ATI5:6:11 will print parameters S6 through S11
ATI6	Show radio packet information about data sent and received on each port. Information on internal data queues. (Used for internal testing)
ATI7	Show timing information about TDM process. (Used for internal testing)
ATI8	Display Device 64–bit unique ID
ATI9	Calibration validation test
ATI10:n	Displays radio S parameter number ‘n’ and valid settings range.
ATI11	Show information on RC data packets sent or received, if any. Only works if the node is configured as an RC input or RC output.
ATO	Exits AT command mode
ATSn=X	Sets radio 'S' parameter number ‘n’ to ‘X’
ATZ	Reboots the radio
AT&F	Resets all parameters to factory defaults
AT&UPDATE	Reset and enter boot mode
AT&R	Record default PPM stream for PPM output (vehicle side)
AT&T	Disables debugging report
AT&T=RSSI	Enables RSSI debugging report
AT&T=TDM	Enables TDM debugging report (Primarily used for internal testing)

Note modem parameters are saved whenever changes are made with AT commands, however, modems must be rebooted for changes to take full effect.

3.3 RTI commands

Command mode can be used to issue commands to other, remote, nodes in the network. This can be done on a broadcast basis by issuing the commands below. Alternatively, the commands can be directed to a target node by adding '@X', without quotes and substituting the desired NODEID for X.

Example:

RTI
All nodes in range will respond with firmware version, country code and hardware revision

RTI@2
Only node 2 will respond with firmware version, country code and hardware revision

AT Command	Description
RTI	Shows the firmware version, country code and hardware revision
RTI1	Shows the firmware version number
RTI2	Shows the board type code
RTI3	Shows board frequency code
RTI4	Shows board version
RTI5	Shows user settable EEPROM parameters and their values (not all values maybe shown due to limitations in the UART buffer)
RTI5:x:y	A subset of the RTI5 command. It displays only the specified parameters in the range x to y inclusive. Example usage ATI5:6:11 will print parameters S6 through S11
RTI6	Show radio packet information about data sent and recevied on each port. Information on internal data queues. (Used for internal testing)
RTI7	Show timing information about TDM process. (Used for internal testing)
RTI8	Display Device 64–bit unique ID
RTI9	Calibration validation test
RTI10:n	Displays radio S parameter number 'n' and valid settings range.
RTI11	Show information on RC data packets sent or received, if any. Only works if the node is configured as an RC input or RC output.
RTSn=X	Sets radio 'S' parameter number 'n' to 'X'
RTZ	Reboots the remote radio
RT&F	Resets all parameters to factory defaults
RT&R	Record default PPM stream for PPM output (vehicle side)

3.4 Errors

AT commands can return a few different error types.

ERROR – Indicates an invalid command was issued directly to the modem.

ERROR2 – Indicates an invalid parameter was entered with and otherwise valid command.

ERROR3 – Indicates and invalid command was issues remotely to the modem.

4 S Parameter Definitions

4.1 S parameter settings table:

Reg #	S Register Name	Default Value	Minimum Value	Maximum Value	Same for all nodes	Master Only
S0	FORMAT (Not user settable. Set by the firmware)	Firmware dependant	N/A	N/A	Yes	No
S1	BITRATE	64	12	2000	Yes	No
S2	FREQMIN	915000 /868000	902000 /865000	928000 /870000	Yes	No
S3	FREQMAX	921000 /869000	903000 /866000	928000 /870000	Yes	No
S4	NUMCHANS	23	1	51	Yes	No
S5	XTRALONGRNG	0	0	1	Yes	No
S6	P2PAUTO	1	0	1	Yes	No
S7	TOTALUS	39891	5000	220000	Yes	No
S8	SLOTS	2	1	64	Yes	No
S9	SLOTIDS	1	0	2^{64} –1	No	No
S10	NODEID	0	0	62	No	No
S11	SUBNETID	0	0	31	Yes (In the same network)	No
S12	SUBNETS	1	1	31	Yes	No
S13	BINDID	0	0	255	Yes	No
S14	DESTID	63	0	63	No	No
S15	HOPSMAX	1	1	7	Yes	No
S16	VALIDHOPSMIN	0	0	7	No	No
S17	VALIDHOPSMAX	7	0	7	No	No
S18	PRI	1	1	3	No	No
S19	SLOTTXMODE	7	0	7	No	No
S20	ENCRYPTLVL	0	0	2	Yes	No
S21	S1BAUD	57600	9600	1500000	No	No
S22	S1DATATYPE	0	0	2	Yes	No
S23	S1KBPS	1000	0	1000	No	No
S24	S1RXROUTE	0	0	3	No	No
S25	S2BAUD	57600	9600	1500000	No	No
S26	S2DATATYPE	0	0	2	Yes	Yes
S27	S2KBPS	1000	0	1000	No	No
S28	S2RXROUTE	1	0	3	No	No
S29	S2ATMODE	0	0	1	No	No
S30	TXPOWER	30	0	30	Yes	Yes
S31	ANTMODE	0	0	3	No	No
S32	RATE/FREQBAND	0	0	1	Yes	No
S33	RSVD1	NA	NA	NA	NA	NA
S34	RSVD2	NA	NA	NA	NA	NA
S35	PIN0TYPE(13)	1	0	30	No	No
S36	PIN1TYPE(15)	0	0	30	No	No

Reg #	S Register Name	Default Value	Minimum Value	Maximum Value	Same for all nodes	Master Only
S37	PIN2TYPE(14)	20	0	30	No	No
S38	PIN3TYPE(12)	21	0	30	No	No
S39	PIN4TYPE(10)	19	0	30	No	No
S40	PIN5TYPE(8)	18	0	30	No	No
S41	PINRTSTYPE(3)	16	0	30	No	No
S42	PINCTSTYPE(11)	0	0	30	No	No
S43	RCFRAMELOSS	50	5	6666	No	No
S44	RCINMINMS	12	5	200	No	No
S45	PINDEFAULT	1,1,0,0,0,0,0,0,	0 (each element)	1 (each element)	No	No
S46	PINMIRROR	0,1,2,3,4,5,6,7,	0 (each element)	7 (each element)	No	No
S47	RCDEFS	1500,1500,1500, 1500,1500,1500, 1500,1500,1500, 1500,1500,1500, 1500,1500,1500, 1500,1000,1000,	900 (each element)	2100 (each element)	No	No
S48	ENCRYPTKEY	96,61,235,16,21, 202,113,190,43, 115,174,240,133 ,125,119,129,31 ,53,44,7,59,97,8, 215,45,152,16,16 3,9,20,223,244,	0 (each element)	255 (each element)	Yes	No
S49	FWDTABLE	64,64,64,64,64, 64,64,64,64,64, 64,64,64,64,64, 64,64,64,64,64,	0 (each element)	64 (each element)	No	No

4.2 S parameter definitions and purposes:

4.2.1 Miscellaneous settings:

FORMAT – Packet Format
The packet format identifier used to signify details about the data formats used by the firmware.

4.2.2 Network Layer Settings:

NODEID – Node Identifier
The NODEID parameter is an address identifier for the node.

Valid assignable values are from 1 to 62 as 63 and 64 are reserved for destination functions.

Each NODEID should only be used once in each subnetwork.

Note NODEID must be unique for each node within a given SUBNETID i.e. all nodes in a network need a unique NODEID but the same NODEID can be reused across different subnetworks (i.e. different SUBNETIDs)

SUBNETS – Number of Subnetworks
The SUBNETS parameter sets the number of subnetworks in the total network.

Groups of modems can operate in subnetworks in the same frequency band and under the control of a single master node limiting the mutual interference of multiple distinct networks.

Note on frequency bands with low numbers of channels the practical maximum setting is (NUMCHANS – 1).

SUBNETID – Subnetwork Identifier
The SUBNETID parameter configures which subnetwork a node is a member of.

Data is only passed within the same subnetwork and cannot move between subnetworks.

Nodes will only be visible to those nodes with the same SUBNETID.

The master network is SUBNETID=0 and must exist.

Valid SUBNETIDS are 0 to (SUBNETS – 1).

BINDID – Binding Identifier
The BindID parameter distinguishes multiple independent networks operating in the same area.

Modems will only decode data sent by radios with the same BINDID.

Note **this functionality is still developmental and should not be used.** Ideally only two networks of radios should be in the same range of each other and **the best method** to ensure proper operation is to **use different frequency bands** for the different networks of radios.

DESTID – Destination Node Identifier
The DESTID parameter dictates which node/s receive data packets.

0 to 62 – Directs message to the modem with a NODEID that matches the DESTID

63 – Broadcast messages to all nodes in range and within the same subnetwork.

64 – Reserved function and should not be set.

HOPSMAX – Maximum Number of Message Hops in the Subnetwork
The HOPSMAX parameter represents the system's absolute maximum number of hops.

Hops refer to forwarded paths.

Hops are used when nodes cannot see the master node.

This parameter must be set the same value for all modems in the network.

VALIDHOPSMIN – Minimum Acceptable Number of Hops

The VALIDHOPSMIN parameter specifies the minimum number of hops required to accept packets.

Note this parameter is for debugging purposes of forwarding networks. In normal operation this parameter needs to be set to the default value of 0 for hopping to behave correctly.

VALIDHOPSMAX – Maximum Acceptable Number of Hops

The VALIDHOPSMAX parameter specifies the maximum number of hops required to accept packets.

Note this parameter is for debugging purposes of forwarding network tests. In normal operation this parameter needs to be set to its default value of 7 for hopping to behave correctly.

PRI – Node Priority

The PRI parameter represents the priority of this node's packets.
1 – **low** priority.
2 – **medium** priority.
3 – **highest** priority.

A lower priority node can be forced to give up half of its slot to priority 3 nodes.

Priority 2 will take over remaining, unused, portions of lower priority nodes slots.

Note an RC input modem should be set to priority 3 and other nodes should be set to lower priorities to ensure minimum latency.

Note priority can also be used when to give a modem more bandwidth than others in the subnetwork but typically assigning extra slots or modifying serial bandwidth on other nodes is a more reliable way to achieve this.

FWDTABLE – Forwarding Table

The FWDTABLE parameter is an array of forwarding directives for routing relayed messages.

The table contains twenty comma-separated entries. These represent 10 pairs of source and destination nodes for messages e.g. source 1, destination 1,source 2,destination 2 … source 10,destination 10

These source destination pairs can be configured in the following ways:
Source
64 – An unused pair in the table.
63 – Forwarded all received broadcast messages, i.e. messages with an original DESTID=63.
Any other setting – Forward messages from the specified node.
Destination
64 – Rebroadcast to using the original destination address in the incoming packet.
63 – Rebroadcast overwriting the destination address of the incoming packet and, instead, broadcast to all nodes.
Any other setting – Rebroadcast overwriting the destination of the incoming packet to that of the specified NODEID from the table.

When updating the table only the required number of entries need to be entered in the AT command e.g. setting three forwarding directives with the AT command would look like, *ATS49=1,2,2,64,3,63* which will set the forwarding table as whole to 1,2,2,64,3,63,64,64,64,64,64,64,64,64,64,64,64,64,64,64,. This example configuration would forward messages from node 1 to node 2, from node 2 to the original destination address, from node 3 to broadcast to all the whole subnetwork, and leave seven unused forward directives.

Note if the forwarding buffer is full, and further data to be forwarded is received, this newest data will be discarded.

4.2.3 Encryption Settings:

ENCRYPTLVL – Encryption Level

The Encrypt parameter specifies the encryption level.
0 – no encryption.
1 – 128–bit AES encryption.
2 – 256–bit AES encryption.

Note this setting must match on all nodes.

ENCRYPTKEY – Encryption Key

Defines the private key is used to encrypt and decrypt data transmitted over the air.

It is a 32–byte value with commas separating each byte. Only the first 16–bytes are used when the encryption level is set to 128-bit AES. All 32–bytes are used when encryption level is set to 256-bit AES encryption.

Note this setting must match on all nodes.

4.2.4 Serial Port Configuration:

Note flow control is enabled by configuring the appropriate pins to the RTS and CTS functions of serial port 1 and 2 respectively.

Note flow control is necessary for the correct operation serial bandwidth limits. It is also highly recommended for use cases where serial baud rates/bandwidth exceeds the node's practical throughput to prevent the loss of data due to serial buffer overwrites.

Serial Port 1:

The first, or primary serial port.

Note to use flow control features the appropriate pin configurations must be set.

S1BAUD – Serial Port 1 Baud Rate

The S1BAUD parameter sets the baud rate for Serial Port 1. Typically, this is set to a value that is similar to the air rate.

S1DATATYPE – Serial Port 1 Data Type

The S1DATATYPE parameter specifies the protocol used for the data on Serial Port 1.
0 – MAVLink1/2 data packets.
1 – SAS binary protocol packets.
2 – Unformatted serial or data in formats not covered above.

Note MAV mode is only for MAVLink1/2 encapsulated data and is not compatible with other types of data. This is different to the behaviour in other RFD modem firmware types.

Note in RAW mode data is broken into chunks based on a 10mS break in data or maximum slot size is reached.

S1KBPS – Serial Port 1 Bandwidth Limit

The S1Kbps parameter represents the bandwidth limit in kilobits per second for Serial 1.

This enables throttling of received data on this port. Use this if you wish to ensure that a fixed bandwidth is not exceeded. Typically, this limit is accurate to within +/−1Kbps of the parameter setting.
0 – disables this port.
1000 – removes any limits.
Any other value – restricts the port to the specified value

S1RXROUTE – Serial Port 1 Input Route

The S1RXROUTE parameter determines the serial port on the receiving node which the data will be output:
0 – Output data to port 1 of the receiving modem.
1 – Sets output to port 2 of the receiving modem.
2 – Sets output to port 1 of the receiving modem and echoes the input to serial port 2 of the transmitting modem.
3 – Sets output to port 2 of the receiving modem and echoes the input to serial port 2 of the transmitting modem.

Serial Port 2:

The second, or auxiliary, serial port of the modem.

Note that the serial port 2 pins must be configured using the relevant PINTYPE parameters

Note to use flow control features the appropriate pin configurations must be set.

S2BAUD – Serial Port 2 Baud Rate

The S2BAUD parameter sets the baud rate for Serial Port 2. Typically, this is set to a value that is similar to the air rate.

S2DATATYPE – Serial Port 2 Data Type

The S2DATATYPE parameter specifies the protocol used for the data on Serial Port 2.
0 – MAVLink1/2 data packets.
1 – SAS binary protocol packets.
2 – Unformatted serial or data in formats not covered above.

Note MAV mode is only for MAVLink1/2 encapsulated data and is not compatible with other types of data. This is different to the behaviour in other RFD modem firmware types.

Note in Raw mode data is broken into chunks based on a 10mS break in data or maximum slot size is reached.

S2KBPS – Serial Port 2 Bandwidth Limit

The S2Kbps parameter represents the bandwidth limit in kilobits per second for Serial 2.

This enables throttling of data on this port. Use this if you wish to ensure that a fixed bandwidth is not exceeded. Typically, this limit is accurate to within +/−1Kbps of this parameter setting.
0 – disables this port.
1000 – removes any limits.
Any other value – restricts the port to the specified value

S2RXROUTE – Serial Port 2 Input Route

The S2RXROUTE parameter determines the serial port on the receiving node which the data will be output:
0 – Output data to port 1 of the receiving modem.
1 – Sets output to port 2 of the receiving modem.
2 – Sets output to port 1 of the receiving modem and echoes the input to serial port 1 of the transmitting modem.
3 – Sets output to port 2 of the receiving modem and echoes the input to serial port 1 of the transmitting modem.

S2ATMODE – Serial Port 2 Default AT Command Mode

The S2ATMODE parameter determines if the port is set to start in AT command mode on boot.

If enabled the Auxiliary Tx and Rx pins will be configured automatically at the baud rate set by the S2BAUD parameter.

There is no text "OK" output on boot, however, any commands will be responded to as per standard AT command.

Note there can be a small delay before the port will respond after boot.

4.2.5 Link and RF Parameters:

BITRATE – RF Air Data Rate in kbps

The BITRATE parameter represents the bit rate of the link in kilobits per second.

Note this does not represent the data throughput of the link as there are various overheads that will reduce the actual throughput.

FREQMIN – Minimum Frequency

The FREQMIN parameter specifies the minimum operating frequency in kHz.

FREQMAX – Maximum Frequency

The FREQMAX parameter specifies the maximum operating frequency in kHz.

NUMCHANS – Number of Radio Frequency Channels

The NUMCHANS parameter indicates the number of RF channels to use within the frequency band defined by FREQMIN and FREQMAX e.g. typically, 23 for Australian 915-921MHz band.

The number of channels should be such that the channel spacing is at least:
500kHz – For 1000kbs and 430kbps air rates.
250kHz – For all other lower air rates.

This can be calculated as Channel Spacing = (FREQMAX–FREQMIN)/(NUMCHANS+1).

Note that if only a single channel is set its frequency will be in the middle of the FREQMIN and FREQMAX parameters.

XTRALONGRANGE – Extended Range Operation

This parameter is only to be used for operation where special antennas are used and when operating beyond standard ranges (typically greater than 40km at 64kbps air Rate). For example, connections between a high altitude ballon and a ground station or two airborne vehicles.

In this mode the modem increases the time between transmissions to compensate for longer time of flight between the modems due to the physical separation.

Note enabling this field **WILL reduce your throughput.** Do not enabled unless you are doing something very extraordinary and can cope with the reduction of throughput.

P2PAUTO – Automatic Point-to-Point Mode

The P2PAUTO parameter determines the radio linking mode.
0 – The modem uses the fixed master linking mode.
1 – The modem uses the automatic linking mode.

Note automatic linking can only operate for a pair of modems. For larger networks fixed master linking must be used and individual NODEIDs must be set.

Note enabling automatic linking noticeably increases the linking time.

Note for optimal operation of automatic linking mode, the two nodes should be powered up with a delay between them to allow the first node time to configure itself as master.

TOTALUS – Slot duration

The TOTALUS parameter represents the total time in microseconds of 1 RF slot, including all idle times.

This time will be automatically altered by the firmware on reboot if slot size, works out smaller than ~300bytes or larger than ~1000 bytes

It must be the same value for all modems in a network.

Note slot duration can also be affected by the HOPSMAX and SUBNETS parameter, ensure all these values matches for all nodes.

SLOTS – Number of slots

The SLOTS parameter specifies the number of RF slots in the total network transmission.

The total network time, i.e. the time taken for all transmissions in a single cycle to occur is approximately SLOTS*TOTALUS.

Typically, SLOTS is equal to the number of nodes in the network but may be increased if nodes need to have more than a single slot allocated to them e.g. if they require more guaranteed bandwidth for data forwarding.

Note this must be the same value for all modems on the network.

SLOTIDS – Slot Bit Mask

The SLOTIDS parameter represents a bitfield with 64 bits and defines the transmission slots allocated to the node.

Each slot is represented by a bit in the bitfield.

Note that the bitfield bits are indexed from 0 to (SLOTS – 1)

Setting a bit in the bitfield corresponds to the windows in the sequence during which the node is permitted to transmit in the network cycle.

The bitfield is a binary string however, this parameter is set by a decimal representation of the binary string. Assigning a single slot would require setting a single bit within the bitfield e.g. 1000…, 0100…, 0010…, 0001…, etc. where a 1 indicates the slot occupied. This corresponds to decimal value SLOTIDS of 1, 2, 4, 8, etc. i.e. those which align with powers of two.

Multiple slots, or transmission windows in a network cycle, can be assigned to increase a node's bandwidth. This is done by assigning multiple bits in the bitfield e.g. bitfields of 1100…, 1010…, 0110…, 1101…, 1001…, etc. where a 1 indicates the slots occupied. This corresponds to decimal value SLOTIDS of 3, 5, 6, 7, 9 etc.

Programmes such as "Microsoft Calculator" in programmer mode can be useful for making the conversion between binary and decimal.

Note SLOTIDS must be unique for each node on a network and no 2 nodes should be assigned a SLOTIDS that contains any of the same bits in the bitfield e.g. node one SLOTIDS=1 node two SLOTIDS=3 would be invalid as both nodes have bit 0 set in their SLOTIDS.

Note that if a node has multiple slots, they should be distributed in the bitfield rather than sequential e.g. a bitfield of 1,0,0,1,0,0 (SLOTIDS=9) rather than 1,1,0,0,0,0 (SLOTIDS=3). Thus improving throughput as it provides adequate time for the modem to process sufficient incoming data to fully utilise subsequent transmissions.

SLOTTXMODE– Slot Radio Transmit Operations

The SLOTTXMODE represents when a node may transmit. It represents a bitfield with 3 bits.
Bit 0 – Transmit on slots the node owns through the SLOTIDS setting. This should always be set.
Bit 1 – Transmit on a slot given up by another node.
Bit 2 – Transmission in the sync slot. This applies to master node only and is ignored by other nodes.

Note: Default value is 7 (all slots enabled).

Note if a network was required to have 2 co–located nodes on different SUBNETWORKS, then each should have the same NODEIDs and have SlOTTXMODE = 1, bit 0 only, to avoid them transmitting whilst the other is receiving which could cause loss of packets due to receiver overload.

TXPOWER – RF Transmit Power

The TXPOWER parameter represents the transmit power in dBm.

ANTMODE – Antenna Port Functions

The ANTMODE parameter specifies the antenna port operating mode.
0 – Automatic antenna port diversity mode. The system will use the port with the highest receive strength for the next transmission.
1 – All transmission and receiving on antenna port A1 only.
2 – All transmission and receiving on antenna port A2 only.
3 – Transmission to use antenna port A1 and receiving to use port A2.

Note unused modem RF ports must not be terminated in short circuits or RF loads as this can interfere with correct operation of the diversity feature. If ports need to be covered a cover that does leaves the port electrically open should be used.

RATE/FREQBAND – Country Rate or Frequency Band Options

The RATE/FREQBAND parameter determines which of the alternative sets of RF parameters to use on a region locked modem.

The exact parameter settings will depend on the region the modem is locked to. The region locked modem restricted settings, such as frequency, number of channels etc.
Settings are updated automatically on reboot of the modem based on the setting of this parameter.

Note this parameter will not affect an unlocked modem.

4.2.6 GPIO Pin Settings:

PIN#TYPE(*) – Pin function for GPIO number **#**.
***** is the corresponding pin number of the pin header on the x2 series modem. This will differ for ux2 modems.

This parameter configures the functions of a given GPIO pin in following ways:

Setting Number	Function Description	Pin Direction
0	GPI – The pin functions as a General Purpose Input (GPI).	Input
1	RESET – Pulling the pin high will force the modem to reset.	Input
2	MIRROR – The pin functions as an input, the state of which will be mirrored on the pin prescribed in the PINMIRR parameter on the remote modem, provided that the remote modem pin is configured as GPO.	Input
3	GPO – sets the pin as a General Purpose Output (GPO).	Output
4	GPO_WOR – General Purpose Output Wired OR gate with high side drive pull down.	Output
5	GPO_WAND – General Purpose Output Wired AND gate with low side drive pull up.	Output
6	STATLED – The state of this pin reflects the modem status (green) LED. High indicates the LED is on and low indicates the LED is off.	Output
7	RXLED – The state of this pin is the same as that of the modem data (red) LED. High indicates the LED is on and low indicates the LED is off.	Output
8	RSVD – Unused value reserved for future functions.	
9	PPMIn – The pin reads a PPM signal, from an external signal source, which will be transmitted in RC passthrough mode.	Input
10	PPMOut – The pin outputs a PPM stream, with failsafe output if signal is lost, when the modem is configured for RC Passthrough. The failsafe is defined by the RCDEFS parameter.	Output
11	PPMOutNoFS – The pin outputs a PPM stream, with no-failsafe functions if signal is lost, when the modem is configured for RC Passthrough.	Output
12	SBUSIn10 – The pin reads a 10 channel SBUS signals, from the external source, which will be transmitted in RC passthrough mode. There is support for 8 analog and 2 digital channels. Using this mode will save some bandwidth compared to SBUSIn18.	Input
13	SBUSIn18 – The pin reads an 18 channel SBUS signals, from the external source, which will be transmitted in RC passthrough mode. There is support for 16 analog and 2 digital channels.	Input
14	SBUSOut – The pin outputs the SBUS stream, with failsafe output if signal is lost, when the modem is configured for RC Passthrough. The failsafe is defined by the RCDEFS parameter.	Output
15	SBUSOutNoFS – The pin outputs the SBUS stream, with no-failsafe functions if signal is lost, when the modem is configured for RC Passthrough.	Output
16	RTS – The pin functions as the Ready to Send (RTS) flow control pin for serial port 1	Output
17	CTS – The pin functions as the Clear to Send (CTS) flow control pin for serial port 1	Input
18	AUXTX – The pin functions as the transmit (TX) pin of serial port 2	Output
19	AUXRX – The pin functions as the receive (RX) pin of serial port 2	Input
20	AUXRTS – The pin functions as the Ready to Send (RTS) flow control pin for serial port 2	Output
21	AUXCTS – The pin functions as the Clear to Send (CTS) flow control pin for serial port 2	Input
22	Not intended for user functions.	
23	Not intended for user functions.	
24	Not intended for user functions.	
25	Not intended for user functions.	
26	Not intended for user functions.	
27	Not intended for user functions.	
28	Not intended for user functions.	

Note that when configured as an input a GPIO pin has Vin Max of 3.3V, a Vhigh > 2.3V, a Vlow < 1.0V, and an average input impedance of approximately 40k Ohms.

Note: that when configured as an output the pin has Vout Max of 3.3V, a Vhigh > 2.6V, a Vlow < 0.7V, and a drive current maximum of approximately 20mA.

PINRTSTYPE(3) – Pin function for x2 modem header pin 3

Configures the operation of pin 3 of the x modem header as hardware flow control RTS pin. Setting options as per PIN#TYPE(*) above.

PINCTSTYPE(11) – Pin function for x2 modem header pin 11

Configures the operation of pin 11 of the x modem header as hardware flow control CTS pin. Setting options as per PIN#TYPE(*) above.

PINMIRR – Pin Mirroring Table

This list specifies the output pins of the receiving modem that will mirror the inputs of MIRROR configured pins of the transmitting modem.

Each position in the list maps the pin of the receiving modem that will output the mirror of PIN0 through PIN7 etc. For example, the default configuration of 0,1,2,3,4,5,6,7, maps each pin of transmitter to the same pin output on receiver, while 1,2,3,4,5,6,7,0, would map PIN0 transmitter to PIN1 receiver, PIN1 transmitter to pin2 receiver, …, PIN7 transmitter to PIN0 receiver.

Note that there is no support for multiple inputs to be mapped to the same output, e.g. 1,1,1,2,3,4,5, would not be valid

Note that values in the table that relate to pins that have not been configured as MIRROR will be ignored.

Note that if the specified pin of the receiving modem is not configured as a GPO, GPO_WOR or GPO_WAND the pin mirror information is ignored.

Note that this function is primarily intended for Point-to-point configurations. If used in a mesh, then all nodes on the same network that have a mapped output pin set as an output will mirror the input signal.

Multiple nodes must not be configured to drive the same output pins on receiving modems as conflicting messages from different modems in the network will result in an indeterminate output state.

4.2.7 RC Parameters

RCFrameLoss – RC Failsafe Loss Threshold

This parameter determines how many RC frames can be missed before fail–safe is triggered.

Each frame is approximately 20 milliseconds long.

RCInMinmS – Minimum RC Update Interval

This parameter specifies the minimum update time in milliseconds for RC input.

If an RC frame arrives before this time, it is discarded. This can be used to limit excess frames going over the air, usually for SBUS outputting frames at 7ms.

RCDEFS – Failsafe Output Definitions

A table of signal levels representing the output signal of the 18 possible channels of an RC signal.

This parameter is only applicable if the output pin is configured to support failsafe modes.

Only 16 channels are applicable for PPM.

The final two values in the table are for digital channels in SBUS configurations. Values below approximately 1500 will represent a low output and values above represent a high output. For elimination of doubt in output values of or close to the minimum and maximum settable should be used to represent low and high outputs respectively.

When updating the table only the required number of entries need to be entered in the AT command e.g. setting the first three channels with the AT command would look like, *ATS47=1000,1100,1200* which will set the failsafe table as whole to be 1000,1100,1200,1500,1500,1500,1500,1500,1500,1500,1500,1500,1500,1500,1500,1500,1000,1000,

5 Example Modem Configurations

Note nodes may need to be rebooted after settings have been modified to activate changes.

Note the TOTALUS may reconfigure automatically and therefore may not exactly match the settings in these examples. This is normal behaviour, but the value may need to be checked on each modem to ensure that it is the same across the network.

Note any setting not specified in these example configurations is assumed to be the default value. If following these guides, it is best to default the modem settings before applying the following.

Note that network mode settings are not tested on or endorsed for use with EU region locked modem.

5.1 Point-to-Point

5.1.1 Modem linking

5.1.1.1 Automatic Master Mode

In the automatic master mode, both modems are configured with the following settings:

Setting	AT Command
P2PAUTO=1	ATS6=1
TOTALUS=40000	ATS7=40000
SLOTS=2	ATS8=2
SLOTIDS=2	ATS9=2
NODEID=1	ATS10=1

5.1.1.2 Fixed Master Mode

In the fixed master mode, the master is configured by the following settings:

Setting	AT Command
P2PAUTO=0	ATS6=0
TOTALUS=40000	ATS7=40000
SLOTS=2	ATS8=2
SLOTIDS=1	ATS9=1
NODEID=0	ATS10=0

The second modem parameters should be configured by the following settings:

Setting	AT Command
P2PAUTO=0	ATS6=0
TOTALUS=40000	ATS7=40000
SLOTIDS=2	ATS9=2
NODEID=1	ATS10=1

5.1.2 Remote Control Signal Passthrough

To configure a node for RC signal input the following parameters should be set:

Setting	AT Command
TOTALUS=40000	ATS7=40000
PRI=3	ATS18=3
PINTYPE(15)=10 (PPM input), or 13 (SBUS input 10 total channels), or 14 (SBUS input 18 total channels)	ATS36=10 or 13 or 14

To configure a node for RC signal output the following parameters should be set:

Setting	AT Command
TOTALUS=40000	ATS7=40000
PINTYPE(15)=11 (PPM output), or 12 (PPM output no-failsafe), or 15 (SBUS output), or 16 (SBUS output no-failsafe)	ATS36=11 or 12 or 15 or 16

If using fail safe streams, please set the failsafe on the output modem by one of the following methods:

Setting	AT Command
RCDEFS= Channel ms counts comma-separated	**Example** ATS47=1500,1500,1500,1500,1500,1500,1500,1500,1000,1000,

- Ensure that both modems are on and linked
- Set the RC such that the desired failsafe signal is generated
- Issue the AT&R command to the output modem to record the current stream
- Verify the RCDEFS settings with the command RTI10:47
- Restart modem to enable the modified settings

Note: The final two channels of the RCDEFS parameter represent the digital channels of the SBUS outputs. Values of 1500 and above will set a high digital output. These last two channels are ignored if PPM output is set.

5.2 Listen Only Nodes

Listen only node specific settings:

Setting	AT Command
SLOTTXMODE=0	ATS19=0

5.3 Networks

5.3.1 Single Network

For small numbers of total nodes or scenarios where all nodes need to be able to intercommunicate, the single network mode is recommended.

An example 4 node network is configured by the following settings:
Master

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=10	ATS8=10
SLOTIDS=1	ATS9=1
NODEID=0	ATS10=0

Network node settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=10	ATS8=10
SLOTIDS=2^N	ATS9=2^N
NODEID=N	ATS10=N

Where N is the node number from 1-4

Nodes can either be directed to broadcast to all nodes in the network or to direct data packets to a particular node in the network. This is controlled by the DESTID parameter as follows:

Broadcast

Setting	AT Command
DESTID=63	ATS14=63

Unicast

Setting	AT Command
DESTID=Target NODEID	ATS14=Target NODEID

5.3.2 Multiple Subnetworks

Where multiple meshes of linked devices are required to operate in proximity, or the throughput limit of a single subnetwork has been reached multiple subnetworks can be configured.

An example 18 nodes across 3 networks of 6 nodes each is configured by the following settings:

Master

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=6	ATS8=6
SLOTIDS=1	ATS9=1
NODEID=0	ATS10=0
NETWORKS=3	ATS12=3

Network 1 nodes settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=6	ATS8=6
SLOTIDS=2^N	ATS9=2^N
NODEID=N	ATS10=N
NETWORKS=3	ATS12=3

Where N is the node number from 1-5

Network 2 node settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=6	ATS8=6
SLOTIDS=2^N	ATS9=2^N
NODEID=N	ATS10=N
NETID=8	ATS11=8
NETWORKS=3	ATS12=3

Where N is the node number from 0-5

Network 3 node settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=6	ATS8=6
SLOTIDS=2^N	ATS9=2^N
NODEID=N	ATS10=N
NETID=15	ATS11=15
NETWORKS=3	ATS12=3

Where N is the node number from 0-5

Nodes can either be directed to broadcast to all nodes in the network or to direct data packets to a particular node in the network. This is controlled by the DESTID parameter as follows:

Broadcast

Setting	AT Command
DESTID=63	ATS14=63

Unicast

Setting	AT Command
DESTID=Target NODEID	ATS14=Target NODEID

Note there is also a limitation that nodes of different networks cannot be co-located, within 3 metres of each other, unless they never transmit whilst other collocated nodes are receiving. This is to avoid overloading the receiver electronics.
Synchronising the co-located node transmissions can mitigate the need for physical separation and can be achieved by using the following settings:
All Networks have the same number of SLOTS.
Co-located nodes belong to different networks.
Co-located nodes have the same SLOTIDS.
Co-located nodes SLOTTXMODE is set to 1.

5.3.3 Forwarding with local data

An example 4 node network with 3 forwarding hops where **forwarding nodes also have local data**, e.g. the relay nodes are also serving as vehicle nodes, is configured by the following settings:
Master (and GCS node)

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=7	ATS8=7
SLOTIDS=1	ATS9=1
NODEID=0	ATS10=0
DESTID=63	ATS14=63
HOPSMAX=3	ATS15=3
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7

Relay and vehicle node 1 settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=7	ATS8=7
SLOTIDS=42	ATS9=42
NODEID=1	ATS10=1
DESTID=0	ATS14=0
HOPSMAX=3	ATS15=3
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7
FWDTABLE=0,64,2,64,3,64,	ATS49=0,64,2,64,3,64,

Relay and vehicle node 2 settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0

Setting	AT Command
TOTALUS=25000	ATS7=25000
SLOTS=7	ATS8=7
SLOTIDS=20	ATS9=20
NODEID=2	ATS10=2
DESTID=0	ATS14=0
HOPSMAX=3	ATS15=3
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7
FWDTABLE=0,64,1,64,3,64,	ATS49=0,64,1,64,3,64,

Vehicle Node 3

Setting	**AT Command**
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=7	ATS8=7
SLOTIDS=64	ATS9=64
NODEID=3	ATS10=3
DESTID=63	ATS14=63
HOPSMAX=3	ATS15=3
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7

For bench testing it is necessary to force the modems to transmit through hops even when in rage of each other. This is done with the following settings:

Master node test settings

Setting	**AT Command**
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=1	ATS17=1

Relay node 1 test settings

Setting	**AT Command**
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=2	ATS17=2

Relay node 2 test settings

Setting	**AT Command**
VALIDHOPSMIN=1	ATS16=1
VALIDHOPSMAX=3	ATS17=3

Vehicle node test settings

Setting	**AT Command**
VALIDHOPSMIN=2	ATS16=2
VALIDHOPSMAX=3	ATS17=3

5.3.4 Forwarding No Local Data

An example 3 node network with 2 hops where **the forwarding node does not have local data**, i.e. the relay node is only relaying data, is configured by the following settings:

Master (and GCS node)

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=4	ATS8=4
SLOTIDS=1	ATS9=1
NODEID=0	ATS10=0
DESTID=63	ATS14=63
HOPSMAX=2	ATS15=2
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7

Relay node 1 settings

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=4	ATS8=4
SLOTIDS=10	ATS9=10
NODEID=1	ATS10=1
DESTID=0	ATS14=0
HOPSMAX=2	ATS15=2
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7
FWDTABLE=0,64,2,64,	ATS49=0,64,2,64,

Vehicle node 2

Setting	AT Command
BITRATE=125	ATS1=125
P2PAUTO=0	ATS6=0
TOTALUS=25000	ATS7=25000
SLOTS=4	ATS8=4
SLOTIDS=4	ATS9=4
NODEID=2	ATS10=2
DESTID=63	ATS14=63
HOPSMAX=2	ATS15=2
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=7	ATS17=7

For bench testing it is necessary to force the modems to transmit through hops even when in rage of each other. This is done with the following settings:

Master node test settings

Setting	AT Command
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=1	ATS17=1

Relay node 1 test settings

Setting	AT Command
VALIDHOPSMIN=0	ATS16=0
VALIDHOPSMAX=2	ATS17=2

Vehicle node 2 test settings

Setting	AT Command
VALIDHOPSMIN=1	ATS16=1
VALIDHOPSMAX=2	ATS17=2

6 Loading firmware

Compatible firmware can be loaded on to the modems by means of:

- The RFD modem tools software.

6.1 Programming with RFD modem tools

Requires the user to connect the modem to the PC by means of the FTDI cable. Then you can open the tools programme select the serial COM port and connect to your modem.

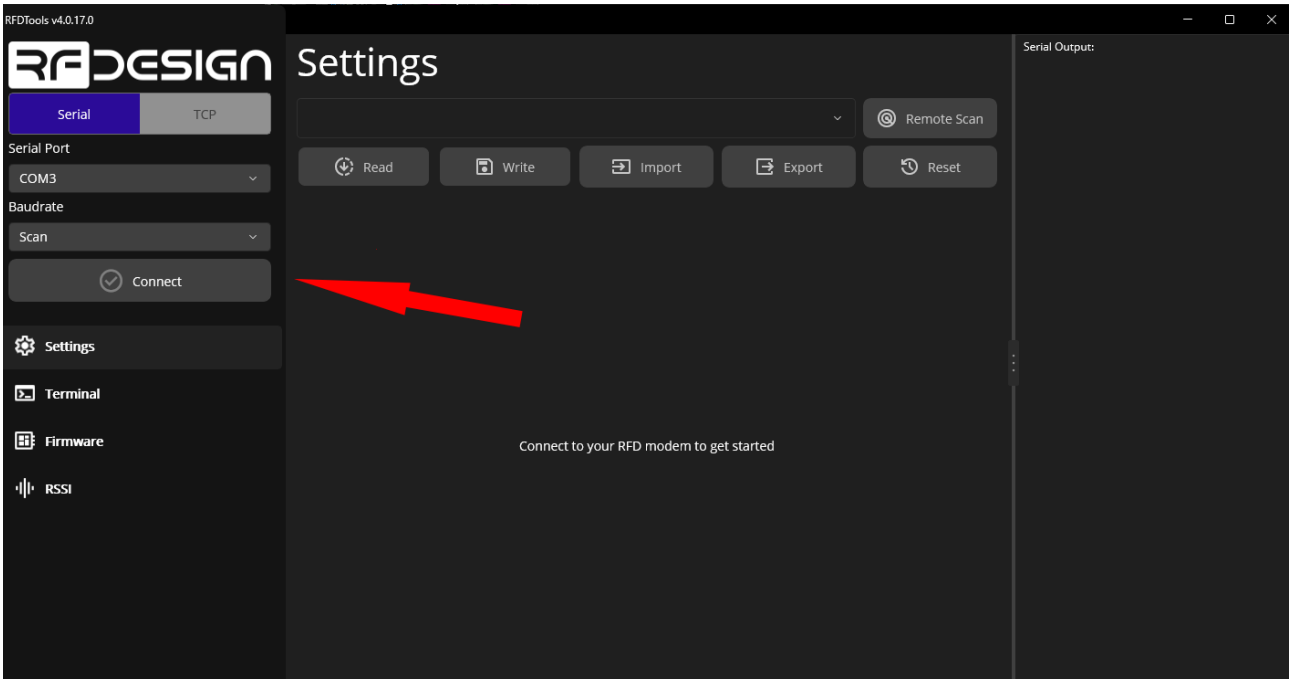

Figure 8: RFD Tools COM Port Connection

Once connected the "Connect" button will change to "Disconnect".

Ensure that the "Local" modem is selected. The tools will populate the "Firmware" box in the "Device Details" with the name of the currently loaded firmware. This tells you that you have correctly connected to the modem and the baud rate is properly set. At the left-hand side, below the serial port settings is the "Firmware" button.

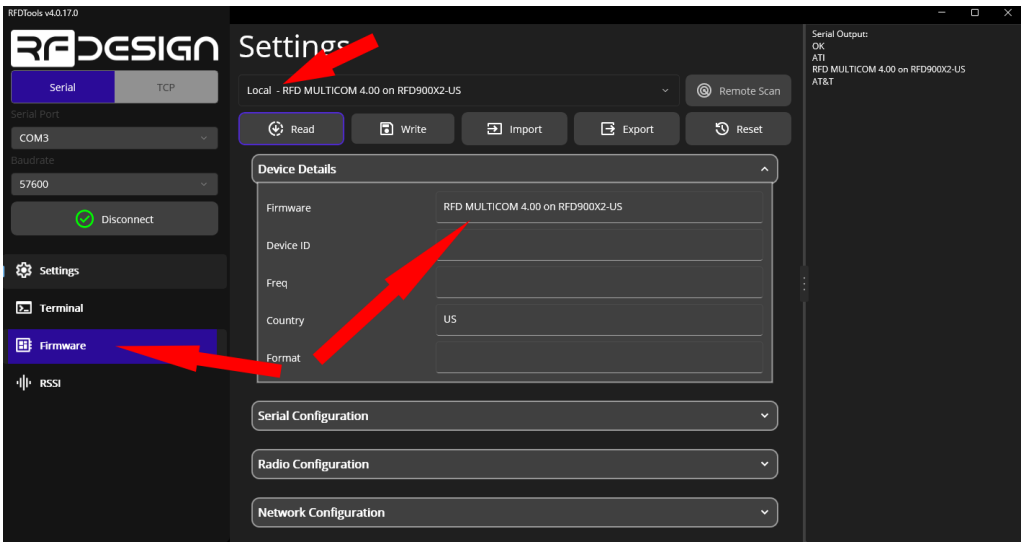

Figure 9 Entering Firmware Mode

From this screen press the "Select Firmware File" button.

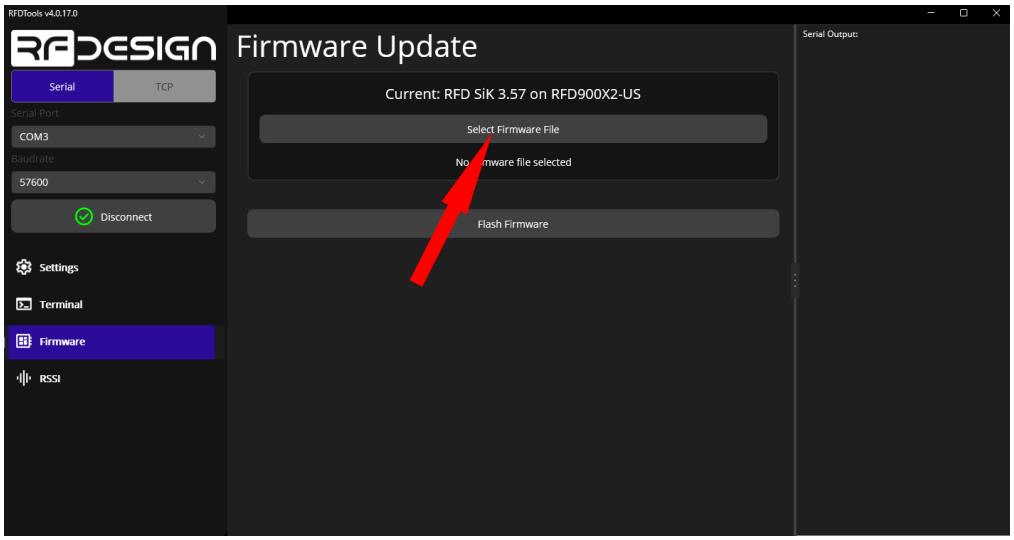

Figure 10 Firmware Update Screen

In the dialog box select the desired firmware appropriate to your device.

If you cannot select or upload a file to your modem check that the correct version for your hardware.

Note that the V1 and V2 modems hardware use different firmware packages, the RFD tools will block you from loading the incorrect version.

Once a file has been selected press open.

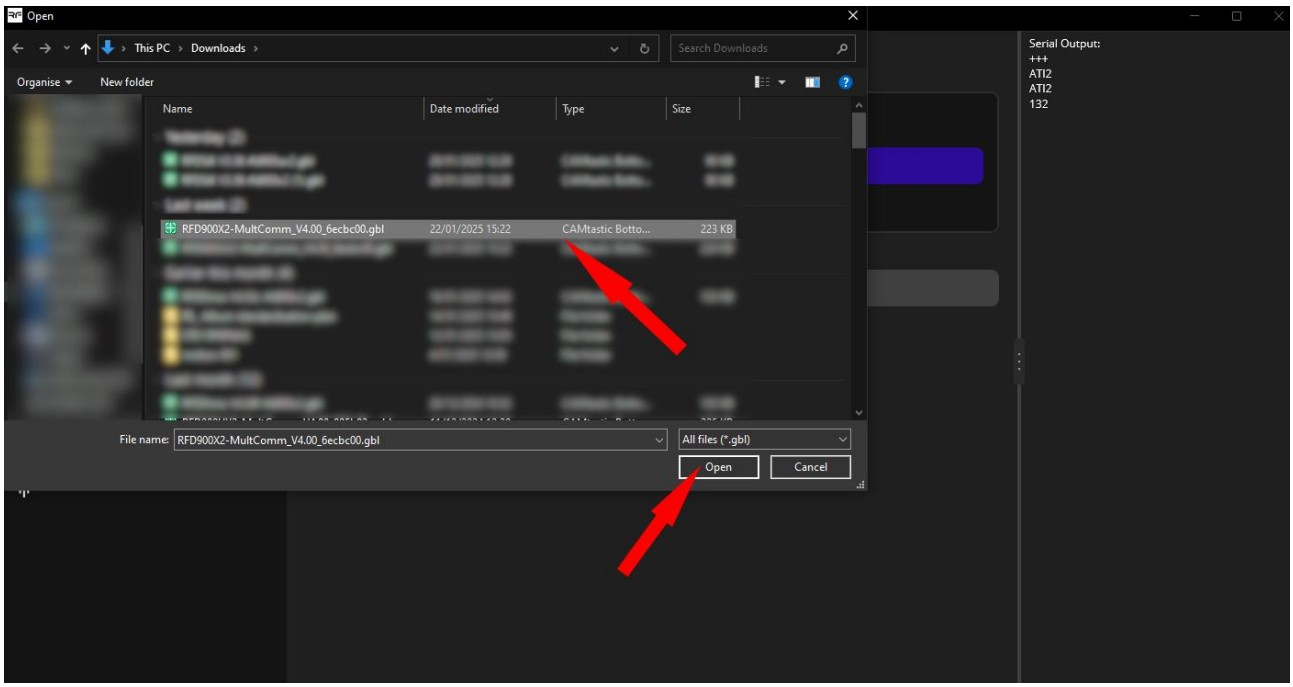

Figure 11 Choosing Firmware File

Once the file has been opened the name of the current firmware as well as the file selected is displayed on either side of the "Select Firmware File" button. This is a final chance to verify that the intended file is selected. Once happy with the selection the "Flash Firmware" button can be pressed

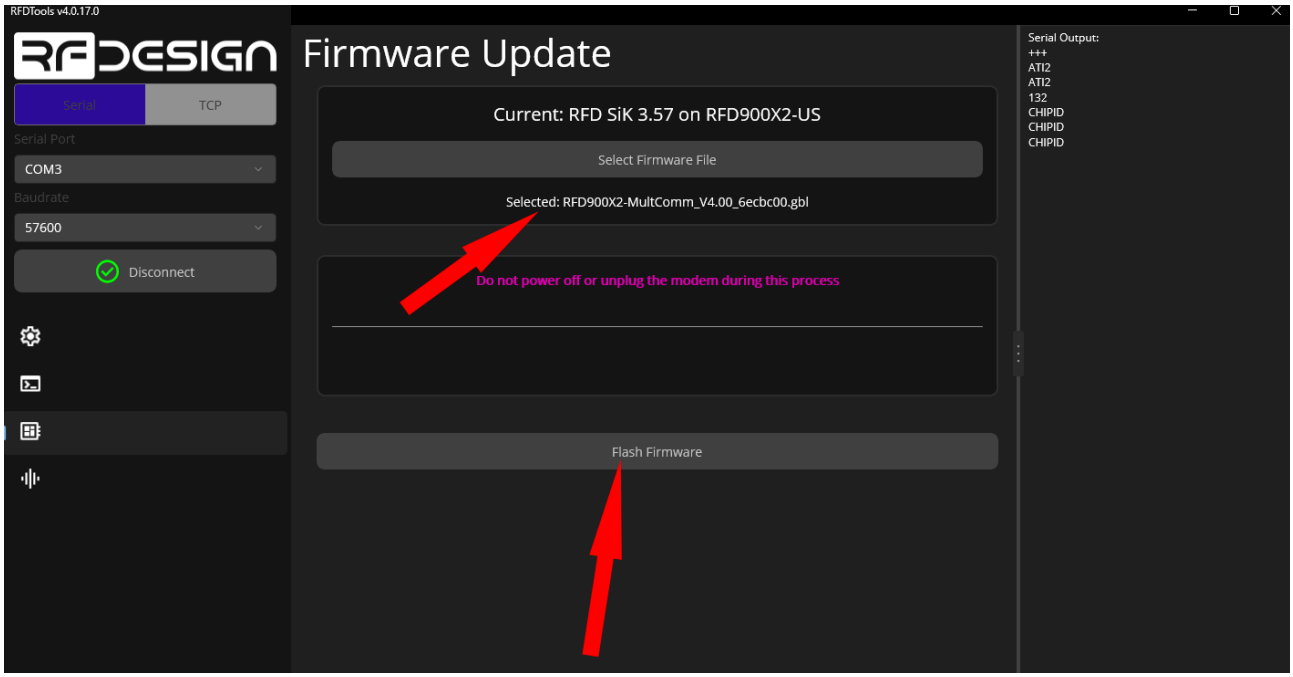

Figure 12 Commencing Programming

The progress bar in the centre of the screen will fill as the file is loaded.

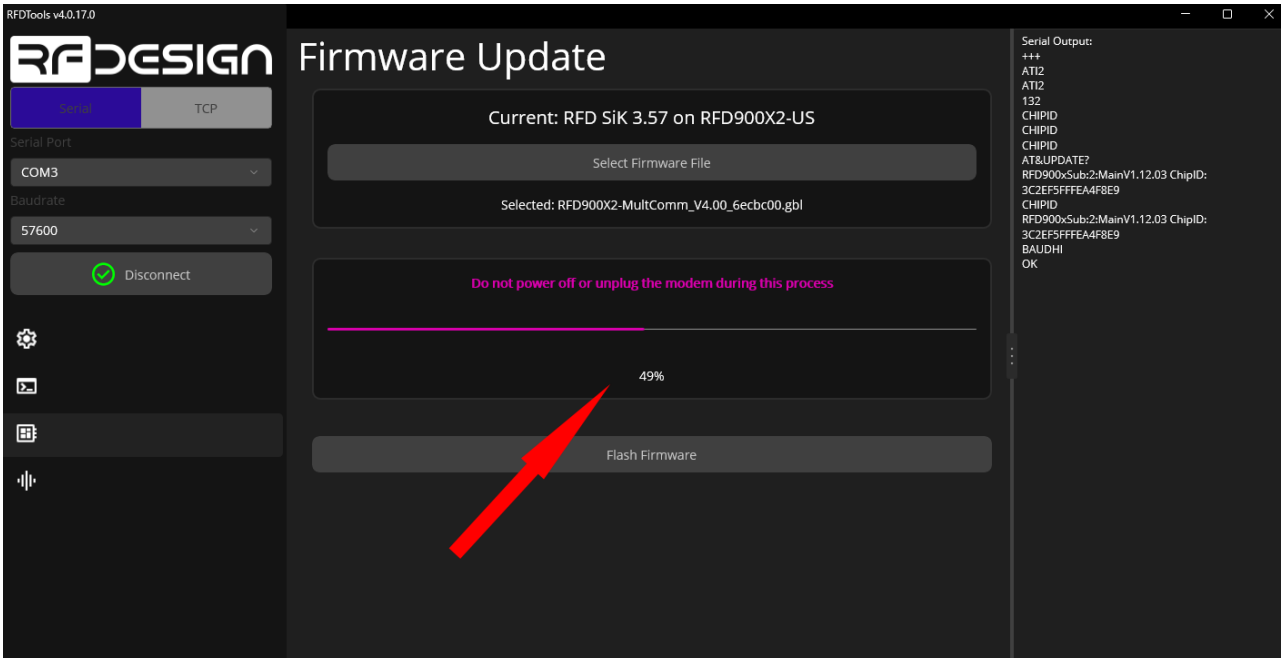

Figure 13: Programming Progress

After programming you will be asked to reconnect to the modem. Then you can choose the "Settings" or "Terminal" modes, using the buttons on the left hand side below the serial settings, and configure the modem/s for use.

7 Pinout

The RFD x series modem electrical connections are outlined in the following section.

7.1 x series modems

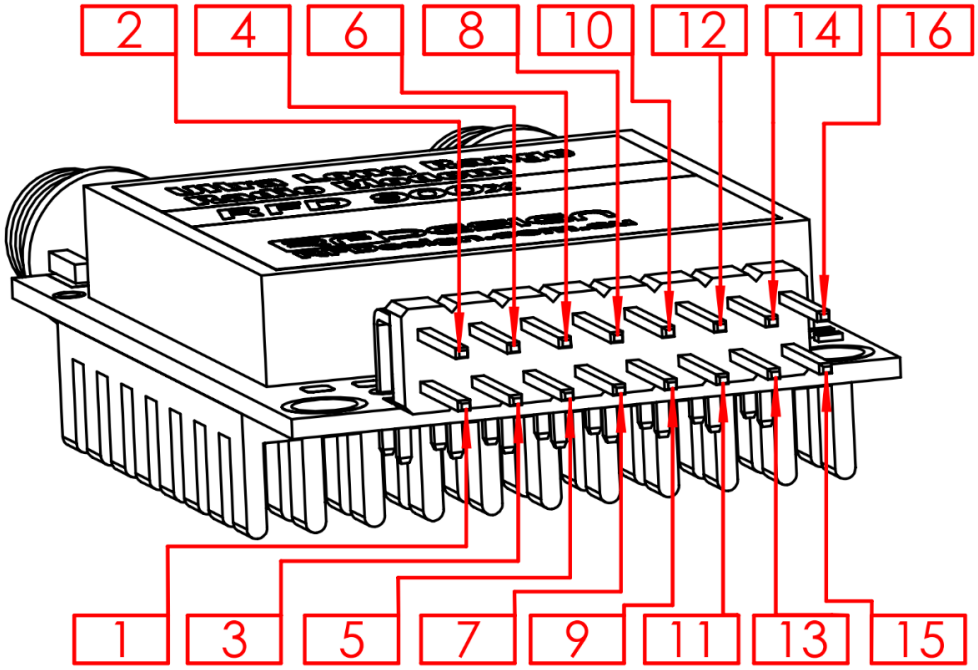

Figure 14: Modem 0.1" header pinout

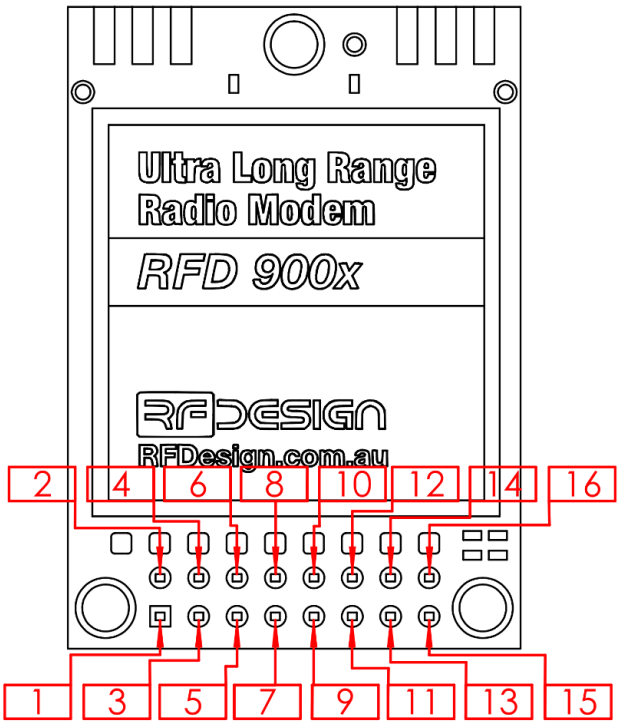

Figure 15: Bare modem pad numbering

Pin #	Name	Direction	Function/s	Max. Voltage
1	GND	—	Ground	0V
2	GND	—	Ground	0V
3	RTS 1	Output	UART 1 Request to Send (RTS) Flow Control	3.3V
4	Vcc	Input	Positive Supply Voltage	5.5V
5	Vusb	Input	Positive Supply Voltage From USB	5.5V
6	Vusb	Input	Positive Supply Voltage From USB	5.5V
7	RX 1	Input	UART 1 Data In (RX)	3.3V
8	GPIO5	I/O	Pin Mirror I/O, UART 2 Data Out (TX)	3.3V (5V input tolerant)
9	TX 1	Output	UART 1 Data Out (RX)	3.3V
10	GPIO4	I/O	Pin Mirror I/O, UART 2 Data Out (RX)	3.3V (5V input tolerant)
11	CTS 1	Input	UART 1 Clear to Send (CTS) Flow Control	3.3V
12	GPIO3	I/O	Pin Mirror I/O, UART 2 Clear to Send (CTS) Flow Control, Status LED	3.3V
13	GPIO0	I/O	Pin Mirror I/O, Reset, Status LED	3.3V
14	GPIO2	I/O	Pin Mirror I/O, UART 2 Request to Send (RTS) Flow Control, RX LED	3.3V (5V input tolerant)
15	GPIO1	I/O	Pin Mirror I/O, PPM I/O, SBUS I/O	3.3V
16	GND	—	Ground	0V

7.2 ux series modems

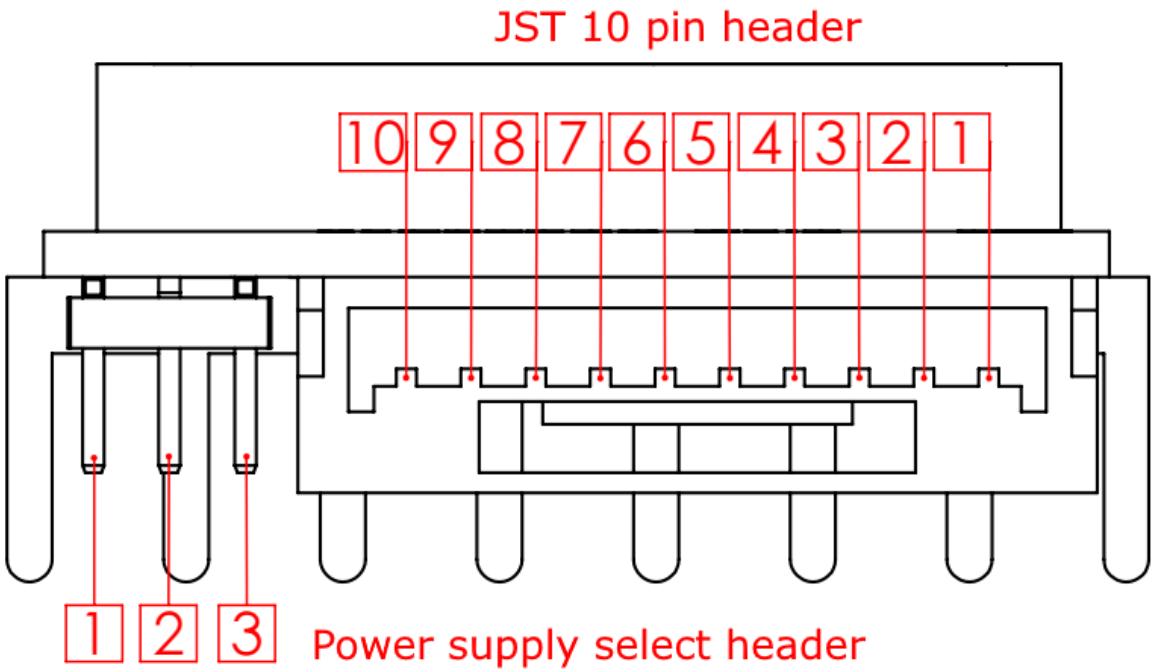

Figure 16: ux modem header pinout

Pin #	Name	Direction	Function/s	Max. Voltage
1	GND	-	Ground	0V
2	V_External	Input	Positive 5V supply voltage from external source	5.5V
3	GND	-	Ground	3.3V
4	GPIO1	I/O	Pin Mirror I/O, PPM I/O, SBUS I/O	3.3V
5	V_Standard	Input	Positive 5V supply voltage from USB	5.5V
6	RX 1	Input	UART 1 Data In/Receive (RX)	3.3V
7	TX 1	Output	UART 1 Data Send (RX)	3.3V
8	CTS 1	Input	UART 1 Clear to Send (CTS) Flow Control	3.3V
9	RTS 1	Output	UART 1 Ready to Send (RTS) Flow Control	3.3V
10	GND	-	Ground	0V

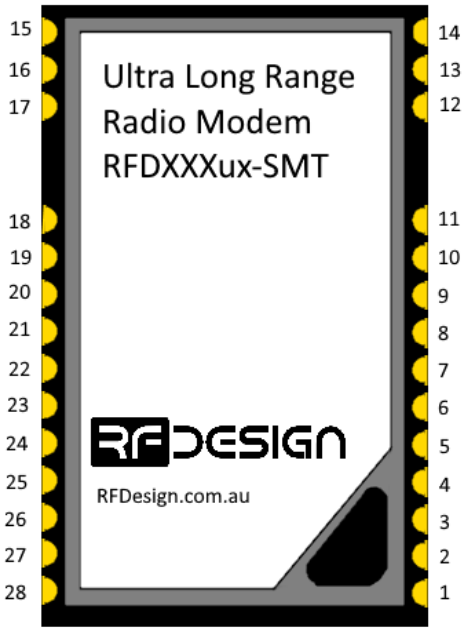

Figure 17: ux-SMT modem pinout

Pin #	Name	Direction	Description	Max Voltage
1	VUSB	Input	5V Power supply from USB	5.5V
2	USB_DM	Input	USB Data - [1]	3.3V
3	USB_DP	Input	USB Data + [1]	3.3V
4	Bootloader	Input	Bootloader mode trigger	3.3V
5	GPIO5	I/O	Pin Mirror I/O, UART 2 Data Out (TX)	3.3V
6	GPIO4	I/O	Pin Mirror I/O, UART 2 Data Out (RX)	3.3V
7	GPIO6	I/O	Digital I/O [1]	3.3V
8	GND	—	Ground	0V
9	GND	—	Ground	0V
10	+3V3	Output	3.3V LDO output	3.3V
11	GND	—	Ground	0V
12	GND	—	Ground	0V
13	ANT1	—	Antenna 1	—
14	GND	—	Ground	0V
15	GND	—	Ground	0V
16	ANT2	—	Antenna 2	—
17	GND	—	Ground	0V
18	GND	—	Ground	0V

Pin #	Name	Direction	Description	Max Voltage
19	+5V	—	5V Power Supply	5.5V
20	GND	—	Ground	0V
21	GPIO0	I/O	Pin Mirror I/O, Reset, Status LED	3.3V
22	GPIO1	I/O	Pin Mirror I/O, PPM I/O, SBUS I/O	3.3V
23	GPIO2	I/O	Pin Mirror I/O, UART 2 Request to Send (RTS) Flow Control, RX LED	3.3V
24	GPIO3	I/O	Pin Mirror I/O, UART 2 Clear to Send (CTS) Flow Control, Status LED	3.3V
25	RX 1	Input	UART 1 Data In/Receive (RX)	3.3V
26	TX 1	Output	UART 1 Data Out/Transmit (TX)	3.3V
27	RTS 1	Output	UART 1 Request to Send signal	3.3V
28	CTS 1	Input	UART 1 Clear to Send signal	3.3V

1. Feature not currently supported in any firmware versions

8 Performance Characteristics

<table>
<tr><th>Feature</th><th colspan="3">Implementation or Performance</th></tr>
<tr><td>RF Data Rates</td><td colspan="3">12, 56, 64, 100, 125, 188, 200, 430 and 1000 kbits/sec
(Available rates depend on modem variant and firmware)</td></tr>
<tr><td>Obstructed Line of Sight Range</td><td colspan="3">0.5 – 1 km (depending on antennas, and settings)</td></tr>
<tr><td>Line of Sight Range</td><td colspan="3">40+km (depending on antennas, and settings)</td></tr>
<tr><td>Serial Interface Data Rate</td><td colspan="3">2400, 4800, 9600, 19200, 38400, 57600, 115200, 230400, 460800, 1000000, 1200000 and 1500000 baud</td></tr>
<tr><td>Modulation</td><td colspan="3">2GFSK (dependent on air data rate)</td></tr>
<tr><td rowspan="9">Interference Mitigation</td><td colspan="3">Frequency Hopping Spread Spectrum, FHSS, (except RFD868x–EU)</td></tr>
<tr><td>Modem Variant</td><td>Frequency Band/s</td><td>Number of Channels</td></tr>
<tr><td>RFD900x Unlocked</td><td>902 – 928 MHz</td><td>User settable (51 Max)</td></tr>
<tr><td>RFD900x–AU locked</td><td>915 – 921MHz
and
922 – 928MHz</td><td>23</td></tr>
<tr><td>RFD900x–NZ locked</td><td>920.75 – 927.25 MHz</td><td>25</td></tr>
<tr><td>RFD900x–US locked</td><td>902 – 915MHz
and
915 – 928MHz</td><td>51</td></tr>
<tr><td>RFD868x Unlocked</td><td>865 – 868 MHz</td><td>User settable (7 Max)</td></tr>
<tr><td>RFD868x–EU locked</td><td>869.85MHz</td><td>1</td></tr>
<tr><td>RFD868ux-IND</td><td>865 – 867 MHz</td><td>7</td></tr>
</table>

<table>
<tr><th>Feature</th><th>Implementation or Performance</th></tr>
<tr><td>Receiver sensitivity</td><td>
<table>
<tr><th>Air data rate</th><th>Sensitivity dBm @ 10–5 BER
x2</th><th>ux2</th></tr>
<tr><td>12</td><td>-112</td><td>-107</td></tr>
<tr><td>64</td><td>-106</td><td>-103.5</td></tr>
<tr><td>125</td><td>-104.5</td><td>-100</td></tr>
<tr><td>188</td><td>-99.5</td><td>-94.5</td></tr>
<tr><td>200</td><td>-99</td><td>-94.5</td></tr>
<tr><td>430</td><td>-97.5</td><td>-93</td></tr>
<tr><td>1000</td><td>-84</td><td>-81</td></tr>
</table>
</td></tr>
</table>

8.1 Thermal Management

RFD modems, except for bare variants, are supplied with a heatsink to improve the cooling of the module. The modems may generate substantial heat whilst operating at full transmitter power. It is advisable to mount the modems in a location where airflow can dissipate this heat from the modem.

Note that unless transmissions are infrequent, or transmission power levels are low, it is not recommended to operate the modems without a heatsink. Likewise, it is not advisable put the modems in environments where the heat from other components may unduly affect the modems.

The modems have an internal silicon temperature sensor. This sensor is not fully calibrated and therefore could vary by a few degrees from the actual temperature. If this exceeds a safe operating temperature the modem will reduce output to reduce the heat produced by the system and thus help to protect the components against suffering a thermal failure. Once below a normal operating temperature the system will return to normal function.

Note that it is not advised to rapidly cool a hot modem with water, alcohol, electronics freeze spray etc. as this could cause damage to solder joints and other components due to thermal shock.

8.2 RSSI Report

The modem will generate a Received Signal Strength Indicator value when receiving data. This will be incorporated in the MAVLink telemetry if used in MAV mode. Alternatively, it can be accessed by the AT&T=RSSI command. In report mode the modem will report a string of values as seen in the illustrative example in figure 18 below.

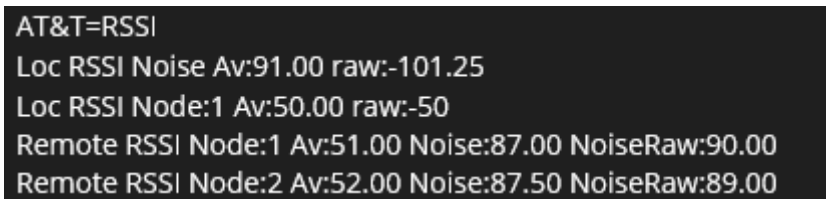

Figure 18:RSSI Report 3 Node Network

AT&T=RSSI – the command to enter reporting mode

LOC – Short for Local, refers to the modem generating the report.

Remote – The other modem/s in the network.

Node:# – The NODEID of the remote modem reporting.

RSSI NOISE – The measure strength of RF noise. (-dBm)

RSSI – The measure strength of the signal transmission. (-dBm)

Av – The average response over a series of measurements.

Raw – The value of the single measurement.

Note that good link performance requires both that the signal power exceed the noise power. A good minimum margin would be 20 dBm. As the measurements are in -dBm the signal value should be smaller than the noise value

Note that good link performance requires the signal power exceed the minimum sensitivity level.

9 Useful Links

FTDI

https://ftdichip.com/drivers/

RFD Modem Firmware and Documentation

https://rfdx.atlassian.net/servicedesk/customer/portal/1/article/452198432

RFD Tools

https://rfdx.atlassian.net/wiki/download/attachments/242712577/RFDTools_4.0.18.0_x64.msix?api=v2

RFD Store

https://store.rfdesign.com.au

10 Glossary

RF: Radio Frequency. A term used to describe a portion of the electromagnetic spectrum. Commonly encompassing frequencies between a few tens of kilohertz and a couple of hundred gigahertz.
Band: For the purposes of this document a band is a value or range of values that are valid for operation. An example would be a frequency band, that is a frequency or range of frequencies at which the modem operates.
Channel: The designator for or nominal frequency of RF
Channel Width: The minimum spread around the channel frequency in which transmission signals occur.
Bandwidth: In the context of this document means the data capacity of the modem link.
Throughput: The amount of data transmitted in a given time period, usually measured in kilobits per second (kbps) in the context of the modems.
FHSS: Frequency Hopping Spread Spectrum. A radio technique used to minimise interference. An RF spectrum allocation into narrow RF channels and the system then hops through those channels.
RSSI: Received Signal Strength indicator. A measurement of received RF power. This can be of an intended signal or of in band noise.
LINK: In the context of this document refers to the establishing the required RF behaviour for the correct transmission of data by RF signal.
GFSK: Gaussian Frequency Shift Keying. A form of modulating data onto a carrier frequency by controlling frequency shifts.
RP–SMA: Reverse Pole Subminature type A. A common form of RF connector on consumer electronics. It offers a reasonable compromise between overall size and rated connection cycles.
AOO (aka AoO): Area of Operations. The space or region in which an operation is permitted/intended to be conducted.
LOS (aka LoS): Line of Sight. This refers to the distance that a radio signal can reach uninterrupted by obstructions or the radio horizon.
PPM: Pulse Position Modulation. This is an encoding standard used by radio controller to send data about the position of multiple servo motors.
SBUS: Serial Bus protocol created by Futaba. This is an encoding standard used by radio controller to send data about the position of multiple servo motors.
MAVLink: Micro Air Vehicle Link. A protocol for telemetry data exchange between compatible ground control software and autonomous vehicle controllers.
AES: Advanced Encryption Standard. A data encryption protocol meeting the specifications established in the ISO/IEC 18033–3 standard.
LED: Light Emitting Diode. A semiconductor device that converts electrical power to light.
Baud: unit of measurement of symbol rate. This is an indication of data transfer speed of serial/UART connections.
Serial: A synonym of UART, a protocol for sending and receiving data in a sequential manner.
UART: Universal Asynchronous Receive Transmit. Hardware that manages serial data transfer between connected devices.
TX: Transmit.
RX: Receive.
RTS: Request to Send. UART hardware flow control flag.
CTS: Clear to Send. UART hardware flow control flag.
GPIO: General Purpose Input Output. A microcontroller pin that can be configured for various input and output functions.
FTDI: Future Technology Devices International, a supplier of electronic components synonymous with their UART to USB converter chips and the cables which use such components.
USB: Universal Serial Bus. An industry standard for data communication and power delivery between devices. Commonly found in type A and C connectors.
Hardware: A physical assembly of parts designed to perform a function.

Firmware: The instructions for the microcontroller/s that directly control the functions of device hardware.
Software: Programmes or instructions for a PC or other computing device to perform functions, usually lacking direct control of hardware.
x and/or ux: In the context of this document these are model designations for radio modem products designed and sold by RFDesign.
RFD: RFDesign. The Australian company who designed, build and support the x/ux series modems among other products.

11 Revision History

Version	Date	Changes
0.1	11/10/24	BETA Tester Pre–release document
1.0	20/02/25	Release version of the document to accompany the full release of the firmware. Revisions from the pre-release to reflect changes in name, valid setting, and function of various parameters. Reworded some sections for clarity, and corrected errors. Updated example network configurations. Updated pin function tables to reflect firmware specific functions. Updated performance data to reflect performance of the system.