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Linx TECHNOLOGIES

HumPRO™ Series 868MHz RF Transceiver Module

Data Guide

Wireless made simple®

Warning: Some customers may want Linx radio frequency ("RF") products to control machinery or devices remotely, including machinery or devices that can cause death, bodily injuries, and/or property damage if improperly or inadvertently triggered, particularly in industrial settings or other applications implicating life-safety concerns ("Life and Property Safety Situations").

NO OEM LINX REMOTE CONTROL OR FUNCTION MODULE SHOULD EVER BE USED IN LIFE AND PROPERTY SAFETY SITUATIONS. No OEM Linx Remote Control or Function Module should be modified for Life and Property Safety Situations. Such modification cannot provide sufficient safety and will void the product's regulatory certification and warranty.

Customers may use our (non-Function) Modules, Antenna and Connectors as part of other systems in Life Safety Situations, but only with necessary and industry appropriate redundancies and in compliance with applicable safety standards, including without limitation, ANSI and NFPA standards. It is solely the responsibility of any Linx customer who uses one or more of these products to incorporate appropriate redundancies and safety standards for the Life and Property Safety Situation application.

Do not use this or any Linx product to trigger an action directly from the data line or RSSI lines without a protocol or encoder/decoder to validate the data. Without validation, any signal from another unrelated transmitter in the environment received by the module could inadvertently trigger the action.

All RF products are susceptible to RF interference that can prevent communication. RF products without frequency agility or hopping implemented are more subject to interference. This module does have a frequency hopping protocol built in, but the developer should still be aware of the risk of interference.

Do not use any Linx product over the limits in this data guide. Excessive voltage or extended operation at the maximum voltage could cause product failure. Exceeding the reflow temperature profile could cause product failure which is not immediately evident.

Do not make any physical or electrical modifications to any Linx product. This will void the warranty and regulatory and UL certifications and may cause product failure which is not immediately evident.

Table of Contents

HumPRO™ Series 868MHz RF Transceiver Module

Data Guide

Description

The HumPRO™ Series is an RF transceiver designed for the reliable transfer of digital data. It incorporates a Listen Before Talk (LBT) and Adaptive Frequency Agility (AFA) algorithm that meets the ETSI requirements for 64% duty cycle transmissions in the 868MHz band. It has a very fast lock time so that it can quickly wake up, send data and go back to sleep, saving power in battery-powered applications.

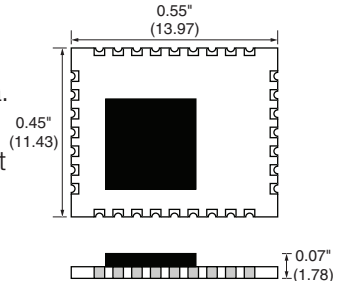


Figure 1: Package Dimensions

The module has several features that increase the data transfer reliability. It ensures that no other modules are transmitting before it begins transmitting data. Automatic acknowledgements ensure that the remote side received valid data. Multiple hopping patterns enable several systems to operate in proximity without interference. A standard UART interface is used for module configuration and data transfer. A few simple serial commands are all that are needed for configuration.

All modules have a unique 32-bit serial number that can be used as an address. Source and destination addressing support point-to-point and broadcast links. Address masking by the receiving module allows for creating subnets. Other network topologies can also be implemented.

Housed in a tiny compact reflow-compatible SMD package, the transceiver requires no external RF components except an antenna, which greatly simplifies integration and lowers assembly costs.

Features

- LBT + AFA Algorithm
- Fast Lock (<30ms at 115kbps)
- Low power modes
- Simple UART interface
- No external RF components required
- No production tuning required
- Tiny PLCC-32 footprint

Revised 9/27/2017

Ordering Information

Ordering Information	
Part Number	**Description**
HUM-868-PRO	868MHz HumPRO™ Series Data Transceiver
HUM-868-PRO-CAS	HumPRO™ Series Data Transceiver with Castellation Connection
HUM-868-PRO-UFL	HumPRO™ Series Data Transceiver with u.FL Connector
EVM-868-PRO	868MHz HumPRO™ Series Carrier Board
MDEV-868-PRO	868MHz HumPRO™ Series Master Development System

Figure 2: Ordering Information

Absolute Maximum Ratings

Absolute Maximum Ratings				
Supply Voltage V_{cc}	–0.3	to	+3.9	VDC
Any Input or Output Pin	–0.3	to	V_{CC} + 0.3	VDC
RF Input		0		dBm
Operating Temperature	–40	to	+85	ºC
Storage Temperature	–40	to	+85	ºC

Exceeding any of the limits of this section may lead to permanent damage to the device. Furthermore, extended operation at these maximum ratings may reduce the life of this device.

Figure 3: Absolute Maximum Ratings

Warning: This product incorporates numerous static-sensitive components. Always wear an ESD wrist strap and observe proper ESD handling procedures when working with this device. Failure to observe this precaution may result in module damage or failure.

Electrical Specifications

HumPRO™ Series Transceiver Specifications						
Parameter	**Symbol**	**Min.**	**Typ.**	**Max.**	**Units**	**Notes**
Power Supply						
Operating Voltage	V_{CC}	2.0		3.6	VDC	
TX Supply Current	I_{CCTX}					
at +10dBm			40.5	41.5	mA	1,2
at 0dBm			22	24	mA	1,2
RX Supply Current	I_{CCRX}		23.5	24.5	mA	1,2,3
Power-Down Current	I_{PDN}		0.7	3.0	µA	1,2
RF Section						
Operating Frequency Band	F_C	863		870	MHz	
Number of hop channels			70			
Channel spacing			100		kHz	
20 dB OBW			48		kHz	
Receiver BW			102		kHz	
FSK deviation			± 14		kHz	
Scan time / channel (avg)			0.91		ms	
Channel Lock time			76		ms	
RF Data Rate			38.4		kbps	
Modulation			GFSK			
Data Encoding			6/7 RLL			
Number of Hop Sequences			6			
Receiver Section						
Spurious Emissions				–47	dBm	
IF Frequency			330.078		kHz	
Receiver Sensitivity		–97	–100		dBm	5
RSSI Dynamic Range			85		dB	
Transmitter Section						
Max Output Power	P_O	+8.5	+10.6		dBm	6
Harmonic Emissions	P_H		–41		dBc	6
Output Power Range		–5		9	dB	6
Antenna Port						
RF Impedance	R_{IN}		50		Ω	4
Environmental						
Operating Temp. Range		–40		+85	ºC	4

HumPRO™ Series Transceiver Specifications						
Parameter	**Symbol**	**Min.**	**Typ.**	**Max.**	**Units**	**Notes**
Timing						
Module Turn-On Time						
Via V_{CC}		71		190	ms	4
Via $\overline{\text{POWER\_DOWN}}$		4.00		4.12	ms	4
Via Standby			4.12		ms	4
Serial Command Response						
Volatile R/W			0.4	5	ms	8
NV Update			2.4	31.5	ms	8
Factory Reset		199		484	ms	14
Channel Dwell Time				400	ms	
CMD low to trigger TX with option TXnCMD	t_{TXnCMD}	2			ms	13
Interface Section						
UART Data rate		9,600		115,200	bps	
Input						
Logic Low	V_{IL}			$0.3*V_{CC}$	VDC	
Logic High	V_{IH}	$0.7*V_{CC}$			VDC	
Output						
Logic Low, MODE_IND, BE	V_{OLM}			$0.3*V_{CC}$	VDC	1,9
Logic High, MODE_IND, BE	V_{OHM}	$0.7*V_{CC}$			VDC	1,9
Logic Low	V_{OL}			$0.3*V_{CC}$		1,10
Logic High	V_{OH}	$0.7*V_{CC}$				1,10
$\overline{\text{CRESP}}$ Hold Time		10			Bits	11
Flash (Non-Volatile) Memory Specifications						
Flash Write Bytes		16,000			bytes	12
Flash Refresh Cycles		2,000			cycles	

1. Measured at 3.3V V_{CC}
2. Measured at 25ºC
3. Input power < -60dBm
4. Characterized but not tested
5. PER = 1%
6. Into a 50-ohm load
7. No RF interference
8. From end of command to start of response
9. 60mA source/sink
10. 6mA source/sink
11. End of CMD_DATA_OUT stop bit to change in $\overline{\text{CRESP}}$
12. Number of register write operations
13. With CSMA disabled
14. Start of factory reset command to end of last ACK response

Figure 4: Electrical Specifications

Typical Performance Graphs

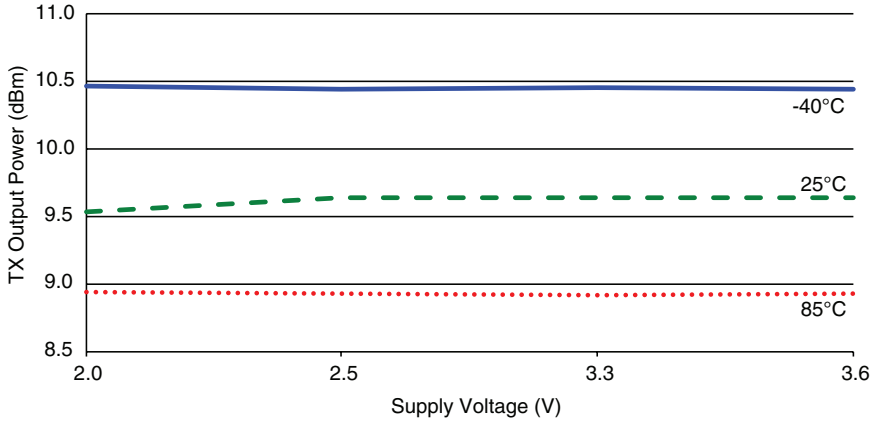


Figure 5: HumPRO™ Series Transceiver Max Output Power vs. Supply Voltage - HUM-868-PRO

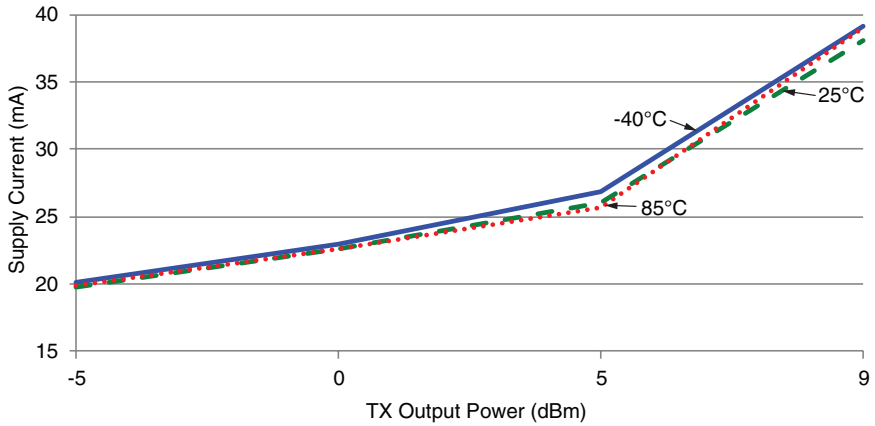


Figure 6: HumPRO™ Series Transceiver Average Current vs. Transmitter Output Power at 2.5V - HUM-868-PRO

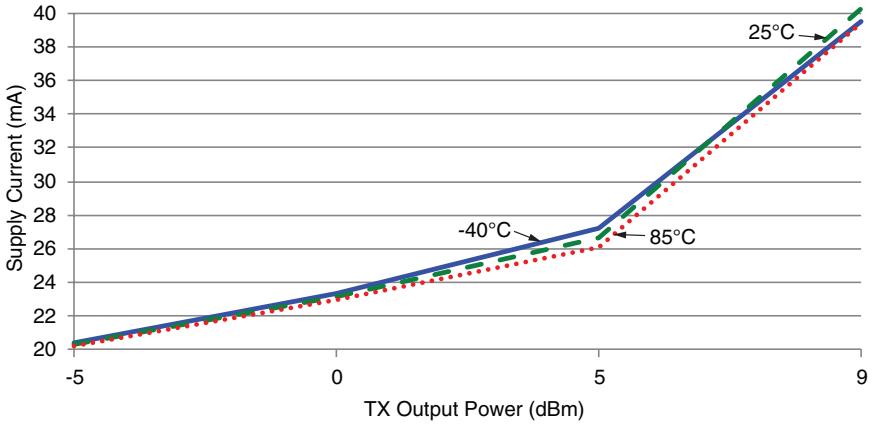


Figure 8: HumPRO™ Series Transceiver Average TX Current vs. Transmitter Output Power at 3.3V -HUM-868-PRO

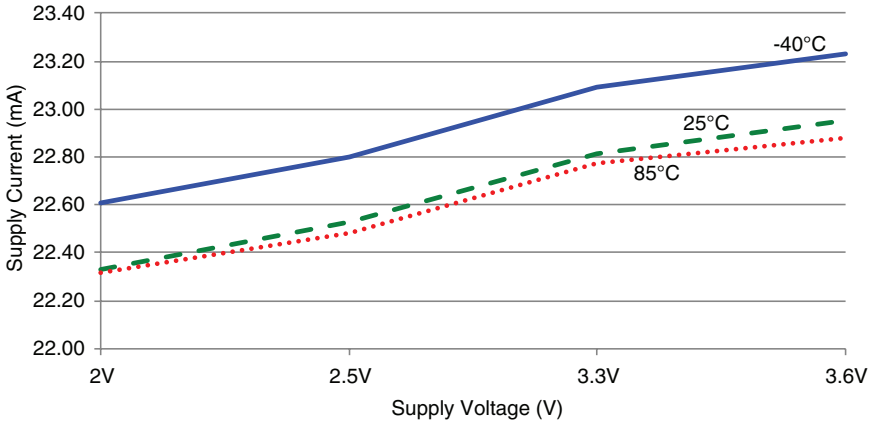


Figure 9: HumPRO™ Series Transceiver TX Current vs. Supply Voltage at 0dBm - HUM-868-PRO

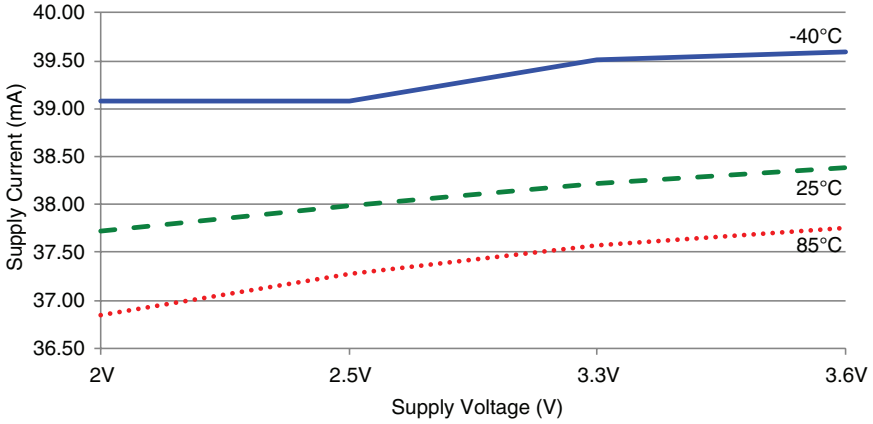


Figure 7: HumPRO™ Series Transceiver TX Current vs. Supply Voltage at Max Power - HUM-868-PRO

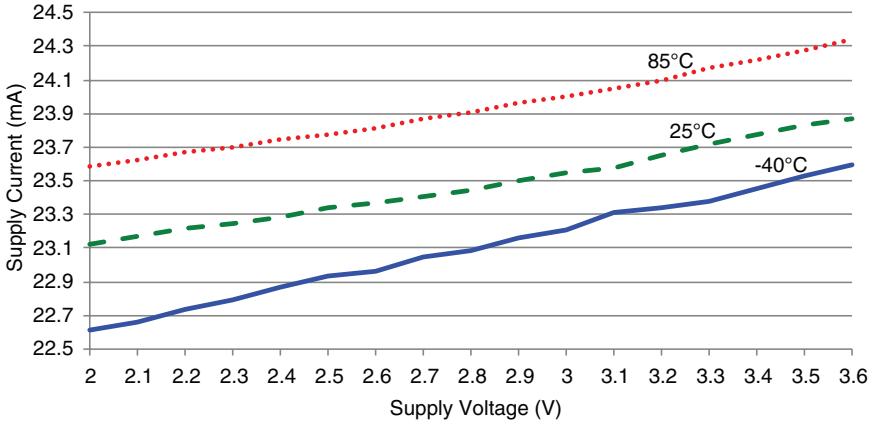


Figure 10: HumPRO™ Series Transceiver RX Scan Current vs. Supply Voltage, 9.6kbps - HUM-868-PRO

Current consumption while the module is scanning for a transmission. The current is approximately 0.5mA higher when receiving data at 9.6kbps.

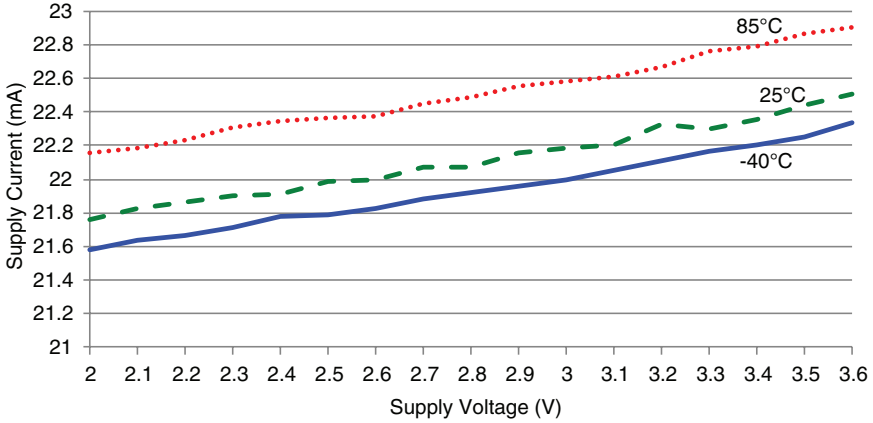


Figure 12: HumPRO™ Series Transceiver RX Scan Current vs. Supply Voltage, 115.2kbps - HUM-868-PRO

Current consumption while the module is scanning for a transmission. The current is approximately 2mA higher when receiving data at 115.2kbps.

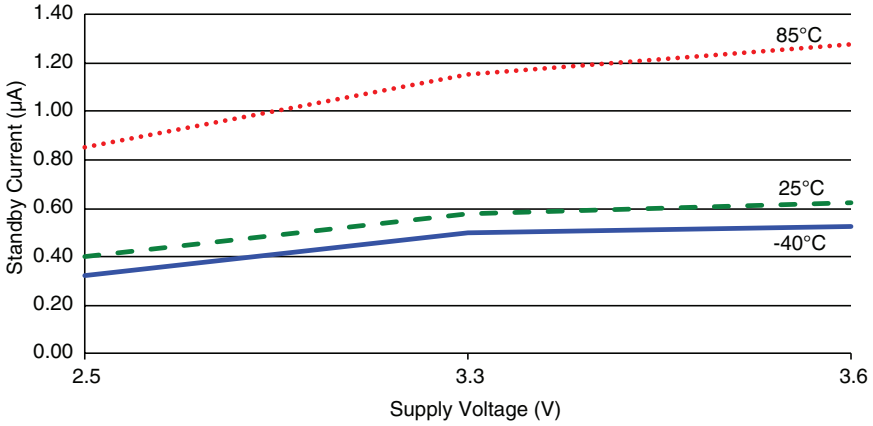


Figure 11: HumPRO™ Series Transceiver Standby Current Consumption vs. Supply Voltage - HUM-868-PRO

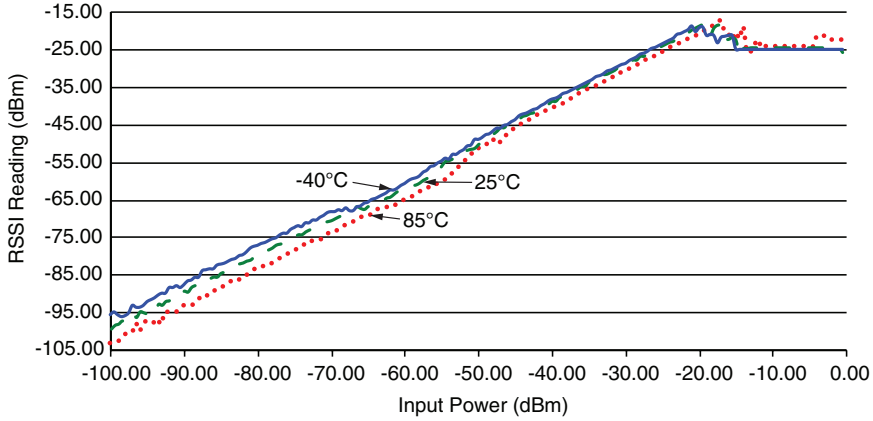


Figure 13: HumPRO™ Series Transceiver RSSI Voltage vs. Input Power - HUM-868-PRO

Pin Assignments

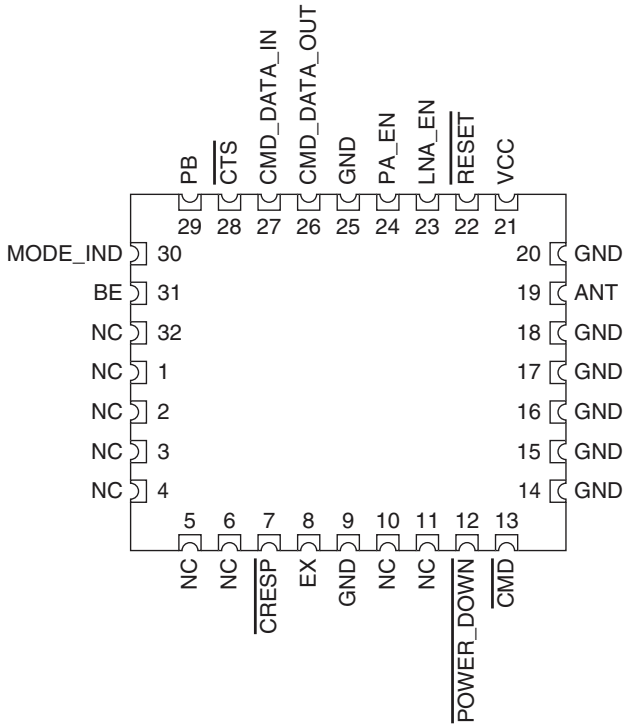


Figure 14: HumPRO™ Series Transceiver Pin Assignments (Top View)

Pin Descriptions

Pin Descriptions			
Pin Number	**Name**	**I/O**	**Description**
1, 2, 3, 4, 5, 6, 10, 11, 32	NC	—	No Electrical Connection. Do not connect any traces to these lines.
7	$\overline{\text{CRESP}}$	O	Command Response. This line is low when the data on the CMD_DATA_OUT line is a response to a command and not data received over the air.
8	EX	O	Exception Output. A mask can be set to take this line high when an exception occurs.
9, 14, 15, 16, 17, 18, 20, 25	GND	—	Ground
12	$\overline{\text{POWER\_DOWN}}$	I	Power Down. Pulling this line low places the module into a low-power state. The module is not functional in this state. Pull high for normal operation. Do not leave floating.

Pin Descriptions			
Pin Number	**Name**	**I/O**	**Description**
13	$\overline{\text{CMD}}$	I	Command Input. When this line is low, incoming bytes are command data. When high, incoming bytes are data to be transmitted.
19	ANTENNA	—	50-ohm RF Antenna Port
21	VCC	—	Supply Voltage
22	$\overline{\text{RESET}}$	I	This line resets the module when pulled low. It should be high for normal operation. This line has an internal 10k resistor to supply, so leave it unconnected if not used.
23	LNA_EN	O	Low Noise Amplifier Enable. This line is driven high when receiving. It is intended to activate an optional external LNA.
24	PA_EN	O	Power Amplifier Enable. This line is driven high when transmitting. It is intended to activate an optional external power amplifier.
26	CMD_DATA_OUT	O	Command Data Out. Output line for data and serial commands
27	CMD_DATA_IN	I	Command Data In. Input line for data ($\overline{\text{CMD}}$ is high) and serial commands ($\overline{\text{CMD}}$ is low).
28	$\overline{\text{CTS}}$	O	UART Clear To Send, active low. This line indicates to the host microcontroller when the module is ready to accept data. When $\overline{\text{CTS}}$ is high, the module is busy. When $\overline{\text{CTS}}$ is low, the module is ready for data.
29	PB	I	Push Button input. This line can be connected to Vcc through a normally open push button. Button sequences can reset configurations to default and join modules into a network. Pull low when not in use; do not leave floating.
30	MODE_IND	O	Mode Indicator. This line indicates module activity. It can source enough current to drive a small LED, causing it to flash. The duration of the flashes indicates the module's current state.
31	BE	O	Buffer Empty. This line is high when the UART input buffer is empty, indicating that all data has been transmitted. If acknowledgment is active, it also indicates that the receiving module has acknowledged the data or a retry exception has occurred.

Figure 15: HumPRO™ Series Transceiver Pin Descriptions

Encapsulated Module Pin Assignments

The encapsulated version of the module has mostly the same pin assignments as the standard version. The antenna connection is routed to either a castellation (-CAS) or a u.FL connector (-UFL), depending on the part number ordered.

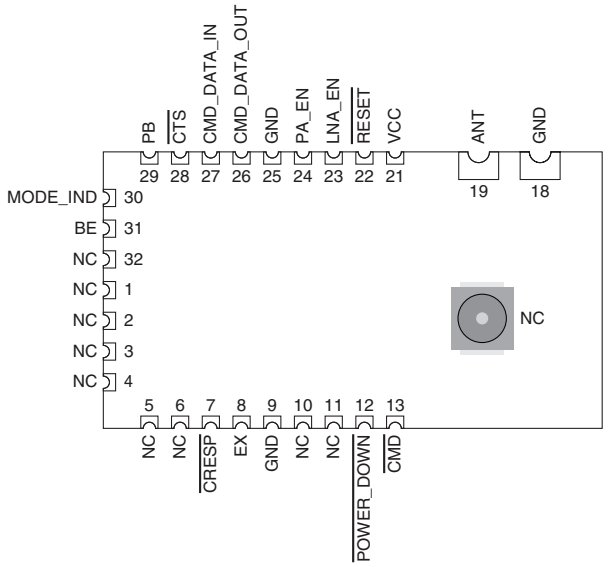


Figure 16: HumPRO™ Series Transceiver Encapsulated Version Pin Assignments - Castellation Connection (Top View)

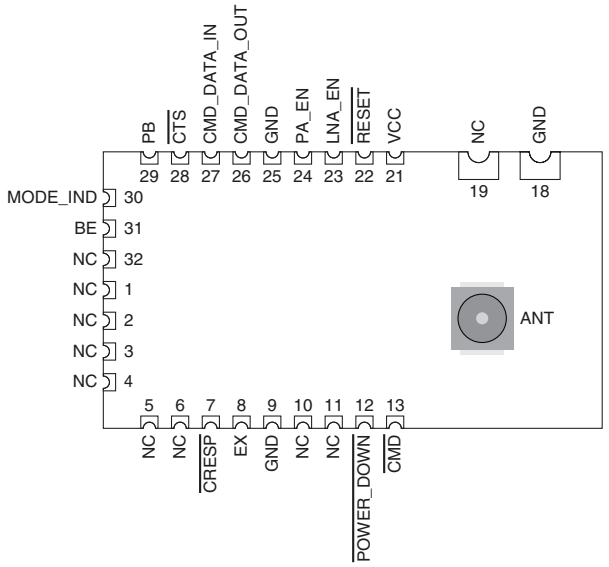


Figure 17: HumPRO™ Series Transceiver Encapsulated Version Pin Assignments - UFL Connection (Top View)

Module Dimensions

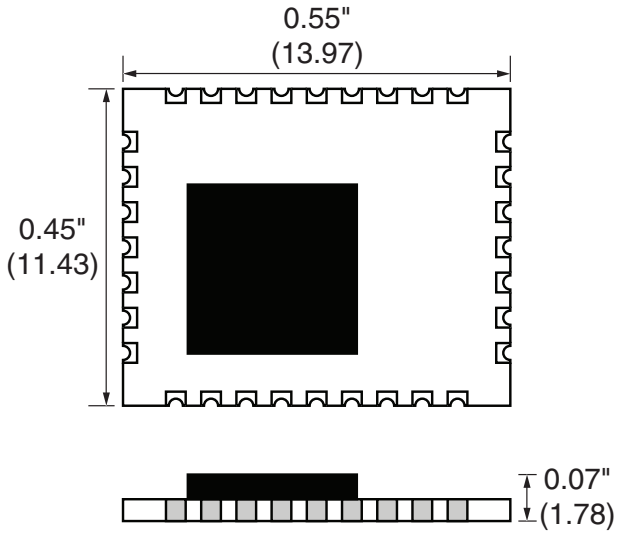


Figure 18: HumPRO™ Series Transceiver Dimensions

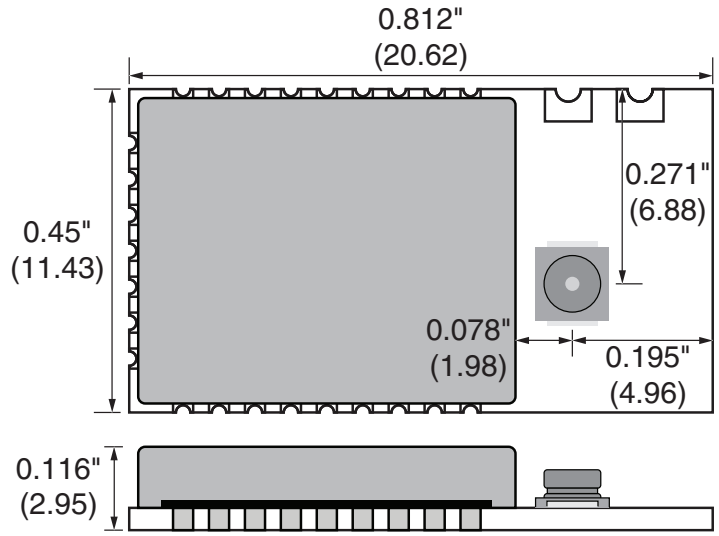


Figure 19: HumPRO™ Series Transceiver Encapsulated Version Dimensions

Theory of Operation

The HumPRO™ Series transceiver is a low-cost, high-performance synthesized FSK / GFSK / MSK transceiver. Figure 20 shows the module's block diagram.

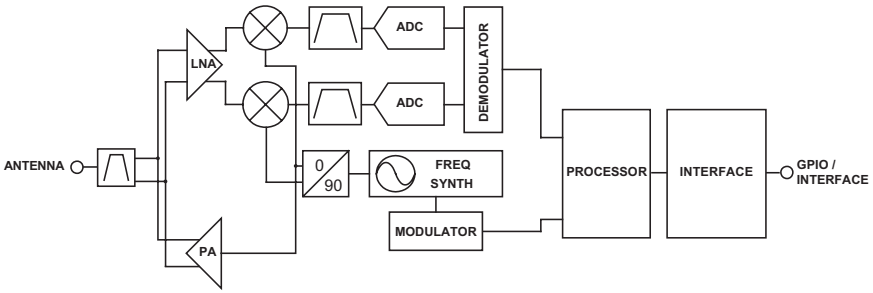


Figure 20: HumPRO™ Series Transceiver RF Section Block Diagram

The HumPRO™ Series transceiver operates in the 863 to 870MHz frequency band. The transmitter output power is programmable. The range varies depending on the antenna implementation and the local RF environment.

The RF carrier is generated directly by a frequency synthesizer that includes an on-chip VCO. The received RF signal is amplified by a low noise amplifier (LNA) and down-converted to I/Q quadrature signals. The I/Q signals are digitized by ADCs.

A low-power onboard communications processor performs the radio control and management functions including Automatic Gain Control (AGC), filtering, demodulation and packet synchronization. A control processor performs the higher level functions and controls the serial and hardware interfaces.

A crystal oscillator generates the reference frequency for the synthesizer and clocks for the ADCs and the processor.

Module Description

The HumPRO™ Series module is a completely integrated RF transceiver and processor designed to transmit digital data across a wireless link. It employs an LBT and AFA system for noise immunity and higher transmitter duty cycle as allowed by government regulations.

When the module does not have data to send it scans all of the channels for incoming data. If it finds a valid preamble, it pauses and looks for the start of a packet. When it receives a valid packet with a matching destination address the module outputs the data through the UART.

The transmitting module accepts data bytes through its UART until a configurable number of bytes is reached or a configurable timeout expires between bytes on the UART. At this point the module transmits the packet.

When the module has data to send it measures the RSSI on the selected channel to ensure that the channel is clear. If the RSSI check passes, then it transmits the packets. If the RSSI fails, then it implements a random wait time and tries again. When the channel is clear, the module transmits the data.

The module can stay on one channel for up to 400ms. If the module is ready to start transmitting near the end of the channel time, it transmits the number of bytes that it can in the remaining time. It then hops to the next channel in its hopping pattern to transmit the remaining data.

The module supports automatic acknowledgements for assured delivery. When enabled, the receiving module responds to a valid transmission with an acknowledgement to let the transmitting module know that it received the data. If an acknowledgement is not received then the transmitting module repeats the transmission for a configurable number of retries. If the retry limit is exceeded without an acknowledgement then the transmitting module issues an exception error to let the host micro know of the communication problem.

A standard UART interface is used to configure the module for operation and for the data input and output. This is suitable for direct connection to UARTs on many microcontrollers, USB converters and RS-232 converters. A simple command set is used for configuration and control.

Modules can be pre-configured for fixed point-to-point or broadcast topologies allowing streaming data (no commands) during operation.

Overview

The HumPRO™ Series RF transceiver module offers a number of features that make it suitable for many data transfer applications. This section provides a basic overview of the features while following sections dive into them in more detail.

Addressing

The modules have a very powerful addressing method. Each module is given a unique 16 or 32 bit address. The receiving modules use an address mask that determines how it responds to a received transmission.

The addressing and masking allow for the creation of point-to-point, many-to-one and one-to-many wireless links. This allows the creation of many network topologies, such as star, tree and mesh. The routing for the network topology is managed outside the module.

The addressing is the primary configuration when getting started with the modules. RG-00105, the HumPRO™ Addressing Mode Reference Guide has details about configuring the addressing.

Acknowledgements and Assured Delivery

The modules support assured delivery in the form of acknowledgements and retries. When the acknowledgements are enabled, the receiving device sends an acknowledge message to let the sender know that the transmission was received. If the sender does not get an acknowledgement it resends the message up to a configurable number of retries. If there is still no acknowledgement, the module triggers an exception to let the host processor know of the error.

Command Mode and Data Mode

The module has two main interface modes controlled by the state of the $\overline{\text{CMD}}$ line. Command mode routes the data coming in on the CMD_DATA_IN line to the processor for configuring the module. Data mode routes the data to the transmitter for transmission over-the-air. The $\overline{\text{CMD}}$ line is normally controlled by an external microcontroller.

Encryption

The module supports AES-128 encryption to provide a secure wireless link. All of the modules must have encryption enabled and be using the same key in order for communication to be successful. There are two ways of entering an encryption key: directly by writing the key to registers through the Command Data Interface or through a JOIN process.

Streaming Data and Explicit Packets

The module's default configuration is for streaming data. At some UART rates the module sends the data at a higher rate over-the-air than it is input on the UART. This hides the time required for the protocol transactions as well as the LBT and AFA. The result is that the data appears to stream through the module with no breaks in the data apparent to the host processor.

Alternatively, the module can be configured for explicit packet transmission. This allows the host processor to control when packets are sent and what data is in each packet

Exceptions and Host Processor Interface

The module has several indicator lines that provide feedback to the host processor on the module's operation and current status. This includes an exception line (EX) that informs the processor when errors occur so that it can take steps to manage the issue gracefully. The state of the status lines can also be read through the module's Command Data Interface to reduce the number of hardware connections that are required.

Command Data Interface

The module has a Command Data Interface that consists of a set of serial commands entered through a UART. These are shorter and simpler than AT commands that are popular with many modules. These commands control the configuration of the module as well as allow feedback on the operation and status of the module.

Listen Before Talk and Adaptive Frequency Agility

The module implements a Carrier Sense Multiple Access method. It listens to the channel and makes sure that it is clear before it transmits. If the channel is in use, the module either waits for it to clear or hops to the next channel depending on its current state. This reduces the overall potential for interference and improves the robustness of the link.

The module provides short pauses between packets to comply with ETSI LBT regulations. It optionally provides additional pauses to limit hourly channel usage limits to ETSI regulations.

Addressing Modes

The module has very flexible addressing methods selected with the ADDMODE register. It can be changed during operation. The transmitting module addresses packets according to the addressing mode configuration. The receiving module processes all addressing types regardless of the ADDMODE configuration. If the received message matches the addressing criteria, it is output on the UART. Otherwise it is discarded. The ADDMODE configuration also enables assured delivery.

There are three addressing modes: DSN, User and Extended User. Each mode offers different communications methods, but all use source and destination addressing. The source address is for the transmitting unit, the destination address is the intended receiver. Each mode uses different registers for the source and destination addresses.

The following sections give brief descriptions of the three modes, but a detailed explanation and examples are given in RG-00105, the HumPRO™ Addressing Mode Reference Guide.

DSN Addressing Mode

Device Serial Number Addressing mode is the simplest mode and supports point-to-point communications. Each module is programmed at the factory with a unique 4-byte serial number that cannot be changed. These bytes are found in the non-volatile read-only MYDSN registers (MYDSN[3-0]). DSN Addressing mode uses this serial number as an address. The transmitting unit's DSN is used as the source address and the intended receiver's DSN is written into the destination address registers (DESTDSN[3-0]). All modules within range hear the transmission, but only the module with the serial number that matches the destination address outputs the data on its UART. All others ignore the transmission.

User Addressing Mode

User Addressing Mode is a more flexible method than DSN Addressing Mode. It uses the customer ID bytes (CUSTID[1-0]) for unencrypted messages and two of the user destination bytes (UDESTID[1-0]) as a destination address. The customer ID bytes are programmed at the factory and cannot be changed. These are determined by the factory for specific customers to prevent their systems from operating with any other systems. Contact Linx for more details.

The module's local address is contained in two of the user source ID registers (USRCID[1-0]). In this mode, USRCID [1-0] contain the node address and USRCID [3-2] must be 0 in the receiver.

In normal operation each module has a user ID mask (UMASK[3-0]) that splits the 32 address bits into up to three fields to provide a network address and address fields for sub-networks, supporting both individual addressing and broadcast addressing within the user's network. A detailed explanation and examples are given in Reference Guide RG-00105. The 16 bits in the UDESTID[1-0] registers are transmitted. The upper 16 bits of USRCID[3-2] in the receiver must be 0.

If acknowledgements are enabled, only the module with a user source ID that exactly matches the transmitted user destination ID responds. The mask is not used for this determination.

Extended User Addressing Mode

Extended User Addressing mode is the same as User Addressing mode but uses 32-bit addresses. The two customer ID bytes are still used (CUSTID[1-0]) for unencrypted messages but four bytes are used for the user destination address (UDESTID[3-0]), user source ID (USRCID[3-0]) and user ID mask (UMASK[3-0]). This provides more addressing capabilities at the expense of more overhead in the packet.

Network Addressing

Network Addressing is selected by setting COMPAT to 0x03. It allows the receiver to receive all messages sent in User Address or Extended User Address mode with a destination address matching the USRCID group 1 bits (continuous high-order zero bits in UMASK). For example, with USRCID = 0x12345678 and UMASK = 0x000FFFFF, messages with destination address 0x123zzzzz, where z is any value, is received.

Automatic Addressing

The module supports an automatic addressing mode that reads the Source Address from a valid received packet and uses it to fill the Destination Address register. This makes sure that a response is sent to the device that transmitted the original message. This also allows the host microcontroller to read out the address of the sending unit. The automatic addressing is enabled for the different addressing modes with register AUTOADDR.

Address Register Use

Figure 21 shows the address registers that are used with each addressing mode.

HumPRO™ Series Transceiver Address Registers						
COMPAT	0x00 (Relaxed Addressing)			0x02 (Normal Addressing)		
ADDMODE	0x04 (DSN)	0x06 (User)	0x07 (Ex User)	0x04 (DSN)	0x06 (User)	0x07 (Ex User)
	0x14 (DSN +ACK)	0x16 (User +ACK)	0x17 (ExUser +ACK)	0x14 (DSN +ACK)	0x16 (User +ACK)	0x17 (ExUser +ACK)
UDESTID[3-0]			X			X
UDESTID[1-0]		X			X	
USRC[3-0]			X		X	X
USRC[1-0]		X				
UMASK[3-0]			X		X	X
UMASK[1-0]		X				
DESTDSN[3-0]	X			X		

Figure 21: HumPRO™ Series Transceiver Address Register Use

Acknowledgements and Assured Delivery

When a module transmits with assured delivery enabled, the receiving module returns an acknowledgement packet. The transmitting module waits for this acknowledgement for a preset amount of time based on the data rate. If an acknowledgement is not received, it retransmits the packet. If the receiver receives more than one of the same packet, it discards the duplicate packet contents but sends an acknowledgment. This way, duplicate data is not output by the module.

If the received destination address matches the local address, the receiving module immediately sends an acknowledgement. This packet lets the sending module know that the message has been received. An acknowledgement packet is sent immediately following reception; CSMA delay is not applied to these packets since permission belongs to the interacting modules. When the sending module receives the acknowledgement packet, it marks the current block of data as completed. If this is the last message in the queue, the sending module takes the BE line high to indicate that all outgoing data has been sent.

Assured delivery should only be used when addressing a specific module in a point-to-point link. It should not be used when multiple receivers are enabled. When address masking is used, only the receiver with an exact match to the address in the transmitted packet responds. If none of the enabled receivers has an exact match, then there is no response and the transmitting module continues to re-transmit the data until the max number of retries is attempted. This causes the transmitting module to appear slow or unresponsive. It also impedes valid communications.

Listen Before Talk and Adaptive Frequency Agility

Europe's ETSI standards have very specific requirements for operating in the 868MHz band. The transmitter on-time is of particular note. This is specified in terms of Duty Cycle, which is the amount of time the transmitter can be active in a one-hour period. The requirements are contained in EN 300 220-1 and ERC Recommendation 70-03 summarizes the use of the 868MHz band by frequency and application.

The on-time for single channel devices depends on the specific transmit frequency and varies across the 868 to 870MHz band. It can be as low as 0.1% or 3.6 seconds per hour. It is normally up to the designer of the end product to ensure that the product cannot exceed this limit.

However, the rules also allow for higher transmit times if the radio uses intelligent or polite spectrum access techniques called Listen Before Talk (LBT) and Adaptive Frequency Agility (AFA). LBT is defined as a method where the radio listens on a channel to ensure it is clear before transmitting. AFA is defined as the capability to dynamically change channels within the available frequencies for proper operation. In other words, the radio listens to the channel to make sure it is clear. If it is occupied, it either waits for it to become clear or automatically goes to another channel.

A system that uses these spectrum access techniques is allowed more transmission time. This is advantageous for systems that need to transmit large data streams or have an unpredictable usage pattern. EN 300 220-1 has very specific requirements for LBT and transmitter on time as well as what declarations must be made by the manufacturer.

Listen Before Talk

EN 300 220-1 has the requirements, limits and methods of testing the LBT system. The main requirements are:

- An RSSI threshold above which the channel is considered busy. This is dependent on the channel bandwidth
- A minimum listening time of 5ms plus a random time between 0 and 5ms in steps of 0.5ms.
- A maximum dead time between the end of listening and start of talking.
- A minimum transmitter off time of more than 100ms.

A provision is made for acknowledgements to a transmission that allows them to transmit immediately, without needing to listen first.

Transmitter On-Time

EN 300 220-1 specifies three transmitter maximum on time limits:

1. 1s for a single transmission
2. 4s for multiple transmissions and acknowledgements for a communication dialogue or polling sequence of other units
3. 100s per hour for any 200 kHz of spectrum

These limits require the module to track the transmission times and impose delays when necessary to ensure compliance with the limits.

The module's packets have at most 192 payload bytes. This, combined with the largest header supported by the module at the 38.4kbps data rate equates to a maximum on time of 130ms. This is well under the limit.

The module imposes a 3.9s maximum on the transmission dialogue.

Since the module supports 100kHz channels, a 200kHz spectrum can bleed over into the higher and lower adjacent channels. This limits the transmission time on any given channel to 100s / 3 = 33.3s. The module uses 70 channels so it can transmit for 2,333s of every hour or about 64% assuming no delay for transmissions by other units.

It is preferable to spread the transmit time out evenly to avoid using all of the time at the start of the hour and then having 21 minutes delay at the end of the hour. To accomplish this, the module divides the time into blocks of 180s called bandspread intervals. The module can transmit on each channel for 1.66s of every 180s (33.3s of every 3600s ÷ 20). The module tracks the transmission time for each channel and limits it as well as monitoring the other required limits.

The LBT options are configured with the ENCSMA register. Setting the register to 0x00 disables LBT and the transmission is immediate. This can be used in applications with an inherent duty cycle <0.1%.

Setting the register to 0x01 enables LBT but without the transmitter on time duty cycle restriction. This can be used in applications with an inherent duty cycle of <10%.

Setting the register to 0x02 enables the full LBT with transmitter on time restriction. This complies with the ETSI regulations for LBT + AFA.

HumPRO™ Series Transceiver EN 300 220-1 Declarations	
Item	**Description**
Receiver Category (4.1.1)	The module incorporates a short range radio device designed for use in applications in category 2 (medium reliable) or 3 (standard reliable)
General Performance Criteria (4.1.2)	The appropriate performance criterion for the HUM-868-PRO is “after demodulation, a message acceptance ratio of 80%”. The test should be performed with bit 4 in the ADDMODE register (ack request) = 0. The external microcontroller normally supplies the indication for message acceptance. The MODE_IND output can be used as a packet received indication when the module is only receiving.
Duty Cycle (7.10.2)	The module is designed to provide up to 64% transmitter duty cycle when used with continuous demand for transmission when CSMAMODE = 2 (default). The actual duty cycle in operation, however, is primarily determined by average data rate and the size and timing of the packets containing the data. Thus, the end equipment has a critical part in determining the duty cycle and the manufacturer must declare the total duty cycle.
FHSS (7.4.1.2)	The module is intended to be certified as part of an AFA device, not an FHSS device.
Acknowledgement (7.10.2)	Acknowledgement can optionally be done at either the module level, application level, or both. If done at the module level through the use of ADDMODE bit 4, the acknowledgement causes the responding module to transmit for 4ms within less than 5ms after receiving the packet. If acknowledgement is provided by the application, the timing is mostly determined by the product response time and length of response message. In this case the applying manufacturer is responsible for declaring the timing.
Minimum TX-off Time (9.2.1.2)	The minimum TX-off time is 101ms. The actual time will be more if the external controller has no data to transmit.
LBT Fixed Minimum Listening Time (9.2.2.2 a)	The fixed minimum listening time is 5ms.
LBT Pseudo-random Listening Time (9.2.2.2 b)	The pseudo-random listening time, t_{PS}, varies from 0 to 5ms in 0.5ms steps: t_{PS} = 0.5ms * int(((Timer1 & 0x1f) + 1)/3) The module serial number is added to a high-speed timer (incremented every 1.23µs) is used as a simple source of random value, due to the variation of time at which t_{PS} is calculated, relative to the timer period. The lower 5 bits of that sum is incremented by 1, giving a random value 1 to 32. That value is divided by 3, giving a value 0 to 10, with the value 0 occurring with p=2/32, other values occurring with 3/32, resulting in an average value over several calculations of 5.33ms, slightly higher than the median value of 5.0.
Dead time (9.2.3)	The dead time between end of timeout of LBT listen time with a clear channel and starting the transmitter is 1.4 - 1.5ms.
TX On-Time for Single Transmission (9.2.5.2.1)	The TX On-time for a single transmission is variable, depending on the address mode used and number of payload bytes. The maximum single transmission time is 130ms (synchronizing preamble, 192 bytes payload, Extended User Address, encrypted).
TX On-time for a Transmission Dialogue (9.2.5.2.2)	The maximum duration for a TX dialogue imposed by the module is 3.9s.
Maximum TX On-Time within a Period of 1 Hour for Devices Using LBT + AFA (9.2.5.2.3)	The maximum module TX on-time for one hour is 64% with continuous transmission request and AFA limits enabled. The down time is 1. 5ms minimum delay before transmitting on a new channel 2. 100ms delay after 3.9s of continuous transmission. 3. Dead time when all channels have exceeded their allotted time within their current 180s bandspread interval. The end-device maximum TX time is primarily determined by the application transmission requests.

Figure 22: HumPRO™ Series Transceiver EN 300 220-1 Declarations

Note: The integrator is solely responsible for ensuring that the final product complies with CE / ETSI requirements. This includes all testing and any application specific requirements.

Transmitting Packets

In default operation when transmitting, the host microcontroller writes bytes to the CMD_DATA_IN line while the $\overline{\text{CMD}}$ line is held high at the baud rate selected by the UARTBAUD register. The incoming bytes are buffered until one of the following conditions triggers the packet to be transmitted:

1. The number of bytes in the buffer exceeds the value in the Byte Count Trigger (BCTRIG) register.
2. The time since the last received byte exceeds the value in the Data Timeout (DATATO) register.
3. A SENDP command is written to the CMD register.
4. The $\overline{\text{CMD}}$ line is taken low with option PKOPT: TXnCMD = 1.
5. The number of buffered bytes exceeds what can be sent before the radio must hop channels.

The first four conditions can be controlled by the host microcontroller. In the last case, the module transmits what it can in the remaining time then sends the rest on the next channel. This can cause the data to be divided up into multiple packets and is not within the control of the host micro.

In cases where all data needs to be sent in the same packet or where the microcontroller needs greater control over the radio, the HumPRO™ offers explicit control of packet transmission with options in the PKTOPT register.

When the TXPKT option is enabled (PKTOPT register, bit 0 = 1), the data is held until a SENDP command is written to the CMD register. Alternatively, if option TXnCMD is enabled (PKTOPT register, bit 1 = 1), then lowering the $\overline{\text{CMD}}$ line triggers the packet transmission, reducing the number of UART transactions that are required. The BCTRIG, DATATO and hop-timing conditions are ignored when the TXPKT option is enabled.

Once triggered, the transmitted packet contains the bytes in the buffer as of the trigger event, even if more data bytes are received before the packet can be sent. Multiple outgoing packets can be buffered in this way.

If the full packet cannot be sent in the time remaining on the current channel, then it is held until the module hops to the next channel.

This option gives the host microcontroller very fine control over when packets are transmitted and what they contain.

Receiving Packets

In default operation when receiving valid packets, the module outputs all received bytes as soon as the packet is validated (CRC checks pass if unencrypted or key-based verification if encrypted) and if the addressing permits it at the baud rate selected by the UARTBAUD register. No command or control bytes are output and no action is required of an external microcontroller. The first byte from a packet directly follows the last byte of the previously received packet.

In cases where the host microcontroller needs more control over the data or where dynamic configuration changes could set up race conditions between incoming data and outgoing commands, the module offers explicit control over received packets.

When the RXPKT option is enabled (PKTOPT register, bit 2 = 1), received data is output on the CMD_DATA_OUT line one packet at a time after a GETPH, GETPD, or GETPHD command is written to the CMD register. Writing one of these commands begins the received packet transfer cycle.

Two lines are used as flow control and indicators during the transfer cycle. The $\overline{\text{CMD}}$ line is controlled by the host microcontroller. The module uses either the $\overline{\text{CTS}}$ line or the $\overline{\text{CRESP}}$ line as a status line, depending on the state of the RXP_CTS option in the PKOPT register.

When a valid packet is received, the EX_RXWAIT exception flag is set in the EEXFLAG1 register. If the corresponding bit in the EEXMASK1 register is set, then the EX line goes high. The host microcontroller can monitor the EX line or periodically check the EEXFLAG or LSTATUS registers to determine if data is ready to be read.

The transfer cycle is begun by writing a Get Packet Header (GETPH), Get Packet Data (GETPD), or Get Packet Header and Data (GETPHD) command to the CMD register. The module sends the command ACK byte and sets the selected status line high. Once the status line goes high, the host microcontroller sets the $\overline{\text{CMD}}$ line high and the module outputs the received data. The command sent determines whether the bytes sent are the header, data, or header followed by data.

When all packet bytes have been sent the control line goes low. When the host microcontroller detects that the line is low, it sets $\overline{\text{CMD}}$ low, completing the transfer cycle. The cycle is shown in Figure 23.

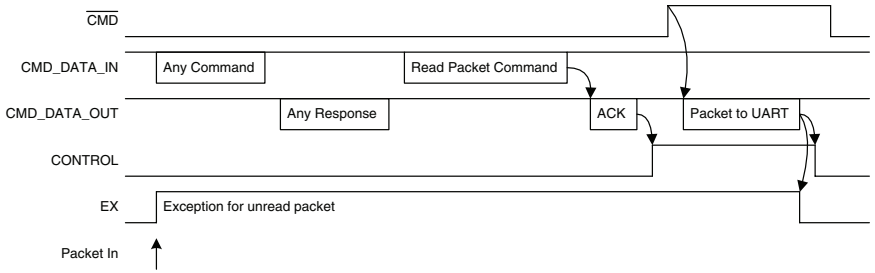


Figure 23: HumPRO™ Series Transceiver Received Packet Transfer Cycle

If a GETPH was sent and header data received, the following data can then be read by repeating the cycle with the GETPD command. If the next GETPx command is a GETPH or GETPHD, the data associated with the header read by GETPH is discarded and the header or header plus data of the following packet is returned.

If there is RF-received data waiting to be sent to the UART and the mask for EX_RXWAIT is set in the EEXMASK register, EX is raised if it is low.

If there is no packet waiting when a GETPx command is sent, the control line is still taken high and not reset until after $\overline{\text{CMD}}$ goes high, thereby performing a zero-byte transfer cycle.

The header and payload structures differ between encrypted packets and unencrypted packets. The header and data structures for explicit unencrypted packets are shown in Figure 24.

The Tag field identifies the start of the block and if it is the header information (0x01) or the packet data (0x02).

The Header Length field identifies the number of header bytes that follow.

The Frame Type field identifies what kind of packet was received. The values are shown in Figure 25.

The Hop ID field is the hop sequence number, 0 - 5.

The Sequence byte is incremented for each new packet, modulo 255. A received packet is discarded if the sequence byte matches the previously received packet to prevent delivering duplicate copies of an automatically retransmitted packet.

DSN Address Packet Header

Tag	Header Length	Frame Type	Hop ID	Sequence	Dest DSN	Source DSN	Data Length
0x01	1	1	1	1	4	4	1

User Address Packet Header

Tag	Header Length	Frame Type	Hop ID	Sequence	Cust ID	Dest Addr	Source Addr	Source DSN	Data Length
0x01	1	1	1	1	2	2 or 4	2 or 4	4	1

Packet Data

Tag	Data Length	Data
0x02	1	Data Length Bytes

Figure 24: HumPRO™ Series Transceiver Unencrypted Packet Header and Data Structure

HumPRO™ Series Transceiver Frame Types

Frame Type	Packet Type
0x04	DSN Addressing Mode
0x06	User Addressing Mode
0x07	Extended User Addressing Mode
+0x10	Acknowledgements Enabled
+0x20	Encrypted Packet
+0x40	Long Preamble Packet

Figure 25: HumPRO™ Series Transceiver Frame Types

The Cust ID field is a number that can be assigned to a specific customer. Only modules with the same customer ID respond to unencrypted transmissions. By default, Cust ID is 0x7FFF for packets transmitted with COMPAT = 2 or 0xFFFF for packets transmitted with COMPAT = 0. This field is not used in DSN mode.

The Dest Addr field has the received destination address. This is 2 bytes long with User Addressing Mode and 4 bytes with DSN and Extended User Addressing Modes.

The Source Addr Field is the address of the transmitting module. This is 2 bytes long with User Addressing Mode and 4 bytes with DSN and Extended User Addressing Modes.

The Data Length byte indicates how many bytes of data are in the packet. This value is the same in the packet header and the associated data block.

The header and data structures for explicit encrypted packets are shown in Figure 26. The header and data blocks returned by the module are the decrypted message contents.

Encrypted DSN Address Packet Header

Tag	Header Length	Frame Type	Hop Key	Sequence	Dest DSN	Source DSN	EBlock Length	Payload Type
0x11	1	1	1	6	4	4	1	1

Encrypted User Address Packet Header

Tag	Header Length	Frame Type	Hop Key	Sequence	Dest Addr	Source Addr	Source DSN	EBlock Length	Payload Type
0x11	1	1	1	6	2 or 4	2 or 4	4	1	1

Encrypted Packet Data

Tag	Data Length	Data
0x12	1	Data Length Bytes

Figure 26: HumPRO™ Series Transceiver Encrypted Packet Header and Data Structure

The Tag, Header Length and Frame Type fields are the same as for unencrypted packets.

The Hop Key field uses the first three low-order bits to indicate the Hop Sequence number, which is the same as unencrypted packets. The upper two bits indicate which key is being used. Either the factory-set key that is used to securely transfer the network key or a network key that has been written or created by the JOIN process. This is shown in Figure 27.

HumPRO™ Series HopKey Byte Values

HopKey Bit	Value
0 - 3	Hop Sequence Number, 1 to 5
4 - 5	= 0
6 - 7	Encryption key 0 = factory 1 = user network

Figure 27: HumPRO™ Series HopKey Byte Values

The Sequence bytes contain a counter that is incremented for each new transmitted message. The initial value is randomized when the module is reset. The extended sequence becomes part of an initialization vector which is used to vary the encrypted contents of identical packets. A received packet is discarded if the sequence byte matches the previously received packet to prevent delivering duplicate copies of an automatically retransmitted packet.

The Dest DSN, Source DSN, Dest Addr and Source Addr fields are the source and destination addresses, the same as in unencrypted packets.

The EBlock length field is the total number of bytes of data in the encrypted payload block. This length includes the Payload Type byte.

The Payload Type byte indicates what data is contained in the payload. 0x00 indicates that the payload is user data. 0x01 indicates that the payload is the 16-byte AES key followed by any user data. This is used for transferring the network encryption key during the JOIN process.

For the Encrypted Packet Data packet, the Data Length byte indicates the number of bytes of data payload that follow. This value is one less than the EBlock length in the header. The reason for this is that the Payload Type byte is included in the encrypted block, but is reported with the header since it is not user data.

Using the Buffer Empty (BE) Line

The BE line indicates the state of the module's UART buffer. It is high to indicate that the UART input buffer is empty, indicating that all data has been transmitted. When the module receives data on the CMD_DATA_IN line and the $\overline{\text{CMD}}$ line is high, the BE line is lowered until all data in the buffer has been processed by the protocol engine. If acknowledgement is not enabled, the BE line is raised as soon as the module transmits the outgoing packets. If acknowledgement is enabled, the buffer is not updated until either the data transmissions are acknowledged by the remote end or delivery fails after the maximum number of retries. When the BE line returns high, the EX line may be sampled, or the EXCEPT or EEXFLAG register polled to determine if an error occurred during transmission.

The state of the BE line can be read in the LSTATUS register, reducing the number of hardware connections that are needed.

Exception Engine

The HumPRO™ is equipped with an internal exception engine to notify the host microcontroller of an unexpected event. If errors occur during module operation, an exception is raised. There are two methods of driving the EX pin when an exception condition exists:

1. From the EXMASK and EXCEPT registers (legacy operation)
2. From the EEXMASKx and EEXFLAGx registers (standard operation)

If EXMASK is non-zero, the first method is used, otherwise the second method is used.

For legacy operation with the 250 and 25 Series, the EX line is set and reset by the Exception (EXCEPT) register processing. It is set when an exception occurs and the exception code ANDed with the current Exception Mask (EXMASK) register is non-zero. It is reset when the EXCEPT register is read through a command. No other operations affect the state of EX. Setting EXMASK non-zero does not change the state of EX.

If an exception code is already present in the register when an error occurs, the new exception code overwrites the old value. Exception codes are organized by type for ease of masking. Figure 28 lists the exception codes and their meanings.

HumPRO™ Series Transceiver Exception Codes

Exception Code	Exception Name	Description
0x08	EX_BUFOVFL	Incoming UART buffer overflowed.
0x09	EX_RFOVFL	Outgoing UART buffer overflowed.
0x13	EX_WRITEREGFAILED	Attempted write to register failed.
0x20	EX_NORFACK	Acknowledgement packet not received after maximum number of retries.
0x40	EX_BADCRC	Bad CRC detected on incoming packet.
0x42	EX_BADHEADER	Bad CRC detected in packet header.
0x43	EX_BADSEQID	Sequence ID was incorrect in ACK packet.
0x44	EX_BADFRAMETYPE	Attempted transmit with Invalid setting in reg:NETMODE or invalid packet type in received packet header

Figure 28: HumPRO™ Series Transceiver Exception Codes

The EX line can be asserted to indicate to the host that an error has occurred. The EXCEPT register must be read to reset the line. Figure 29 lists some example exception masks.

HumPRO™ Series Transceiver Example Exception Masks

Exception Mask	Exception Name
0x08	Allows only EX_BUFOVFL and EX_RFOVFL to trigger the EX line
0x10	Allows only EX_WRITEREGFAILED to trigger the EX line
0x20	Allows only EX_NORFACK to trigger the EX line
0x40	Allows only EX_BADCRC, EX_BADHEADER, EX_BADSEQID and EX_BADFRAMETYPE exceptions to trigger the EX line
0x60	Allows EX_BADCRC, EX_BADHEADER, EX_BADSEQID, EX_BADFRAMETYPE and EX_NORFACK exceptions to trigger the EX line
0xFF	Allows all exceptions to trigger the EX line

Figure 29: HumPRO™ Series Transceiver Example Exception Masks

The exception mask has no effect on the exceptions stored in the exception register. It only controls which exceptions affect the EX line.

The extended exception registers offer more functionality with more exceptions and a separate bit for each exception. These registers are the default and should be used with new applications. When an exception sets an exception code in the EXCEPT register, the corresponding flag in the EEXFLAG register is also set.

The EX line is set and reset by the Extended Exception Flags (EEXFLAG) and Extended Exception Mask (EEXMASK) register processing. It is set whenever the EEXFLAG value ANDed with the EEXMASK value is non-zero. EX can change on any write to either of these registers that affects the result of ANDing the registers. Clearing an EEXFLAG register bit or value can leave EX set if there is another masked condition bit set.

The state of the EX line can also be read in the LSTATUS register, reducing the number of hardware lines that are required.

Networking

The HumPRO™ Series modules can be used to create many types of wireless networks. The modules do not provide network routing since the internal memory size of the module would limit the overall network size. The HumPRO™ can work as the MAC/PHY layers of a network stack and the memory and processing speed of the external microcontroller can be sized according to the size of the network that is needed for the application.

This requires more software development, but avoids the cost of adding extra memory on the module for applications that don't need it. Linx can assist with network frameworks and concepts and can create custom designs on a contract basis. Contact Linx for more details.

Using the Command Response ($\overline{\text{CRESP}}$) Line

The $\overline{\text{CRESP}}$ line is high when sending data bytes and low when sending command response bytes. This indicates to an external host microcontroller that the data on the CMD_DATA_OUT line is a response to a command and not data received over-the-air. $\overline{\text{CRESP}}$ is held in the correct state at least one byte time after the last byte for the indicated source (command response or data, although it normally stays in the same state until a change is required).

If a data packet is received when the module is processing a command, it sends the command response, raises $\overline{\text{CRESP}}$, and then sends the received data bytes.

When reading or writing the module's register settings, it is possible for incoming RF data to intermix with the module's response to a configuration command. This can make it difficult to determine if commands were successfully processed as well as to capture the received RF data. Setting the CMDHOLD register to 0x01 causes the module to store incoming RF traffic (up to the RF buffer capacity) while the $\overline{\text{CMD}}$ line is low. When the $\overline{\text{CMD}}$ line is returned high, the module outputs the buffered data on the UART. This allows the external host microcontroller to have separate configuration times and data times instead of potentially having to handle both at once.

The $\overline{\text{CRESP}}$ line stays low for at least ten bit times after the stop bit of the last command response. Figure 30 shows the timing.

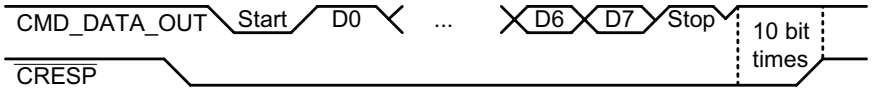


Figure 30: HumPRO™ Series Transceiver $\overline{\text{CRESP}}$ Line Timing

Using the $\overline{\text{CMD}}$ Line

The $\overline{\text{CMD}}$ line informs the module where incoming UART data should be routed. When the line is high, all incoming UART data is treated as payload data and is routed to the transmitter to be sent over the air. If the $\overline{\text{CMD}}$ line is low, the incoming UART data is treated as command bytes and is routed to the controller for processing.

Since the module's controller looks at UART data one byte at a time, the $\overline{\text{CMD}}$ line must be held low for the entire duration of the command plus time for ten bits as margin for processing. Leaving the line low for additional time (for example, until the ACK byte is received by the application) does not adversely affect the module. If RF packets are received while the $\overline{\text{CMD}}$ line is active, they are still processed and output on the module's UART (assuming CMDHOLD=0 and PKOPT:RXPKT=0). Figure 31 shows this timing.

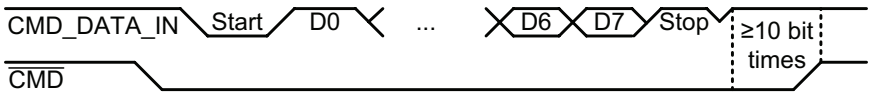


Figure 31: HumPRO™ Series Transceiver $\overline{\text{CMD}}$ Line Timing

Commands can be entered sequentially without having to raise the $\overline{\text{CMD}}$ line after each one. The $\overline{\text{CMD}}$ line just needs to be raised to be able to enter data for transmission.

If the CMDHOLD register is 0x01 then any received data is held until the $\overline{\text{CMD}}$ line is raised. This prevents received data from being intermingled with command responses.

External Amplifier Control

The HumPRO™ Series transceiver has two output lines that are designed to control external amplifiers. The PA_EN line goes high when the module activates the transmitter. This can be used to activate an external power amplifier to boost the signal strength of the transmitter. The LNA_EN line goes high when the module activates the receiver. This can be used to activate an external low noise amplifier to boost the receiver sensitivity. These external amplifiers can significantly increase the range of the system at the expense of higher current consumption and system cost.

The states of the PA_EN and LNA_EN lines can be read in the LSTATUS register. This offers a quick way to determine the current state of the radio.

AES Encryption

HumPRO™ Series modules with firmware version 2.0 and above offer AES encryption. Encryption algorithms are complex mathematical calculations that use a large number called a key to scramble data before transmission. This is done so that unauthorized persons who may intercept the signal cannot access the data. To decrypt the data, the receiver must use the same key that was used to encrypt it. It performs the same calculations as the transmitter and if the key is the same, the data is recovered.

The HumPRO™ Series module has the option to use AES encryption, arguably the most common encryption algorithm on the market. This is implemented in a secure mode of operation to ensure the secrecy of the transmitted data. It uses a 128-bit key to encrypt the transmitted data. The source and destination addresses are sent in the clear.

Encryption is disabled by default. There are two ways to enable encryption and set the key: sending serial commands and using the JOIN process.

Writing an encryption key to the module with the CDI

The module has no network key when shipped from the factory. An encryption key can be written to the module using the CDI. The CMD register is used to write or clear a key. The key cannot be read.

The same key must be written to all modules that are to be used together. If they do not have the same key then they will not communicate in encrypted mode.

The JOIN Process

The JOIN process is a method of generating an encryption key and distributing the key and addresses to associated modules through a series of button presses. This makes it very simple to establish an encrypted network in the field or add new nodes to an existing network without any additional equipment. It is also possible to trigger the JOIN process through commands on the Command Data Interface.

The JOIN process configures a star network with the central unit as system administrator. Other units are added to the network one at a time.

The hardware required is a pushbutton that is connected to the PB line. This takes the line to VCC when it is pressed and ground when it is released. An LED connected to the MODE_IND line provides visual indication of the module's state.

A module is set as an administrator by pressing and holding the button for 30 seconds to start the Generate Key function. While the button is held, the MODE_IND line is on. After 30s, the MODE_IND line repeats a double blink, indicating that the function has begun. When the button is released the key and address generation are complete and the module is an administrator.

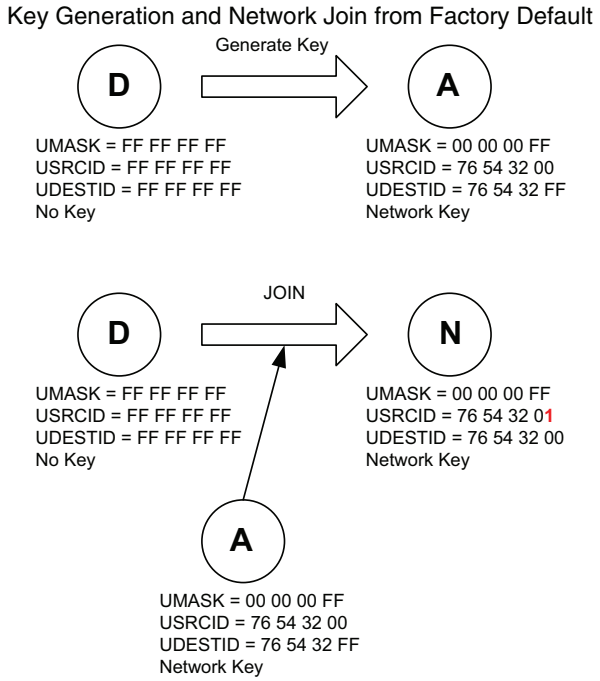
When Generate Key is performed, the unit is set as the network administrator. It generates a random 128-bit AES encryption key based on ambient RF noise and scrambled by an encryption operation. If UMASK is the default value (0xFFFFFFFF), it is set to 0x000000FF, supporting up to 255 nodes, and ADDMODE is set to Extended User Address with encryption (0x27) (or without encryption (0x07) if flag PGKEY in the SECOPT register is 0). UMASK and ADDMODE are not changed if UMASK is not 0xFFFFFFFF. A random 32-bit address is generated. By default, the lower 8 bits are 0, forming the network base address. Other nodes are assigned sequential addresses, starting with network base address +1. UDESTID is set to the bitwise OR of USRCID and UMASK, which is the network broadcast address.

A module becomes a node by joining with an administrator. This is done by pressing and releasing the PB button on both units. The modules automatically search for each other using a special protocol. When they find each other, the administrator sends the node the encryption key, UMASK and its network address. The UDESTID is set to the address of the administrator. The values are encrypted using a special factory-defined key. Once the JOIN process is complete, the MODE_IND blinks on both units and they now operate together. This is shown in Figure 32 A.

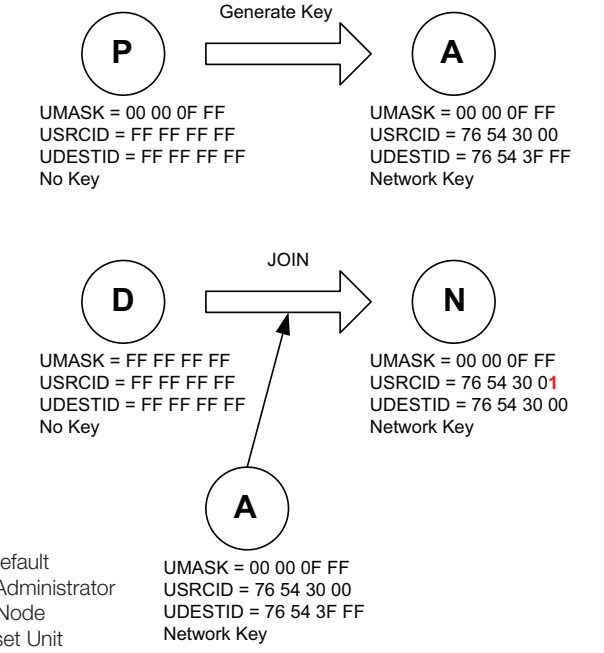
If UMASK is pre-set when Generate Key is initiated, then the JOIN process uses that mask and sets the address accordingly. This can allow more nodes in the network. This is shown in Figure 32 B. Likewise, the network key can be written to the module with the CDI interface and the JOIN process used to create an address and associate new modules. Or the administrator can be completely configured through the CDI and the JOIN process used to associate nodes in the field. This gives the system designer many options for configuration.

The SECOPT register is used to configure options related to the JOIN process. This allows the OEM to set desired values at the factory and allow final network configuration in the field. This includes disabling the ability to change the address, change the key and share the key. The built-in security prohibits changing a node to an administrator without changing the key.

A)



B)



D = Factory Default
A = Network Administrator
N = Network Node
P = OEM Preset Unit

Figure 32: HumPRO™ Series JOIN Process

Using the MODE_IND Line

The MODE_IND line is designed to be connected to an LED to provide visual indication of the module's status and current actions. The pattern of blinks indicates the particular feedback from the module. Figure 33 shows the different blink patterns and their meanings.

HumPRO™ Series Transceiver MODE_IND Line Timing

Display [on/off time in seconds]	Module Status
Join Operation	
Two quick blinks	Administrator Join. The administrator is looking for a node to join with.
One quick blink	Node Join. The node is looking for an administrator to join with.
Quick blink	Key Transfer Active. Key transfer is taking place (administrator and node).
Slow Blink	Key Transfer Complete. The module has completed a key transfer (administrator and node).
Temporary On	On when the PB line is high
Two quick blinks, one time	Join Canceled.
Slow blink, repeat 3 times	Failure. For Share Key or Get Key, there are multiple units attempting to pair, protocol error, or timeout without response
Slow blink and two quick blinks	Long Hold Acknowledgement. The long hold period for Generate Key or Reset Sequence was recognized (PB is asserted)
Key Test Results	
One quick blink Three times	No Key. There is no network key or network address.
Two quick blinks Three times	Key Set, node. The network key and network address are set on a node.
Three quick blinks Three times	Key Set, administrator. The network key and network address are set on an administrator.
Normal operation	
Off	No activity
Temporarily on	Transmitting or receiving packet

Figure 33: HumPRO™ Series MODE_IND Line Timing

Figure 35 shows the MODE_IND displays in a graphical format.

Operation	MODE_IND Display	Comments
Administrator Join		Repeats for 30 seconds or until JOIN is complete
Node Join		Repeats for 30 seconds or until JOIN is complete
Key Transfer Active		Repeats for the duration of the transfer
Key Transfer Complete		Six blinks total
JOIN Cancelled		
Long Hold		Repeats for as long as the PB line is asserted after the long hold period has been recognized
Failure		
No Key Set		Repeats, three times total
Key Set, Node		Repeats, three times total
Key Set, Administrator		Repeats, three times total
Time (seconds)	0 0.5 1 1.5 2 2.5	

Figure 35: HumPRO™ Series MODE_IND Displays

Using the PB Line

The PB Line is used to trigger functions associated with the JOIN process. This line should be connected to a momentary pushbutton that pulls the line to VCC when it is pressed and opens the circuit when it is released. There is no internal pull-down, so a resistor to ground should be used to pull the line down when the button is not pressed. A value of 10kΩ to 100kΩ works well.

The sequence of presses determines which function is triggered. Figure 34 shows the sequences.

HumPRO™ Series Transceiver PB Line Operation

Function	Sequence
Join a network	1 short pulse
Cancel a Join Process that is in progress	1 short pulse
Generate a network key and address	Hold PB high for 30 seconds
Reset to factory defaults	4 short pulses and hold high for 3 seconds
Test key and address	3 short pulses

A short pulse is a logic high that is between 100 and 2,000ms in duration.

Figure 34: HumPRO™ Series PB Line Operation

Restore Factory Defaults

The transceiver is reset to factory default by taking the PB line high briefly 4 times, then holding PB high for more than 3 seconds. Each brief interval must be high 0.1 to 2 seconds and low 0.1 to 2 seconds. (1 second nominal high / low cycle). The sequence helps prevent accidental resets. Once the sequence is recognized, the MODE_IND line blinks in groups of three until the PB line goes low. After PB goes low, the non-volatile configurations are set to the factory default values and the module is restarted. The default UART data rate is 9,600bps.

If the timing on PB does not match the specified limits, the sequence is ignored. Another attempt can be made after lowering PB for at least 3 seconds.

Using the Low Power Features

The module supports several low-power features to save current in battery-powered applications. This allows the module to be asleep most of the time, but be able to quickly wake up, send data and go back to sleep.

Taking the Power Down ($\overline{\text{POWER\_DOWN}}$) line low places the module into the lowest power state. In this mode, the internal voltage regulator and all oscillators are turned off. All circuits powered from the voltage regulator are also off. The module is not functional while in this mode and current consumption drops to below 6µA. Taking the line high wakes the module.

When the $\overline{\text{POWER\_DOWN}}$ line is high, the IDLE register determines sleep operation.

If IDLE is set to 1 during normal operation, the module sends an ACK byte, waits for completion of an active transmission, then goes into sleep mode. Unsent data in the incoming UART data buffer does not inhibit sleep. During sleep mode, the output lines are in the states in Figure 36.

A rising transition on the $\overline{\text{POWER\_DOWN}}$ or CMD_DATA_IN lines wakes the module. If a negative-going pulse is needed to generate a rising edge, the pulse width should be greater than 1 µs.

Other lines also wake the module but it immediately goes back to sleep. Floating inputs should be avoided since they may cause unintended transitions and cause the module to draw additional current.

HumPRO™ Series Transceiver Output Line Sleep States	
Output Line	**Sleep State**
EX	Unchanged
$\overline{\text{CRESP}}$	Low
LNA_EN	Low
PA_EN	Low
TXD	High
$\overline{\text{CTS}}$	High
MODE_IND	Low
BE	Unchanged

Figure 36: HumPRO™ Series Output Line Sleep States

If the volatile registers have been corrupted during sleep, a software reset is performed. This restarts the module as if power were cycled. This can be caused by power surges or brownout among other things.

After the module wakes up, it sets the IDLE register to 0 (active). If the WAKEACK register is set to 1, then the module outputs the 0x06 byte on the CMD_DATA_OUT line. The $\overline{\text{CRESP}}$ line is taken high and the module then begins normal operation.

Pulsing $\overline{\text{RESET}}$ low causes the module to restart rather than continue from sleep.

The Command Data Interface

The HumPRO™ Series transceiver has a serial Command Data Interface (CDI) that is used to configure and control the transceiver through software commands. This interface consists of a standard UART with a serial command set. The CMD_DATA_IN and CMD_DATA_OUT lines are the interface to the module's UART. The UART is configured for 1 start bit, 1 stop bit, 8 data bits, no parity and a serial data rate set by register UARTBAUD (default 9,600bps). The $\overline{\text{CMD}}$ line tells the module if the data on the UART is for configuration commands (low) or data transmission (high).

The module has a 256 byte buffer for incoming data. The module starts transmitting when the buffer reaches a specified limit or when the time since the last received byte on the UART reaches a specified value. This allows the designer to optimize the module for fixed length and variable length data.

If the buffer gets nearly full (about 224 bytes), the module pulls the $\overline{\text{CTS}}$ line high, indicating that the host should not send any more data. Data sent by the host while the buffer is full is lost, so the $\overline{\text{CTS}}$ line provides a warning and should be monitored. When there is outgoing data waiting to be transmitted or acknowledged the BE line is low, otherwise BE is high.

Configuration settings are stored in two types of memory inside the module. Volatile memory is quick to access, but it is lost when power is removed from the module. Non-volatile memory has a limited number of write cycles, but is retained when power is removed. When a configuration parameter has both a non-volatile and volatile register, the volatile register controls the operation unless otherwise stated. The non-volatile register holds the default value that is loaded into the volatile register on power-up.

Configuration settings are read from non-volatile memory on power up and saved in volatile memory. The volatile and non-volatile registers have different address locations, but the same read and write commands. The two locations can be changed independently.

The general serial command format for the module is:

[FF] [Length] [Command]

The Length byte is the number of bytes in the Command field. The

Command field contains the register address that is to be accessed and, in the case of a write command, the value to be written. Neither Length nor Command can contain a 0xFF byte.

Byte values of 128 (0x80) or greater can be sent as a two-byte escape sequence of the format:

0xFE, [value - 0x80]

For example, the value 0x83 becomes 0xFE, 0x03. The Length count includes the added escape bytes.

A response is returned for all valid commands. The first response byte is CMD_ACK (0x06) or CMD_NACK (0x15). Additional bytes may follow, as determined by the specific command.

Reading from Registers

A register read command is constructed by placing an escape character (0xFE) before the register number. The module responds by sending an ACK (0x06) followed by the register number and register value. The register value is sent unmodified, so if the register value is 0x83, 0x83 is returned. If the register number is invalid, the module responds with a NACK (0x15). The command and response are shown in Figure 37.

HumPRO™ Series Read From Configuration Register

Command

Header	Size	Escape	Address
0xFF	0x02	0xFE	REG

Response

ACK	Address	Value
0x06	REG	V

Command for an Address greater than 128 (0x80)

Header	Size	Escape	Addr1	Addr2
0xFF	0x03	0xFE	0xFE	REG-80

Response

ACK	Address	Value
0x06	REG	V

Figure 37: HumPRO™ Series Read from Configuration Register Command and Response