Excellence in Compliance Testing

Certification Exhibit

FCC ID: HSW-DNT2400
IC: 4492A-DNT2400

FCC Rule Part: 15.247
IC Radio Standards Specification: RSS-210

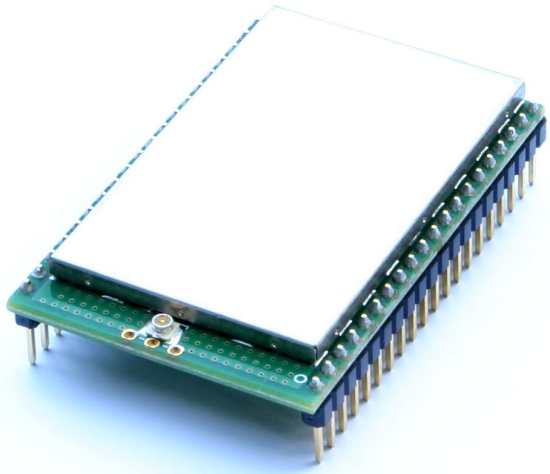
ACS Report Number 09-0199-15C

Manufacturer: **RFM / Cirronet Inc.**
Model(s): **DNT2400C, DNT2400P**

Manual

DNT2400 Series

2.4 GHz Spread Spectrum Wireless Transceivers



Integration Guide

Important Regulatory Information

RFM Product FCC ID: HSW-DNT2400
IC 4492A-DNT2400

Note: This unit has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at their expense.

FCC Antenna Gain Restriction:

The DNT2400 has been designed to operate with any dipole antenna of up to 9 dBi of gain, or any patch of up to 6 dBi gain.

The antenna(s) used for this transmitter must be installed to provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

IC RSS-210 Detachable Antenna Gain Restriction:

This device has been designed to operate with the antennas listed below, and having a maximum gain of 9 dB. Antennas not included in this list or having a gain greater than 9 dB are strictly prohibited for use with this device. The required antenna impedance is 50 ohms:

RFM OMNI249 Omnidirectional Dipole Antenna, 9 dB
RFM PA2400 Patch Antenna, 6 dB

To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that permitted for successful communication.

See Section 3.10 of this manual for regulatory notices and labeling requirements. Changes or modifications to a DNT2400 not expressly approved by RFM may void the user's authority to operate the module.

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1.0 Introduction

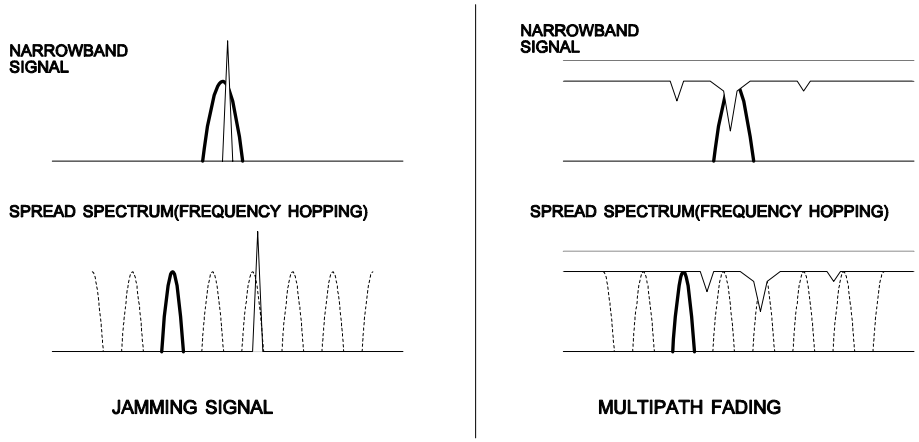
The DNT2400 series transceivers provide highly reliable wireless connectivity for point-to-point, point-to-multipoint and peer-to-peer applications. Frequency hopping spread spectrum (FHSS) technology ensures maximum resistance to multipath fading and robustness in the presence of interfering signals, while operation in the 2.4 GHz ISM band allows license-free use world wide. The DNT2400 supports all standard serial data rates for host communications from 1.2 to 460.8 kb/s. On-board data buffering and an error correcting radio protocol provide smooth data flow and simplify the task of integration with existing applications. Key DNT2400 features include:

- Multipath fading resistant frequency hopping technology with up to 37 frequency channels per subband
- Support for point-to-point or point-to-multipoint applications
- FCC 15.247, IC and ETSI certified for license-free operation
- 10 mile plus range with omnidirectional antennas (antenna height dependent)
- Transparent ARQ protocol with data buffering ensures data integrity
- Analog and digital I/O simplifies wireless sensing
- Dynamic TDMA slot assignment that maximizes throughput and CSMA modes that maximizes network size
- AES encryption provides protection from eavesdropping
- Nonvolatile memory stores DNT2400 configuration when powered off
- Selectable 1, 10 and 63 mW transmit power levels
- Selectable RF data rates of 38.4, 155.2, 200 and 500 kb/s
- Auto-reporting I/O mode simplifies application development

1.1 Why Spread Spectrum?

A radio channel can be very hostile, corrupted by noise, path loss and interfering transmissions from other radios. Even in an interference-free environment, radio performance faces serious degradation from a phenomenon known as multipath fading. Multipath fading results when two or more reflected rays of the transmitted signal arrive at the receiving antenna with opposing phases, thereby partially or completely canceling the signal. This problem is particularly prevalent in indoor installations. In the frequency domain, a multipath fade can be described as a frequency-selective notch that shifts in location and intensity over time as reflections change due to motion of the radio or objects within its range. At any given time, multipath fades will typically occupy 1% - 2% of the band. From a probabilistic viewpoint, a conventional radio system faces a 1% - 2% chance of signal impairment at any given time due to multipath fading.

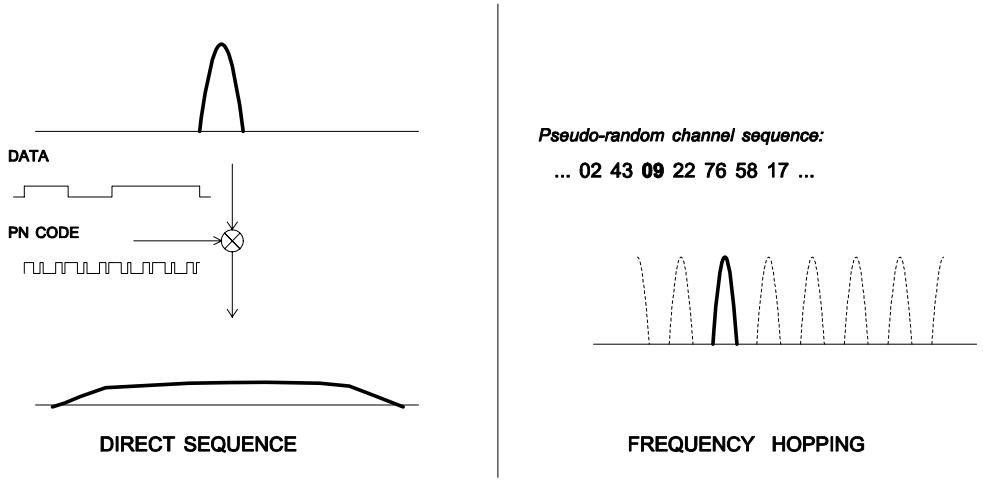
Spread spectrum reduces the vulnerability of a radio system to both multipath fading and jammers by distributing the transmitted signal over a larger frequency band than would otherwise be necessary to send the information. This allows a signal to be reconstructed even though part of it may be lost or corrupted in transmission.



Narrow-band versus spread-spectrum transmission
Figure 1.1.1

1.2 Frequency Hopping versus Direct Sequence

The two primary approaches to spread spectrum are direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS), either of which can generally be adapted to a given application. Direct sequence spread spectrum is produced by multiplying the transmitted data stream by a much faster, noise-like repeating pattern. The ratio by which this modulating pattern exceeds the bit rate of the base-band data is called the processing gain, and is equal to the amount of rejection the system affords against narrow-band interference from multipath and jammers. Transmitting the data signal as usual, but varying the carrier frequency rapidly according to a pseudo-random pattern over a broad range of channels produces a frequency hopping spread spectrum system.



Forms of spread spectrum - direct sequence and frequency hopping
Figure 1.1.2

One disadvantage of direct sequence systems is that due to design issues related to broadband transmitters and receivers, they generally employ only a minimal amount of spreading, often no more than the minimum required by the regulating agencies. For this reason, the ability of DSSS systems to overcome fading and in-band jammers is relatively weak. By contrast, FHSS systems are capable of hopping throughout the entire band, statistically reducing the chances that a transmission will be affected by fading or interference. This means that a FHSS system will degrade gracefully as the band gets noisier, while a DSSS system may exhibit uneven coverage or work well until a certain point and then give out completely.

Because it offers greater immunity to interfering signals, FHSS is often the preferred choice for co-located systems. Since direct sequence signals are very wide, they can offer only a few non-overlapping channels, whereas multiple hoppers can interleave, minimizing interference. Frequency hopping does carry some disadvantage, in that it requires an initial acquisition period during which the receiver must lock on to the moving carrier of the transmitter before any data can be sent, which typically takes several seconds. In summary, frequency hopping systems generally feature greater coverage and channel utilization than comparable direct sequence systems. Of course, other implementation factors such as size, cost, power consumption and ease of implementation must also be considered before a final radio design choice can be made.

2.0 DNT2400 Radio Operation

2.1 Network Synchronization and Registration

As discussed above, frequency hopping spread spectrum radios such as the DNT2400 periodically change the frequency at which they transmit. In order for the other radios in the network to receive the transmission, they must be listening to the frequency on which the current transmission is being sent. To do this, all the radios in the network must be synchronized to the same hopping pattern.

In point-to-point or point-to-multipoint networks, one radio module is designated as the base. All other radios are designated as remotes. One of the responsibilities of the base is to transmit a synchronization signal (beacon) to the remotes to allow them to synchronize with the base. Since the remotes know the hopping pattern, once they are synchronized with the base, they know which frequency to hop to and when. Every time the base hops to a different frequency, it immediately transmits a synchronizing signal.

When a remote is powered on, it rapidly scans the frequency band for the synchronizing signal. Since the base is transmitting on up to 37 frequencies and the remote is scanning up to 37 frequencies, it can take several seconds for a remote to synchronize with the base.

Once a remote has synchronized with the base, it will request registration information to allow it to join the network. Registration is handled automatically by the base. When a remote is registered, it receives several network parameters from the base, including *HopDuration*, *InitialNwkID*, *FrequencyBand* and *Nwk_Key* (see Section 4.2 for parameter details). Note that if a registration parameter is changed at the base, it will update the parameter in the remotes over the air.

Among other things, registration allows the tracking of remotes entering and leaving a network, up to a limit of 254 remotes. The base builds a table of serial numbers of registered remotes using their three-byte serial numbers (MAC addresses). To detect if a remote has gone offline or out of range, the registration is “leased” must be “renewed” once every 250 hops. Any transmission from a remote running on a leased registration renews the lease with the base. Note that more remotes can join the network but their

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entering and leaving the network cannot be tracked by the base radio. The DNT2400 base can be configured to send join announcements to a host application for an unlimited number of remotes. The application can then verify the continued presence of remotes in the network through periodic polling of each remote.

In addition, the DNT2400 supports a *RemoteLeave* command that allows a host application to cause a remote to leave the network. This is useful to remove any rogue remotes that may have joined when authentication is not being used. It is also useful to remove remotes from the network once they have been serviced by the application. In this manner, the base can use the lease times to keep track of remotes that have not yet been serviced thereby allowing networks of more than 254 remotes to be tracked. The *RemoteLeave* command includes the amount of time the remote must leave the network which can be set from 2 seconds to more than 36 hours. In addition, a remote can be told to leave and not rejoin until it has been power-cycled or reset.

2.2 Authentication

In many applications it is desirable to control which remote devices may join the network. This provides security from rogue nodes joining the network and simplifies network segregation for co-located networks. Network registration of remotes is controlled by the *AuthMode* parameter in the base. The *AuthMode* parameter can be set to one of four values, 0..3. The default value is 0, which allows any remote to register with a base.

When the *AuthMode* parameter is set to 1, a remote's address must be listed in Parameter Bank 7 before it will be allowed to register with the base. This is referred to as base authentication. Bank 7 must be preloaded with the addresses of the authorized remotes before using base authentication. If a remote whose MAC address is not in Bank 7 attempts to join the network the base radio will deny the registration request. A maximum of 16 remotes can be entered into Bank 7. To support larger networks, mode 2 must be used.

When the *AuthMode* parameter is set to 2, the address of a remote attempting to register with the base is sent to the host for authentication in a *JoinRequest* message. The host application determines if the remote should be allowed to register and returns a *JoinReply* message to the base containing a *PermitStatus* parameter that allows or blocks the remote from registering. The host application has 30 seconds in which to respond, after which time the base denies registration to the remote. Up to 16 join requests can be pending at any one time. If more than 16 remotes are asking to join, the first 16 will be serviced and additional remotes will be serviced after the earlier requests are handled. The *RegDenialDelay* parameter controls how often a remote will request registration after it has been denied. If it is anticipated that more than 16 remotes will request registration before the application can service the first 16, this parameter should be set to the time it will take the application to service four requests as this will speed the authentication process by freeing the base from issuing multiple denials to the same remotes.

When the *AuthMode* parameter is set to 3, authentication is locked to the addresses of the remotes currently registered with the base. Mode 3 is typically used in conjunction with Mode 0 during a commissioning process. *AuthMode* is set to 0, remotes are turned on and allowed to register with the base, and *AuthMode* is then switched to 3 to lock the network membership.

2.3 Transparent and Protocol Serial Port Modes

DNT2400 radios can work in two serial port data modes: transparent and packet protocol. Transparent mode formatting is simply the raw user data. Protocol mode formatting includes a start-of-packet framing character, length byte, addressing, command bytes, etc. Transparent mode operation is especially useful in point-to-point systems that act as simple cable replacements. In point-to-multipoint systems where the base needs to send data specifically to each remote, protocol formatting must be used unless the data being sent includes addressing information that the devices connected to the remote radios can use to determine the intended destination of the broadcast data. Protocol formatting is also required for configuration commands and responses, and sensor I/O commands and responses. Protocol mode can be used at the base radio while transparent mode is used at the remotes. The one caution about protocol mode is that the length of a protocol mode message cannot exceed the *BaseSlotSize* or *RemoteSlotSize* or the packet will be discarded. Protocol formatting details are covered in Section 4.

The DNT2400 provides two ways to switch between transparent and protocol modes. If /CFG input Pin 18 on the DNT2400 is switched from logic high to low, protocol mode is invoked. Or if the *EnterProtocolMode* command is sent, the DNT2400 will switch to the protocol mode. When input Pin 18 is switched from logic low to high, or an *ExitProtocolMode* command is sent to the primary serial input, the DNT2400 will switch to transparent operation. Note that it is possible that part of the *EnterProtocolMode* command will be sent over the air as transparent data.

When operating in transparent mode, two configuration parameters control when a DNT2400 radio will send the data in its transmit buffer. The *MinPacketLength* parameter sets the minimum number of bytes that must be present in the transmit buffer to trigger a transmission. The *TxTimeout* parameter sets the maximum time data in the transmit buffer will be held before transmitting it, even if the number of data bytes is less than *MinPacketLength*. The default value for *MinPacketLength* parameter is one and the *TxTimeout* parameter is zero, so that any bytes that arrive in the DNT2400 transmit buffer will be sent on the next hop. As discussed in Section 2.7.2, it is useful to set these parameters to values greater than their defaults in point-to-multipoint systems where some or all the remotes are in transparent mode.

2.4 RF Data Communications

At the beginning of each hop the base transmits a beacon, which always includes a synchronizing signal. After synchronization is sent, the base will transmit any user data in its transmit buffer, unless in transparent mode the *MinPacketLength* and/or *TxTimeout* parameters have been set above their default values. The maximum amount of user data bytes that the base can transmit per hop is limited by the *BaseSlotSize* parameter, as discussed in Section 2.7.1. If there is no user data or reception acknowledgements (ACKs) to be sent on a hop, the base will only transmit the synchronization signal in the beacon.

The operation for remotes is similar to the base, but without a synchronizing signal. The *RemoteSlotSize* parameter indicates the maximum number of user data bytes a remote can transmit on one hop and is a read-only value. The *RemoteSlotSize* is determined by the *HopDuratio*n and *BaseSlotSize* parameters and the number of registered remotes. The *MinPacketLength* and *TxTimeout* parameters operate in a remote in the same manner as in the base.

2.5 RF Transmission Error Control

The DNT2400 supports two error control modes: automatic transmission repeats (ARQ), and redundant transmissions for broadcast packets. In both modes, the radio will detect and discard any duplicates of

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messages it receives so that the host application will only receive one copy of a given message. In the redundant transmission mode, broadcast packets are repeated a fixed number of times based on the value of the *ARQ_AttemptLimit* parameter. In ARQ mode, a packet is sent and an acknowledgement is expected on the next hop. If an acknowledgement is not received, the packet is transmitted again on the next available hop until either an ACK is received or the maximum number of attempts is exhausted. If the ARQ_*AttemptLimit* parameter is set to its maximum value, a packet transmission will be retried without limit until the packet is acknowledged. This is useful in some point-to-point cable replacement applications where it is important that data truly be 100% error-free, even if the destination remote goes out of range temporarily.

2.6 Transmitter Power Management

The DNT2400 includes provisions for setting the base transmit power level and the remote maximum transmit power level with the *TxPower* parameter. DNT2400 networks covering a small area can be adjusted to run at lower transmitter power levels, reducing potential interference to other nearby systems such as 802.11 networks. Remotes that are located close to their base can be adjusted to run at lower maximum power, further reducing potential interference. Base units transmit at the fixed power level set by the *TxPower* parameter. Remotes automatically adjust their transmitter power to deliver packets to the base at an adequate but not excessive signal level, while not transmitting more power than set by their *TxPower* parameter. Remotes make transmitter power adjustments using the strength of the signals received from the base and the base transmitter power setting, which is periodically transmitted by the base. The remote automatic transmit power adjustment is enabled by default but can be disabled if so desired. Refer to Section 4.2.1 for details.

2.7 Network Configurations

The DNT2400 supports three network configurations: point-to-point, point-to-multipoint, and peer-to-peer. In a point-to-point network, one radio is set up as the base and the other radio is set up as a remote. In a point-to-multipoint network, a star topology is used with the radio set up as a base acting as the central communications point and all other radios in the network set up as remotes. In this configuration, each communication takes place between the base and one of the remotes. Peer-to-peer communications between remotes using the base as a relay is also supported, as discussed in Section 2.7.3.

2.7.1 Point-to-Point Network Operation

Most point-to-point networks act as serial cable replacements and both the base and the remote use transparent mode. Unless the *MinPacketLength* and *TxTimeout* parameters have been set above their default values, the base will send the data in its transmit buffer on each hop, up to a limit controlled by the *BaseSlotSize* parameter. In transparent mode, if the base is buffering more data than can be sent on one hop, the remaining data will be sent on subsequent hops. The base adds the address of the remote, a packet sequence number and error checking bytes to the data when it is transmitted. These additional bytes are not output at the remote in transparent mode. The sequence number is used in acknowledging successful transmissions and in retransmitting corrupted transmissions. A two-byte CRC and a one-byte checksum allow a received transmission to be checked for errors. When a transmission is received by the remote, it will be acknowledged if it checks error free. If no acknowledgment is received, the base will retransmit the same data on the next hop. Note that acknowledgements from remotes are suppressed on broadcast packets from the base.

In point-to-point operation, by default a remote will send the data in its transmit buffer on each hop, up to the limit controlled by its *RemoteSlotSize* parameter. If desired, the *MinPacketLength* and *TxTimeout* parameters can be set above their default values, which configures the remote to wait until the specified amount of data is available or the specified delay has expired before transmitting. In transparent mode, if the remote is buffering more data than can be sent on one hop, it will send the remaining data in subsequent hops. The remote adds its own address, a packet sequence number and error checking bytes to the data when it is transmitted. These additional bytes are not output at the base if the base is in transparent mode. When a transmission is received by the base, it will be acknowledged if it checks error free. If no acknowledgment is received, the remote will retransmit the same data on the next hop.

2.7.2 Point-to-Multipoint Network Operation

In a point-to-multipoint network, the base is usually configured for protocol formatting, unless the applications running on each remote can determine the data's destination from the data itself. Protocol formatting adds addressing and other overhead bytes to the user data. If the addressed remote is using transparent formatting, the source (originator) address and the other overhead bytes are removed. If the remote is using protocol formatting, the source address and the other overhead bytes are output with the user data.

A remote can operate in a point-to-multipoint network using either transparent or protocol formatting, as the base is the destination by default. In transparent operation, a remote DNT2400 automatically adds addressing, a packet sequence number and error checking bytes as in a point-to-point network. When the base receives the transmission, it will format the data to its host according to its formatting configuration. A remote running in transparent mode in a point-to-multipoint network can have the *MinPacketLength* and *TxTimeout* parameters set to their default values to reduce latency, or above their default values to reduce the volume of small packet transmissions.

2.7.3 Peer-to-Peer Network Operation

After a remote has joined the network, it can communicate with another remote through peer-to-peer messaging, where the base acts as an automatic message relay. In protocol mode, if a remote specifies a destination address other than the base address, peer-to-peer messaging is enabled. In transparent mode, the *RmtTransDestAddr* parameter sets the destination address. Changing *RmtTransDestAddr* from the default base address to the address of another remote enables peer-to-peer messaging. The broadcast address can also be used as a peer-to-peer destination address. In this case, the message will be unicast from the remote to the base (using ARQ) and then broadcast by the base (no ARQ). For peer-to-peer broadcasts, no acknowledgement is sent and no *TxDataReply* packet is reported to the host.

2.8 Full-Duplex Serial Data Communications

From a host application's perspective, DNT2400 serial communications appear full duplex. Both the base host application and each remote host application can send and receive serial data at the same time. At the radio level, the base and remotes do not actually transmit at the same time. If they did, the transmissions would collide. As discussed earlier, the base transmits a beacon with a synchronization signal at the beginning of each hop, followed by its user data. After the base transmission, the remotes can transmit. Each base and remote transmission may contain all or part of a complete message from its host application. From an application's perspective, the radios are communicating in full duplex since the base can receive data from a remote before it completes the transmission of a message to the remote and vice-versa.

2.9 Channel Access

The DNT2400 provides five methods of channel access: one Polling, two CSMA and three TDMA, as shown in the table and figure below. The channel access method is selected by the *AccessMode* parameter in Bank 1. See section 4.2.2. The channel access setting is distributed to all remotes by the base, so changing it at the base sets the entire network. Polling refers to an application sending a command from the base to one or more remote devices where only one remote device will respond at a time. Polling is suitable for both large and small networks where unsolicited or event reporting by remotes is not required. Carrier Sense Multiple Access (CSMA) is very effective at handling packets with varying amounts of data and/or packets sent at random times from a large number of remotes. Time Division Multiple Access (TDMA) provides a scheduled time slot for each remote to transmit on each hop. The default DNT2400 access mode is TDMA dynamic mode.

Access Mode	Description	Max Number of Remotes
0	Polling	unlimited
1	CSMA	unlimited
2	TDMA dynamic slots	up to 16
3	TDMA fixed slots	up to 16
4	TDMA with PTT	up to 16

Table 2.9.1

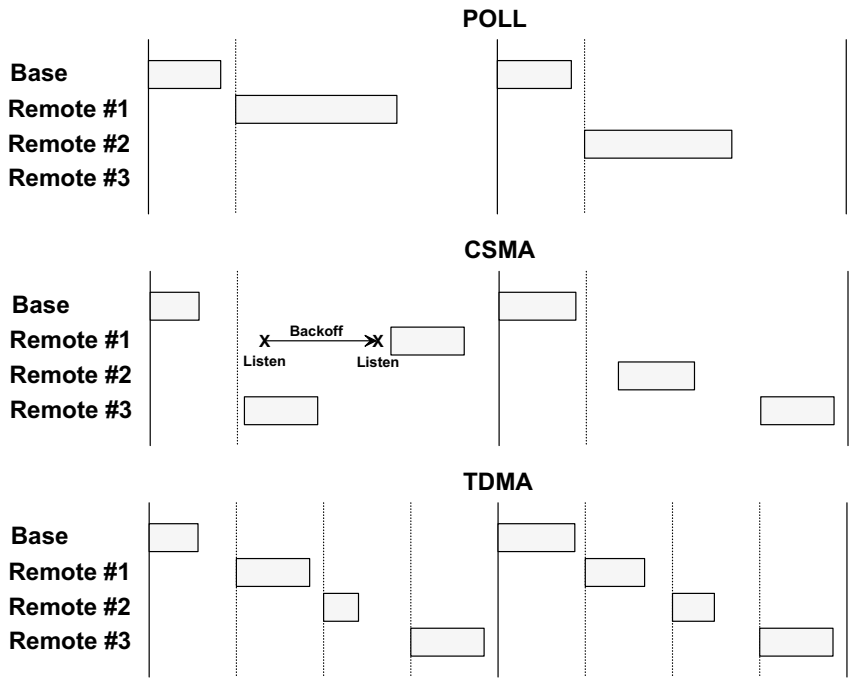

Figure 2.9.1

2.9.1 Polling Mode

Polling channel access is used for point-to-point and point-to-multipoint systems where only one remote will attempt to transmit data at a time, usually in response to a command from the base.

Polling (mode 0) is a special case of CSMA mode 1. The user can set the *BaseSlotSize* and *CSMA_RemtSlotSize* parameters when using this mode. Since only one remote will attempt to transmit at a time,

to minimize latency, the *CSMA_Predelay* and *CSMA_Backoff* parameters are not used. Lease renewals are also not used, again to minimize latency. Thus, when the base is operated in protocol mode with Announce messages enabled, only join messages are generated. This mode provides high throughput since there is no contention between remotes and the entire portion of the hop frame following the base transmission is available for a remote to transmit. Applications where more than one remote may attempt to transmit at a time, or where periodic reporting and/or event reporting are enabled should not use this mode.

2.9.2 CSMA Mode

When using CSMA channel access, each remote with data to send listens to see if the channel is clear and then transmits. If the channel is not clear, a remote will wait a random period of time and listen again. CSMA works best when a large or variable number of remotes transmit infrequent bursts of data. There is no absolute upper limit on the number of remote radios that can be supported in this mode - it depends on message density. A maximum of 254 remotes can be supported if base join-leave tracking is required, or an unlimited number of remotes if base join-leave tracking is not required or will be handled by the host application.

There are two important parameters related to CSMA operation. The *CSMA_Backoff* parameter defines the initial time that a remote will wait when it determines the channel is busy before again checking to see if the channel is clear (back-off interval). If, after finding the channel busy and backing off, the radio finds the channel busy a second time, the amount of time the remote will wait before checking the channel will increase. It will continue to increase each subsequent time the channel is busy until the channel is finally found idle. This is the classic CSMA technique that handles the situation where a number of remotes hold data to send at the same time. The *CSMA_ Predelay* parameter controls the maximum time that a remote will wait before first listening to see if the channel is clear for a transmission. This parameter is used to make sure that all the remotes do not transmit immediately after the base finishes transmitting.

CSMA (mode 1) provides classical CSMA channel access, and gives the user control over both the *CSMA_Predelay* and *CSMA_Backoff* parameters. This mode is well suited for large numbers of uncoordinated remotes, and/or where periodic/event reporting is used. In addition to *CSMA_ Predelay* and *CSMA_ MaxBackoff*, the user can set the *BaseSlotSize* and CSMA_*RemtSlotSize* parameters when using this mode. The following guidelines are suggested for setting *CSMA_Predelay*:

- For lightly loaded CSMA contention networks, decrease *CSMA_Predelay* to 0x20 or less to reduce latency.
- For heavily loaded CSMA contention networks, increase *CSMA_Predelay* to 0x80 or more for better throughput.

As an option, CSMA mode allows the base to directly track remotes entering and leaving the network, for up to 254 remotes. The base is operated in protocol mode and is configured to send Announce messages to its host when a remote joins and when the remote's registration lease expires.

While a base in a CSMA network can track a maximum of 254 remotes entering and leaving the network, it can generate join Announce messages for an unlimited number of remotes. This allows the host application to track remotes entering and leaving a CSMA network with more than 254 remotes by creating its own table of MAC addresses and periodically sending a *GetRemoteRegister* command to each remote in the table. Failure to answer a *GetRemoteRegister* command indicates the remote is no longer active in the network.

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CSMA modes work well in many applications, but CSMA has some limitations, as summarized below:

- Bandwidth is not guaranteed to any remote.
- Marginal RF links to some remotes can create a relatively high chance of collisions in heavily loaded networks.

2.9.3 TDMA Modes

TDMA modes provide guaranteed bandwidth to some or all of the remotes in a network. Remotes that register with the base receive several special parameters, including ranging information and a specific channel access time slot assignment. TDMA registrations are always leased and must be renewed every 250 hops. The DNT2400 provides three TDMA access modes, as discussed below.

TDMA Dynamic Slots (mode 2) is used for general-purpose TDMA applications where scaling the capacity per slot to the number of active remotes is automatic. Each remote that registers with the base receives an equal time slice. As new remotes join, the size of the TDMA remote slots shrinks accordingly. The number of slots, individual slot start times, and the *RemoteSlotSize* are computed automatically by the DNT2400 network in this mode. The user should note that the bandwidth to each remote will change immediately as remotes join or leave the network. When running in protocol mode on a remote, care must be taken not to generate messages too long to be sent in a single hop due to automatic *RemoteSlotSize* reduction.

TDMA Fixed Slots (mode 3) is used for applications that have fixed data throughput requirements, such as isochronous voice or streaming telemetry. The slot start time and the *RemoteSlotSize* are computed automatically by the DNT2400 network in this mode. The user must set the number of slots using the *MaxSlots* parameter. The base radio will allocate remote slot sizes as if *MaxSlots* are linked with the base, even when fewer remotes are actually linked. In this mode, the remote slot sizes are constant.

TDMA with PTT (mode 4) supports remotes with a "push-to-talk" feature, also referred to as "listen-mostly" remotes. This mode uses fixed slot allocations. Remotes can be registered for all but the last slot. The last slot is reserved for the group of remotes that are usually listening, but occasionally need to transmit. In essence, the last slot is a shared channel for this group of remotes. When one of them has data to send it keys its transmitter much like a walkie-talkie, hence the name push-to-talk (PTT).

The slot start time and the *RemoteSlotSize* are computed automatically by the DNT2400 network in mode 4. The user must specify the number of slots using the *MaxSlots* parameter. The last slot is reserved for the PTT remotes. The user must configure PTT remotes individually to select mode 4 operation. The user's application must ensure that only one PTT remote at a time is using the slot.

2.10 Transmission Configuration Planning

Because frequency hopping radios change frequency periodically, a single message may be sent in one or more RF transmissions. The length of time the radio stays on a frequency, the hop duration, impacts both latency and throughput. The longer the radio stays on a single frequency, the higher the throughput since the radio is transmitting for a higher percentage of the time, but latency is also higher since radios may have to wait longer to transmit. So latency and throughput trade off against one another. The DNT2400 has several configuration parameters that allow latency and throughput to be optimally balanced to the needs of an application.

2.10.1 TDMA Throughput

For TDMA channel access, throughput and latency are controlled by the RF data rate, the serial port baud rate, the *BaseSlotSize*, the *HopDuration*, and the number of remotes. A wide range of throughput and latency combinations can be obtained by adjusting these parameters. The throughput of a radio in a TDMA network is simply:

Number of bytes per hop/Hop Duration

For the base, the number of byes per hop is controlled by the *BaseSlotSize* parameter so the throughput of the base radio is:

BaseSlotSize/HopDuration

Note that if fewer bytes than the *BaseSlotSize* limit are sent to the base radio by its host during the hop duration time in transparent mode, the observed throughput of the base radio will be reduced. If the base is in protocol mode, it will wait until a protocol formatted message is completely received from its host before transmitting it. If the message is not completely received by the time the base transmits, the base will wait until the next hop to transmit the message. The throughput for each remote is:

RemoteSlotSize/HopDuration

In a TDMA mode, the *RemoteSlotSize* is set automatically based on the number of remotes and the *BaseSlotSize*. Note that the base radio always reserves *BaseSlotSize* amount of time in each hop whether or not the base has user data to send.

To help select appropriate parameter values, RFM provides the *DNT2400 Throughput Calculator* utility program. This program is on the development kit CD. Enabling encryption (security) adds additional bytes to the data to be sent but the *Calculator* has a mode to take this into account.

2.10.2 Polling Throughput

In polling mode, the application sends data from the base to a specific remote, which causes the remote and/or its host to send data back to the application. The network operates like a point-to-point network in this case. In polling, the *HopDuration* should be set just long enough to accommodate a base transmission up to the limit allowed by the *BaseSlotSize* parameter, plus one remote transmission up to the limit allowed by the *CSMA_RemtSlotSize* parameter. These slot sizes and the hop duration set the polling throughput as in TDMA channel access.

The throughput in Polling mode is also determined by the amount of time it takes for the remote host device to respond to the poll. For example, consider the situation where a remote host device communicates with the DNT2400 at 38.4 kb/s, receives a 16-byte poll command, and takes 1 ms to generate a 32-byte response which it then sends to the DNT2400. Sixteen bytes over a UART port is 160 bits using 8,N,1 serial parameters. Sending 160 bits at 38.4 kb/s takes 4.2 ms. Add 1 ms for the host device to process the command and begin sending the 32-byte response. The 32-byte response takes 8.4 ms to send at 38.4 kb/s, for a total turnaround time of 13.6 ms. This amount of time could be added to the base and remote slot times to allow the entire transaction to take place in a single hop. However, except at the 38.4 kb/s over-the-air data rate, this is likely to be much longer than the base and remote slot times. Thus, in practice, lengthening the hop duration to complete the transaction in a single hop doesn't really affect the throughput. Nevertheless, it is important to note that the throughput for the remote in the example above is substantially less than the remote slot size in bytes divided by the hop duration.

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It is not a radio requirement that the complete application message be sent in a single hop, nor that the remote response is returned in a single hop, when in transparent mode. If either transmission occurs over more than one hop, then depending on the length of the data, the RF data rate and the serial port data rate at the receiving end, there may be a gap in the serial data. Some protocols, such as Modbus RTU, use gaps in data to determine packet boundaries.

2.10.3 CSMA Throughput

In CSMA mode, remote radios do not have a fixed throughput, which is why applications requiring guaranteed throughput should use polling or a TDMA mode. The reason that the throughput of a CSMA remote is not fixed is because its ability to transmit at any given time depends on whether another radio is already transmitting. The throughput of a remote is further affected by how many other remotes are waiting for the channel to become clear so they can transmit. This is not a problem when remotes, even a large numbers of remotes, only send data infrequently. The DNT2400 includes several configuration parameters that can be used to optimize the performance of a CSMA network.

It is often desirable to limit the amount of data a CSMA remote can send in one transmission. This prevents one remote from hogging network throughput. To accommodate this, the DNT2400 provides a CSMA_*RemtSlotSize* parameter that is user configurable. When a remote has transmitted CSMA_ *RemtSlotSize* bytes on a given hop, it will stop transmitting until the next hop. Note that this remote will have to contend for the channel on the next hop, so it is not guaranteed that it will be the first remote to transmit on the next hop or that it will be able to transmit on the next hop at all. To allow multiple remotes a chance to transmit on the same hop, the *HopDuration* parameter must be set long enough to support the *BaseSlotSize*, plus the number of remotes to transmit per hop times CSMA_ *RemtSlotSize*, plus the number of remotes to transmit per hop times the *CSMA_Backoff*. Because of the way CSMA channel access works, this does not guarantee that the desired number of remotes to transmit on a hop will always be able to transmit on a single hop. This is due to the fact that when a remote with data to send finds the channel busy a second time, it waits for a longer period to time before testing the channel again. This time will continue to increase until the remote finds the channel clear. In practice this is unlikely to present a problem, as CSMA networks are used with devices that infrequently have data to send.

The *DNT2400 Throughput Calculator* can be used to determine the *HopDuration,* but it will be necessary to increase the number of slots to a value greater than the number of remotes to transmit on a single hop to account for the backoffs. It is indeterminate how many backoffs may occur during a single hop, which is why the number of remotes that transmit on a given hop cannot be guaranteed. Note that the *CSMA_ Backoff* parameter sets the length of time a remote will wait to recheck the channel when it has detected that the channel is busy. The second time a remote detects that the channel is busy, it will increase the amount of time it waits until it checks again. Every subsequent time it detects a busy channel it will increase the amount of time it will wait in a geometric fashion. This continues until it detects an idle channel. So while a short *CSMA_Backoff* can decrease the time between when one remote transmits and the next remote transmits, it can actually lead to a longer time between remote transmissions than a longer backoff. This can occur when the remote checks the channel multiple times during the transmitting remote's transmission causing the back-off time to be increased.

2.10.4 Latency

The worst case latency for TDMA access, excluding retries, occurs when the radio receives data just after its turn to transmit. In this instance, it will have to wait the length of time set by the *HopDuration* to begin

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transmitting the data. If the radio is receiving data over its serial port at a rate higher than its throughput, this will only occur at the beginning of a transmission that spans several hops.

In a polling application, latency is affected by how long the remote and/or its host takes to respond, and when in the hop data is ready to be transmitted. Since a remote can begin transmitting at practically any time during the hop after the base has transmitted, the latency can be less than *HopDuration*. However, the remote transmission may extend over two hops if it starts late in the first hop.

Latency for any given remote in a CSMA network is particularly difficult to characterize. If many remotes have data to send, the latency for the last remote to send will be the length of time it takes all the other remotes to send. The CSMA scheme used in the DNT2400 is designed to allow each remote an equal opportunity to transmit, so the concern is not that one remote is locked out, but just how long it will take a number of remotes with data to sent to each gain access to the channel and send their data. The more data that needs to be sent, the more time will be consumed checking the channel and backing off when the channel is busy. Again, this is why CSMA networks are best used when there are a large number of nodes that send data infrequently.

The other factor impacting latency is retries. This impact is not unique to frequency hopping radios but is common among all wireless technologies. A radio only transmits data once per hop. It needs to wait until the next hop to see if the transmission was received at the destination. If not, the radio will transmit the data again and wait for the acknowledgement. This can happen up to *ARQAttemptLimit* number of times which is equal to *ARQAttemptLimit* times *HopDuration* amount of time.

2.10.5 Configuration Validation

Although slot durations are automatically calculated by the DNT2400, the RF data rate, hop duration, etc., must be coordinated by the user to assure a valid operating configuration based on the following criteria:

1. Regardless of the RF data rate, the maximum DNT2400 hop duration is limited to 200 ms. A DNT2400 network must be configured accordingly.

2. In protocol mode, the *BaseSlotSize* and *RemoteSlotSize* parameters must be large enough to hold all the data bytes in the largest protocol formatted message being used. Protocol formatted messages must be sent in a single transmission. Any protocol formatted messages too large for the slot size setting will be discarded

3. In TDMA mode 2, the *RemoteSlotSize* may be reduced automatically when a new remote joins the network. This can cause a network to suddenly malfunction if the hop duration is not set to provide an adequately large remote slot allocation when fully loaded with remotes

4. When operating in polling mode 0, the *CSMA_RemtSlotSize* and *HopDuration* parameters are usually set to accommodate the number of data bytes in a maximum size transmission. This configuration provides low latency for polled messages.

5. When operating in CSMA mode 1, the *CSMA_RemtSlotSize* and *HopDuration* parameters are usually set to accommodate three times the number of data bytes in one maximum size transmission, to allow time for more than one remote to attempt to transmit during a single hop.

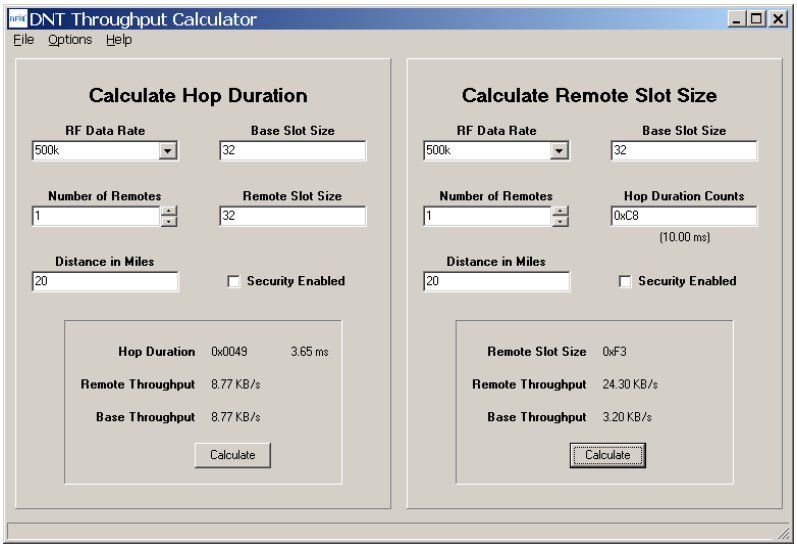

Figure 2.10.5.1

The *DNT Throughput Calculator* utility program is shown in Figure 2.10.5.1. Decimal data is entered by default. Hexadecimal data can also be entered using a 0x prefix, as shown in the *Hop Duration Counts* text box. When using the *DNT Throughput Calculator*, parameter coordination depends on the operating mode of a DNT2400 network, as outlined below:

Polling (mode 0) - the user can set and must coordinate the RF data rate, hop duration, base slot size and remote slot size. First, set the *BaseSlotSize* to accommodate the maximum number of data bytes in a base transmission. Next, set the *CSMA_RemtSlotSize* to accommodate the maximum number data bytes in a remote transmission. Use these slot sizes, the RF data rate and the maximum operating range (20 miles is the default) as inputs to the *Calculator* program to determine minimum valid *HopDuration*.

CSMA contention (mode 1) - the same procedure as for polling is used, except that the *CSMA_ RemtSlotSize* typically should be set at three times the maximum number of data bytes. The default values for CSMA pre-delay and back-off are assumed.

TDMA dynamic (mode 2) - this is the DNT2400's default operating mode and the default settings are optimized for point-to-point transparent operation. For other configurations the user must coordinate the RF data rate, hop duration, base slot size and maximum number of remotes. Although the remote slot size and remote slot time allocation are automatically set in mode 2, the user must predetermine these values to assure a valid operating configuration. First, set the *BaseSlotSize* to accommodate the maximum number of data bytes in a base transmission. Next, determine the *RemoteSlotSize* required to accommodate the maximum number of data bytes in a remote transmission. Use these slot sizes, the maximum number of remotes that will be used in the network, the RF data rate and the maximum operating range as inputs to the *Calculator* to determine the minimum valid *HopDuration* time. Note that when there are fewer remotes on the network than the maximum specified, the remotes will automatically be configured with a bigger *RemoteSlotSize* parameter.

TDMA fixed (mode 3) - First, set the *BaseSlotSize* to accommodate the maximum number of data bytes in a transmission. Next, determine the *RemoteSlotSize* required to accommodate the maximum number of data bytes in a remote transmission. Then set the number of remote slots. Use the slot sizes, the number of remotes, the RF data rate and maximum operating range as inputs to the *Calculator* to determine the minimum valid hop duration.

TDMA PTT (mode 4) - use the same procedure as for TDMA fixed mode 3.

The DNT2400 base firmware can detect a significant number of invalid configurations and override the *HopDuration* parameter to establish a valid configuration. To take advantage of this feature, configure a DNT2400 network in the following order:

1. In all system radios, set the *RF_DataRate* parameter and save it. Then reset all radios to establish the new RF data rate.

2. Set the *BaseSlotSize* and *TDMA_MaxSlots* or *CSMA_RemtSlotSize* as needed. Use the default maximum operating range unless links of more than 20 miles are planned.

3. Set the *HopDuration* parameter and then read it back. If the *HopDuration* parameter readout is different than the value set, the firmware detected an invalid configuration and is overriding it.

2.11 Serial Port Operation

DNT2400 networks are often used for wireless communication of serial data. The DNT2400 supports serial baud rates from 1.2 to 460.8 kb/s. Listed in Table 2.11.1 below are the supported data rates and their related byte data rates and byte transmission times for an 8N1 serial port configuration:

Baud Rate kb/s	Byte Data Rate kB/s	Byte Transmission Time ms
1.2	0.12	8.3333
2.4	0.24	4.1667
4.8	0.48	2.0833
9.6	0.96	1.0417
19.2	1.92	0.5208
28.8	2.88	0.3472
38.4	3.84	0.2604
57.6	5.76	0.1736
76.8	7.68	0.1302
115.2	11.52	0.0868
230.4	23.04	0.0434
460.8	46.08	0.0217

Table 2.11.1

To support continuous full-duplex serial port data flow, an RF data rate higher than the serial port baud rate is required for FHSS. Radios transmissions are half duplex, and there are overheads related to hopping frequencies, assembling packets from the serial port data stream, transmitting them, sending ACK's to confirm error-free reception, and occasional transmission retries when errors occur.

For example, consider a TDMA mode 2 system with one remote operating up to 20 miles at 500 kb/s with the *BaseSlotSize* parameter set to 64 bytes and the *RemoteSlotSize* parameter at 64 bytes. As shown in Figure 2.11.1, the hop duration from the *DNT Throughput Calculator* program for this configuration is 4.70 ms

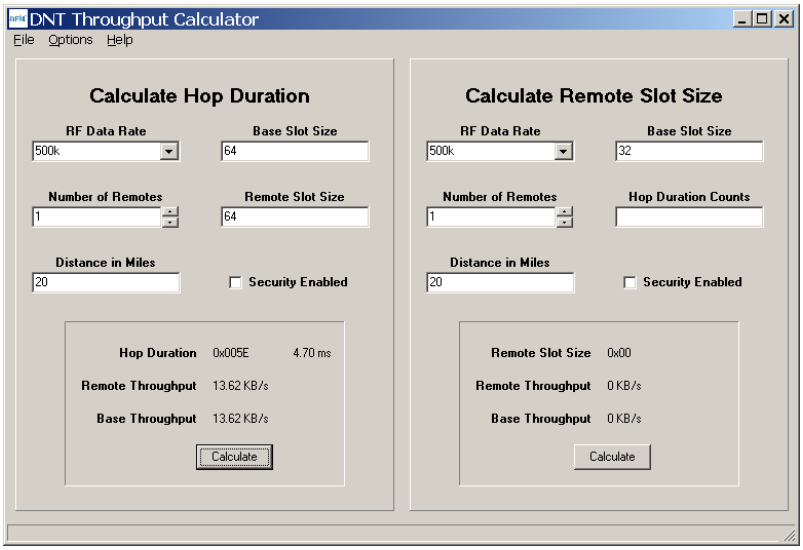

Figure 2.11.1

The average full-duplex serial port byte rate that can be supported under error free conditions is:

64 Bytes/4.70 ms = 13.62 kB/s, or 136.2 kb/s for 8N1

Continuous full-duplex serial port data streams at a baud rate of 115.2 k/bs can be supported by this configuration, provided only occasional RF transmission errors occur. Plan on an average serial port data flow of 90% of the calculated error-free capacity for general-purpose applications.

The DNT2400 transmit and receive buffers hold at least 1024 bytes and will accept brief bursts of data at high baud rates, provided the average serial port data flow such as shown in the example above is not exceeded. It is strongly recommended that the DNT2400 host use hardware flow control in applications where the transmit buffer can become full. The host must send no more than 32 additional bytes to the DNT2400 when the DNT2400 de-asserts the host's CTS line. In turn, the DNT2400 will send no more than one byte following the host de-asserting its RTS line. Three-wire serial port operation is allowed through parameter configuration, as discussed in Section 4.2.4. However, data loss is possible under adverse RF channel conditions when using three-wire serial operation due to buffer overruns.

2.12 Sleep Modes

To save power in applications where a remote transmits infrequently, the DNT2400 supports hardware and firmware sleep modes. Hardware sleep mode is entered by switching SLEEP/DTR Pin 11 on the DNT2400 from logic low to high. While in hardware sleep mode, the DNT2400 consumes less than 50 µA at room temperature. This mode allows a DNT2400 to be powered off while its host device remains powered. After leaving hardware sleep mode, the radio must re-synchronize with the base and re-register.

In addition to the sleep mode controlled by Pin 11, in CSMA mode the DNT2400 remotes support an additional sleep mode to support battery-powered applications. When this mode is enabled, the DNT2400 is in a low-power state and only wakes up in response to the I/O report triggers. The following list explains the rules that sleeping remotes follow:

- The DNT2400 will wake up when any of the enabled I/O report trigger conditions fire. When any of the ADC triggers are enabled, the radio will also wake up every *ADC_SampleIntvl* long enough to sample the ADCs, and then go back to sleep.

- When a sleeping radio wakes up, it must acquire and synchronize to its base before it can send or receive any data. To prevent excessive battery use, if the remote is unable to acquire before the *WakeLinkTimeout* elapses, it will cancel any pending event trigger(s) and go back to sleep.

- If a remote is linking for the first time or if its last attempt to acquire and synchronize was unsuccessful, it will scan and record the entire broadcast system parameter list before it goes back to sleep. Otherwise, in order to conserve battery life, a sleeping remote will update any values that it may hear while it is awake, but is not required to listen to the entire list.

- If a remote is linking for the first time or if its last attempt to acquire and synchronize was unsuccessful, it will send a registration request to the base, allowing it to announce its presence to the host. Otherwise, in order to conserve battery life, a sleeping remote will not register each time it reacquires link with its base on successive wakeups.

- After a remote has received an acknowledgement for its I/O report, a *WakeResponseTime* timer is started before the remote goes back to sleep. This allows the base host time to send a message to the remote. Note that the only notification that the base host application has that a remote is awake is its report packet. In order to send it data, the base host must ensure that the message is transmitted and received before the remote's *WakeResponseTime* window elapses. If this function is not needed, the *WakeResponseTime* can be set to zero to disabled it.

The lease renewal mechanism is not supported for sleeping remotes. In order to successfully use sleeping remotes, the user must ensure that the system is configured for CSMA mode and that leases are disabled. If these settings are not used, there is no guarantee that the remotes will be able to communicate reliably. Because leases are not supported, there is no built-in mechanism for the base to detect or announce to its host if a remote leaves the network.

To summarize, while a remote is awake, the following list of condition checks are used to determine if and when it is allowed to go back to sleep:

- If the remote is linking for the first time or was unsuccessful linking on its last attempt, it will remain awake to record the beacon system parameter list.

- At wakeup, the *WakeLinkTimeout* timer is started. If the remote is unable to acquire link before this elapses, it goes back to sleep.

- If the remote receives an acknowledgement for a data packet it has sent (typically an Event packet, but in theory it could be any other type of message), it starts or resets the *WakeResponseTime* timer to remain awake.

- So long as a GPIO for which I/O reporting is enabled for a level trigger remains in its triggered state, the remote will remain awake.

- The remote will remain awake while it still has any ARQ attempts left for a queued transmit packet of any type.

- The remote will remain awake while it is has serial characters in its buffer left to transmit to its local host.

Sleep functions are controlled by the following registers (see Section 4.2):

- *SleepMode* - enables/disables sleep mode.
- *WakeResponseTime* - sets the amount of time that a remote will wait for a response after sending an I/O report.
- *WakeLinkTimeout* - sets the maximum time that a remote will spend trying to acquire it base before giving up.

Sleep is also affected by the following registers associated with I/O reporting: *IO_ReportTrigger, IO_ReportInterval, ADC_SampleIntvl,* and *GPIO_EdgeTrigger.* The following table indicates how the status and control pins function on sleeping remotes (see Table 2.12.1):

Pin	Awake	Sleep
/HOST_RTS	Normal operation	high impedance
/HOST_CTS	Normal operation	0 V
/DCD	Normal operation	0 V
ACT	3 V	0 V
DIVERSITY	Normal operation	0 V
RADIO_TXD	Normal operation	Hi-Z
RADIO_RXD	Normal operation	0 V

Table 2.12.1

Note that the ACT pin may be used by a local host to detect when a sleeping remote is awake. The behavior of the GPIOs during sleep is governed by the *GPIO_ SleepMode*, *GPIO_SleepDir*, and *GPIO_SleepState* configuration registers. Refer to the register definitions in Section 4.2.

2.13 Encryption

The DNT2400 supports 128-bit AES encryption of data and configuration packets. Encryption is enabled by setting the *EncryptionKey* register to a value other than a string of NULL (0x00) bytes. A remote without encryption enabled cannot link to an encrypted base, and an encrypted remote will not attempt to link to an unencrypted base. A remote's encryption key must match that of the base before it can link. The *EncryptionKey* register can be set over the air so it can be changed periodically if desired.

2.14 Synchronizing Co-located Bases

The EX_SYNC input (Pin 15) on the DNT2400 allows co-located bases to synchronize their transmissions so they all transmit at the same time. This prevents the situation where one base is transmitting while another nearby base is trying to hear a distant remote. Even though the base radios may be on different frequencies, because of their close proximity, the transmitting base can reduce the receiving base's ability to hear distant remotes. The EX_SYNC input has the following characteristics:

1. Base radios trigger on the rising edge of the pulse applied to their EX_SYNC input.

2. All co-located bases must use the same hop duration and the period of the pulse train applied to the EX_SYNC input must be within ±10 µs of this hop duration.

3. The co-located bases must use *different* network IDs but the *same* frequency subband, which assures they are using different hopping patterns.

4. A “narrow” pulse of 50 to 800 µs triggers base beacon synchronization. A train of narrow pulses as described above will synchronize a group of co-located base stations after a period of time.

5. An optional “wide” pulse of 1 to 2 ms triggers a hopping pattern reset. **Note: a wide pulse can only be used in ETSI applications. It is not allowed under FCC and Canadian IC regulations.** The benefit provided by the wide pulse is to keep co-located networks from ever being on the same frequency at the same time. When the wide pulse is not used, it is possible that co-located networks may occasionally try to transmit on the same frequency at the same time. This can slightly reduce the network throughput. Where a wide pulse can be used, it should be sent to reset all base patterns to their first frequency following the reset or power-up of any of the co-located bases. Thereafter a cycle of N -1 narrow pulses and then 1 wide pulse should be sent, where N is the number of frequencies in the subband being used. For example, if the frequency subband contains 15 frequencies, a repeating cycle containing 1 wide pulse followed by 14 narrow pulses should be used.

3.0 DNT2400 Hardware

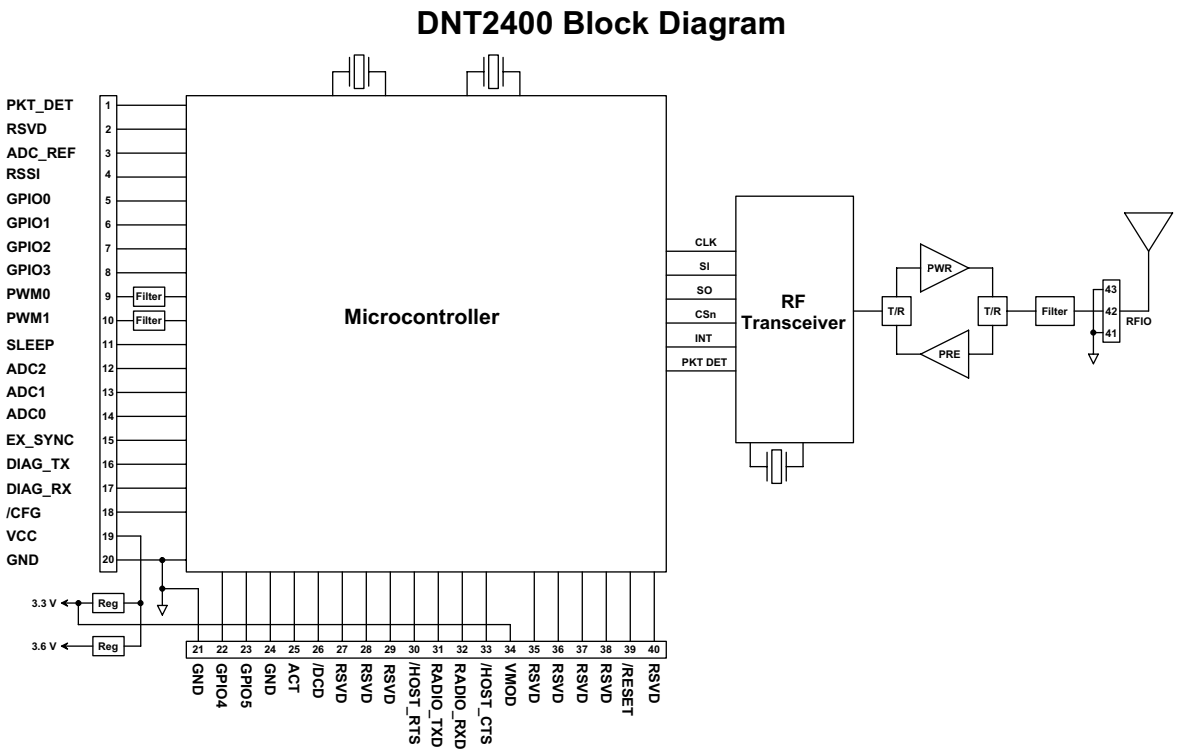

Figure 3.0.1

The major components of the DNT2400 include a 2.4 GHz FHSS transceiver and a low current 32-bit microcontroller. The DNT2400 operates in the 2.4 GHz ISM band. The module includes nine frequency subbands and 37 total frequency channels to support the various 2.4 GHz frequency allocations used throughout the world. The DNT2400 has three selectable RF output power levels: 1, 10, and 63 mW. Also, there are four selectable RF transmission rates: 38.4, 115.2, 200 and 500 kb/s. The DNT2400 includes a low-noise receiver preamplifier and a high efficiency transmitter amplifier, providing excellent range in outdoor applications.

The DNT2400 provides a variety of hardware interfaces. There are two UART serial ports, one for data and a second for diagnostics. The data port supports standard baud rates from 1.2 to 460.8 kb/s, with the diagnostic port fixed at 38.4 kb/s. The module also includes three 10-bit ADC inputs, two 8-bit PWM outputs, and six general-purpose digital I/O ports. Four of the digital I/O ports support an optional interrupt-from-sleep mode when configured as inputs. The radio is available in two mounting configurations. The DNT2400C is designed for solder reflow mounting, and the DNT2400P is designed for plug-in connector mounting.

3.1 DNT2400 Specifications

Characteristic	Sym	Minimum	Typical	Maximum	Units
Operating Frequency Range		2409.3		2467.1	MHz
Hop Dwell Time		5		200	ms
Number of Frequency Hopping Subbands				9	
Number of RF Channels in a Subband		15		37	
Modulation			FSK/MSK		
RF Data Transmission Rates			38.4, 115.2, 200 and 500		kb/s
Receiver Sensitivity:					
10^{-5} BER @ 38.4 kb/s			-104		dBm
10^{-5} BER @ 200 kb/s			-96		dBm
10^{-5} BER @ 500 kb/s			-90		dBm
Transmitter RF Output Power Levels			1, 10, 63		mW
Optimum Antenna Impedance			50		Ω
RF Connection			DNT2400P - U.FL Connector DNT2400C - U.FL Connector or PCB Pad		
Network Topologies			Point-to-Point, Point-to-Multipoint		
Access Schemes			TDMA and CSMA		
Number of Network Nodes:					
TDMA				16	
CSMA				unlimited	
ADC Input Range		0		3.3	V
ADC Input Resolution			10		bits
Signal Source Impedance for ADC Reading				10	KΩ
PWM (DAC) Output Range		0		3.3	V
PWM (DAC) Output Resolution				8	bits
PWM Output Period			20		µs
Primary Serial Port Baud Rates			1.2, 2.4, 4.8, 9.6, 19.2, 28.8, 38.4, 57.6, 76.8, 115.2, 230.4, 460.8		kb/s
Diagnostic Serial Port Baud Rate			38.4		kb/s
Digital I/O:					
Logic Low Input Level		-0.5		0.8	V
Logic High Input Level		2		3.3	V
Logic Input Internal Pull-up Resistor		50		200	KΩ
Logic Input Internal Pull-down Resistor		50		180	KΩ
Power Supply Voltage Range	V_{CC}	+3.3		+5.5	Vdc
Power Supply Voltage Ripple				10	mV_{P-P}
Peak Transmit Mode Current, 63 mW Output				300	mA
Average Operating Receive Current:					
Base			105		mA
Remote, No Data Transmission			35		mA
Remote, 9.6 kb/s Continuous Data Stream			40		mA
Remote, 115.2 kb/s Continuous Data Stream			53		mA
Sleep Current			50	225[1]	µA
Operating Temperature Range		-40		85	°C
Operating Relative Humidity Range (non condensing)		10		90	%

1. Maximum sleep current occurs at +85 °C

Table 3.1.1

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3.2 Module Interface

Electrical connections to the DNT2400C are made through the I/O pads and through the I/O pins on the DNT2400P. The hardware I/O functions are detailed in the table below:

Pad	Name	I/O	Description
1	PKT_DET	O	Packet detect output. Signal switches logic high at the end of the start-of-packet symbol and switches logic low at the end of the end-of-packet symbol on both received and transmitted packets. PKT_DET provides a timing reference for use in network timing evaluations, etc.
2	RSVD	-	Reserved pad. Leave unconnected.
3	ADC_REF	I	ADC supply and external full scale reference voltage input. Voltage range is 2.4 to 3.3 Vdc. Connect pad 34 to this input to reference the ADC full scale reading to the module's 3.3 V regulated supply.
4	RSVD	-	Reserved pad. Leave unconnected.
5	GPIO0	I/O	Configurable digital I/O port 0. When configured as an input, an internal pull-up resistor can be selected and interrupt from sleep can be invoked. When configured as an output, the power-on state is also configurable.
6	GPIO1	I/O	Configurable digital I/O port 1. Same configuration options as GPIO0.
7	GPIO2	I/O	Configurable digital I/O port 2. Same configuration options as GPIO0.
8	GPIO3	I/O	Configurable digital I/O port 3. Same configuration options as GPIO0.
9	PWM0	O	8-bit pulse-width modulated output 0 with internal low-pass filter. Filter is 1st order, 159 Hz 3 dB BW.
10	PWM1	O	8-bit pulse-width modulated output 1 with internal low-pass filter. Filter is 1st order, 159 Hz 3 dB BW.
11	SLEEP/DTR	I	Default functionality is active high module sleep input (active low DTR). When switched low after sleep, the module executes a power-on reset. Usually connected to host DTR.
12	ADC2	I	10-bit ADC input 0. Full scale reading is referenced to the ADC_REF input.
13	ADC1	I	10-bit ADC input 1. Full scale reading is referenced to the ADC_REF input.
14	ADC0	I	10-bit ADC input 2. Full scale reading is referenced to the ADC_REF input.
15	EX_SYNC	I	Rising-edge triggered input for synchronizing co-located bases. Synchronization pulse interval must equal the hop dwell time ±10 µs. Pulse width must be in the range of 50 µs to 2 ms.
16	DIAG_TX	O	Diagnostic UART transmitter output.
17	DIAG_RX	I	Diagnostic UART receiver input.
18	/CFG	I	Protocol selection input. Leave unconnected when using software commands to select transparent/protocol mode (default is transparent mode). Logic low selects protocol mode, logic high selects transparent mode.
19	VCC	I	Power supply input, +3.3 to +5.5 Vdc.
20	GND	-	Power supply and signal ground. Connect to the host circuit board ground.
21	GND	-	Power supply and signal ground. Connect to the host circuit board ground.
22	GPIO4	I/O	Configurable digital I/O port 4. When configured as an input, an internal pull-up resistor can be selected. When configured as an output, the power-on state is configurable.
23	GPIO5	I/O	Configurable digital I/O port 5. Same configuration options as GPIO4.
24	GND	-	Logic ground.
25	ACT	O	Data activity output, logic high when data is being transmitted or received.
26	/DCD	O	Default functionality is data carrier detect output, which provides a logic low on a remote when the module is locked to FHSS hopping pattern and logic low on a base when at least one remote is connected to it.

Pad	Name	I/O	Description
27	RSVD	-	Reserved pad. Leave unconnected.
28	RSVD	-	Reserved pad. Leave unconnected.
29	RSVD	-	Reserved pad. Leave unconnected.
30	/HOST_RTS	I	UART flow control input. The host sets this line low to allow data to flow from the DNT2400 on the RADIO_TXD pin. When the host sets this line high, the DNT2400 will stop sending data.
31	RADIO_TXD	O	UART transmitter output. The DNT2400 sends serial data to the host on this pin.
32	RADIO_RXD	I	UART receiver input. The DNT2400 receives serial data from the host on this pin.
33	/HOST_CTS	O	UART flow control output. The DNT2400 sets this line low to indicate it is ready to accept data from the host on the RADIO_RXD input. When the DNT2400 sets this line high, the host must stop sending data.
34	VMOD	O	Module's +3.3 V regulated supply output. Connect to pad 3 to support 3.3 V full scale and/or ratiometric ADC readings, etc. Current drain on this output should be no greater than 5 mA.
35	RSVD	-	Reserved pad. Leave unconnected.
36	RSVD	-	Reserved pad. Leave unconnected.
37	RSVD	-	Reserved pad. Leave unconnected.
38	RSVD	-	Reserved pad. Leave unconnected.
39	/RESET	I	Active low module hardware reset.
40	RSVD	-	Reserved pad. Leave unconnected.
41	GND	-	RF ground (DNT2400C only). Connect to the host circuit board ground plane.
42	RFIO	I/O	Alternate RF port to the U.FL connector (DNT2400C only). The antenna can be connected to this port with a 50 ohm stripline or coaxial cable. Leave unconnected when using the U.FL connector.
43	GND	-	RF ground (DNT2400C only). Connect to the host circuit board ground plane.

Table 3.2.1

3.3 DNT2400C RFIO Stripline

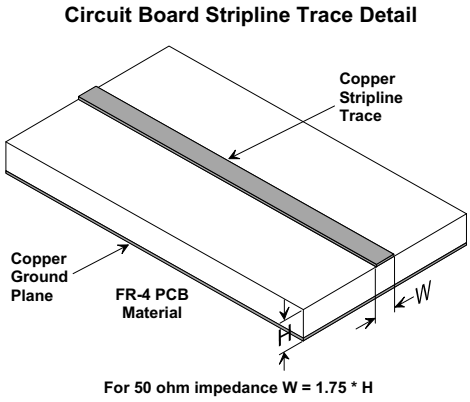

Figure 3.3.1

The DNT2400C has a U.FL coaxial connector mounted near pad 42 for antenna connection (see Antenna Connector discussion below). It is also possible to connect an antenna using a stripline from pad 42. It is

important that this connection be implemented as a 50 ohm stripline. Referring to Figure 3.3.1, the width of this stripline depends on the thickness of the circuit board between the stripline and the groundplane. For FR-4 type circuit board materials (dielectric constant of 4.7), the width of the stripline is equal to 1.75 times the thickness of the circuit board. Note that other circuit board traces should be spaced away from the stripline to prevent signal coupling, as shown in Table 3.3.1. The stripline trace should be kept short to minimize its insertion loss.

Trace Separation from 50 ohm Microstrip	Length of Trace Run Parallel to Microstrip
100 mil	125 mill
150 mil	200 mil
200 mil	290 mil
250 mil	450 mil
300 mil	650 mil

Table 3.3.1

3.4 DNT2400 Antenna Connector

A U.FL miniature coaxial connector is provided on both DNT2400 configurations for connection to the RFIO port. A short U.FL coaxial cable can be used to connect the RFIO port directly to an antenna. In this case the antenna should be mounted firmly to avoid stressing the U.FL coaxial cable due to antenna mounting flexure. Alternately, a U.FL coaxial jumper cable can be used to connect the DNT2400 module to a U.FL connector on the host circuit board. The connection between the host circuit board U.FL connector and the antenna or antenna connector on the host circuit board should be implemented as a 50 ohm stripline. Referring to Figure 3.3.1, the width of this stripline depends on the thickness of the circuit board between the stripline and the groundplane. For FR-4 type circuit board materials (dielectric constant of 4.7), the width of the stripline is equal to 1.75 times the thickness of the circuit board. Note that other circuit board traces should be spaced away from the stripline to prevent signal coupling, as shown in Table 3.3.1. The stripline trace should be kept short to minimize its insertion loss.

3.5 Input Voltages

DNT2400 radio modules can operated from an unregulated DC input (Pad 19) in the range of 3.3 (trough) to 5.5 V (peak) with a maximum ripple of 5% over the temperature range of -40 to 85 ^{o}C. *Applying AC, reverse DC, or a DC voltage outside the range given above can cause damage and/or create a fire and safety hazard. Further, care must be taken so logic inputs applied to the radio stay within the voltage range of 0 to 3.3 V. Signals applied to the analog inputs must be in the range of 0 to ADC_REF (Pad/Pin 3). Applying a voltage to a logic or analog input outside of its operating range can damage the DNT2400 module.*

3.6 ESD and Transient Protection

The DNT2400C and DNT2400P circuit boards are electrostatic discharge (ESD) sensitive. ESD precautions must be observed when handling and installing these components. Installations must be protected from electrical transients on the power supply and I/O lines. This is especially important in outdoor installations, and/or where connections are made to sensors with long leads. *Inadequate transient protection can result in damage and/or create a fire and safety hazard.*

3.7 Interfacing to 5 V Logic Systems

All logic signals including the serial ports on the DNT2400 are 3.3 V signals. To interface to 5 V signals, the resistor divider network shown in Figure 3.5.1 below must be placed between the 5 V signal outputs and the DNT2400 signal inputs. The output voltage swing of the DNT2400 3.3 V signals is sufficient to drive 5 V logic inputs.

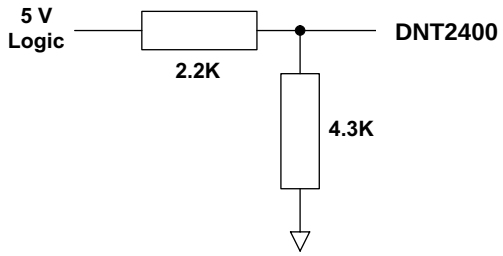

Figure 3.7.1

3.8 Power-On Reset Requirements

When applying power to the DNT2400, the /RESET pin should be held low until the power supply voltage reaches 3.3 volts for 100 milliseconds.

3.9 Mounting and Enclosures

DNT2400C radio modules are mounted by reflow soldering them to a host circuit board. DNT2400P modules are mounted by plugging their pins into a set of mating connectors on the host circuit board. Refer to Section 8.3 and/or the DNT2400 Data Sheet for DNT2400P connector details.

DNT2400 enclosures must be made of plastics or other materials with low RF attenuation to avoid compromising antenna performance where antennas are internal to the enclosure. Metal enclosures are not suitable for use with internal antennas as they will block antenna radiation and reception. Outdoor enclosures must be water tight, such as a NEMA 4X enclosure.

3.10 Labeling and Notices

DNT2400 FCC Certification - The DNT2400 hardware has been certified for operation under FCC Part 15 Rules, Section 15.247.

DNT2400 FCC Notice - *This device complies with Part 15 of the FCC rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.*

DNT2400 FCC Label - *A clearly visible label is required on the outside of the user's (OEM) enclosure stating "Contains FCC ID: HSW-DNT2400."*

WARNING: This device operates under Part 15 of the FCC rules. Any modification to this device, not expressly authorized by RFM, Inc., may void the user's authority to operate this device.

Canadian Department of Communications Industry Notice - IC: 4492A-DNT2400

This apparatus complies with Health Canada's Safety Code 6 / IC RSS-210.

IC RSS-210 Notice - *Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.*

Canadian ICES-003 - This digital apparatus does not exceed the Class B limits for radio noise emissions from digital apparatus as set out in the radio interference regulations of Industry Canada.

Le present appareil numerique n'emet pas de bruits radioelectriques depassant les limites applicables aux appareils numeriques de Classe B prescrites dans le reglement sur le brouillage radioelectrique edicte par Industrie Canada.

4.0 Protocol Messages

4.1 Protocol Message Formats

The DNT2400 is configured and controlled through a series of protocol mode messages. All protocol mode messages have a common header format:

0	1	2	3 …
SOP	Length	PktType	variable number of arguments …

Figure 4.1.1

The scale above is in bytes.

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

The *Length* byte is defined as the length of the remainder of the message following the length byte itself (or the length of the entire message - 2).

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

Bits	*7-6*	Reserved for future use
Bit	*5*	Event - set to indicate this message is an event
Bit	*4*	Reply - set to indicates this message is a reply
Bits	*3-0*	Type - indicates the message type/command

As indicated, the lower 4 bits (3-0) specify a message type. Bit 4 is a modifier indicating that the message is a command or a reply. A reply message has the original command type in bits 3:0, with bit 4 set to one.

Arguments vary in size and number depending on the type of message and whether it is a message sent from the host or is a reply from the radio; see Table 4.1.2.1 below. Messages that are generated on the serial interface by the user are referred to as host messages. Messages that are generated by the radio are referred to as reply messages. For many message types, there is a reply message that corresponds to a host message. For example, when the host sends a *TxData* message, the radio will reply to indicate the status of the transmission, whether it succeeded or failed. Some message types are host-only or reply-only; refer to Table 4.1.2.1 for specifics.

4.1.1 Message Types

Each message generally has two forms, a command from the host and a reply from the radio. Depending on the direction, they have different arguments as shown in Table 4.1.2.1. Event messages from the radio such as received data packets or status announcements make up a third category of messages. To assist in interpreting the command-reply data flow, the direction is indicated by the high nibble in the message type. For example, an *EnterProtocolMode* command from the host is a message type 0x00, and the *EnterProtocolModeReply* from the radio is a message type 0x10. Event messages, including *RxData*, *RxEvent* and *Announce* packets are indicated by 0x20 in the high nibble of the type byte**.** If multiple arguments are to be provided, they are to be concatenated in the order shown. Little-Endian byte format

is used for all multi-byte arguments, where the lowest order byte is the left-most byte of the argument and the highest order byte in the right-most byte of the argument.

4.1.2 Message Format Details

Com-mand	Reply	Event	Description	Direction	Arguments
0x00	-	-	EnterProtocolMode	*from Host*	DNT2400 (ASCII characters)
-	0x10	-	EnterProtocolModeReply	*from Radio*	*none*
0x01	-	-	ExitProtocolMode	*from Host*	*none*
-	0x11	-	ExitProtocolModeReply	*from Radio*	*none*
0x02	-	-	SoftwareReset	*from Host*	BootSelect
-	0x12	-	SoftwareResetReply	*from Radio*	none
0x03	-	-	GetRegister	*from Host*	Reg, Bank, Span
-	0x13	-	GetRegisterReply	*from Radio*	Reg, Bank, Span,Val
0x04	-	-	SetRegister	*from Host*	Reg, Bank, Span, Val
-	0x14	-	SetRegisterReply	*from Radio*	none
0x05	-	-	TxData	*from Host*	Addr, Data
-	0x15	-	TxDataReply	*from Radio*	TxStatus, Addr, RSSI
-	-	0x26	RxData	*from Radio*	Addr, RSSI, Data
-	-	0x27	Announce	*from Radio*	AnnStatus, additional fields
-	-	0x28	RxEvent	*from Radio*	Addr, RSSI, Reg, Bank, Span,Val
0x0A	-	-	GetRemoteRegister	*from Host*	Addr, Reg, Bank, Span
-	0x1A	-	GetRemoteRegisterReply	*from Radio*	If command successful: TxStatus, Addr, RSSI, Reg, Bank, Span, Val If command failed: TxStatus, Addr
0x0B	-	-	SetRemoteRegister	*from Host*	Addr, Reg, Bank, Span, Val
-	0x1B	-	SetRemoteRegisterReply	*from Radio*	TxStatus, Addr, RSSI
-	-	0x2C	JoinRequest	*from Radio*	Addr,3 Reserved Bytes ,
0x0C	-	-	JoinReply	*from Host*	Addr, PermitStatus
0x0D	-	-	RemoteLeave	*from Host*	Addr, BackOffTime

Table 4.1.2.1

Arguments:

Reg = Register location *(1 byte)*
Bank = Register bank, which provides logical isolation from other data regions *(1 byte)*
Span = Number of bytes of register data to get or set; must align to a parameter boundary *(1 byte)*
Val = Value to read/write to/from a register *(see table 4.1.2.1 for size and acceptable range).*
Data = User data *(must fit within the slot size allocation)*
Addr = the MAC address of the destination node in a command, the MAC address of a node sending a reply or event message, or the MAC address of the originating node in an RxData message *(3 bytes)*
TxStatus = Result of last TxData operation *(1 byte)*

0 = Acknowledgement received
1 = No acknowledgement received
2 = Not linked (remote)
3 = No ACK due to recipient holding for flow control

RSSI = 2's complement value in dBm, with a range of -128 (0x80) to +125 (0x7D) dBm *(1 byte);* large positive RSSI values will not occur under ordinary circumstances. RSSI values 126 (0x7E) and 127 (0x7F) have special meaning:

0x7F = No RSSI measured because no ACK was received
0x7E = reserved for future use

NwkID = Network identifier of network joined *(1 byte).*
BaseMacAddr = MAC address of base that the remote joined *(3 bytes).*
AnnStatus = Status announcement *(1 byte).* Additional fields are also reported depending on the status code:

Status code	*Additional fields*
A0 = Radio has completed startup initialization	none
A2 = Base: a remote has joined the network	Addr, reserved, Range
A3 = Remote: joined a network, ready for data	NwkID, BaseMacAddr, Range
A4 = Remote: exited network (base is out of range)	NwkID
A7 = Base: remote has left the network.	Addr

Status codes for error conditions	*Additional fields*
E0 = Protocol error - invalid message type	none
E1 = Protocol error - invalid argument	none
E2 = Protocol error - general error	none
E3 = Protocol error - parser timeout	none
E4 = Protocol error - register is read-only	none
E8 = UART receive buffer overflow	none
E9 = UART receive overrun	none
EA = UART framing error	none

Range = Range measurement of joining radio *(1 byte)*. Each count equals 0.29 miles.
BootSelect = Code indicating whether to do a normal reset or a reset to the bootloader *(1 byte)*
(0 = normal reset, 1 = reset to bootloader)
PermitStatus = Permission for new node to join, 0x00 = denied, 0x01 = permitted *(1 byte)*
BackoffTime = Time that a node will avoid trying to join a network, in seconds *(2 bytes)*
(0xFFFF = back off until reset or power cycled)

4.1.3 /CFG Select Pin

A falling edge on the /CFG pin is the equivalent of the *EnterProtocolMode* command. A rising edge on the /CFG pin is the equivalent to sending the *ExitProtocolMode* command. The input to the /CFG pin is de-bounced to make it compatible with a mechanical switch or jumper.

4.1.4 Flow Control

There are two flow control signals between the radio and the host, /HOST_RTS and /HOST_CTS. See Section 2.11 for flow control details.

4.1.5 Protocol Mode Data Message Example

In this example, ASCII text *Hello World* is sent from the base to a remote using a *TxData* command. The MAC address of the remote is 0x000102. The protocol formatting for the host message is:

0xFB **0x0F** 0x05 **0x02 0x01 0x00** 0x48 0x65 0x6C 0x6C 0x6F 0x20 0x57 0x6F 0x72 0x6C 0x64

There are 15 bytes following the length byte, so the length byte is set to 0x0F. Note that the 0x000102 MAC address is entered in Little-Endian byte order 0x02 0x01 0x00.

When an ACK to this message is received from the remote, the base outputs a *TxDataReply* message to its host:

0xFB 0x06 0x15 **0x00** 0x02 0x01 0x00 **0xC4**

The 0x00 *TxStatus* byte value indicates the ACK reception from the remote. The *RSSI* value of the received ACK is 0xC4 (-60 dBm).

If the remote is in protocol mode, the message is output in the following format:

0xFB 0x10 **0x26** 0x00 0x00 0x00 **0xC4** 0x48 0x65 0x6C 0x6C 0x6F 0x20 0x57 0x6F 0x72 0x6C 0x64

The message is output as an 0x26 event. The address field contains the base (originator) address. Note that the RSSI value 0xC4 is inserted between the base MAC address and the *Hello World* user data.

4.2 Configuration Registers

The configuration registers supported by the DNT2400 are described below. Registers are sorted into banks according to similar functions. Default register values are in **bold**. All changes to parameters are temporary and will not persist through power cycling until 0x01 has been written to the *MermorySave* parameter in Bank FF. Writing 0x00 to the *MemorySave* parameter will reload the factory default values which also require writing 0x01 to the *MemorySave* location. Also note that some parameter changes do not take effect until they are saved and the module is reset or power cycled. Modules can be reset by writing 0x00 to the *UcReset* parameter in Bank FF.

4.2.1 Bank 0 - Transceiver Setup

Bank	***Loc'n***	***Name***	***R/W***	***Size in bytes***	***Range***	***Default, Options***
00	00	DeviceMode	*R/W*	1	0..2	**0 = Remote**, 1= Base, 2 = PTT Remote
00	01	RF_DataRate	*R/W*	1	0..4	**0 = 500**, 1 = 200, 2 = 115.2, 3 = 38.4 kb/s, 0XFF = auto
00	02	HopDuration	*R/W*	2	4..4000	**10 ms (0x00C8)**
00	04	InitialNwkID	*R/W*	1	0..255	**0xFF = join any network**
00	05	SecurityKey	*R/W*	16	$0..2^{128}$	**all null bytes (0x00) = security disabled**
00	15	SleepMode	*R/W*	1	0..1	**0 = off**, 1 = timer, 2 = interrupt
00	16	WakeResponseTime	*R/W*	1	0..255	**1 = 50 ms**, 0 to disable
00	17	WakeLinkTimeout	*R/W*	1	0..255	**5 s**
00	18	TxPower	*R/W*	1	0..2	**0 = 1 mW**; 1 = 10 mW, 2 = 63 mW
00	19	ExtSyncEnable	*R/W*	1	0..1	**0 = off**; 1 = enable
00	1A	DiversityMode	R/W	1	0..2	**0 = 0 V**, 1 = 3.3 V, 2 = toggle
00	1B	Reserved		1		
00	1C	UserTag	*R/W*	16		"**DNT2400**"
00	2C	RegDenialDelay	*R/W*	2		**10 s**
00	2E	RmtTransDestAddr	*R/W*	3		**0x000000 (Base)**

Note: These settings are individual to each module.

DeviceMode - selects the operating mode for the radio: remote, base, or PTT remote (listen mostly remote). Note that changing this setting does not take effect immediately. It must be followed by a *MemorySave* command (See Section 4.2.9) and then a hardware reset.

RF_DataRate - this sets the over-the-air data rate. DNT2400's with different RF data rates cannot intercommunicate. The following codes are defined:

0x00 = 500 kb/s (default)
0x01 = 200 kb/s
0x02 = 115.2 kb/s
0x03 = 38.4 kb/s
0xff = auto

The *auto* setting will cause a remote to try all four over-the-air rates when scanning for a network to join. Setting the *RF_DataRate* to a fixed value on the remotes will allow a network to link much faster than using the *auto* setting. However, if the base *RF_DataRate* is changed when the remotes are set to a fixed rate, the network will not link. Note that changing this setting does not take effect immediately. It must be followed by a *MemorySave* command (See Section 4.2.9) and then a hardware reset.

HopDuration - this sets the duration of the hop frame. The duration is set as a 12-bit value, 0.05 ms/count. Changing the hop duration must be followed by a *MemorySave* command to allow the change to persist through a reset or power cycle. A *HopDuration* change takes effect immediately. Remotes will re-link following a *HopDuration* parameter change.

InitialNwkID - selects the initial network ID that the radio will start (if a base) or join (if a remote). A value of 0xFF instructs a remote to operate in 'promiscuous mode' and join any network it finds (if set for a base, this will select the default network ID of 0x00.) The network ID also sets the base frequency at which the hopping pattern starts, as illustrated by the following equation:

FrequencyIndex[n] = HoppingPattern[n + NetworkID mod 32]

This allows the user to coordinate frequency spacing of co-located networks to maintain a constant separation as they hop. The *InitialNwkID* values of co-located networks should be two apart (0, 2, 4 … or 1, 3, 5 …) for best results.

SecurityKey - this sets the 128-bit AES encryption key to be used. To protect the key, this is a write-only parameter for the user (always reads back as 0x2A). Refer to the Section 2.13 for further information.

SleepMode - this parameter enables sleep mode, which may be used in conjunction with the automatic I/O reporting feature to wake up on specified triggers. Sleep mode is only available for remotes, and the channel access mode for the network must be one of the CSMA modes.

WakeResponseTime - this parameter sets the length of time that a remote in sleep mode will wait for a response after sending an I/O report before going back to sleep, from a minimum of 10 ms to a maximum of 2.5 seconds in 10 ms units. This time interval is set to allow the base host application to respond to a remote with a packet before the remote returns to sleep. If this parameter is set to 0, the remote will stay awake indefinitely after sending an I/O report. This allows the application as much time as needs for any initial configuration after which it can cause the remote to re-enter sleep by setting this to the operating value.

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WakeLinkTimeout - this parameter sets the maximum length of time that a remote in sleep mode will spend trying to acquire a link to its base before going back to sleep, from a minimum of 100 ms to 25.5 s in 100 ms units. If this value is set to 0, the remote will stay awake and continue trying to link to its base indefinitely.

TxPower - this parameter sets the transmit power level used by the base (fixed), and the maximum transmit power level used by a remote. A remote may automatically adjust its power below the *TxPower* settings based on the signal strength it receives from the base plus the *TxPower* setting being used by the base. The default 1 mW *TxPower* setting is useful for desktop testing. *TxPower* is usually set to a higher level to increase operating range in actual applications. Setting bit 4 (0001xxxx) disables the remote automatic transmit power function.

0x00 = 0 dBm or 1 mW (default)
0x01 = 10 dBm or 10 mW
0x02 = 18 dBm or 63 mW

ExtSyncEnable - this parameter enables or disables the hardware EX_SYNC function on Pin 15. When enabled, a pulse train can be input on Pin 15 to synchronize the transmission of co-located bases. Disabled by default.

DiversityMode - the following diversity antenna switching options are supported as an output on GPIO5:

0 = 0 V output (default)
1 = 3.3 V output
2 = hop-by-hop toggle between 0 and 3.3 V

UserTag - this is a user definable field intended for use as a location description or other identifying tag such as a “friendly name”.

RegDenialDelay - when a remote has been removed from a network through a *RemoteLeave*, the *RegDenialDelay* parameter sets the length of time the remote will wait before considering that network a candidate for joining again. Units are in seconds; the default is 10 s.

RmtTransDestAddr - this parameter sets the destination address that a remote will send packets to when configured to use transparent mode. The default destination is the base (0x000000). If this field is set to another remote's MAC address or to the broadcast address, a peer-to-peer packet will be sent. Note that peer-to-peer packets have higher latency than direct packets between base and remote. This setting has no effect on the base.

4.2.2 Bank 1 - System Settings

Bank	Loc'n	Name	R/W	Size in bytes	Range	Default; Options
01	00	FrequencyBand	*R/W*	1	0..FF	**0x00** to 0x08 = general purpose, 0x04, 0x05 & 0x07 = France, 0xFF = auto
01	01	AccessMode	*R/W*	1	0..4	**2 = TDMA Dynamic Slots**
01	02	BaseSlotSize	*R/W*	1	6..233	**50 bytes**
01	03	LeasePeriod	*R/W*	1	0..250	**5 s** (0 to disable)
01	04	ARQ_Mode	*R/W*	1	0..3	**1 = redundant broadcast to *ARQ_AttemptLimit*, *ARQAttemptLimit* pass to remotes enabled**
01	05	ARQ_AttemptLimit	*R/W*	1	0..63	**8 attempts**
01	06	MaxSlots	*R/W*	1	0..15	**16 slots**
01	07	CSMA_Predelaty	*R/W*	1	0..255	**0x03**
01	08	CSMA_Backoff	*R/W*	1	0..255	**0x0A**
01	09	MaxPropDelay	*R/W*	1	0..255	**0x45** (20 mi, 32.18 km)
01	0A	LinkDropThreshold	*R/W*	1	0..255	**0x0C**

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01	0B	CSMA_RemtSlotSize	*R/W*	1	1..255	**50**
01	0C	CSMA_BusyThreshold	*R/W*	1	1..255	**20**
01	0D	RangingInterval	*R/W*	1	0..255	**0** = disable
01	0E	AuthMode	R/W	1	0..3	**0** = authentication disabled
01	0F	PeerReplyTimeout	R/W	1		**8** hops

Bank 1 holds configuration parameters to be input to the base only. The base passes these parameters to the remotes as needed. The exception is the *ARQ_AttemptLimit* parameter. If *ARQ_Mode* bit 1 is set to 1 at the base, the *ARQ_AttemptLimit* parameter can be set in the remotes and used.

FrequencyBand - this parameter selects the frequency hopping subband. Nine subbands are available, as shown below. Note that operation in France is limited to subbands 0x04, 0x05 and 0x07.

Subband	Channels	Frequency Range(s)	Notes
0x00	37	2409.3-2467.1 MHz	General purpose 37 channel subband
0x01	17	2441.1-2467.1 MHz	17 channel subband, avoids 802.11b/g channels 1-4
0x02	17	2409.3-2416.6 MHz, 2451.2-2467.1 MHz	17 channel subband, avoids 802.11b/g channels 5-6
0x03	17	2409.3-2426.7 MHz, 2461.3-2467.1 MHz	17 channel subband, avoids 802.11b/g channels 7-8
0x04	17	2409.3-2435.3 MHz	17 channel subband, avoids 802.11b/g channels 9-10, also for use in France
0x05	21	2409.3-2441.1 MHz	21 channel subband, avoids 802.11b/g channels 11-13, also for use in France
0x06	21	2428.1-2461.3 MHz	21 channel subband, avoids 802.11 b/g channel 1
0x07	15	2409.3-2432.4 MHz	15 channel subband, avoids 802.11b/g channels 8-13, also for use in France
0x08	15	2433.9-2455.6 MHz	15 channel subband, avoids 802.11b/g channels 1-2 and 13
0xFF	15 to 37	Auto	Autoscan for remote to match base

AccessMode - this sets the channel access mode that remotes will use to communicate with the base:

Access Mode	Description	Max # of Remotes	Remote Slot Size
0	Polling	unlimited	manual
1	CSMA	unlimited	manual
2 (default)	TDMA dynamic slots	up to 16	automatic
3	TDMA fixed slots	up to 16	automatic
4	TDMA with PTT	up to 16	automatic

BaseSlotSize - This parameter set the maximum number of user data bytes that the base can send on a single hop. This value must be set by the user for all access modes. The default value is 50 bytes.

LeasePeriod - this sets the duration in seconds for leases that remotes receive from the base. If a period of zero is specified, then lease functions are disabled. The minimum valid lease period is two seconds. Remotes will attempt to renew their leases at an interval equal to half the lease period. For example, if the lease period is set to four seconds, remotes will renew their leases every two seconds.

ARQ_Mode - this sets the ARQ mode for delivery of application messages. In ARQ mode, an ACK is expected from the receiving radio for each message addressed and sent to it. If no ACK is received, up to *ARQ_AttemptLimit,* attempts to send the data will be made, after which the message is discarded. In redundant broadcast mode, each broadcast message is sent exactly *ARQ_AttemptLimit* times. No ACKS are sent or expected. The following bit options control this function:

bits 7..2	Not used
bit 1	If set to 0, the base can pass a new *ARQ_AttemptLimit* to the remotes If set to 1, the remotes use their own *ARQ_AttemptLimit in Bank 1*
bit 0	If set to 1, ARQ mode is enabled for Protocol mode; the base will send broadcast packets *ARQ_AttemptLimit* times instead of once. If set to 0, broadcast packets are sent once

ARQ_AttemptLimit - this sets the maximum number of attempts that will be made to send a data packet on the RF link. Setting this parameter to the maximum value of 63 is a flag value indicating that there should be no limit to the number of attempts to send each packet (infinite number of attempts). This mode is intended for point-to-point networks in serial data cable replacement applications where absolutely no packets can be lost. Note - if this mode is used in a multipoint network, one remote that has lost link will shut down the entire network if the base is trying to send it data.

MaxNumSlots - in TDMA access modes, this sets the number of slots that are allowed. In fixed slot mode, this allocates the number of slots directly. In dynamic slot mode, this sets the maximum number of slots that may be generated regardless of the number of remotes that attempt to link with the base. Any remotes requesting registration after this limit is reached will be denied registration by the base.

CSMA_Predelay - in CSMA mode 1, this parameter sets the maximum delay between when the base transmission has finished and when a remote checks for a clear channel. Refer to Section 2.9.2 for more information.

CSMA_Backoff - in a CSMA mode 1, this sets the length of time that a remote will back off after it detects a busy channel. Refer to Section 2.9.2 for more information.

MaxPropDelay - this is the maximum propagation delay that the base and the remotes will use in their slot timing calculations, in units of 3.1 µs. This is used to increase the amount of time dedicated to the registration slot. Increasing this value will subtract slightly from the overall slot time available to remotes for sending data. Note that the free-space round trip propagation delay for one mile is 10.72 µs. Each increment of *MaxPropDelay* thus corresponds to a maximum radius from the remote to the base of 0.29 mi (0.46 km). The default setting provides enough time to handle remotes up to 20 miles away. It is recommended to use the default setting unless a path greater than 20 miles is planned at start up. Once linked to the base, remotes will periodically update their timing based on ranging information from the base, except in Polling Mode. The frequency with which this value is updated is set by the *RangingInterval* parameter discussed below. The current range information is available in the *CurrPropDelay* parameter.

LinkDropThreshold - this is the number of consecutive beacons missed by a remote that causes the remote to restart a link acquisition search. Please contact RFM technical support before making changes to the parameter.

CSMA_RemtSlotSize - this sets the maximum size for a remote data transmission in polling or CSMA channel access modes. Setting this parameter to a large value allows a remote to send more data in a single hop, but can result in fewer remotes having time to send on a given hop. The default is 50 bytes.

CSMA_BusyThreshold - this sets the RSSI energy detection threshold that remotes use to determine whether the channel is occupied. The factory default should be sufficient for most applications and it is recommended that this value not be changed.

RangingInterval - this sets the period at which remotes will reassess their range to the base. Polling (mode 0) disables the ranging interval mechanism, so remotes receive ranging information only once each time they join a network. The *RangingInterval* timer does not advance while a remote is sleeping.

AuthMode - this parameter is valid on the base only. It controls how remotes are permitted to join the network. Permitted values are:

0 = Any remote may join
1 = Authentication by base radio permission table
2 = Authentication by request to host application
3 = Lock authentication to permit only currently registered remotes

PeerReplyTimeout - This sets the reply timeout for peer-to-peer packets sent from one remote to another. Because each leg of the journey from one remote to another and back may take multiple transmit attempts, the length of time to confirm receipt and issue a *TxDataReply* is subject to more variation than a normal transmission between base and remote. The *PeerReplyTimeout* parameter specifies the maximum number of hops that a remote will wait for a reply from its recipient. If a reply returns sooner than the timeout, the remote will send a *TxDataReply* indicating success to its host as soon as it is received and cancel the timeout. If a reply does not come back before the timeout expires, the remote will send a *TxDataReply* to its host indicating failure. If a reply should come back after the timeout expires the remote will ignore it, as a *TxDataReply* has already been sent. Units are in hops; the default is 8 hops.

4.2.3 Bank 2 - Status Registers

Bank	*Loc'n*	*Name*	*R/W*	*Size in bytes*	*Range*	*Default*
02	00	MacAddress	*R*	3	0..0x0ffffff	fixed value
02	03	Reserved	*R*	1	0..255	reserved
02	04	CurrNwkID	*R*	1	0..255	as set
02	05	CurrRF_DataRate	*R*	1	0..4	as set
02	06	CurrFreqBand	*R*	1	0..1	as set
02	07	LinkStatus	*R*	1	0..1	current status
02	08	RemoteSlotSize	*R*	1	0..243	as set
02	09	TDMA_NumSlots	*R*	1	0..16	as set
02	0A	Reserved	*R*	1	0..255	reserved
02	0B	TDMA_CurrSlot	*R*	1	0..16	current slot
02	0C	HardwareVersion	*R*	1	0..255	0x00 = DNT2400 rev A
02	0D	FirmwareVersion	*R*	1	0..255	current firmware load
02	0E	FirmwareBuildNum	*R*	2	$0..2^{16}$	current firmware load
02	10	Reserved	*R*	1	0..255	reserved
02	11	SuperframeCount	*R*	1	0..255	current value
02	12	RSSI_Idle	*R*	1	0..255	as set
02	13	RSSI_Last	*R*	1	0..255	as set
02	14	CurrTxPower	*R*	1	0..255	as set
02	15	CurrAttemptLimit	*R*	1	0..255	as set
02	16	CurrRangeDelay	*R*	1	0..255	as set
02	17	FirmwareBuildDate	*R*	8	ASCII	as set
02	1F	FirmwareBuildTime	*R*	8	ASCII	as set
02	27	ModelNumber	*R*	1	0..255	0x02

MacAddress - returns the radio's unique 24-bit MAC address.

CurrNwkID - This returns the network ID of the network that the radio is currently assigned to or connected to. A value of 0xFF means the radio is scanning for a network but has not yet joined one.

CurrRF_DataRate - this returns the RF data rate of the network that the radio is currently assigned to or connected to. A value of 0xFF means the radio is scanning for a network but has not yet joined one.

CurrFreqBand - this returns the frequency band of the network that the radio is currently assigned to or connected to. A value of 0xFF means the radio is scanning for a network but has not yet joined one.

LinkStatus - this returns the radio's current connection status to the network. The following codes are defined:

LinkStatus	**Remote Status**	**Base Status**
0	initializing	initializing
1	unlinked, scanning for a network	not used
2	linked, acquiring network parameters	not used
3	linked, registering with the base	not used
4	linked and registered	ready for data transfer

RemoteSlotSize - returns the current remote slot size, defined as the maximum number of bytes a remote can send on a single hop. When using protocol mode, the entire packet, including overhead bytes must be less than or equal to this value or the packet will be discarded. In the three TDMA modes the remote slot size is automatically computed, and this value is read-only. In polling and CSMA modes, the remote slot size must be set by the user. The parameter to set this is *CSMA_RemtSlotSize* in Bank 1.

TDMA_NumSlots - in TDMA access modes, this returns the number of slots currently allocated.

TDMA_CurrSlot - returns the current TDMA slot number assigned to the remote in modes where the slot position is automatically computed. In modes where this number is not applicable, it is read as 0xFF.

HardwareVersion - returns an identifier indicating the type of radio. A value of 0x41 is defined for the DNT2400 Rev A hardware.

FirmwareVersion - returns the firmware version of the radio in 2-digit BCD format.

FirmwareBuildNum - returns the firmware build number, in binary format.

SuperframeCount - returns the current superframe count. The count increments every 64 hops.

RSSI_Idle - returns the last measurement of RSSI made during a time when the RF channel was idle. Can be used to assess the noise floor or detect interferers.

RSSI_Last - returns the last measurement of RSSI made during the receipt of an RF packet with a valid CRC. Can be used for network commissioning and diagnostic purposes.

CurrTxPower - returns the current transmitter power setting, allowing the automatic power setting to be tracked. This parameter is the nominal output power setting in dBm, and is a 2's complement value.

CurrAttemptLimit - this returns the value of *ARQ_AttemptLimit* currently in use (depending on the selected ARQ_Mode, it may not always match the local EEPROM value).

CurrRangeDelay - returns the current propagation delay for this remote as measured from the base (applies to remote nodes only).

FirmwareBuildDate - date of firmware build in MM/DD/YY format.

FirmwareBuildTime - time of firmware build in HH:MM:SS format.

ModelNumber - DNT model number parameter, 0x01 = DNT900, 0x02 = DNT2400.

4.2.4 Bank 3 - Serial

Bank	Loc'n	Name	R/W	Size in bytes	Range	Default
03	00	SerialRate	*R/W*	2	$0..2^{16}$	9.6 kb/s (0x0030)
03	01	SerialParams	*R/W*	1	0..7	8N1
03	03	SerialControls	*R/W*	1	0..7	0x07

SerialRate - sets the serial rate divisor according to the following formula:

Serial rate in b/s = 460800/SerialRate

Serial rate division settings for commonly used baud rates are:

Setting	Serial rate
0x0000	460.8 kb/s
0x0001	460.8 kb/s
0x0002	230.4 kb/s
0x0004	115.2 kb/s
0x0006	76.8 kb/s
0x0008	57.6 kb/s
0x000C	38.4 kb/s
0x0010	28.8 kb/s
0x0018	19.2 kb/s
0x0030	9.6 kb/s (default)
0x0060	4.8 kb/s
0x00C0	2.4 kb/s
0x0180	1.2 kb/s

Note that if a value of 0x0000 is specified, the maximum data rate of 460.8 kb/s will be selected.

SerialParams - sets the serial mode options for parity and stop bits:

Setting	Mode
0x00	No parity, 8 data bits, 1 stop bit (default)
0x01	No parity, 8 data bits, 2 stop bits
0x02	Reserved
0x03	Reserved
0x04	Even parity, 8 data bits, 1 stop bit
0x05	Even parity, 8 data bits, 2 stop bits
0x06	Odd parity, 8 data bits, 1 stop bit
0x07	Odd parity, 8 data bits, 2 stop bits

Note that 8-bit data with no parity is capable of carrying 7-bit data with parity for compatibility without loss of generality for legacy applications that may require it.

SerialControls - this parameter affects the way the radio responds to the various serial control lines. Enabling or disabling response to some serial control signals can facilitate communicating with devices that support only a reduced serial interface. The parameter is defined as a bitmask, with the following options:

bits 7..3 Reserved
bit 2 Base /DCD mode:
1 = The base will only assert /DCD when at least one remote is registered (default).
0 = The base always asserts /DCD, regardless of whether any remotes are attached.
bit 1 /HOST_RTS enable:
1 = Radio will respond to changes on the /HOST_RTS control line (default).
0 = Radio ignores the /HOST_RTS pin and assumes flow control is always asserted.
bit 0 SLEEP/DTR enable.
1 = Radio will respond to changes on the SLEEP Pin (default)
0 = Radio ignores the SLEEP Pin and is always in the awake state.

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4.2.5 Bank 4 - Host Protocol Settings

Bank	Loc'n	Name	R/W	Size in bytes	Range	Default; Options
04	00	ProtocolMode	*R/W*	1	0..1	**0 = transparent**; 1 = protocol
04	01	ProtocolOptions	*R/W*	1	0..255	**0x05**
04	02	TxTimeout	*R/W*	1	0..255	**0 ms**
04	03	MinPacketLength	*R/W*	1	1..255	**1 byte**
04	04	AnnounceOptions	*R/W*	1	0..7	**0x07 all enabled**
04	05	TransLinkAnnEn	*R/W*	1	0..1	**0 = disabled**; 1 = <LINK> announce
04	06	ProtocolSequenceEn	*R/W*	1	0..2	0 = disabled; 1 = startup, **2 = anytime**
04	07	TransPtToPtMode	*R/W*	1	0..1	**0 = multipoint**, 1 = point-to-point

ProtocolMode - this parameter selects the host protocol mode. The default is 0, which is transparent mode, meaning the radio conveys whatever characters that are sent to it transparently, without requiring the host to understand or conform to the DNT2400's built-in protocol. This setting is recommended for point-to-point applications for legacy applications such as wire replacements where another serial protocol may already exist. Setting this parameter to 1 enables the DNT2400 host protocol, which is recommended for point-to-multipoint applications and is preferred for new designs. It is not necessary to define the same protocol mode for all radios in a network. For example, it is frequently useful to configure all the remotes for transparent mode and the base for protocol mode. Note that it is possible for the host to switch the radio from transparent mode to protocol mode and back if desired by transmitting an *EnterProtocolMode* command.

ProtocolOptions - this is a bitmask that selects various options for the protocol mode. The default is 0x05.

bits 7..3	Reserved
bit 2	Enable output of TxReply packets
bit 1	Reserved
bit 0	Enable output of Announce packets

AnnounceOptions - this is a bitmask that enables/disables different types of Announce packets:

bit 7..3	Reserved
bit 2	Enable bit for Announce types E0-EA (error notification)
bit 1	Enable bit for Announce types A1-A7 (<LINK> notifications)
bit 0	Enable bit for Announce types A0 (initialization)

TxTimeout - this parameter is the transmit timeout used for determining message boundaries in transparent data mode. Units are in milliseconds. A message boundary is determined whenever a gap between consecutive characters is equal to or greater than the *TxTimeout* value, or the number of bytes reaches the *MinPacketLength*. Either condition will trigger a transmission. The default *TxTimeout* value is 0 ms.

MinPacketLength - sets the minimum message length used for determining packet boundaries in transparent data mode. The default is one byte. A transmission is triggered when either the number of bytes reaches *MinPacketLength* or a gap is detected between consecutive characters greater than *TxTimout*.

TransLinkAnnEn - enables a link announcement function for transparent mode. Whenever link is acquired or dropped, the strings "<LINK>" or "<DROP>" are sent to the local host.

ProtocolSequenceEn - enables or disables the *EnterProtocolMode* ASCII command string to switch from transparent mode to protocol mode. Valid settings are 0 = disabled, 1 = one time at startup, 2 = enabled at any time. The default is enabled at anytime.

TransPtToPtMode- controls the behavior for addressing packets in transparent mode. When this setting is zero (default), in transparent mode the base will direct packets to the broadcast address. This is useful for

point-to-multipoint where the base is sending data to multiple remotes, for instance in applications where a wireless link is replacing an RS-485 serial bus. When this setting is one, in transparent mode the base will direct packets to the last remote that registered with it. This is useful for point-to-point networks where there are only two endpoints, for instance in applications where a simple serial cable is being replaced.

4.2.6 Bank 5 - I/O Peripheral Registers

Bank	Loc'n	Name	R/W	Size in bytes	Range in bits	Default
05	00	GPIO0	*R/W*	1	1	0
05	01	GPIO1	*R/W*	1	1	0
05	02	GPIO2	*R/W*	1	1	0
05	03	GPIO3	*R/W*	1	1	0
05	04	GPIO4	*R/W*	1	1	0
05	05	GPIO5	*R/W*	1	1	0
05	06	ADC0	*R*	2	10	N/A
05	08	ADC1	*R*	2	10	N/A
05	0A	ADC2	*R*	2	10	N/A
05	0C	Event Flags	*R*	2	10	N/A
05	0E	PWM0	*R/W*	2	9	0
05	10	PWM1	*R/W*	2	9	0

GPIO0..5 - writing to these registers sets the corresponding driver for pins that are enabled outputs. Writing to pins that are enabled as inputs enables or disables the internal pull-up. Reading these registers returns the current level detected on the corresponding pins.

ADC0..2 - read-only, returns the current 10-bit ADC reading for the selected register. See the discussion of the *ADC_SampleIntvl* parameter below.

EventFlags - used with the automatic I/O reporting feature, this parameter indicates which I/O events have been triggered since the last report message:

bits 15..8	Reserved
bit 7	ADC2 high/low threshold excursion
bit 6	ADC1 high/low threshold excursion
bit 5	ADC0 high/low threshold excursion
bit 4	Periodic timer report
bit 3	GPIO3 edge transition
bit 2	GPIO2 edge transition
bit 1	GPIO1 edge transition
bit 0	GPIO0 edge transition

PWM0..1 - sets the PWM (DAC) outputs. The DC voltage derived from the integrated low-pass filters on the PWM output provides an effective DAC resolution of 7 bits (8 bits achievable with external filtering). The range of this parameter is 0x0000 to 0x00FF.

4.2.7 Bank 6 - I/O setup

Bank	Loc'n	Name	R/W	Size in bytes	Range in bits	Default; Options
06	00	GPIO_Dir	*R/W*	1	6	**0** (all inputs)
06	01	GPIO_Init	*R/W*	1	6	**0** (all zeros)
06	02	GPIO_Alt	*R/W*	1	6	**0x08** = use GPIO3 for RS485 enable
06	03	GPIO_Edge Trigger	*R/W*	1	8	**0x00**
06	04	GPIO_SleepMode	*R/W*	1	1	**0 = off**; 1 = use sleep I/O states
06	05	GPIO_SleepDir	*R/W*	1	6	**0** (all inputs)
06	06	GPIO_SleepState	*R/W*	1	6	**0** (all zeros)
06	07	PWM0_Init	*R/W*	2	10	**0x0000**
06	09	PWM1_Init	*R/W*	2	10	**0x0000**
06	0B	ADC_SampleIntvl	*R/W*	2	16	**0x0001** (10 ms)
06	0D	ADC0 ThresholdLo	*R/W*	2	10	**0x0000**
06	0F	ADC0_ThresholdHi	*R/W*	2	10	**0x03FF**

06	11	ADC1_ThresholdLo	*R/W*	2	10	**0x0000**
06	13	ADC1_ThresholdHi	*R/W*	2	10	**0x03FF**
06	15	ADC2_ThresholdLo	*R/W*	2	10	**0x0000**
06	17	ADC2_ThresholdHi	*R/W*	2	10	**0x03FF**
06	19	IO_ReportTrigger	*R/W*	1	0..1	**0x01 (GPIO0)**
06	1A	IO_ReportInterval	*R/W*	4	32	**0x00000BB8** (every 30 seconds)

GPIO_Dir - this parameter is a bitmask that sets whether the GPIOs are inputs (0) or outputs (1). The default is all inputs.

GPIO_Init - this parameter is a bitmask that sets the initial value for any GPIOs which are enabled as outputs. For GPIOs enabled as inputs, this sets the initial pull-up setting.

GPIO_Alt - provides and alternate function for GPIO3 as an RS-485 driver enable.

GPIO_EdgeTrigger - when GPIO triggers are enabled for automatic I/O reporting, this function controls the trigger behavior:

bits 7..6	GPIO3 edge function
bits 5..4	GPIO2 edge function
bits 3..2	GPIO1 edge function
bits 1..0	GPIO0 edge function

The bit values for each GPIO map to the following settings:

Value	GPIO edge behavior
11	Rising edge trigger, neither level keeps remote awake
10	Bidirectional edge trigger, neither level keeps remote awake
01	Rising edge trigger, holding high keeps remote awake
00	Falling edge trigger, holding low keeps remote awake

GPIO_SleepMode - when set to 1, this parameter enables setting of GPIOs to the designated direction and state whenever a device is asleep.

GPIO_SleepDir - when *GPIO_SleepMode* is enabled, this parameter functions as a secondary *GPIO_Dir* to set the direction of the GPIOs during a device's sleep period. This enables the user to provide alternate configurations during sleep that will help minimize current consumption. Bits 0..5 correspond to GPIO0..GPIO5. Set a *GPIO_SleepDir* bit to 1 to specify an output, or to 0 to specify an input.

GPIO_SleepState - when *GPIO_SleepMode* is enabled, this parameter functions as a bitmask to control the states of the GPIOs, the RADIO_TXD output, and the /HOST_CTS and /DCD outputs during a device's sleep period. This allows the user to set alternate configurations during sleep to minimize current consumption. Bits 0..5 correspond to GPIO0..GPIO5 respectively. Bit 6 sets the state of RADIO_TXD, and bit 7 sets the states of /HOST_CTS and /DCD. A sleep state bit is set to 1 to specify a high output or an internal pull-up on an input, or to 0 to specify a low output or no internal pull-up on an input. Bit 6 must be set low in order to achieve minimum sleep current (high impedance load assumed), and the other bits may need to be set low or high depending on their external loads. When bit 6 is set low, expect a serial "break" condition to occur as the module wakes from sleep. The serial break condition can be eliminated by setting bit 6 high, but sleep current will be increased.

PWM0_Init - this parameter sets the initial value for PWM0 at startup.

PWM1_Init - this parameter sets the initial value for PWM1 at startup.

ADC_SampleIntvl - this parameter sets the interval between the beginning of one ADC read cycle and the next ADC read cycle. The three ADC inputs are read on each ADC read cycle. Each *ADC_SampleIntvl* count equals 10 ms. This interval will be the worst-case latency for ADC generated interrupts. This interval is independent of the *IO_ReportInterval* as the ADCs will be read again on that interval.

ADC0..2_ThresholdLo/Hi - these values define thresholds to trigger an I/O report based on ADC measurements. If I/O reporting is enabled, a single EVENT report containing the contents of the I/O bank is generated when a threshold is crossed. Reporting is "edge-triggered" with respect to threshold boundaries, not "level-triggered"; i.e., if the measurement remains there, additional reports are not triggered until the value crosses the threshold again. The thresholds are met whenever one of the following inequalities are satisfied:

ADC*x* < ADC*x*_ThresholdLo
ADC*x* > ADC*x*_ThresholdHi

IO_ReportTrigger - when a selected trigger source is enabled, a trigger event will cause the remote to send an EVENT message to its base containing the entire current values of the I/O Register Bank from GPIO0 up to and including the *EventFlags*, but not the PWM settings which are output-only.

bit 7	ADC2 high/low thresholds
bit 6	ADC1 high/low thresholds
bit 5	ADC0 high/low thresholds
bit 4	Periodic report timer
bit 3	GPIO3 edge
bit 2	GPIO2 edge
bit 1	GPIO1 edge
bit 0	GPIO0 edge

I/O reporting is supported for remotes only, not the base.

IO_ReportInterval - when periodic I/O reporting is enabled, this parameter sets the interval between reports. Units are 10 ms increments, and the default report interval is every 30 seconds but can be set as long as 497 days.

4.2.8 Bank 7 - Authentication List

Bank	***Loc'n***	***Name***	***R/W***	***Size in bytes***
07	00	ApprovedAddr0	*R/W*	3
07	03	ApprovedAddr1	*R/W*	3
07	06	ApprovedAddr2	*R/W*	3
07	09	ApprovedAddr3	*R/W*	3
07	0C	ApprovedAddr4	*R/W*	3
07	0F	ApprovedAddr5	*R/W*	3
07	12	ApprovedAddr6	*R/W*	3
07	15	ApprovedAddr7	*R/W*	3
07	18	ApprovedAddr8	*R/W*	3
07	1B	ApprovedAddr9	*R/W*	3
07	1E	ApprovedAddr10	*R/W*	3
07	21	ApprovedAddr11	*R/W*	3
07	24	ApprovedAddr12	*R/W*	3
07	27	ApprovedAddr13	*R/W*	3
07	2A	ApprovedAddr14	*R/W*	3
07	2D	ApprovedAddr15	*R/W*	3

ApprovedAdd0..15 - the three-byte parameters in Bank 7 are the MAC addresses of the remotes authorized to join the network. The addresses are entered in little-endian format such that a radio with MAC address 012345 would be entered 0x452301.

4.2.9 Bank FF - Special Functions

This bank contains three user functions, *UcReset*, *SleepModeOverride* and *MemorySave*:

Bank	***Loc'n***	***Name***	***R/W***	***bytes***	***Range***	***Description***
FF	00	UcReset	*W*	1	0..90	0x00 = reset, 0x5A = reset with factory defaults,
FF	0C	SleepModeOverride	R/W	1	0..2	0 = inactive, 1 = stay awake, 2 = cancel stay awake
FF	FF	MemorySave	*W*	1	0..1	0 = load factory defaults, 1 = save settings to EEPROM

UcReset - writing a value of 0x00 to this location forces a software reset of the microcontroller. This will enable those changes which require a reset. If this is written to before 0x01 is written to the *MemorySave* parameter, the last parameter values saved before the reset will be in effect. A reply packet, either local or over-the-air, may not be received when writing a value to this register. Writing 0x5A to this location will reset the radio and load the factory default settings. This is equivalent to writing 0x00 to *UcReset* followed by writing 0x00 to *MemorySave*. Note that 0x01 must be written to *MemorySave* to save the retrieved factory defaults.

SleepModeOverride - when remotes are operating in sleep mode, writing 0x01 to the location will cause the remotes to say awake. Writing 0x00 to this location causes the remotes to resume sleeping in 10 seconds. Writing 0x02 to this location causes the remotes to resume sleeping immediately (subject to their configuration).

MemorySave - writing a 0x00 to this location clears all registers back to factory defaults. Writing 0x01 to this location commits the current register settings to EEPROM. When programming registers, all changes are considered temporary until this command is executed.

4.2.10 Protocol Mode Configuration Example

In this example, the host configures the base to transmit 10 dBm (10 mW) of RF power using the *SetRegister* command, 0x04. The *TxPower* parameter is stored in bank 0x00, register 0x18. A one-byte parameter value of 0x01 selects the 10 dBm (10 mW) power level. The protocol formatting for the command is:

0xFB 0x05 0x04 **0x18 0x00 0x01 0x01**

Note the order of the bytes in the command argument: register, bank, span, parameter value. When the base receives the command it updates the parameter setting and return a *SetRegisterReply* message as follows:

0xFB 0x01 **0x14**

In order for this new RF power setting to persist through a base power down, *MemorySave* must be invoked. This is done by setting a one-byte parameter in register 0xFF of bank 0xFF to 0x01 with another *SetRegister* command:

0xFB 0x05 0x04 **0xFF 0xFF 0x01 0x01**

The base will write the current parameter values to EEPROM and return a *SetRegisterReply* message:

0xFB 0x01 **0x14**

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4.2.11 Protocol Mode Sensor Message Example

In this example, the base host requests an ADC1 reading from a remote using the *GetRemoteRegister* command, 0x0A. The MAC address of the remote is 0x000102. The current ADC1 measurement is read from register 0x08 in bank 0x05. The ADC reading spans two bytes. The protocol formatting for this command is:

0xFB 0x07 0x0A **0x02 0x01 0x00** 0x08 0x05 0x02

Note the remote MAC address 0x000102 is entered in Little-Endian byte order, 0x02 0x01 0x00. The ADC reading is returned in a *GetRemoteRegisterReply* message:

0xFB 0x0B 0x1A **0x00** 0x02 0x01 0x00 **0xC4** 0x08 0x05 0x02 **0xFF 0x02**

Substantial information is returned in the message. The last two byes of the message give the ADC reading in Little-Endian format, 0xFF 0x02. The ADC reading is thus 0x02FF. The RSSI value is the byte following the address, 0xC4 (-60 dBm). The *TxStatus* byte to the right of the *GetRemoteRegisterReply* Packet Type is 0x00, showing the packet was acknowledged on the RF channel.

4.2.12 Protocol Mode Event Message Example

In this example, the *IO_ReportInterval* is set to 10 seconds and the *periodic report timer* bit in the *IO_ReportTrigger* parameter is set on the remote, with MAC address 0x123456. This causes event messages to be sent from this remote every 10 seconds. The *IO_ReportInterval* and the *IO_ReportTrigger* parameters are loaded using *SetRemoteRegister* commands. The command to set the *IO_ReportInterval* to 10 seconds is:

0xFB 0x0B 0x0B 0x56 0x34 0x12 0x1A 0x06 0x04 **0xE8 0x03 0x00 0x00**

The *IO_ReportInterval* parameter starts in location 0x1A of bank 0x06. The report interval is set in 10 ms units, so a 10 second report interval is 1000 units or 0x000003E8 (Little-Endian format E8 03 00 00). The *IO_ReportInterval* parameter is updated and *SetRemoteRegisterReply* is returned:

0xFB 0x06 0x1B 0x00 0x56 0x34 0x12 0xC4

The command to set the *periodic report timer* bit in *IO_ReportTrigger* to is:

0xFB 0x08 0x0B 0x56 0x34 0x12 0x19 0x06 0x01 **0x10**

The *periodic report timer* bit in *IO_ReportTrigger* is located in bit position four (00010000b) or 0x10. The *IO_ReportTrigger* parameter is updated and *SetRemoteRegisterReply* is returned:

0xFB 0x06 0x1B 0x00 0x56 0x34 0x12 0xC4

The remote will start sending event messages on 10 second intervals as shown in the log records below:

```
FB 16 28 56 34 12 CB 00 05 0E 01 00 00 00 01 01 F9 01 DF 01 C9 01 10 00
FB 16 28 56 34 12 B6 00 05 0E 01 00 00 00 01 01 F8 01 DF 01 CC 01 10 00
FB 16 28 56 34 12 B3 00 05 0E 01 00 00 00 01 01 F8 01 E0 01 CC 01 10 00
FB 16 28 56 34 12 B1 00 05 0E 01 00 00 00 01 01 F9 01 DF 01 C9 01 10 00
FB 16 28 56 34 12 AE 00 05 0E 01 00 00 00 01 01 F9 01 DF 01 C8 01 10 00
FB 16 28 56 34 12 AD 00 05 0E 01 00 00 00 01 01 F9 01 E1 01 CF 01 10 00
```

IO_ReportTrigger generates *RxEvent* messages (*PktType* 0x28). The message payload consists of the first 14 bytes in Bank 5, including the state of GPIO0 through GPIO5, the input voltages measured by ADC0 through ADC2, and the state of the event flags. Note the ADC readings and the event flags are presented in Little-Endian order.

5.0 DNT2400DK Developer's Kit

Figure 5.0.1 shows the main contents of a DNT2400DK Developer's kit:

Figure 5.0.1

5.1 DNT2400DK Kit Contents

- Two DNT2400P radios installed in DNT2400 interface boards (labeled Base and Remote)
- Two 2 dBi dipole antennas with two U.FL coaxial jumper cables
- Two 9 V wall-plug power suppliers, 120/240 VAC, plus two 9 V batteries (not show above)
- Two RJ-45/DB-9F cable assemblies, one RJ-11/DB-9F cable assembly, two A/B USB cables
- One DNT2400DK documentation and software CD

5.2 Additional Items Needed

To operate the kit, the following additional items are needed:

- One PC with Microsoft Windows XP or Vista Operating System. The PC must be equipped with a USB port or a serial port capable of operation at 9.6 kb/s.

5.3 Developer's Kit Operational Notes:

DNT2400DK kits are preconfigured to run at a 500 kb/s RF data rate with 1 mW of RF transmitter power. Due to the high sensitivity of the DNT2400 radio module which provides its exceptional range, if the RF transmit power is increased from the default 1 mW, the DNT2400 nodes must be separated by a minimum of 6 feet for 10 mW or 25 feet at 63 mW in order to reliably link.

5.4 Developer's Kit Default Operating Configuration

The default operating configuration of the DNT2400DK developer's kit is TDMA Mode 2, point-to-point, with transparent serial data at 9.6 kb/s, 8N1. One DNT2400P is preconfigured as a base and the other as a remote. Labels on the bottom of the interface boards specify Base or Remote. The defaults can be overridden to test other operating configurations using the DNT Demo utility discussed in Section 5.5. The default RF power setting is 0 dBm (1 mW), which is suitable for operation at a spacing of about 1.5 to 2 m (4 to 6 ft). The RF power level should be set higher as needed for longer range operation. Note that setting the RF power to a high level when doing testing at 2 m can overload the DNT2400P receiver and cause erratic operation. See Section 5.3.

5.5 Developer's Kit Hardware Assembly

Observe ESD precautions when handling the kit circuit boards. The components that make up a development board are shown in Figure 5.5.1, and are shipped with the DNT2400P radios and U.FL coax jumper cables installed in the interface board. If a DNT2400P radio and/or the U.FL jumper cable has been unplugged after receipt, confirm the DNT2400P is correctly plugged into its interface board with the radio oriented so that its U.FL connector is next to the U.FL connector on the interface board, as shown in Figure 5.5.2. Also check the radio's alignment in the socket on the interface board. No pins should be hanging out over the ends of the connector. Next, install the dipole antennas.

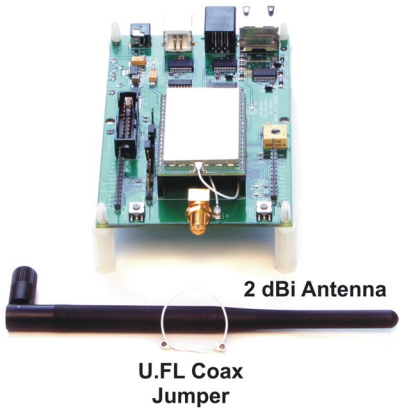

Figure 5.5.1

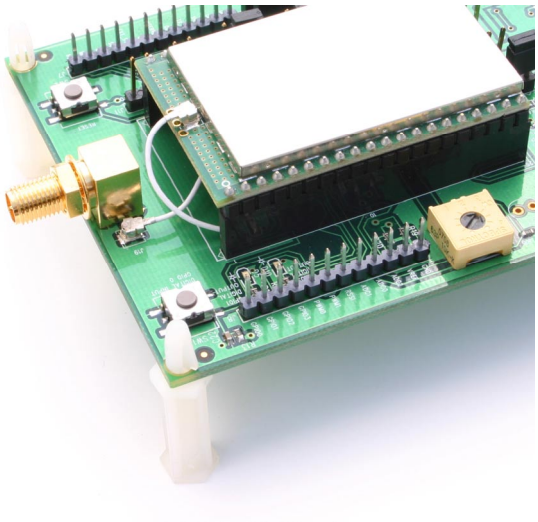

Figure 5.5.2

As shown in Figure 5.5.3, there is a jumper on pins J14. This jumper can be removed and a current meter connected across J14 to measure just the DNT2400's current consumption during operation.

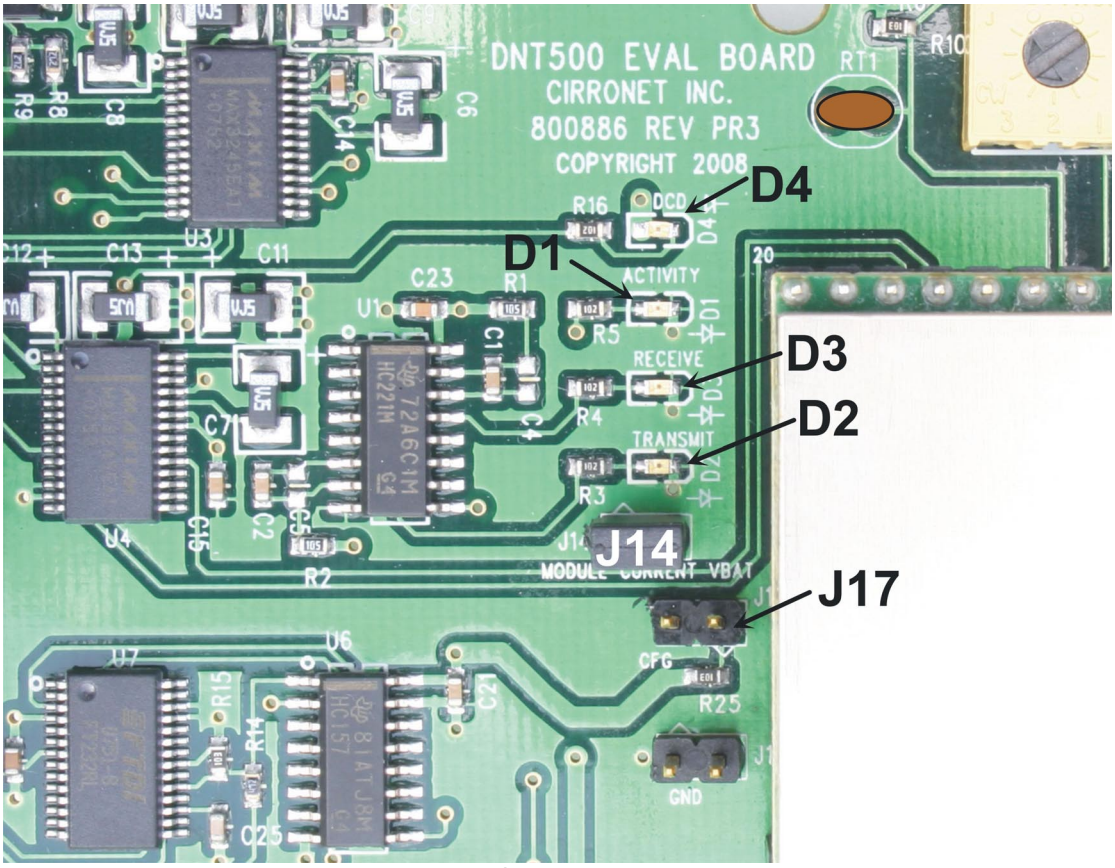

Figure 5.5.3

There are three serial connectors on the interface boards, as shown in Figure 5.5.4. The RJ-45 connector provides a high-speed RS232 interface to the DNT2400P's main serial port. The USB connector provides an optional interface to the radio's main serial port. The RJ-11 connector provides a high-speed RS232 interface to the radio's diagnostic port. The DNT Demo utility program runs on the radio's main port.

Figure 5.5.4

Many desktop PCs have a built-in serial port capable of operation at 9.6 kb/s. The kit can be run satisfactorily at the 9.6 kb/s data rate, but not at its fastest throughput. Use the RJ-45 to DB-9F cable assemblies for serial port operation.

Optionally, the kit development boards can be run from USB ports. Plugging in the USB cable automatically switches operation from the RJ-45 connector. The USB interface is based on an FT232RL serial-to-USB converter IC manufactured by FTDI. The FT232RL driver files are located in the i386 and AMD64 folders on the kit CD, and the latest version of the drivers can downloaded from the FTDI website, www.ftdichip.com. The drivers create a virtual COM port on the PC. Power the Base using one of the supplied wall-plug power supplies. Next connect the Base to the PC with a USB cable. The PC will find the new USB hardware and open a driver installation dialog box. Enter the letter of the drive holding the kit CD and click *Continue*. The installation dialog will run *twice* to complete the FT232R driver installation.

5.6 DNT Demo Utility Program

The DNT Demo utility requires only one PC for initial kit operation and sensor applications (ADC, PWM and digital I/O). Two serial/USB ports are required for bidirectional serial communications. Section 5.6.1 below covers using the DNT Demo utility for initial kit operation and familiarization. Section 5.6.2 covers serial message communication and radio configuration.

5.6.1 Initial Kit Operation

Create a file folder on the PC and copy the contents of the kit CD into the folder.

The DNT Demo utility program runs on the radio's main port. The preferred PC interface is a serial port capable of operating at 9.6 kb/s or faster. As discussed above, the USB interface can also be used, Connect the Base to the PC and power up the Base and the Remote development boards with the supplied wall-plug power supplies.

The DNT Demo utility program is located in the *PC Programs* folder. The DNT Demo requires no installation and can be simply copied to the PC and run. Start the DNT Demo on the PC. The start-up window is shown in Figure 5.6.1.1.

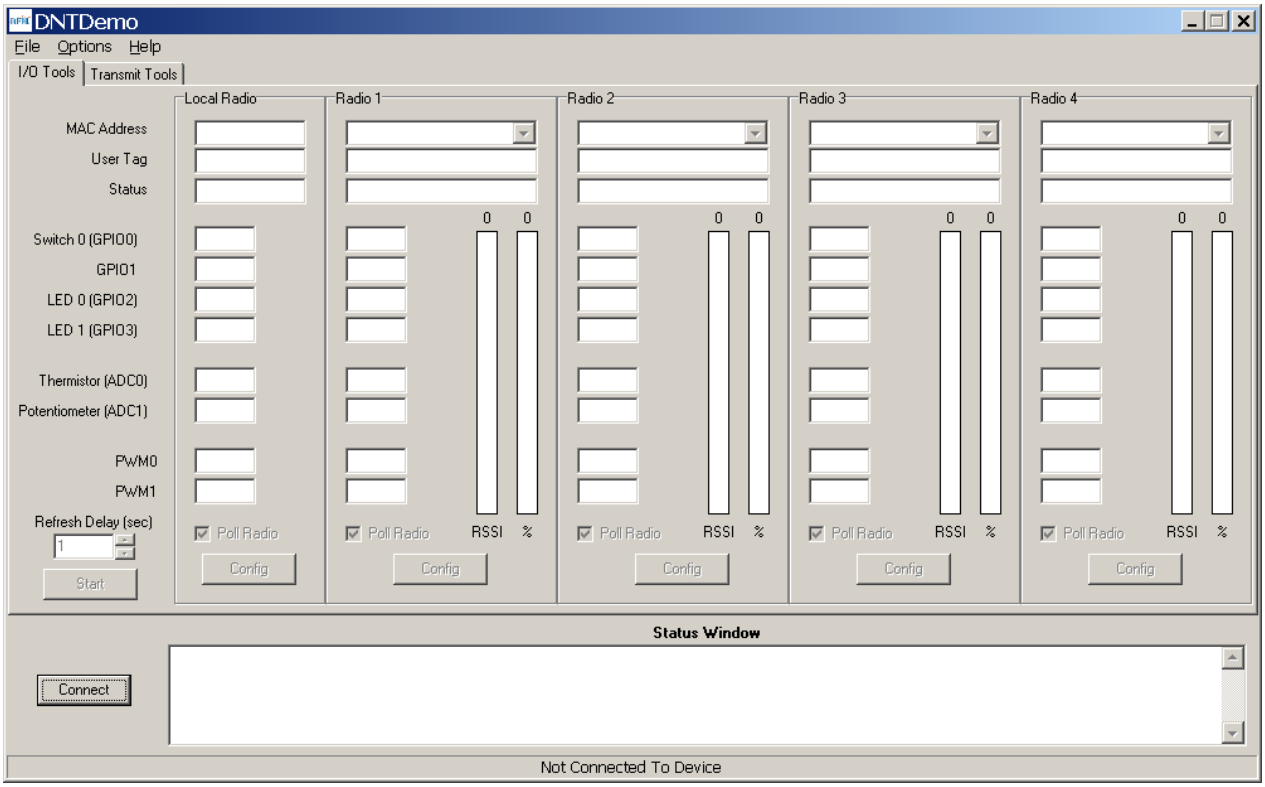

Figure 5.6.1.1

Click on *Connect* to open the *Select Comm Port Settings* dialog box, as shown in Figure 5.6.1.2. Set the baud rate to 9600 (9.6 kb/s). Set the *CommPort* to match the serial port connected to the Base, either the hardware port or the USB virtual serial port. Then click *OK* to activate the serial connection.

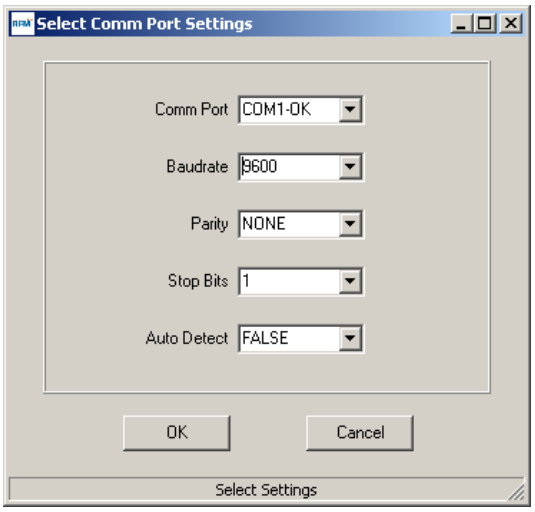

Figure 5.6.1.2

At this point the Demo will collect data from the Base, filling in data in the *Local Radio* column on the Demo window as shown in Figure 5.6.1.3. The *Status Window* should also show that the Remote has joined the Base. Click on the drop-down box at the top of the *Radio 1* column and select the *MAC Address* for the Remote. Next press the *Start* button using the default 1 second *Refresh Delay*.

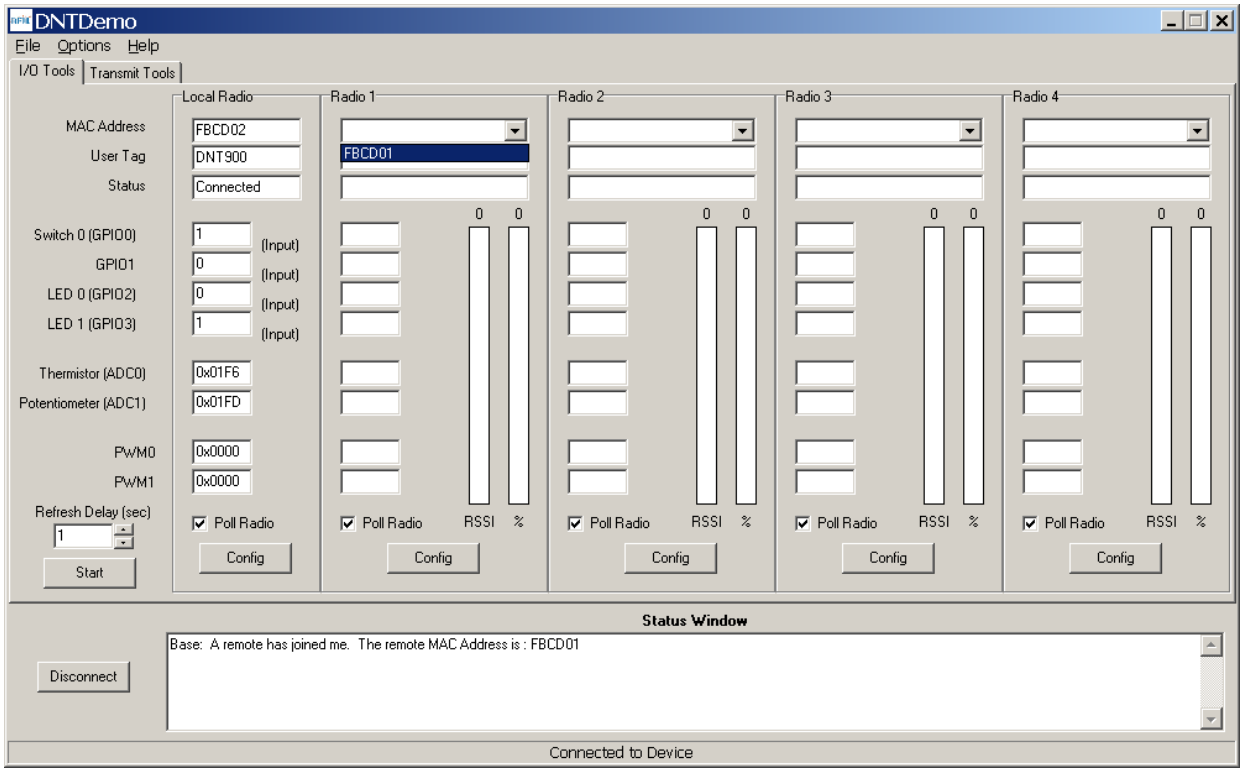

Figure 5.6.1.3

The Demo will display updated data on the Remote in the *Radio 1* column, including bar graphs of *RSSI* signal strength in dBm and percent packet success rate, as shown in Figure 5.6.1.4. Adjusting the large pot on the Remote can be observed on the *Potentiometer (ADC1)* row.

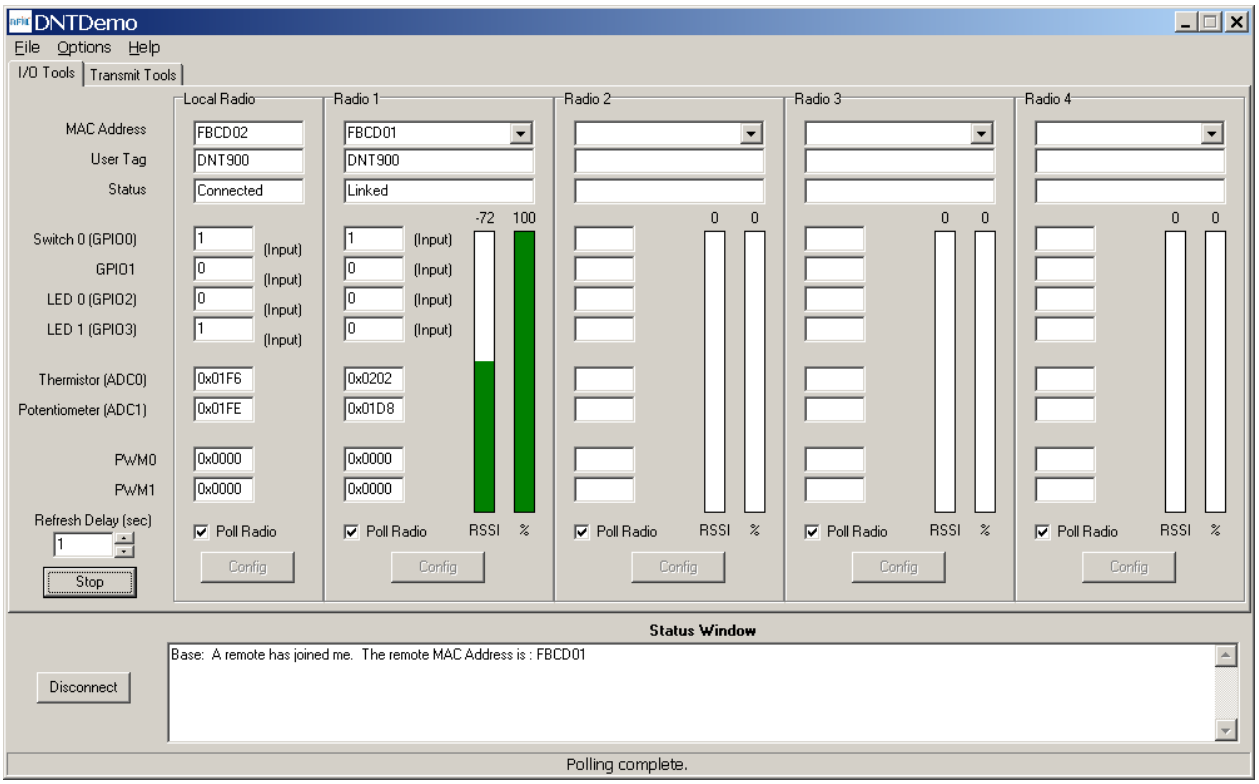

Figure 5.6.1.4

To perform serial data loop back testing with the kit, move the two jumpers on the Remote board labeled *Ext_TX* and *Ext_RX* to connect the center and right header pins. This disconnects the module's TX and RX pins from the USB and RS-232C circuits. Use a banana clip or other short jumper to connect together the two pins on the header labeled *Ext_MICRO*. See Figure 5.6.1.5. Attempting loop back testing by connecting Pins 2 and 3 of the DB9 serial connector can cause erratic behavior due to noise coupling from the serial TX and RX lines into the weakly pulled up flow control lines on the board.

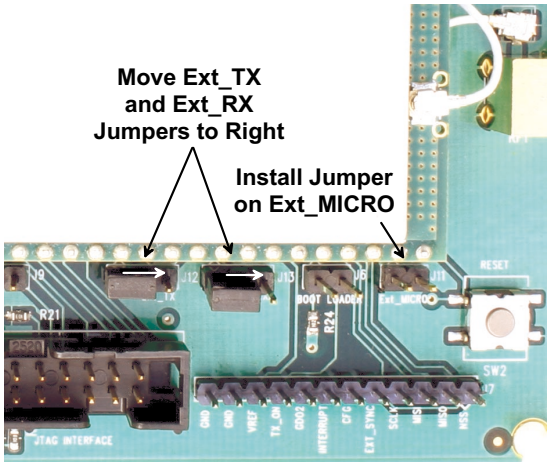

Figure 5.6.1.5

In order to turn off the DCD LED (D4) on the development board in sleep mode, the *GPIO_ SleepState* parameter in the DNT2400P has been set to 0xC0 rather than the factory default value of 0x00. If the DNT2400P is reset to its factory defaults, the DCD LED with remain on in sleep mode until the *GPIO_ SleepState* is set to 0xC0. See Section 4.2.7 for additional information on the *GPIO_SleepState* parameter.

If any difficulty is encountered in setting up the DNT2400DK development kit, contact RFM's module technical support group. The phone number is +1.678.684.2000. Phone support is available from 8:30 AM to 5:30 PM US Eastern Time Zone, Monday through Friday. The E-mail address is tech_sup@rfm.com.

5.6.2 Serial Communication and Radio Configuration

Connect PCs to both the Base and the Remote for serial communication testing. Click the *Stop* button under the *Refresh Delay* label on the *I/O Tools* tab and move to the *Transmit Tools* tab, as shown in Figure 5.6.2.1.

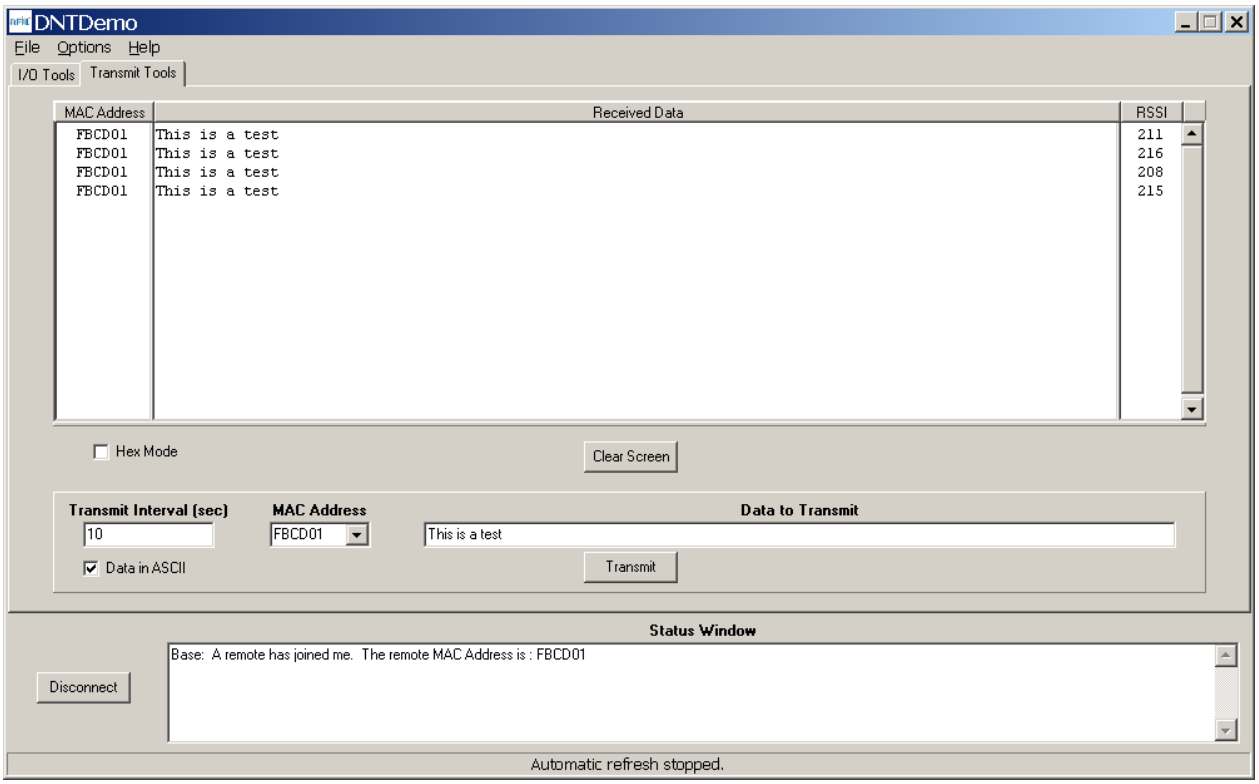

Figure 5.6.2.1

Pressing the *Transmit* button on this screen sends the message in the *Data to Transmit* text box to the selected *MAC Address*. Data sent to the local radio is displayed in the *Received Data* text box. Received data can be displayed as ASCII (default) or in Hexadecimal format by checking the *Hex Mode* check box. When the *Transmit Interval* is set to zero, *Data to Transmit* is sent once when the *Transmit* button is clicked. When the *Transmit Interval* is set to a positive number, Pressing the *Transmit* button once will cause a transmission each transmit interval (seconds) until the button is pressed again.

Returning to the *I/O Tools* tab, the multi-tab *Configuration* window for each radio can be accessed by clicking on its *Config* button. The data presented on the first six tabs corresponds to configuration register Banks 0 through 5 as discussed in Section 4.2 above, with the data on the last two tabs corresponding to configuration register Bank 6.

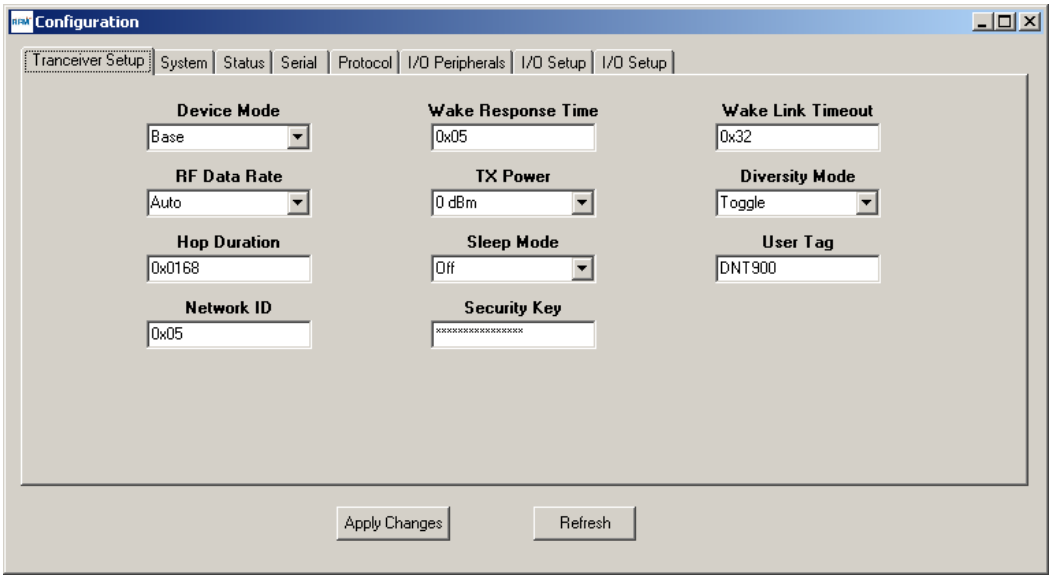

Figure 5.6.2.2

The *Transceiver Setup* Tab is shown in Figure 5.6.2.2 and corresponds to Bank 0. The current values of each Bank 0 parameter are displayed and can be updated by selecting from the drop-down menus or entering data from the keyboard, and then pressing the *Apply Changes* button. Note that data is *displayed and entered in Big-Endian order*. The Demo automatically reorders multi-byte data to and from Little-Endian order when building or interpreting messages.

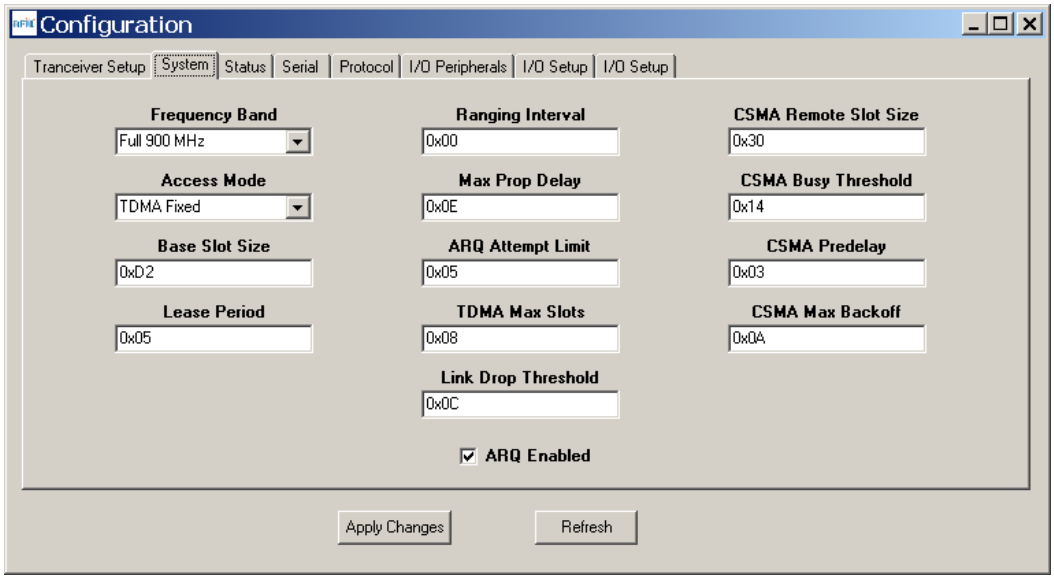

Figure 5.6.2.3

Figure 5.6.2.3 shows the *System* tab contents, corresponding to Bank 1. The current values of each parameter are displayed and can be updated by selecting from the drop-down menus or entering data

from the keyboard, and then pressing the *Apply Changes* button. Note that Bank 1 holds configuration parameters for the base only except for *ARQ_Mode,* which applies to both the base and the remotes.

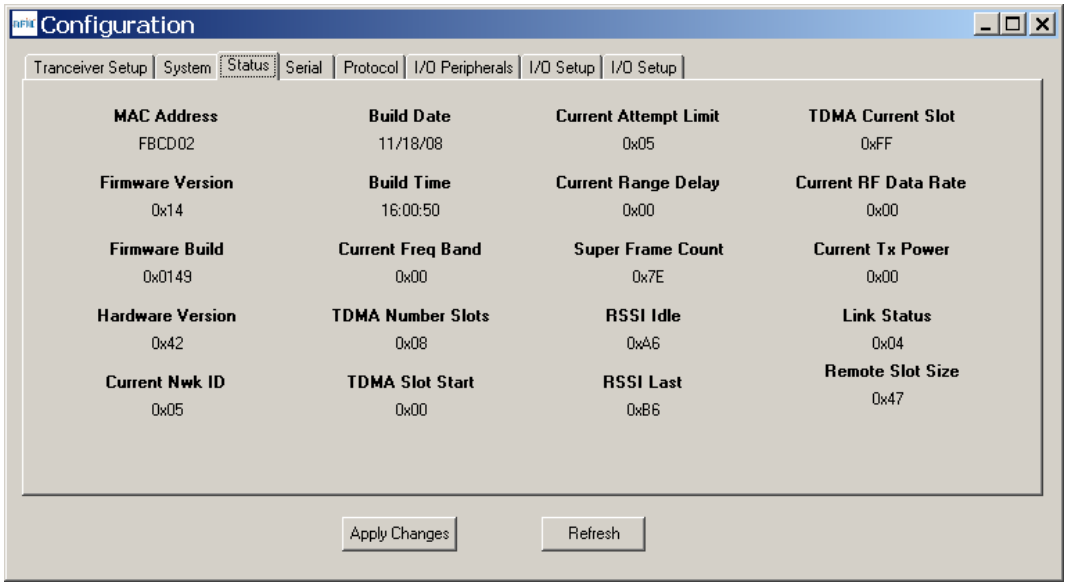

Figure 5.6.2.4

Figure 5.6.2.4 shows the *Status* tab contents, corresponding to Bank 2. Note the *Status* tab contains read-only parameters.

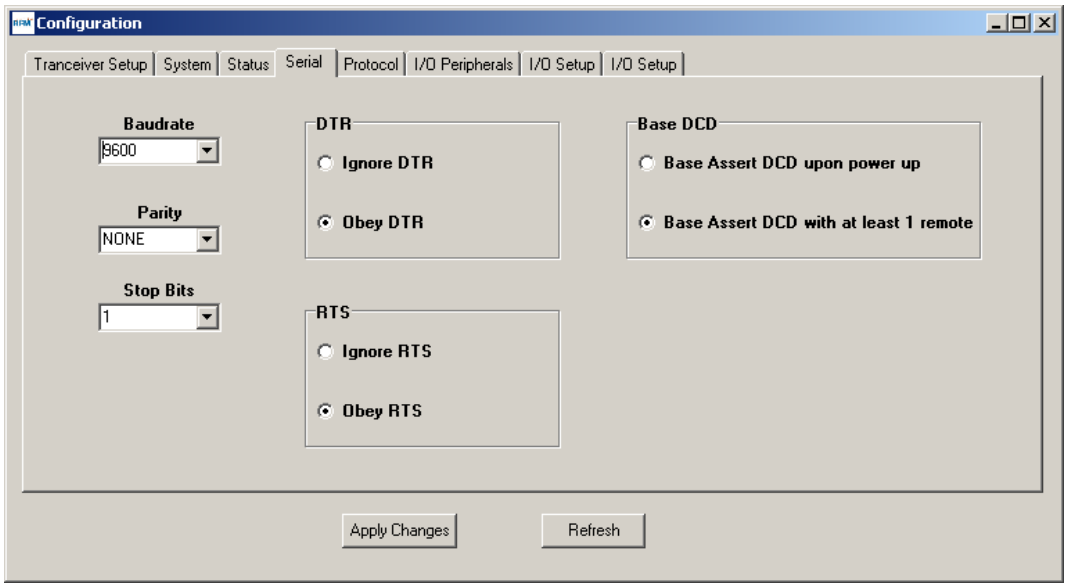

Figure 5.6.2.5

Figure 5.6.2.5 shows the *Serial* tab contents corresponding to Bank 3. The values shown are the defaults for serial port operation.

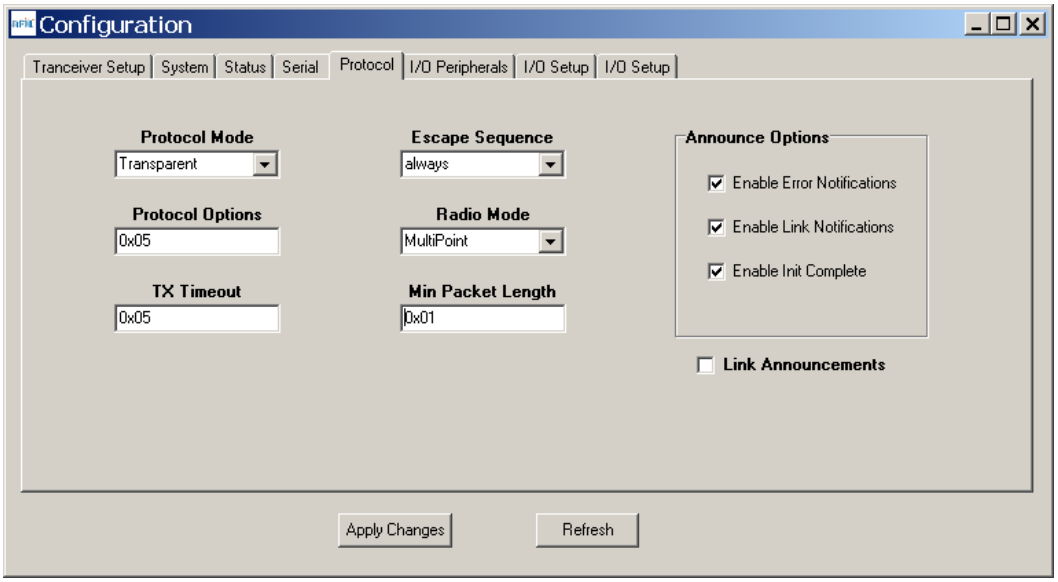

Figure 5.6.2.6

Figure 5.6.2.6 shows the *Protocol* tab contents, corresponding to Bank 4. Transparent data serial communication is currently chosen.

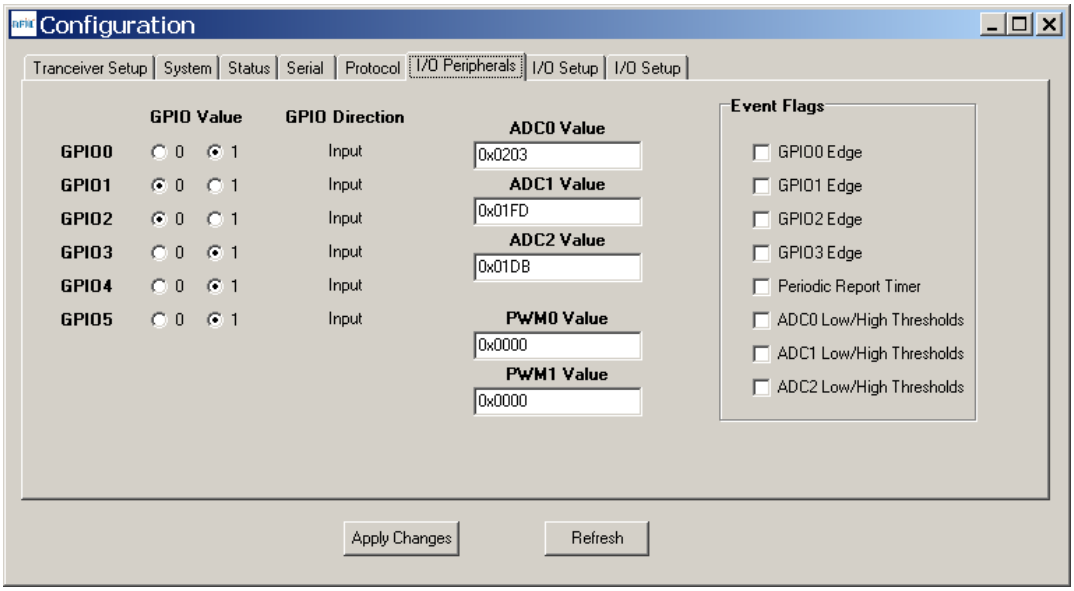

Figure 5.6.2.7

Figure 5.6.2.7 shows the *I/O Peripherals* tab contents, corresponding to Bank 5. GPIO ports 1, 3, 4 and 5 are logic high, GPIO port 1 and 2 are logic low. The 10-bit ADC input readings and PWM output settings are given in *Big-Endian* byte order. Event flags are presented on the right side of the window.

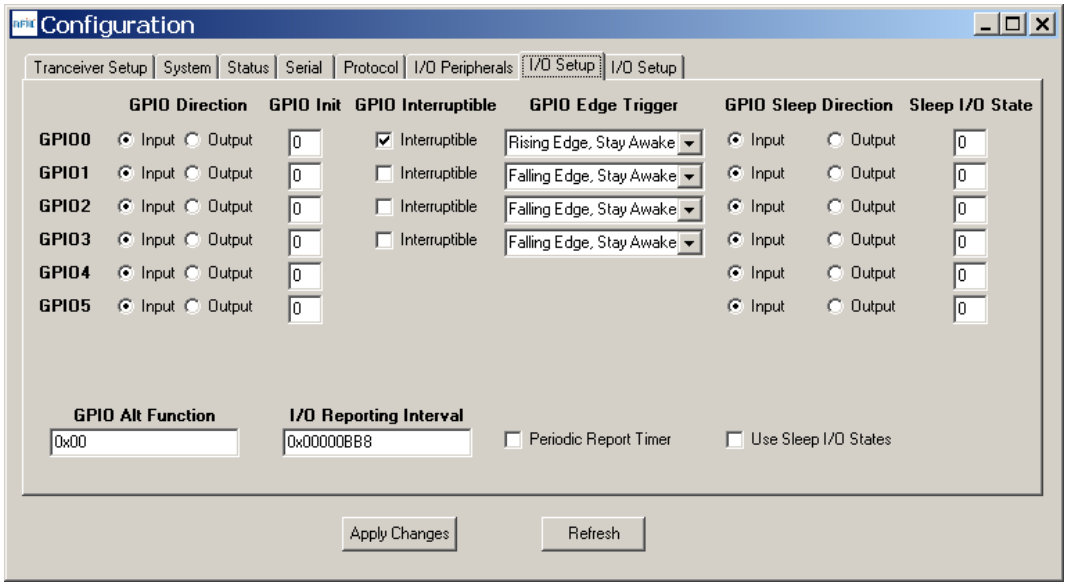

Figure 5.6.2.8

Figure 5.6.2.8 shows the first *I/O Setup* tab contents, corresponding to Bank 6 GPIO parameters. This tab allows the direction of the GPIO ports to be set both for active and sleep modes, and in the case of GPIO outputs, the initial power up states and sleep mode states to be set. When GPIO ports 0 - 3 are configured as inputs, event interrupts can be set for them with check boxes. The type of interrupt trigger is selected from the drop-down boxes to the right of the check boxes. GPIO alternate function, periodic I/O reporting, reporting interval and enable/disable sleep I/O states can also be specified under this tab.

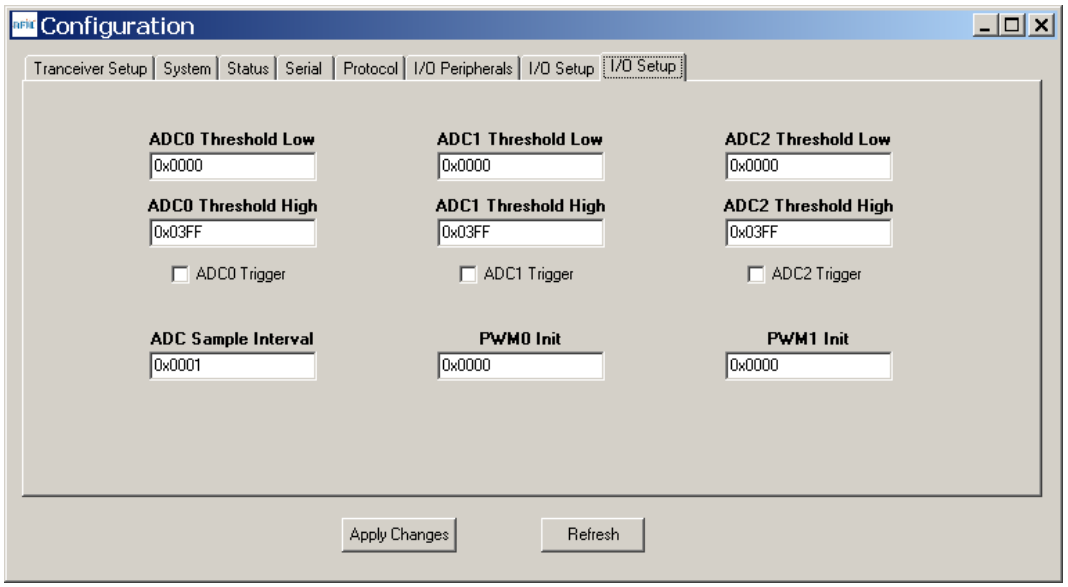

Figure 5.6.2.9

Figure 5.6.2.9 shows the second *I/O Setup* tab contents, corresponding to Bank 6 ADC input and PWM output parameters. The ADC sampling interval, high and low thresholds for event reporting and event reporting triggers on each ADC channel can be set, along with the start-up output values for each PWM (DAC) channel.

5.7 DNT Wizard Utility Program

The DNT Wizard is a complementary program to the DNT Demo that emphasizes the details of serial communication between a DNT2400 and its host computer. The DNT Wizard start-up window is shown in Figure 5.7.1.

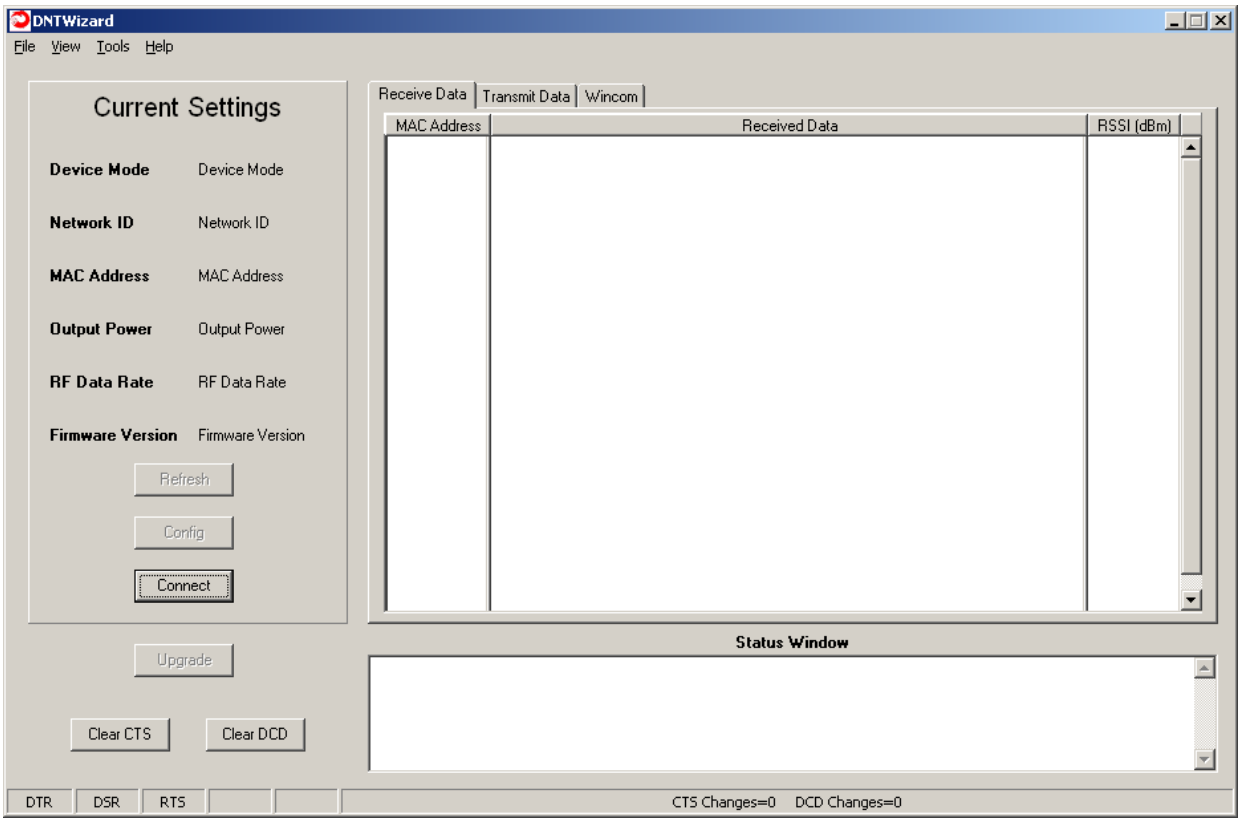

Figure 5.7.1

The DNT Wizard uses three Function keys:

F1 toggles the SLEEP/DTR input to the DNT2400 on and off. This allows the DNT2400 to be reset.
F2 toggles the RTS input to the DNT2400 on and off, providing manual flow control.
F6 toggles test transmissions on and off. The test message is “This is a test”.

The DNT Wizard also includes the ability to log messages to and from the DNT2400. This feature is especially useful in confirming the format of protocol command and reply messages. Control of the log file is under the *View* menu. Logging is enabled by default. The log file created is *logfile.dat*, and is in ASCII text format. An example log is shown at the end of this section.

Click on *Connect* to open the *Select Comm Port Settings* dialog box, as shown in Figure 5.7.2. Set the baud rate to 9600 (9.6 kb/s). Set the *CommPort* to match the serial port connected to the Base, either the hardware port or the USB virtual serial port. Then click *OK* to activate the serial connection.

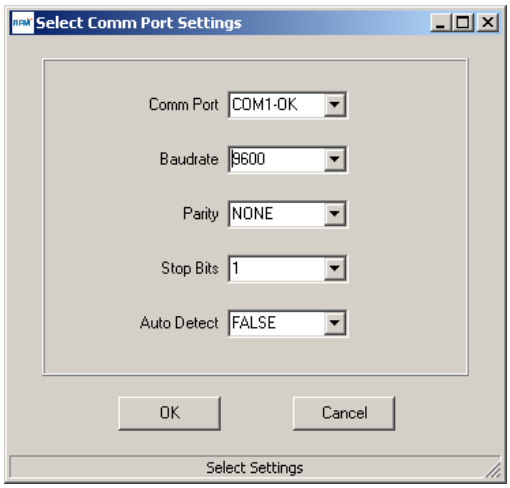

Figure 5.7.2

At this point the Wizard will collect data from the Base, filling in data under *Current Settings* as shown in Figure 5.7.3. The *Status Window* should also show that the Remote has joined the Base.

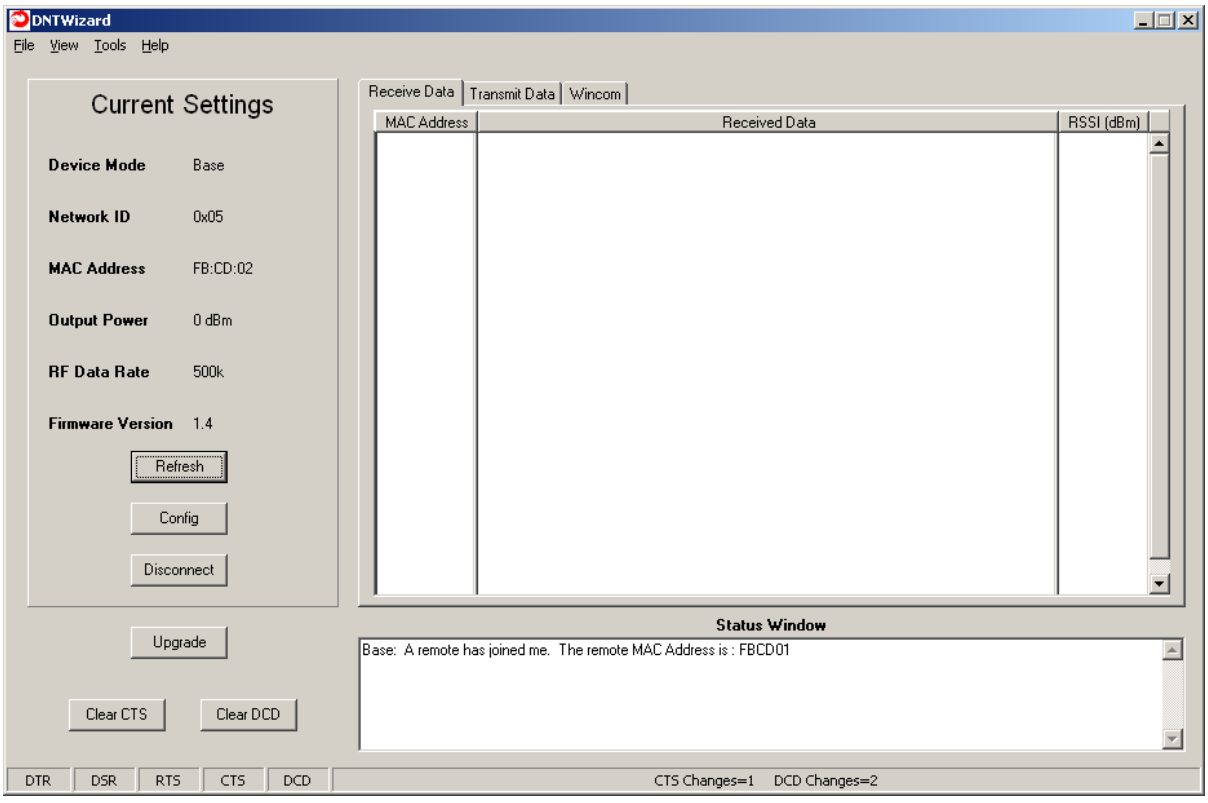

Figure 5.7.3

There are three tabs on the DNT Wizard main window: *Receive Data*, *Transmit Data* and *Wincom*.

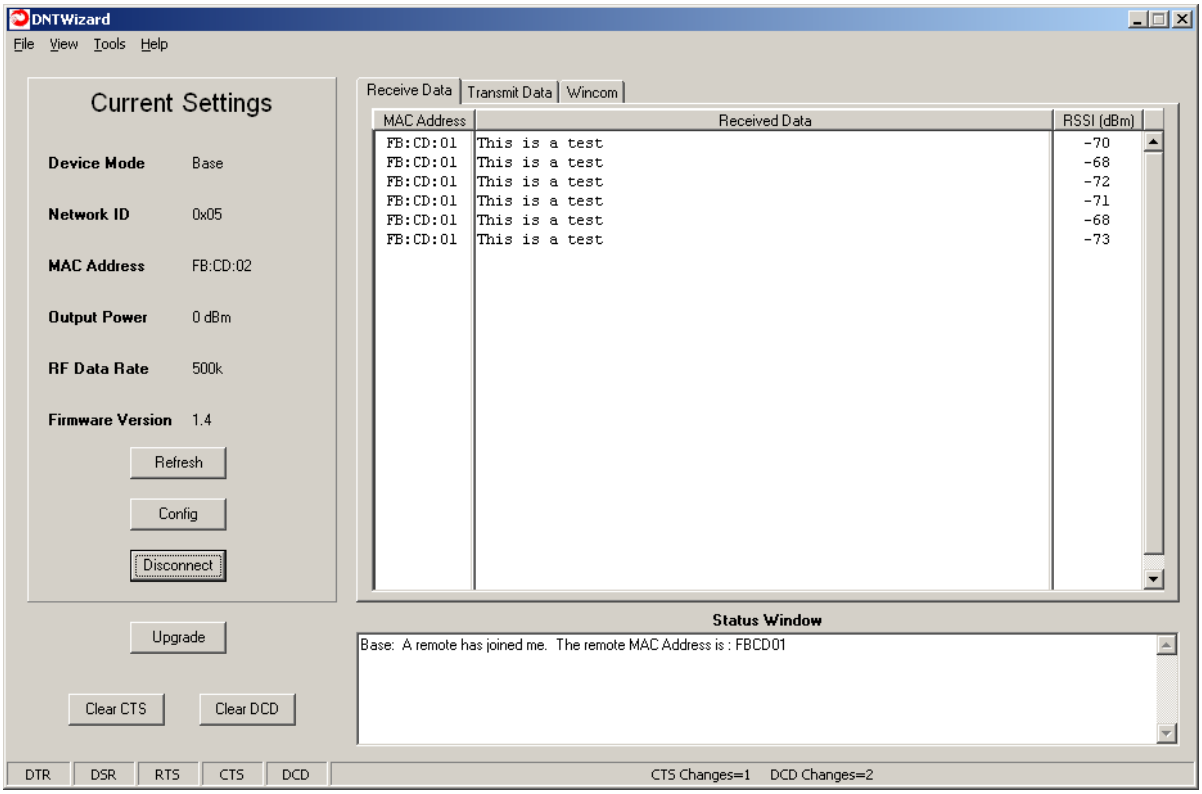

Figure 5.7.4

Received messages are displayed in the *Receive Data* tab, along with the MAC address of the sender and the RSSI (signal strength) of the received message in dBm. See Figure 5.7.4.

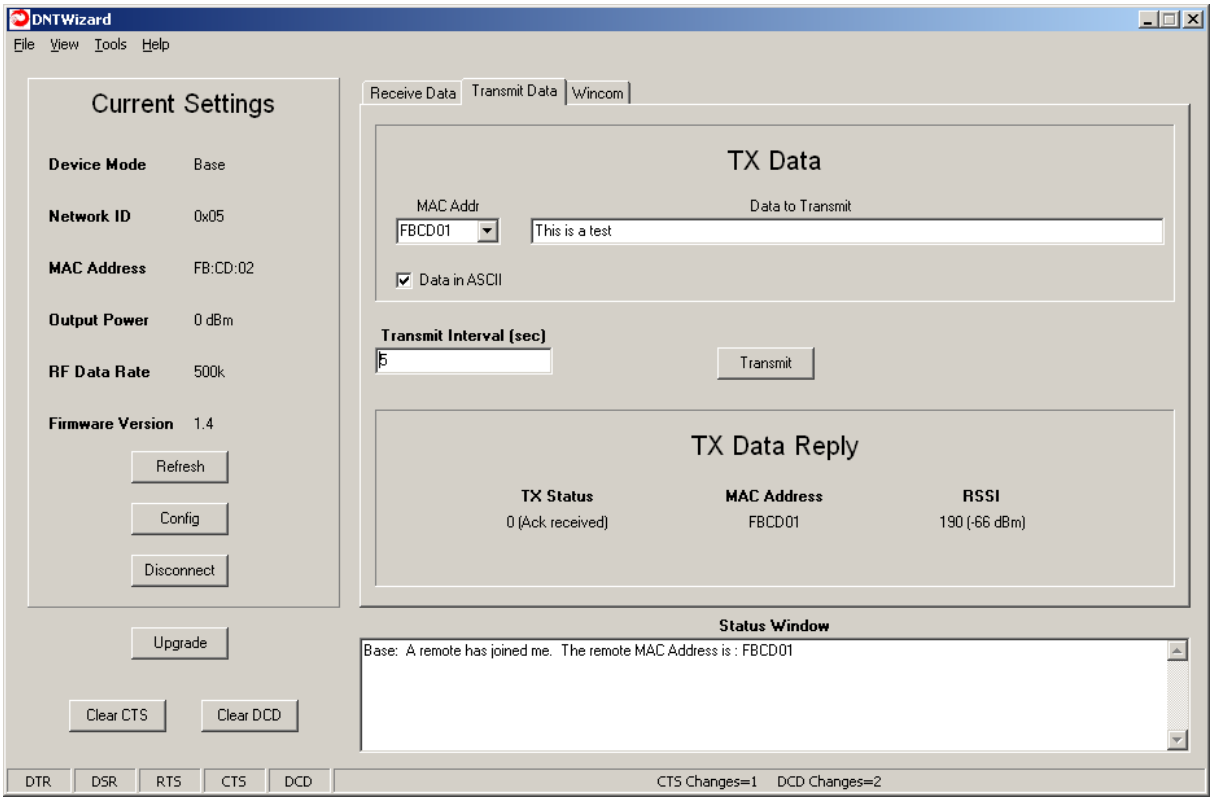

Figure 5.7.5

The *Transmit Data* tab is shown in Figure 5.7.5. The message to send is input in the *Data to Transmit* text box. The address to send the message can be chosen or input in the *MAC Addr* drop-down box. Note that the address for the base is always 0x000000. If the *Transmit Interval* is set to 0, the message is sent once each time the *Transmit* button is clicked. When the *Transmit Interval* is set to an integer greater than zero, the message will sent at the beginning of each interval until the *Stop* button (was *Transmit* button) is clicked. The status of each transmission is shown below *TX Data Reply*. Figure 5.7.5 shows that the transmitted message was ACKed, with the received signal strength of the ACK -66 dBm.

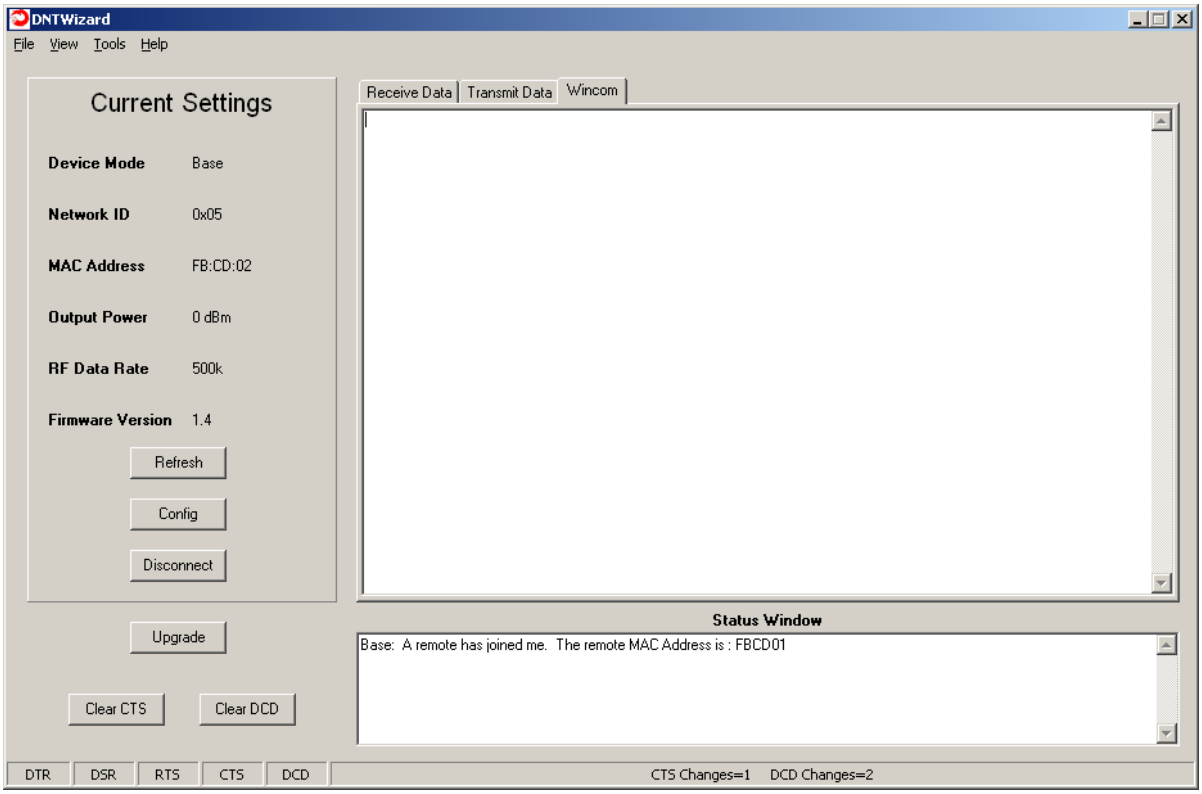

Figure 5.7.6

As shown in Figure 5.7.6, the *Wincom* tab provides the basic functionality of a serial terminal program. Messages typed in are sent, and messages received are appended to the bottom of the on-screen text.

The multi-tab *Configuration* window is accessed by clicking on its *Config* button. The data presented on the first six tabs corresponds to configuration register Banks 0 through 5 as discussed in Section 4.2 above, with the data on the last two tabs corresponding to configuration register Bank 6.

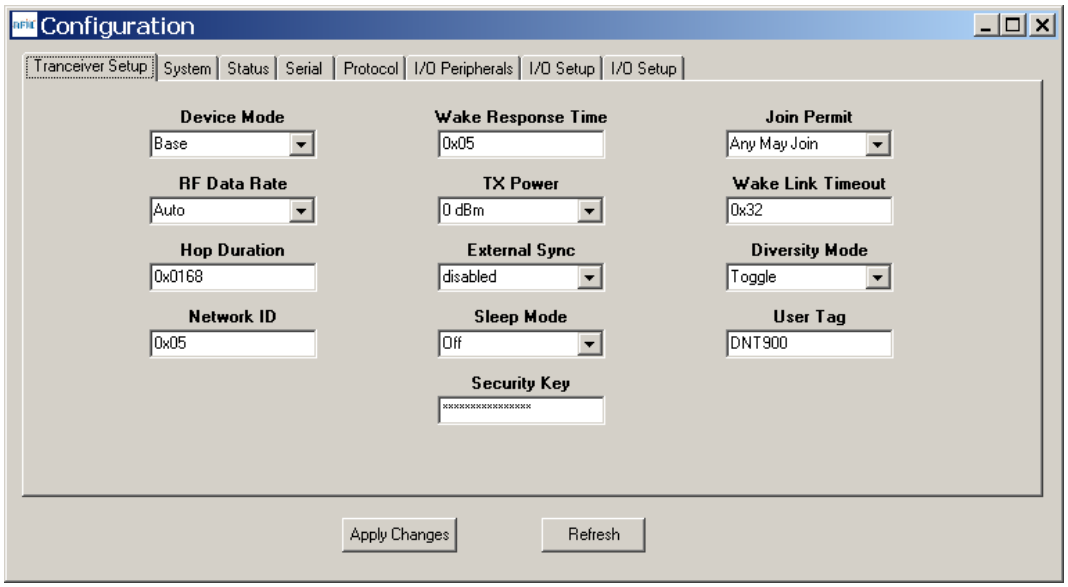

Figure 5.7.7

The *Configuration* window in the DNT Wizard is identical the *Configuration* window in the DNT Demo. See Figures 5.6.2.2 through 5.6.2.9 for *Configuration* window details.

Details of the *File*, *View* and *Tools* menus are shown in Figure 5.7.8.

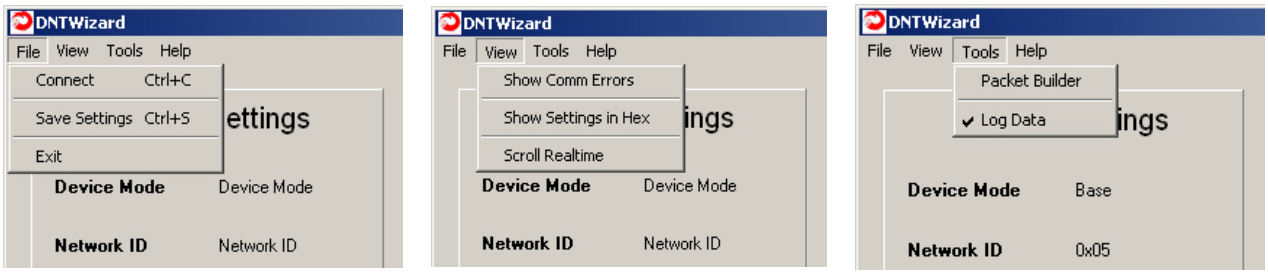

Figure 5.7.8

The *Tools* menu contains two very useful items. *Packet Builder* opens the window shown in Figure 5.7.9. On the left, the *Packet Type* drop-down box provides a selection of all packet types used in the DNT2400 protocol. On the right, the reply packet types are presented.

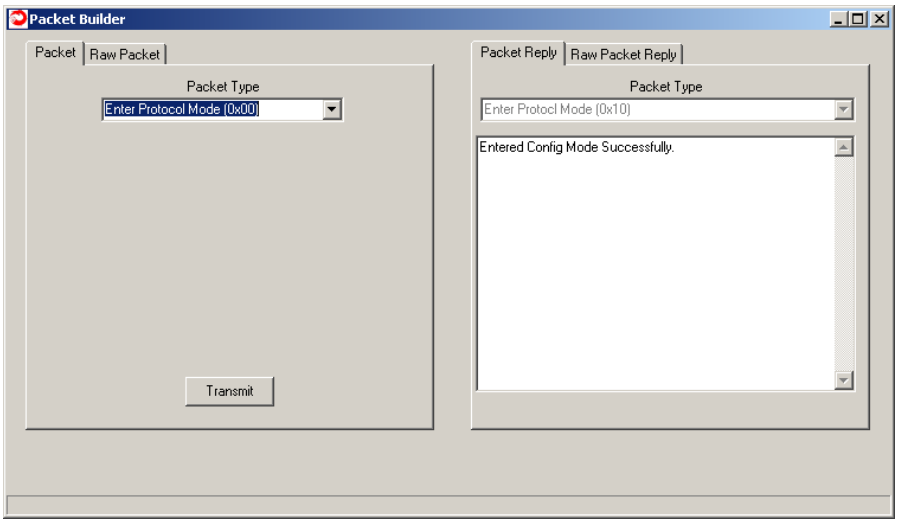

Figure 5.7.9

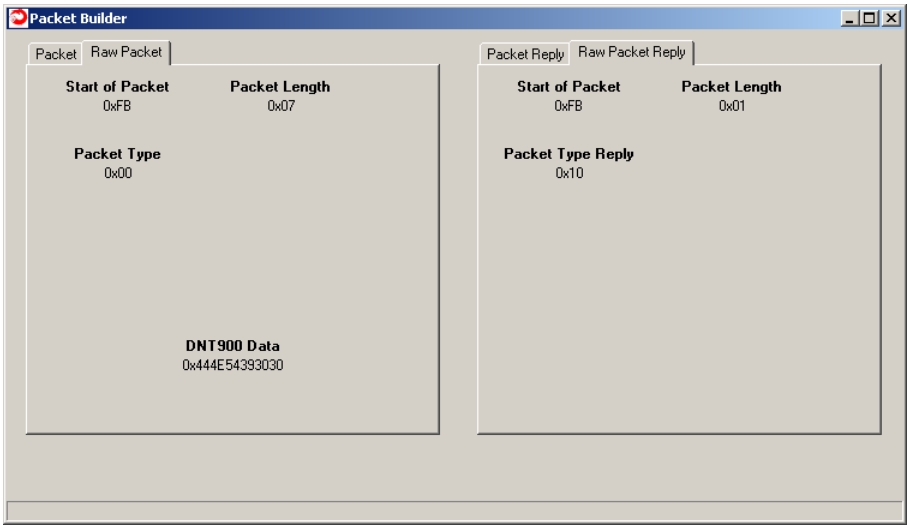

Figure 5.7.10

Figure 5.7.10 shows the *Raw Packet* and *Raw Packet Reply* tabs. Components of the protocol messages are shown in hexadecimal format.

Log Data controls the log file. Logging is enabled by default. The log file created is *logfile.dat*, and is in ASCII text format. An example log is shown below:

```
New Data-----------------------------------------
12/7/2008  |  7:05:39 AM
DNT Wizard Version 0.92
Sent Data : FB 07 00 44 4E 54 35 30 30 (Enter Protocol Mode)
Recv Data : FB 01 10 (Enter Protocol Mode Reply)
Sent Data : FB 04 03 00 00 2C (Get Register)
Recv Data : FB 30 13 00 00 2C 01 FF 68 01 05 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A 2A
00 05 32 00 00 02 02 44 4E 54 39 30 30 00 00 00 00 00 00 00 00 00 00 (Get Register Reply)
Sent Data : FB 04 03 00 01 0E (Get Register)
Recv Data : FB 12 13 00 01 0E 00 03 D2 05 00 05 08 03 0A 0E 0C 30 14 00 (Get Register Reply)
Sent Data : FB 04 03 00 02 27 (Get Register)
Recv Data : FB 2B 13 00 02 27 02 CD FB 00 05 00 00 04 47 08 00 FF 42 14 49 01 18 00 A9 00 00
05 00 31 31 2F 31 38 2F 30 38 31 36 3A 30 30 3A 35 30 (Get Register Reply)
Sent Data : FB 04 03 00 03 04 (Get Register)
Recv Data : FB 08 13 00 03 04 04 00 00 07 (Get Register Reply)
Sent Data : FB 04 03 00 04 08 (Get Register)
Recv Data : FB 0C 13 00 04 08 00 05 05 01 07 00 02 00 (Get Register Reply)
Sent Data : FB 04 03 00 05 12 (Get Register)
Recv Data : FB 16 13 00 05 12 01 00 00 00 01 01 F5 01 FD 01 DA 01 00 00 00 00 00 00 (Get
Register Reply)
Sent Data : FB 04 03 00 06 1E (Get Register)
Recv Data : FB 22 13 00 06 1E 00 00 00 01 00 00 00 00 00 00 00 01 00 00 00 FF 03 00 00 FF 03
00 00 FF 03 01 B8 0B 00 00 (Get Register Reply)
Recv Data : FB 07 27 A2 01 CD FB 01 01 (Announce)
Sent Data : FB 12 05 01 CD FB 54 68 69 73 20 69 73 20 61 20 74 65 73 74 (TX Data)
Recv Data : FB 06 15 00 01 CD FB BB (TX Data Reply)
Sent Data : FB 12 05 01 CD FB 54 68 69 73 20 69 73 20 61 20 74 65 73 74 (TX Data)
Recv Data : FB 06 15 00 01 CD FB B6 (TX Data Reply)
Sent Data : FB 12 05 01 CD FB 54 68 69 73 20 69 73 20 61 20 74 65 73 74 (TX Data)
Recv Data : FB 06 15 00 01 CD FB BA (TX Data Reply)
Sent Data : FB 12 05 01 CD FB 54 68 69 73 20 69 73 20 61 20 74 65 73 74 (TX Data)
Recv Data : FB 06 15 00 01 CD FB B8 (TX Data Reply)
Sent Data : FB 12 05 01 CD FB 54 68 69 73 20 69 73 20 61 20 74 65 73 74 (TX Data)
Recv Data : FB 06 15 00 01 CD FB B3 (TX Data Reply)
```

The log file is especially useful in confirming the format of specific protocol commands and replies.

5.8 DNT2400 Interface Board Features

The location of LEDs D1 through D4 and jumper pin sets J14 and J17 are shown in Figure 5.8.1.

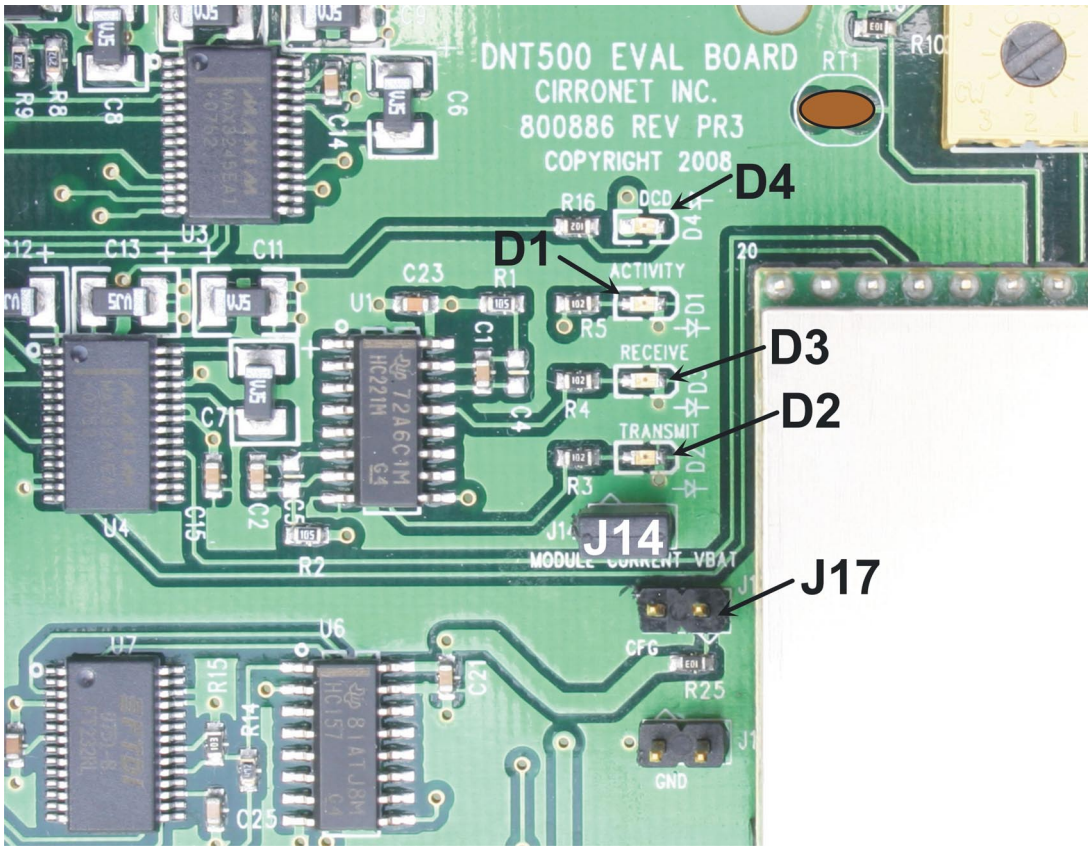

Figure 5.8.1

Amber DCD LED D4 illuminates on a remote to indicate it is registered with the base and can participate in RF communications. DCD LED D4 illuminates on the base when one or more remotes are registered to it, unless the base has been configured to assert DCD on power up. In this case it will be on as long as the dev board is powered. Green Activity LED D1 illuminates when transmitting or receiving RF data. Red Receive LED D3 illuminates when sending received data through the serial port to the PC. Green Transmit LED D2 illuminates when the PC sends data through the serial port to be transmitted.

Jumper pin set J14 is provided to allow measurement of the DNT2400P current. For normal operation J14 has a shorting plug installed. Jumper pin set J17 allows the DNT2400P /CFG pin to be grounded by installing a shorting plug. This places the DNT2400P in protocol mode.

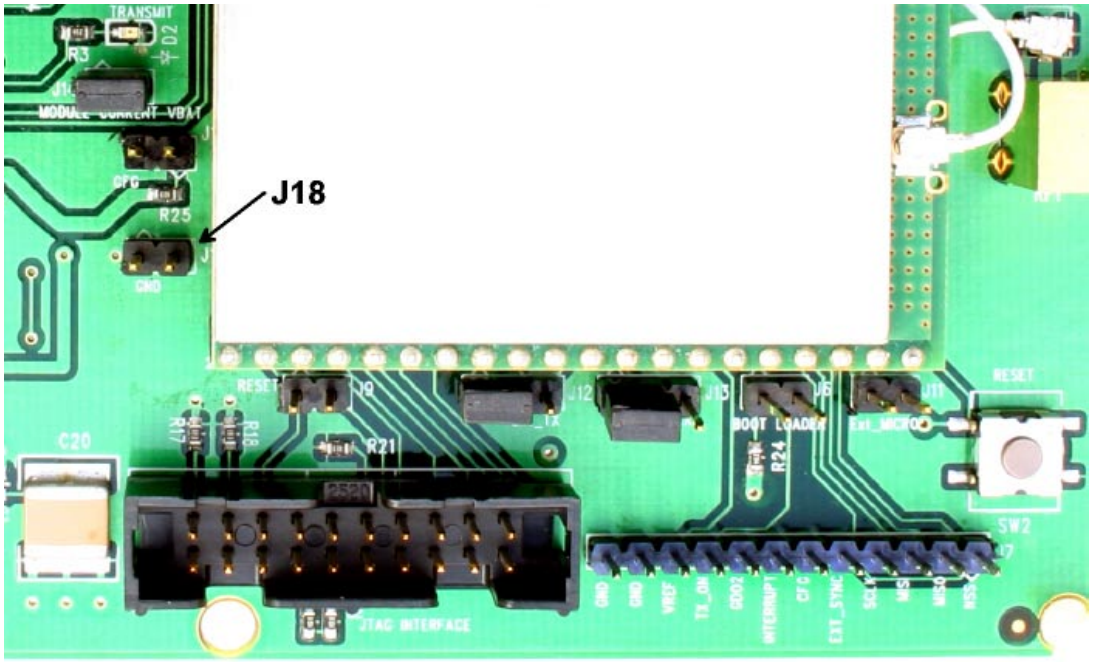

Figure 5.8.2

Figure 5.8.2 shows the connectors to the right of the DNT2400P mounting socket. Jumper pin set J9 allow the DNT2400P reset line to be routed to the JTAG interface connector J10. J18 allows the DNT2400P reset line to be grounded. Note that the JTAG operation is usually limited to factory testing. For normal operation pin sets J9 and J18 should *not* have a shorting block installed. Jumper pin sets J12 and J13 normally have shorting plugs installed as shown in Figure 5.8.2, which connects the DNT2400P RADIO_TXD and RADIO_RXD pins to the respective serial data lines on the evaluation board. It is possible to connect directly to RADIO_TXD and RADIO_RXD by moving the jumpers over. In this case, J11-1 is the input for transmitted data and J11-2 is the output for received data. *Note this a 3 V logic interface.* Placing a shorting plug on jumper pin set J6 allows the DNT2400P to be powered up in boot loader mode. This is used for factory code loads and functional testing. The DNT2400 has its own boot loader utility that allows the protocol firmware to be installed with a terminal program that supports YMODEM. Pin strip J7 provides access to various DNT2400 pins as shown on the silkscreen. Pressing switch SW2 will reset the DNT2400P.

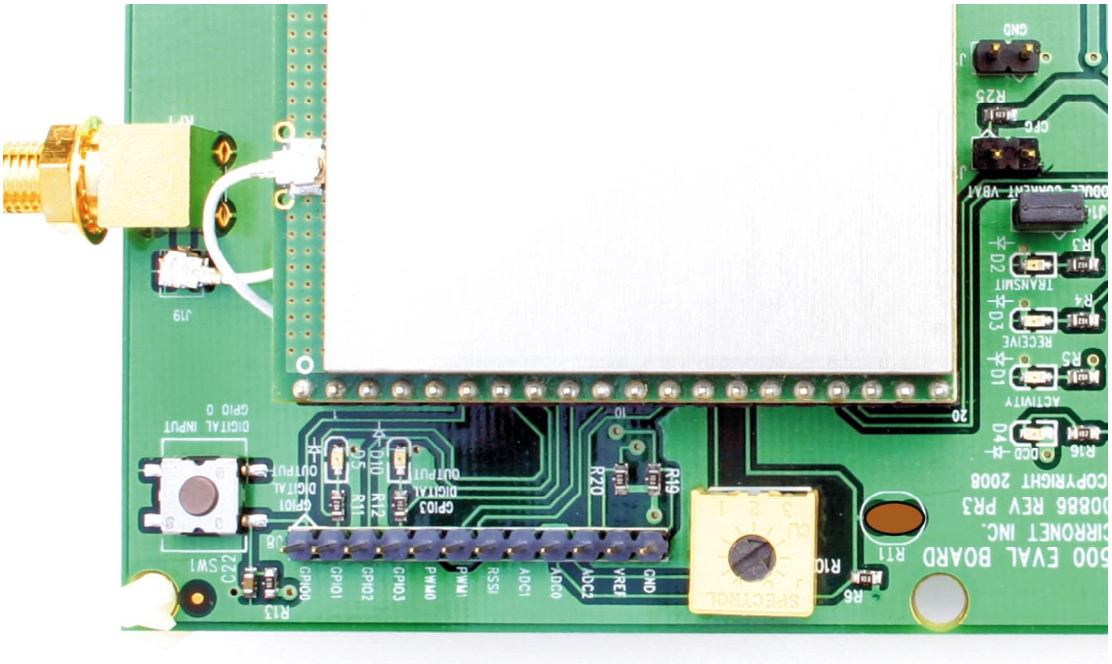

Figure 5.8.3

Figure 5.8.3 shows the connectors to the left of the DNT2400P mounting socket. Pressing switch SW2 switches GPIO0 from logic high to logic low. Pin strip J8 provides access to various DNT2400 pins as shown on the silkscreen. The wiper of pot R10 drives the input of ADC1. Clockwise rotation of the pot wiper increases the voltage. Thermistor RT1 is part of a voltage divider that drives ADC0. LED D5 illuminates when GPIO1 is set as a logic high output. LED D10 illuminates when GPIO3 is set as a logic high. The DNT2400P interface board includes a 5 V regulator to regulate the input from the 9 V wall-plug power supply. Note: do not attempt to use the 9 V wall-plug power supply to power the DNT2400P directly. The maximum allowed voltage input to the DNT2400P is 5.5 V.

6.0 Demonstration Procedure

The procedure below provides a quick demonstration of the DNT2400P using a DNT2400DK development kit:

1. Confirm that each DNT2400P transceiver is installed correctly in an interface board, and that the U.FL jumpers between the DNT2400P radios and the interface boards are installed. Also confirm that a dipole antenna is installed on each interface board, and that J14 has a jumper block installed on each interface board. See Figures 5.4.1, 5.4.2 and 5.4.3 above.

2. Attach the Base (see label on bottom of interface board) to a computer with the DNT Demo program installed.

3. Place the transceiver/interface boards at least 6 feet (two meters) apart.

4. Start the DNT Demo program.

5. Click the *Connect* button on the Demo window. This will open a serial port setup dialog box. Set the baud rate to 9600 (9.6 kb/s) and select the COM port where the Base is connected.

6. At this point the Demo will collect data from the Base, filling in data in the *Local Radio* column on the Demo window. The *Status Window* should also show that the Remote has joined the Base.

7. Click on the drop-down box at the top of the *Radio 1* column and select the *MAC Address* for the Remote. Next press the *Start* button using the default 1 s *Refresh Delay*.

8. The Demo will display updated data on the Remote in the *Radio 1* column, including bar graphs of *RSSI* signal strength in dBm and percent packet success rate. Adjusting the large pot on the Remote can be observed on the *Potentiometer (ADC1)* row.

7.0 Troubleshooting

DNT2400 not responding - make sure SLEEP/DTR is not asserted (logic low) to bring the radio out of sleep mode.

Can not enter protocol mode - make sure the host data rate is correct. The DNT2400 defaults to 9.6 kb/s. If using the *EnterProtocolMode* command, send the complete protocol format for this command.

A remote never detects carrier (DCD) - check that the base is running, and that the remote *InitialNwkID* parameter is the same as the base, or is set to 0xFF. If a remote is operating near the base (less than 6 ft or 2 m), be sure the transmitter power setting on both the base and remote is set to 1 mW. If the remote is operating far from the base, be sure the transmitter power setting on the base and remote is adequate for communication. Also make sure that the security keys are the same.

Carrier is detected, but no data appears to be received - make sure that RTS is asserted to enable receive character flow. Make sure the RF transmit power is not on a high settings if the nodes are close together.

Range is extremely limited - this is usually a sign of a poor antenna connection or the wrong antenna. Check that the antenna is firmly connected. If possible, remove any obstructions near the antenna.

Transmitting terminal flashes (drops) CTS occasionally - this indicates that the transmit buffer is filling up. This most often is caused by using a higher serial port data rate than RF data rate. Adjusting the protocol parameters may increase the network efficiency.

7.1 Diagnostic Port Commands

FSTAT <option> - enables a frequency-ordered channel activity status log.

Available options are:

0 - off
1 - on

For either a base or remote, FSTAT shows the DataTx (data packet transmitted), AckRx (ACK received) and RegRx (registration or renewal request or reply received) activity status on each frequency with ASCII characters as follows:

‘.’ (0x2E) - no activity
‘1’ (0x31) - DataTx activity only
‘2’ (0x32) - AckRx activity only
‘3’ (0x33) - DataTx and AckRx activity
‘4’ (0x34) - RegRx activity only
‘5’ (0x35) - DataTx and RegRx activity
‘6’ (0x36) - AckRx and RegRx activity
‘7’ (0x37) - DataTx, AckRx and RegRx activity

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A sample FSTAT output for 37 channel operation is shown below. The status data is order from the lowest operating frequency on the left to the highest operating frequency on the right. An ASCII CR-LF terminates each line. On most frequencies, DataTx and AckRx occur on the same frequency ('3'). Occasionally there is DataTx, AckRx and RegRx activity ('7'), DataTx only activity ('1'), or no activity ('.').

```
333333 33333333 33333373 33333333 3333333
333333 33333333 33333333 33333333 3333333
333333 31333333 33333333 33333333 3333333
23.333 333133.3 3.333323 31333.33 333.333
333333 23333331 33313333 33333333 23.3333
```

INSTR <option>

Available options are:

0 - off
1 - on

For either a base or a remote, INSTR streams instrumentation packets including a time stamp and seven data values. The time stamp is a string of four characters. The first three characters are ASCII representations of hexadecimal numbers. The fourth character is a '>' character. Each time stamp count is 100 µs. The time stamp rolls over to 0x000 after count 0xCE5. The content of the seven data values are detailed below. ASCII representations of the hexadecimal value of each byte are output, separated by space characters:

Byte 0: current channel, 0 to 36
Byte 1: same data as FSTAT 1, except no activity is 0x30
Byte 2: RSSI_Last, RSSI of last RF packet received in dBm, 8-bit signed value
Byte 3: RSSI_Idle, most recent RSSI value on a channel with no expected activity
Byte 4: Range delay estimate, remote only, 3.1 µs/tick
Byte 5: Status bits 1
- b7.. b4 - reserved
- b3 - inbound data RF flow control, 1 = device has disabled RF flow
- b2 - outbound data RF flow control, 1 = base has disabled RF flow
- b1 - /HOST_CTS, status of CTS line, 1 = hold
- b0 - /DCD, link LED on; on a remote indicates registration with base, on the base it indicates at least on remote is registered (default)

Byte 6: Status bits 0
- b7 - CSMA channel busy
- b6 - Parser/CRC error
- b5 - valid RF packet received (any type)
- b4 - DataRx, data packet received
- b3 - RegTx, registration or renewal request or reply transmitted
- b2 - RegRx, registration or renewal request or reply received
- b1 - AckRx, ACK received
- b0 - DataTx, data packet transmitted

A sample INSTR output is shown below.

```
896> 21 01 DA 98 00 01 01
940> 0A 03 DA 9C 00 01 23
9E2> 1D 03 DA 99 00 03 23
A8A> 1E 01 D6 9F 00 03 21
B36> 11 03 D6 99 00 03 23
```

Looking a the first line in detail:

```
896> 21 01 DA 98 00 01 01
```

The time stamp is 0x896>
Byte 0, 0x21, indicates the channel of operation is 33 (decimal)
Byte 1, 0x01, is the same status data as FSTAT data above. In this case, DataTx activity only.
Byte 2, 0xDA, is the last RSSI value, -38 dBm
Byte 3, 0x98, is the RSSI idle value, -100 dBm
Byte 4, 0x00, is the range delay estimate (remote only). The remote is very close to the base.
Byte 5, 0x01, provides the serial port status - /HOST_CTS is high
Byte 6, 0x01, provides the communication status - DataTx active only. Note that this byte provides additional status bytes compared to byte index 1.

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8.0 Appendices

8.1 Ordering Information

DNT2400C: transceiver module for solder-pad mounting
DNT2400P: transceiver module for pin-socket mounting

8.2 Technical Support

For DNT2400 technical support call RFM at (678) 684-2000 between the hours of 8:30 AM and 5:30 PM Eastern Time.

8.3 DNT2400 Mechanical Specifications

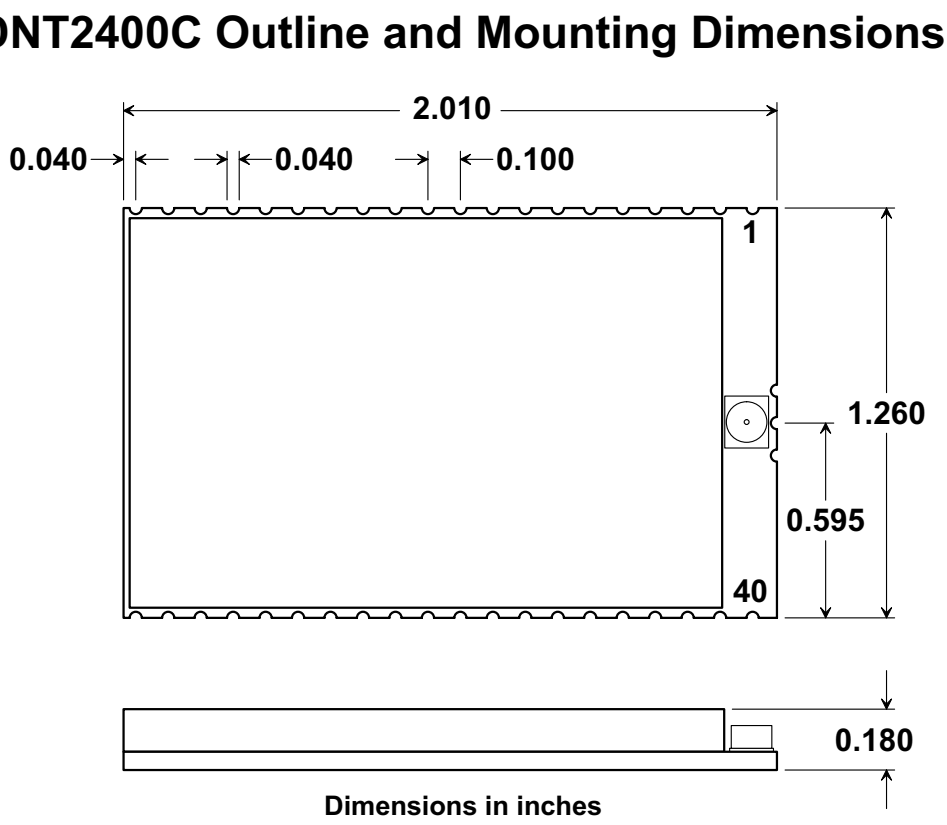
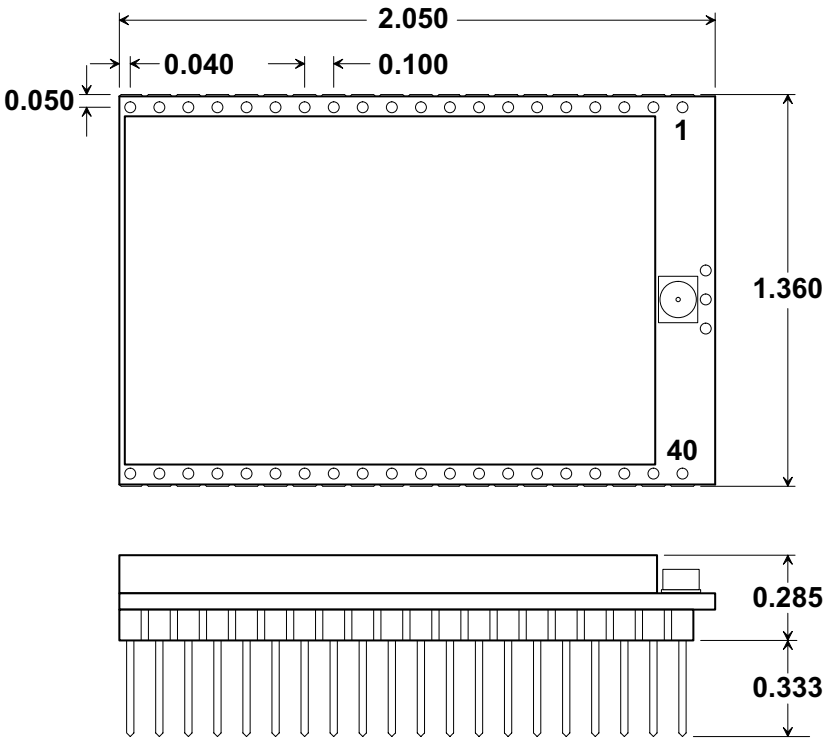


Figure 8.3.1

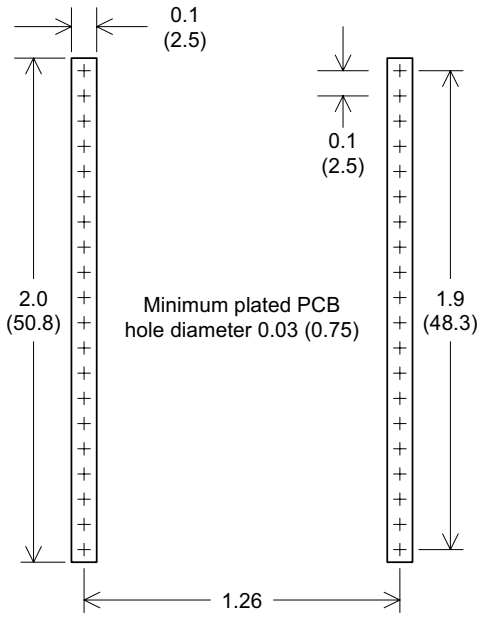
DNT2400P Outline and Mounting Dimensions



Dimensions in inches

Figure 8.3.2

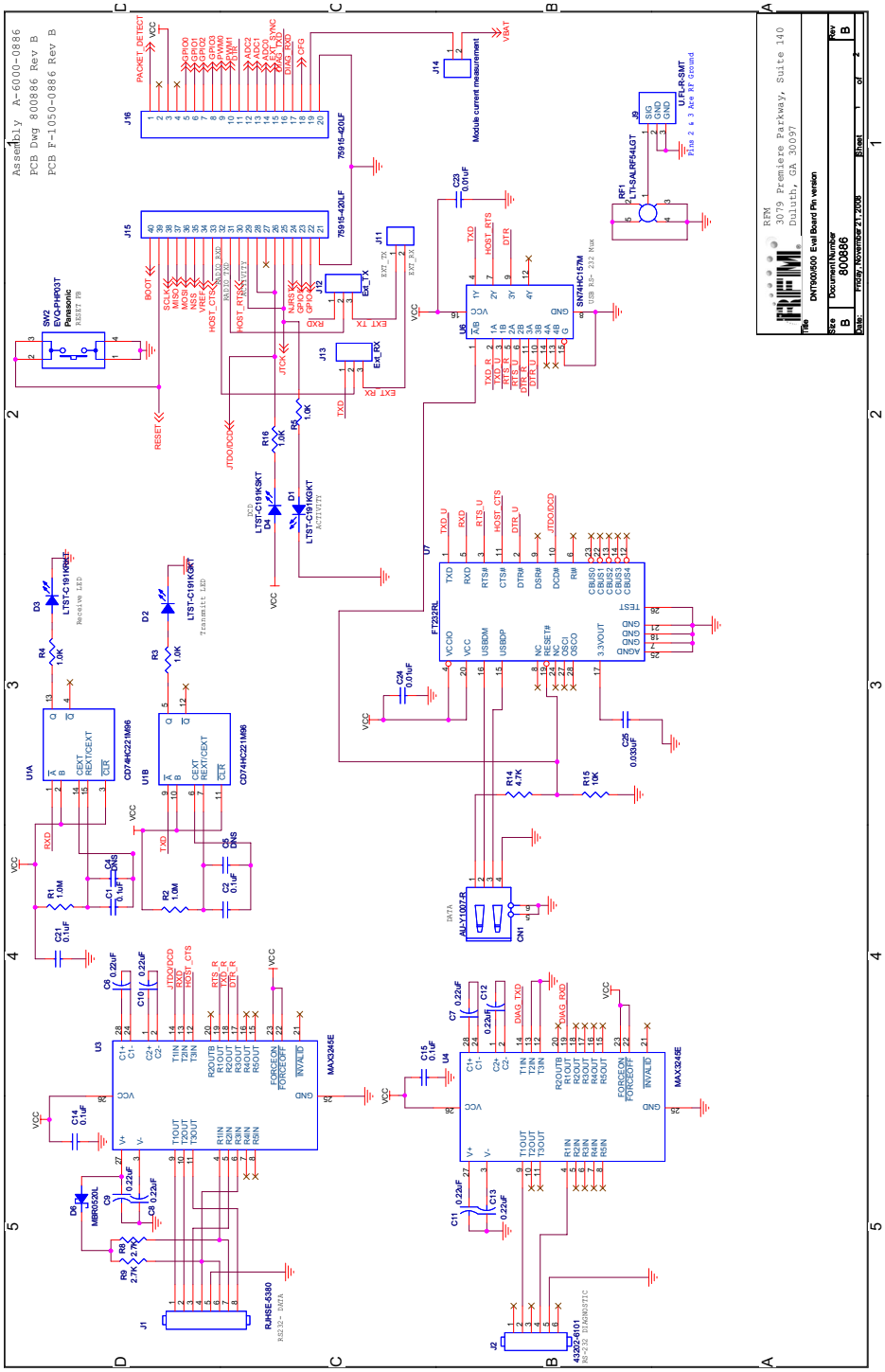
DNT2400P Interface Connector
PCB Layout Detail

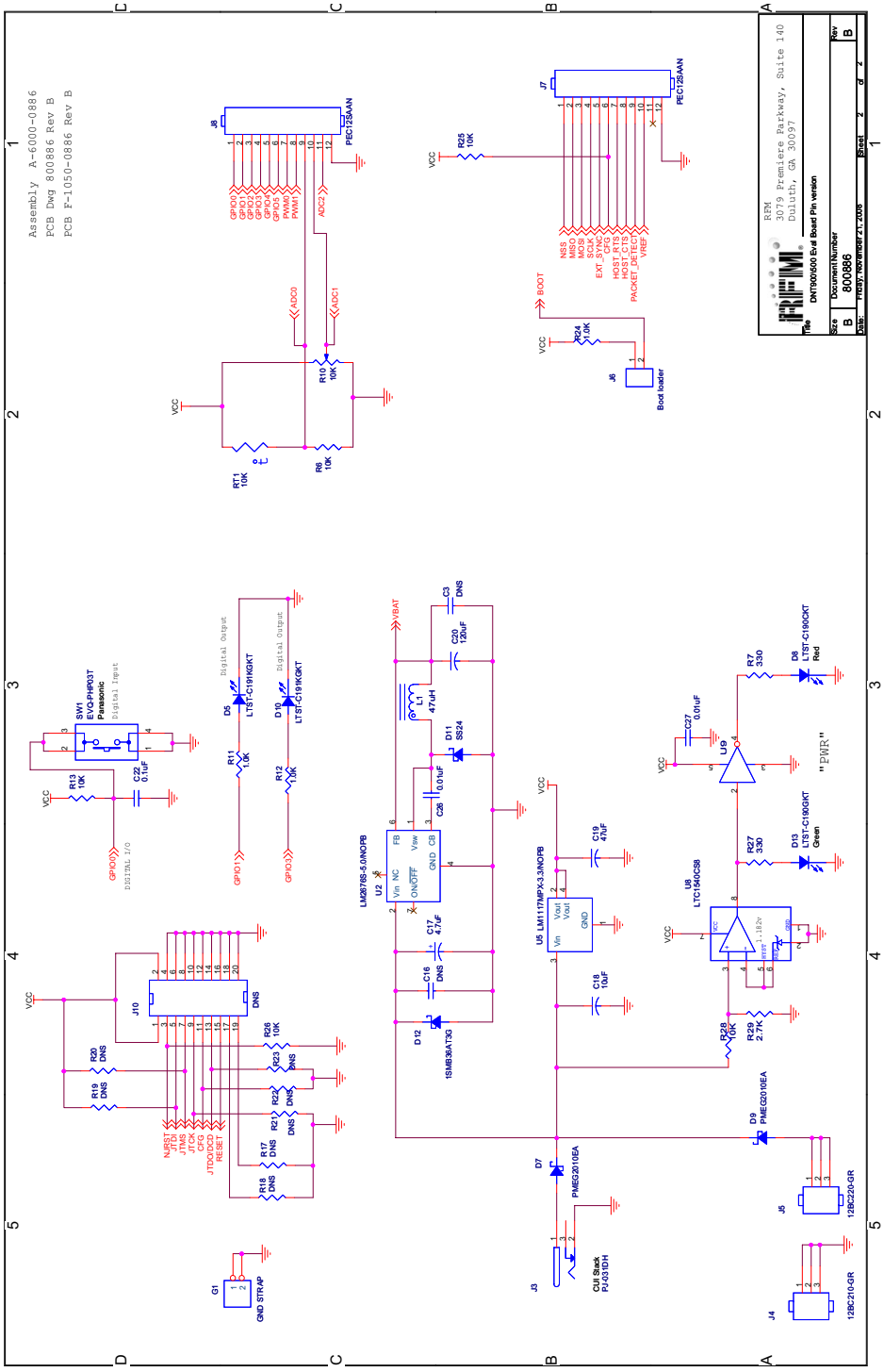


Connectors are FCI Electronics 75915-420LF or equivalent
Dimensions in inches and (mm)

Figure 8.3.3

8.4 DNT2400 Development Board Schematic




Assembly A-6000-0886
PCB Dwg 800886 Rev B
PCB F-1050-0886 Rev B
RFM
3079 Premiere Parkway, Suite 140
Duluth, GA 30097
DNT900500 Eval Board Pin version
Document Number
800886
Rev
B
Size
B
Date: Friday, November 21, 2008
Sheet 2 of 2
J8
PEC12SAAN
J7
PEC12SAAN
GPIO0
GPIO1
GPIO2
GPIO3
GPIO4
PWM0
PWM1
ADC2
ADC0
ADC1
R10 10K
RT1 10K
R6 10K
R25 10K
NSS
MISO
MOSI
SCLK
EXT_SYNC
CTS
HOST_RTS
HOST_CTS
PACKET_DETECT
VREF
BOOT
R24 0.0K
J6
Boot loader
SW1
EVQ-PHR03T
Panasonic
Digital Input
C22 0.1uF
R13 10K
GPIO0
D5
LTST-C191KGKT
D10
LTST-C191KGKT
Digital Output
R11 10K
R12 10K
GPIO1
GPIO3
VBAT
C3 DNS
C20 120uF
L1 47uH
D11 SS24
C26 0.01uF
U2 LM2678S-5.0/NOPB
C17 47uF
C16 DNS
D12 1SMB36AT3G
U5 LM1117MPX-3.3/NOPB
C19 47uF
C18 10uF
D7 PMEG2010EA
J3 CUI Stack PJ-037DH
J4 128C210-GR
J5 128C220-GR
D9 PMEG2010EA
C27 0.01uF
U9
R7 330
D8 LTST-C190CKT Red
"PWR"
R27 330
D13 LTST-C190GKT Green
U8 LTC1540CS8
R28 10K
R29 2.7K
J10 DNS
R26 10K
R23 DNS
R22 DNS
R21 DNS
R17 DNS
R18 DNS
R20 DNS
R19 DNS
NJRST
JTDI
JTMS
JTCK
CFG
JTDO/TRACESWO
RESET
G1
GND STRAP
VCC

9.0 Warranty

Seller warrants solely to Buyer that the goods delivered hereunder shall be free from defects in materials and workmanship, when given normal, proper and intended usage, for twelve (12) months from the date of delivery to Buyer. Seller agrees to repair or replace at its option and without cost to Buyer all defective goods sold hereunder, provided that Buyer has given Seller written notice of such warranty claim within such warranty period. All goods returned to Seller for repair or replacement must be sent freight prepaid to Seller's plant, provided that Buyer first obtain from Seller a Return Goods Authorization before any such return. Seller shall have no obligation to make repairs or replacements which are required by normal wear and tear, or which result, in whole or in part, from catastrophe, fault or negligence of Buyer, or from improper or unauthorized use of the goods, or use of the goods in a manner for which they are not designed, or by causes external to the goods such as, but not limited to, power failure. No suit or action shall be brought against Seller more than twelve (12) months after the related cause of action has occurred. Buyer has not relied and shall not rely on any oral representation regarding the goods sold hereunder, and any oral representation shall not bind Seller and shall not be a part of any warranty.

THE PROVISIONS OF THE FOREGOING WARRANTY ARE IN LIEU OF ANY OTHER WARRANTY, WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL (INCLUDING ANY WARRANTY OR MERCHANT ABILITY OR FITNESS FOR A PARTICULAR PURPOSE). SELLER'S LIABILITY ARISING OUT OF THE MANUFACTURE, SALE OR SUPPLYING OF THE GOODS OR THEIR USE OR DISPOSITION, WHETHER BASED UPON WARRANTY, CONTRACT, TORT OR OTHERWISE, SHALL NOT EXCEED THE ACTUAL PURCHASE PRICE PAID BY BUYER FOR THE GOODS. IN NO EVENT SHALL SELLER BE LIABLE TO BUYER OR ANY OTHER PERSON OR ENTITY FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING, BUT NOT LIMITED TO, LOSS OF PROFITS, LOSS OF DATA OR LOSS OF USE DAMAGES ARISING OUT OF THE MANUFACTURE, SALE OR SUPPLYING OF THE GOODS. THE FOREGOING WARRANTY EXTENDS TO BUYER ONLY AND SHALL NOT BE APPLICABLE TO ANY OTHER PERSON OR ENTITY INCLUDING, WITHOUT LIMITATION, CUSTOMERS OF BUYERS.