ember

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EM35x

EM260

EZSP-SPI Host Interfacing Guide

This document describes the EZSP-SPI Protocol that used by a host microcontroller to communicate with an Ember Network Co-Processor, or NCP, running the EmberZNet stack. It includes recommended procedures for developing and testing a driver for the EZSP-SPI Protocol on a new host microcontroller.

Contents

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EZSP-SPI Protocol

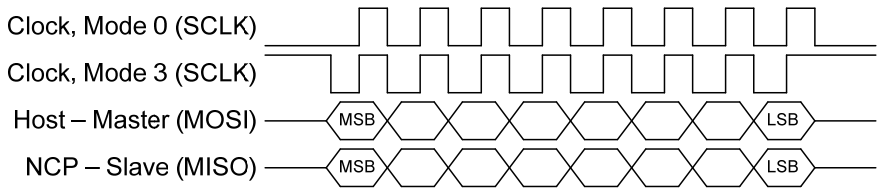
The EZSP-SPI Protocol uses an SPI interface to communicate with a pair of GPIOs for handshake signaling.

- To the Host the NCP looks like a hardware peripheral.
- The NCP is the slave device and all transactions are initiated by the Host (the master).
- The SPI interface supports a reasonably high data rate.

Physical Interface Configuration

The NCP supports both SPI Slave Mode 0 (clock is idle low, sample on rising edge) and SPI Slave Mode 3 (clock is idle high, sample on rising edge) at a maximum SPI clock rate of 5MHz, as illustrated in Figure 1. The convention for the waveforms in this document is to show Mode 0.

Figure 1. SPI Transfer Format, Mode 0 and Mode 3



The nHOST_INT signal and the nWAKE signal are both active low. The Host must supply a pull-up resistor on the nHOST_INT signal to prevent errant interruptions during undefined events such as the NCP resetting. The NCP supplies an internal pull-up on the nWAKE signal to prevent errant interruptions during undefined events such as the Host resetting.

Low-Power Operation and Signal Configurations

To minimize current consumption, the host should use matching pin configurations. While the NCP supports both Mode 0 and Mode 3, the NCP uses Mode 0. This means that when the NCP is awake, the idle state of the clock is low. When the NCP is sleeping, the host needs to use a configuration that does not conflict with the NCP's configuration to achieve the lowest power. Table 1 describes the NCP's signal configuration in sleep.

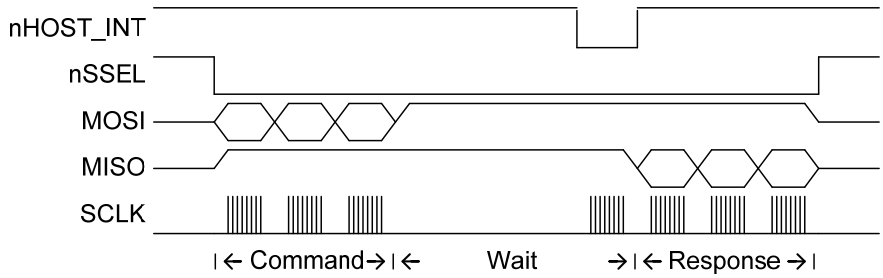
Table 1. NCP Signal Configuration in Sleep

Signal	Configuration
MOSI	input, pullup
MISO	input, pullup
SCLK	input, pullup
nSSEL	input, pullup
nHOST_INT	Input, pullup
nWAKE	Input, pullup

SPI Transaction

The basic EZSP-SPI transaction is half-duplex to ensure proper framing and to give the NCP adequate response time. The basic transaction, as shown in Figure 2, is composed of three sections: Command, Wait, and Response. The transaction can be considered analogous to a function call. The Command section is the function call, and the Response section is the return value.

Figure 2. General Timing Diagram for a SPI Transaction



Command Section

The Host begins the transaction by asserting the Slave Select and then sending a command to the NCP. This command can be of any length from 2 to 136 bytes and must not begin with `0xFF`. During the Command section, the NCP will respond with only `0xFF`. The Host should ignore data on MISO during the Command section. Once the Host has completed transmission of the entire message, the transaction moves to the Wait section.

Wait Section

The Wait section is a period of time during which the NCP may be processing the command or performing other operations. This section can be any length of time up to 200ms (milliseconds). Because of the variable size of the Wait section, an interrupt-driven or polling-driven method is suggested for clocking the SPI as opposed to a DMA method. Since the NCP can require up to 200ms to respond, as long as the Host keeps Slave Select active, the Host can perform other tasks while waiting for a Response.

To determine when a Response is ready, use one of two methods:

- Clock the SPI until the NCP transmits a byte other than `0xFF`.
- Interrupt on the falling edge of nHOST_INT.

The first method, clocking the SPI, is recommended due to simplicity in implementing. During the Wait section, the NCP will transmit only `0xFF` and will ignore all incoming data until the Response is ready. When the NCP transmits a byte other than `0xFF`, the transaction has officially moved into the Response section. Therefore, the Host can poll for a Response by continuing to clock the SPI by transmitting `0xFF` and waiting for the NCP to transmit a byte other than `0xFF`. The NCP will also indicate that a Response is ready by asserting the nHOST_INT signal. The falling edge of nHOST_INT is the indication that a Response is ready. Once the nHOST_INT signal asserts, nHOST_INT will return to idle after the Host begins to clock data.

Response Section

When the NCP transmits a byte other than `0xFF`, the transaction has officially moved into the Response section. The data format is the same format used in the Command section. The response can be of any length from 2 to 136 bytes and must not begin with `0xFF`. Depending on the actual response, the length of the response is known from the first or second byte. This length should be used by the Host to clock out exactly the correct number of bytes.

Once all bytes have been clocked, the Host is allowed to deassert chip select. Since the Host is in control of clocking the SPI, there are no ACKs or similar signals needed back from the Host because the NCP assumes the Host could accept the bytes being clocked on the SPI. After every transaction, the Host must hold the Slave Select high for a minimum of 1ms. This timing requirement is called the inter-command spacing and is necessary to allow the NCP to process a command and become ready to accept a new command.

Asynchronous Signaling

When the NCP has data to send to the Host, it will assert the nHOST_INT signal. The nHOST_INT signal is designed to be an edge-triggered signal as opposed to a level-triggered signal; therefore, the falling edge of nHOST_INT is the true indicator of data availability. The Host then has the responsibility to initiate a transaction to ask the NCP for its output. The Host should initiate this transaction as soon as possible to prevent possible backup of data in the NCP. The NCP will deassert the nHOST_INT signal after receiving a byte on the SPI. Due to inherent latency in the NCP, the timing of when the nHOST_INT signal returns to idle can vary between transactions. nHOST_INT will always return to idle for a minimum of 25µs before asserting again. If the NCP has more output available after the transaction has completed, the nHOST_INT signal will assert again after Slave Select is deasserted and the Host must make another request.

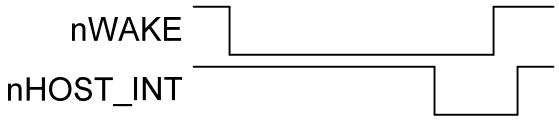
Spacing

To ensure that the NCP is always able to deal with incoming commands, a minimum inter-command spacing is defined at 1ms. After every transaction, the Host must hold the Slave Select high for a minimum of 1ms. The Host must respect the inter-command spacing requirement, or the NCP will not have time to operate on the command; additional commands could result in error conditions or undesired behavior. If the nHOST_INT signal is not already asserted, the Host is allowed to use the Wake handshake instead of the inter-command spacing to determine if the NCP is ready to accept a command.

Waking the NCP from Sleep

Waking up the NCP involves a simple handshaking routine is illustrated in Figure 3. This handshaking insures that the Host will wait until the NCP is fully awake and ready to accept commands from the Host. If the NCP is already awake when the handshake is performed (such as when the Host resets and the NCP is already operating), the handshake will proceed as described below with no ill effects.

Figure 3. NCP Wake Sequence



Note: A wake handshake cannot be performed if nHOST_INT is already asserted.

Note: nWAKE should not be asserted after the NCP has been reset until the NCP has fully booted, as indicated by the NCP asserting nHOST_INT. If nWAKE is asserted during this boot time, the NCP may enter bootloader mode. Refer to “Bootloading the NCP.”

Waking the NCP involves the following steps:

1. Host asserts nWAKE.
2. NCP interrupts on nWAKE and exits sleep.
3. NCP performs all operations it needs to and will not respond until it is ready to accept commands.
4. NCP asserts nHOST_INT within 10ms of nWAKE asserting.

   If the NCP does not assert nHOST_INT within 10ms of nWAKE, it is valid for the Host to consider the NCP unresponsive and to reset the NCP.
5. Host detects nHOST_INT assertion. Because the assertion of nHOST_INT indicates the NCP can accept SPI transactions, the Host does not need to hold Slave Select high for the normally required minimum 1ms of inter-command spacing.
6. Host deasserts nWAKE after detecting nHOST_INT assertion.
7. NCP will deassert nHOST_INT within 25µs of nWAKE deasserting.
8. After 25µs, any change on nHOST_INT will be an indication of a normal asynchronous (callback) event.

Error Conditions

If two or more different error conditions occur back to back, only the first error condition will be reported to the Host (if it is possible to report the error). The following are error conditions that might occur with the NCP.

- **Unsupported SPI Command:** If the SPI Byte of the command is unsupported, the NCP will drop the incoming command and respond with the Unsupported SPI Command Error Response. This error means the SPI Byte is unsupported by the current Mode the NCP is in. Bootloader Frames can only be used with the bootloader, and EZSP Frames can only be used with the EZSP.
- **Oversized Payload Frame:** If the transaction includes a Payload Frame, the Length Byte cannot be a value greater than 133. If the NCP detects a length byte greater than 133, it will drop the incoming Command and abort the entire transaction. The NCP will then assert nHOST_INT after Slave Select returns to Idle to inform the Host through an error code in the Response section what has happened. The NCP not only drops the Command in the problematic transaction, but the next Command is also dropped because it is responded to with the Oversized Payload Frame Error Response.
- **Aborted Transaction:** An aborted transaction is any transaction where Slave Select returns to Idle prematurely and the SPI Protocol dropped the transaction. The most common reason for Slave Select returning to Idle prematurely is the Host unexpectedly resetting. If a transaction is aborted, the NCP will assert nHOST_INT to inform the Host through an error code in the Response section what has happened. When a transaction is aborted, the NCP not only drops the Command in the problematic transaction, but the next Command also gets dropped because it is responded to with the Aborted Transaction Error Response.
- **Missing Frame Terminator:** Every Command and Response must be terminated with the Frame Terminator byte. The NCP will drop any Command that is missing the Frame Terminator. The NCP will then immediately provide the Missing Frame Terminator Error Response.
- **Long Transaction:** A Long Transaction error occurs when the Host clocks too many bytes. As long as the inter-command spacing requirement is met, this error condition should not cause a problem because the NCP will send only `0xFF` outside of the Response section and ignore incoming bytes outside of the Command section.
- **Unresponsive:** Unresponsive can mean the NCP is not powered, not fully booted yet, incorrectly connected to the Host, or busy performing other tasks. The Host must wait the maximum length of the Wait section before it can consider the NCP unresponsive to the Command section. This maximum length is 200ms, measured from the end of the last byte sent in the Command section. If the NCP ever fails to respond during the Wait section, it is valid for the Host to consider the NCP unresponsive and to reset the NCP. Additionally, if nHOST_INT does not assert within 10ms of nWAKE asserting during the wake handshake, the Host can consider the NCP unresponsive and reset the NCP.

SPI Protocol Timing

Figure 4 illustrates all critical timing parameters in the SPI Protocol. These timing parameters are a result of the NCP's internal operation and both constrain Host behavior and characterize NCP operation. The parameters shown are discussed elsewhere in this document. Note that Figure 4 is not drawn to scale, but is instead drawn only to illustrate where the parameters are measured.

Figure 4. SPI Protocol Timing Waveform

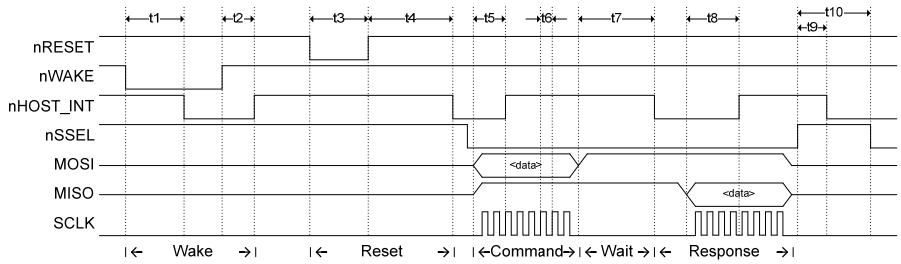


Table 2 lists the timing parameters of the SPI Protocol. These parameters are illustrated in Figure 4. Refer to Ember document 120-0260-000: *EM260 Datasheet* for the EM260's timing parameters.

Table 2. EZSP-SPI Protocol Timing Parameters for an EM35x NCP

Parameter	Description	Min.	Typ.	Max.	Unit
t1 (a)	Wake handshake, while NCP is awake		100	150	µs
t1 (b)	Wake handshake, while NCP is asleep		3.5	10	ms
t2	Wake handshake finish	0.5	1	25	µs
t3	Reset pulse width	26			µs
t4 (a)	Startup time, entering application		250	1500	ms
t4 (b)	Startup time, entering bootloader		2.5	7.5	s
t5	nHOST_INT deasserting after Command	5	8	50	µs
t6	Clock period	200			ns
t7	Wait section	25	755	200000	µs
t8	nHOST_INT deasserting after Response	5	10	50	µs
t9	nHOST_INT asserting after transaction	5	13	50	µs
t10	Inter-command spacing	1			ms

Data Format

The data format, also referred to as a *command*, is the same for both the Command section and the Response section. The data format of the SPI Protocol is straightforward, as illustrated in Figure 5.

Figure 5. EZSP-S PI Protocol Data Format

The total length of a command must not exceed 136 bytes.

All commands must begin with the **SPI Byte**. Some commands are only two bytes—that is, they contain the SPI Byte and Frame Terminator only.

The **Length Byte** is only included if there is information in the Payload Frame and the Length Byte defines the length of just the Payload Frame. Therefore, if a command includes a Payload Frame, the Length Byte can have a value from 3 through 133 and the overall command size will be from 6 through 136 bytes. The SPI Byte can be a specific value indicating if there is a Payload Frame or not. If there is a Payload Frame, then the Length Byte can be expected.

The **Error Byte** is used by the error responses to provide additional information about the error and appears in place of the length byte. This additional information is described in the following sections.

The **Payload Frame** contains the data needed for operating EmberZNet. The EZSP Frame and its format are explained in Ember document 120-3009-000: *EZSP Reference Guide*. The Payload Frame may also contain the data needed for operating the bootloader, which is called a Bootloader Frame. Refer to Ember document 120-3021-000: *EmberZNet Application Developer's Reference Manual* for more information on the bootloader.

The **Frame Terminator** is a special control byte used to mark the end of a command. The Frame Terminator byte is defined as `0xA7` and is appended to all Commands and Responses immediately after the final data byte. The purpose of the Frame Terminator is to provide a known byte the SPI Protocol can use to detect a corrupt command. For example, if the NCP resets during the Response Section, the Host will still clock out the correct number of bytes. But when the host attempts to verify the value `0xA7` at the end of the Response, it will see either the value `0x00` or `0xFF` and know that the NCP just reset and the corrupt Response should be discarded.

Note: The Length Byte only specifies the length of the Payload Frame. It does not include the Frame Terminator.

SPI Byte

Table 3 lists the possible commands and their responses in the SPI Byte.

Table 3. SPI Commands and Responses

Command Value	Command	Response Value	Response
Any	Any	0x00	NCP reset occurred—This is never used in another Response; it always indicates an NCP Reset.
Any	Any	0x01	Oversized Payload Frame received. This is never used in another Response; it always indicates an overflow occurred.
Any	Any	0x02	Aborted Transaction occurred. This is never used in another Response; it always indicates an aborted transaction occurred.
Any	Any	0x03	Missing Frame Terminator—This is never used in another Response; it always indicates a Missing Frame Terminator in the Command.
Any	Any	0x04	Unsupported SPI Command—This is never used in another Response; it always indicates an unsupported SPI Byte in the Command.
0x00 – 0x09	Reserved	[none]	[none]
0x0A	SPI Protocol Version	0x81 – 0xBF	bit[7] is always set. bit[6] is always cleared. bit[5:0] is a number from 1 to 63.
0x0B	SPI Status	0xC0 – 0xC1	bit[7] is always set. bit[6] is always set. bit[0]—Set if alive and ready for commands.
0x0C – 0xFC	Reserved	[none]	[none]
0xFD	Bootloader Frame	0xFD	Bootloader Frame
0xFE	EZSP Frame	0xFE	EZSP Frame
0xFF	Invalid	0xFF	Invalid

Primary SPI Bytes

There are four primary SPI Bytes: SPI Protocol Version, SPI Status, Bootloader Frame, and EZSP Frame.

- **SPI Protocol Version [0x0A]:** Sending this command requests the SPI Protocol Version number from the SPI Interface. The response will always have bit 7 set and bit 6 cleared. In this current version, the response will be `0x82`, because the version number corresponding to this set of Command-Response values is version number 2. The version number can be a value from 1 to 63 (`0x81–0xBF`).

- **SPI Status [0x0B]:** Sending this command asks for the NCP status. The response status byte will always have the upper 2 bits set. In this current version, the status byte only has one status bit [0], which is set if the NCP is alive and ready for commands.
- **Bootloader Frame [0xFD]:** This byte indicates that the current transaction is a Bootloader transaction and there is more data to follow. This SPI Byte will cause the transaction to look like the full data format illustrated in Figure 5. The byte immediately after this SPI Byte will be a Length Byte, and it is used to identify the length of the Bootloader Frame. Refer to Ember document 120-3021-000: *EmberZNet Application Developer's Reference Manual* for more information on the bootloader. If the SPI Byte is `0xFD`, the minimum transaction size is 4 bytes.
- **EZSP Frame [0xFE]:** This byte indicates that the current transaction is an EZSP transaction and there is more data to follow. This SPI Byte will cause the transaction to look like the full data format illustrated in Figure 5. The byte immediately after this SPI Byte will be a Length Byte, and it is used to identify the length of the EZSP Frame. The EZSP Frame is defined in Ember document 120-3009-000: *EZSP Reference Guide.* If the SPI Byte is `0xFE`, the minimum transaction size is six bytes.

Special Response Bytes

There are only five SPI Byte values, `0x00–0x04`, ever used as error codes (see Table 4). When the error condition occurs, any command sent to the NCP will be ignored and responded to with one of these codes. These special SPI Bytes must be trapped and dealt with. In addition, for each error condition, the Error Byte (instead of the Length Byte) is also sent with the SPI Byte.

Table 4. Byte Values Used as Error Codes

SPI Byte Value	Error Message	Error Description	Error Byte Description
0x00	NCP Reset	See “ Powering On, Power Cycling, and Rebooting”.	The reset type. Refer to Ember’s API documentation discussing EmberResetType.
0x01	Oversized EZSP Frame	The command contained an EZSP frame with a Length Byte greater than 133. The NCP was forced to drop the entire command.	Reserved
0x02	Aborted Transaction	The transaction was not completed properly and the NCP was forced to abort the transaction.	Reserved
0x03	Missing Frame Terminator	The command was missing the Frame Terminator. The NCP was forced to drop the entire command.	Reserved
0x04	Unsupported SPI Command	The command contained an unsupported SPI Byte. The NCP was forced to drop the entire command.	Reserved

Powering On, Power Cycling, and Rebooting

When the Host powers on (or reboots), it cannot guarantee that the NCP is awake and ready to receive commands. Therefore, the Host should always perform the Wake NCP handshake to guarantee that the NCP is awake. If the NCP resets, it needs to inform the Host so that the Host can reconfigure the stack if needed.

When the NCP resets, it will assert the nHOST_INT signal, telling the Host that it has data. The Host should request data from the NCP as usual. The NCP will ignore whatever command is sent to it and respond only with two bytes. The first byte will always be `0x00` and the second byte will be the reset type as defined by `EmberResetType`. This specialty SPI Byte is never used in another Response SPI Byte. If the Host sees `0x00` from the NCP, it knows that the NCP has been reset. The NCP will deassert the nHOST_INT signal shortly after receiving a byte on the SPI and process all further commands in the usual manner. In addition to the Host having control of the reset line of the NCP, the EmberZNet Serial Protocol also provides a mechanism for a software reboot.

Bootloading the NCP

The SPI Protocol supports a Payload Frame called the Bootloader Frame for communicating with the NCP when the NCP is in bootloader mode. The NCP can enter bootload mode through either an EZSP command or holding one of two pins low while the NCP exits reset. Both the nWAKE pin and the PTI_DATA pin are capable of activating the bootloader while performing a standard NCP reset procedure. Assert nRESET to hold the NCP in reset. While nRESET is asserted, assert (active low) either

nWAKE or PTI_DATA and then deassert nRESET to boot the NCP. Do not deassert nWAKE or PTI_DATA until the NCP asserts nHOST_INT, indicating that the NCP has fully booted and is ready to accept data over the SPI Protocol. Once nHOST_INT is asserted, nWAKE or PTI_DATA way be deasserted. Refer to Ember document 120-3021-000: *EmberZNet Application Developer's Reference Manual* for more information on the bootloader and the format of the Bootloader Frame.

Unexpected Resets

The NCP is designed to protect itself against undefined behavior due to unexpected resets. The protection is based on the state of Slave Select since the inter-command spacing mandates that Slave Select must return to idle. The NCP's internal SPI Protocol uses Slave Select returning to idle as a trigger to reinitialize its SPI Protocol. By always reinitializing, the NCP is protected against the Host unexpectedly resetting or terminating a transaction. Additionally, if Slave Select is active when the NCP powers on, the NCP will ignore SPI data until Slave Select returns to idle. By ignoring SPI traffic until idle, the NCP will not begin receiving in the middle of a transaction.

If the Host resets, in most cases it should also reset the NCP so that both devices are once again in the same state: freshly booted. Alternately, the Host can attempt to recover from the reset by recovering its previous state and re-synchronizing with the state of the NCP.

If the NCP resets during a transaction, the Host can expect either a Wait Section timeout or a missing Frame Terminator indicating an invalid Response.

If the NCP resets outside of a transaction, the Host should proceed normally.

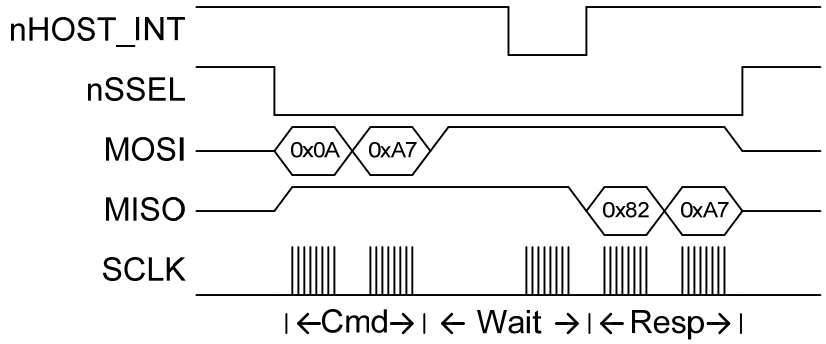
Transaction Examples

This section contains the following transaction examples:

- SPI Protocol Version
- EmberZNet Serial Protocol Frame—Version Command
- NCP Reset
- Three-Part Transaction: Wake, Get Version, Stack Status Callback

SPI Protocol Version

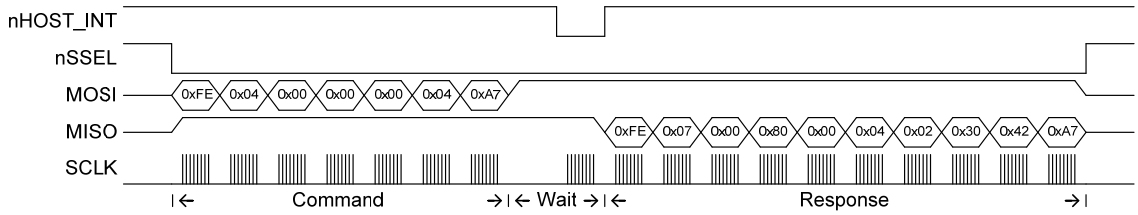
Figure 6. SPI Protocol Version Example



1. Activate Slave Select (nSSEL).
2. Transmit the command `0x0A` - SPI Protocol Version Request.
3. Transmit the Frame Terminator, 0xA7.
4. Wait for nHOST_INT to assert.
5. Transmit and receive 0xFF until a byte other than 0xFF is received.
6. Receive response 0x82 (a byte other than 0xFF), then receive the Frame Terminator, 0xA7.
7. Bit 7 is always set and bit 6 is always cleared in the Version Response, so this is Version 2.
8. Deactivate Slave Select.

EmberZNet Serial Protocol Frame—Version Command

Figure 7. EmberZNet Serial Protocol Frame - Version Command Example



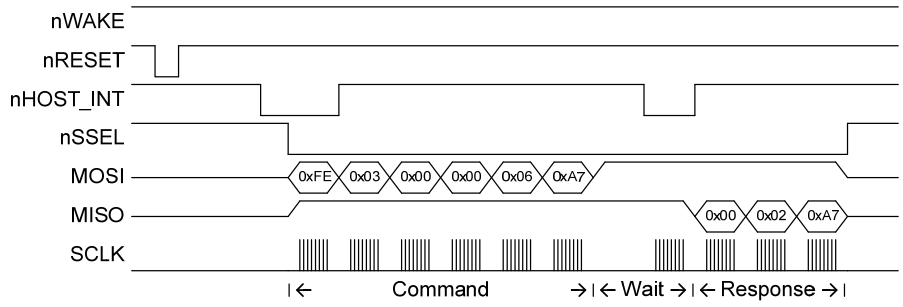
1. Activate Slave Select (nSSEL).
2. Transmit the appropriate command:
   - `0xFE`: SPI Byte indicating an EZSP Frame
   - `0x04`: Length Byte showing the EZSP Frame is 4 bytes long
   - `0x00`: EZSP Sequence Byte (Note that this value should vary based upon previous sequence bytes)
   - `0x00`: EZSP Frame Control Byte indicating a command with no sleeping
   - `0x00`: EZSP Frame ID Byte indicating the `Version` command
   - `0x04`: EZSP Parameter for this command (`desiredProtocolVersion`)
   - `0xA7`: Frame Terminator
3. Wait for nHOST_INT to assert.
4. Transmit and receive `0xFF` until a byte other than `0xFF` is received.
5. Receive response `0xFE` (a byte other than `0xFF`) and read the next byte for a length.
6. Stop transmitting after the number of bytes (length) is received plus the Frame Terminator.
7. Decode the response:
   - `0xFE`: SPI Byte indicating an EZSP Frame
   - `0x07`: Length Byte showing the EZSP Frame is 7 bytes long
   - `0x00`: EZSP Sequence Byte (Note that this value should vary based upon previous sequence bytes)
   - `0x80`: EZSP Frame Control Byte indicating a response with no errors and with no pending callbacks
   - `0x00`: EZSP Frame ID Byte indicating the `Version` response
   - `0x04`: EZSP Parameter for this response (`protocolVersion,` note that this value may vary)
   - `0x02`: EZSP Parameter for this response (`stackType`)
   - `0x30`: EZSP Parameter for this response (`stackVersion`, note that this value may vary)

- `0x42`: EZSP Parameter for this response (`stackVersion`, note that this value may vary)
- `0xA7`: Frame Terminator

8. Deactivate Slave Select.

NCP Reset

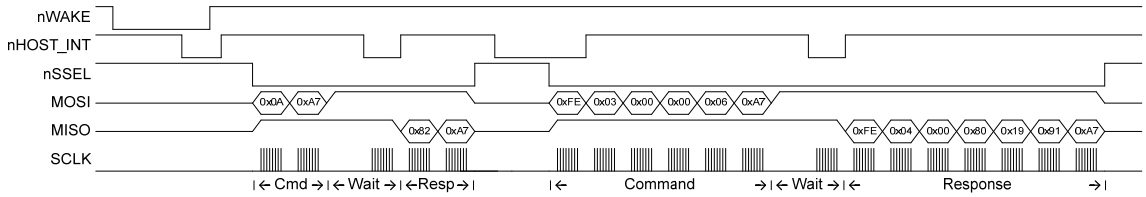
Figure 8. NCP Reset Example



1. nRESET toggles active low to reset the NCP.
2. nWAKE stays idle high between nRESET and nHOST_INT indicating the NCP should continue with normal booting (do not enter the bootloader).
3. nHOST_INT asserts.
4. Activate Slave Select (nSSEL).
5. Transmit the command:
   - `0xFE`: SPI Byte indicating an EZSP Frame
   - `0x03`: Length Byte showing the EZSP Frame is 3 bytes long
   - `0x00`: EZSP Sequence Byte (Note that this value should vary based upon previous sequence bytes)
   - `0x00`: EZSP Frame Control Byte indicating a command with no sleeping
   - `0x06`: EZSP Frame ID Byte indicating the `callback` command
   - `0xA7`: Frame Terminator
6. Wait for nHOST_INT to assert.
7. Transmit and receive `0xFF` until a byte other than `0xFF` is received.
8. Receive response `0x00` (a byte other than `0xFF`).
9. Receive the Error Byte and decode (`0x02` is enumerated as RESET_POWERON).
10. Receive the Frame Terminator (`0xA7`).
11. Response `0x00` indicates the NCP has reset and the Host should respond appropriately.
12. Deactivate Slave Select.
13. Since nHOST_INT does not assert again, there is no more data for the Host.

Three-Part Transaction: Wake, Get Version, Stack Status Callback

Figure 9. Timing Diagram of the Three-Part Transaction



1. Activate nWAKE and activate timeout timer.
2. NCP wakes up (if not already) and enables communication.
3. nHOST_INT asserts, indicating the NCP can accept commands.
4. Host sees nHOST_INT activation within 10ms and deactivates nWAKE and timeout timer.
5. nHOST_INT deasserts immediately after nWAKE.
6. Activate Slave Select.
7. Transmit the Command 0x0A - SPI Protocol Version Request.
8. Transmit the Frame Terminator, 0xA7.
9. Wait for nHOST_INT to assert.
10. Transmit and receive 0xFF until a byte other than 0xFF is received.
11. Receive response 0x82 (a byte other than 0xFF), then receive the Frame Terminator, 0xA7.
12. Bit 7 is always set and bit 6 is always cleared in the Version Response, so this is Version 2.
13. Deactivate Slave Select.
14. Host begins timing the inter-command spacing of 1ms in preparation for sending the next command.
15. nHOST_INT asserts shortly after deactivating Slave Select, indicating a callback.
16. Host sees nHOST_INT, but waits for the 1ms before responding.
17. Activate Slave Select.
18. Transmit the command:
    - `0xFE`: SPI Byte indicating an EZSP Frame
    - `0x03`: Length Byte showing the EZSP Frame is 3 bytes long
    - `0x00`: EZSP Sequence Byte (Note that this value should vary based upon previous sequence bytes)
    - `0x00`: EZSP Frame Control Byte indicating a command with no sleeping
    - `0x06`: EZSP Frame ID Byte indicating the `callback` command
    - `0xA7`: Frame Terminator

19. Wait for nHOST_INT to assert.
20. Transmit and receive `0xFF` until a byte other than `0xFF` is received.
21. Receive response `0xFE` (a byte other than `0xFF`), read the next byte for a length.
22. Stop transmitting after the number of bytes (length) is received plus the Frame Terminator.
23. Decode the response:
    - `0xFE`: SPI Byte indicating an EZSP Frame
    - `0x04`: Length Byte showing the EZSP Frame is 3 bytes long
    - `0x00`: EZSP Sequence Byte (Note that this value should vary based upon previous sequence bytes)
    - `0x80`: EZSP Frame Control Byte indicating a response with no errors
    - `0x19`: EZSP Frame ID Byte indicating the `stackStatusHandler` command
    - `0x91`: EZSP Parameter for this response `(EmberStatus EMBER_NETWORK_DOWN)`
    - `0xA7` – Frame Terminator
24. Deactivate Slave Select.
25. Since nHOST_INT does not assert again, there is no more data for the Host.

EZSP-SPI Protocol Development Procedures

This section describes recommended practices and procedures for designing, developing, and testing the EZSP-SPI Protocol on a new microcontroller interfaced to an Ember Network Co-Processor (NCP). The NCP may be an EM260, EM351 or EM357 running the EmberZNet 3.0 or later stack software. The descriptions and recommendations illustrate a workflow that should help produce a solid EZSP-SPI Protocol module for a new host microcontroller.

Caution: This application note applies to EmberZNet 3.0 (or later) and should not be used with previous versions.

This document assumes that you have an overall understanding of the EZSP-SPI Protocol, the terminology used, the basic sequences described, and the transaction examples.

For debugging, a logic analyzer—preferably with at least seven channels—is highly recommended for examining the state of and the transitions on the NCP interface.

Physical Interface

This section describes the EZSP-SPI Protocol pin connections and how to verify them.

EZSP-SPI Protocol Pin Connections

The physical pin connections are straightforward, and there is only a special recommendation for the nHOST_INT pin. nHOST_INT can be connected to any input. For interrupt-based operation, nHOST_INT must be connected to an external interrupt that can generate an interrupt on a falling edge. Furthermore, if the host intends to sleep and to be woken up by the NCP, nHOST_INT should be connected to a pin that is capable of waking the host. nHOST_INT should have a pull-up applied to it so that nHOST_INT does not bounce in an unknown state if the NCP is reset. An internal pull-up on the pin that nHOST_INT is connected to is acceptable.

Connect the three SPI signals (MOSI, MISO, and SCLK) to the host's SPI. Connect nSSEL (remember, for the EM260 nSSEL_INT *must* also be tied to nSSEL) to any output from the host that can operate Slave Select. For many microcontrollers, nSSEL will simply be connected to a general-purpose output. Connect nWAKE and nRESET to any general-purpose output from the host (remember, the NCP supplies an internal pull-up on both the nWAKE and nRESET pins).

Verifying EZSP-SPI Protocol Pin Connections

Once all of the signals are connected and a logic analyzer is attached, begin by pulling the nRESET signal low for a short period to reset the NCP. The required duration of the low nRESET depends on the type of NCP: for the EM260 it must be low for at least 8 µs, while for the EM351 or EM357 it must be low for at least 26 µs. nHOST_INT will return to idle (go high) almost immediately after reset (if it is not already). Note that nHOST_INT will not be driven high by a reset, but instead will default to an input. Therefore, if an external pull-up is not applied to nHOST_INT, it is possible for nHOST_INT to not go high immediately after reset but a short while later. During the startup sequence, the NCP will switch nHOST_INT to an output and actively drive it high. After approximately 250ms, the nHOST_INT signal will assert (go low) and stay asserted until the host initiates a transaction. The startup time of the NCP can vary widely, but 250ms is a good rule of thumb for when nHOST_INT will assert after reset. nHOST_INT asserting after pulling on the nRESET pin indicates that both the nRESET pin and nHOST_INT are connected and operating correctly. If nHOST_INT is tied to an external interrupt on the host, this is also a good time to test the interrupt generation by pulling on the nRESET pin to trigger nHOST_INT assertion.

The simplest method to test nSSEL (as well as nSSEL_INT, which must be tied to nSSEL) is to simply assert nSSEL (set low) and then deassert nSSEL. When nSSEL deasserts, nHOST_INT will return to idle and then approximately 70µs later will assert again and stay asserted.

Testing the three SPI signals (MOSI, MISO, and SCLK) is best done by formulating a complete transaction. Unfortunately, the nWAKE signal cannot be used or tested until a first, complete transaction has occurred (refer to the section First Transaction: EZSP-SPI Protocol Version). This is because the nHOST_INT signal must deassert after reset for a proper Wake Handshake to be performed. Once a complete transaction has finished and nHOST_INT has deasserted, nWAKE may be asserted. Approximately 140µs

after nWAKE asserts, nHOST_INT will assert in response, indicating that the nWAKE signal is connected properly.

First Transaction: EZSP-SPI Protocol Version

Obtaining the EZSP-SPI Protocol Version is a compact, simplified, and special transaction that illustrates a full transaction. Being able to properly obtain the EZSP-SPI Protocol Version not only verifies five of the seven interface pins (MOSI, MISO, SCLK, nSSEL, and nHOST_INT), but it is also useful as a test for verifying that the NCP is active and that the EZSP-SPI Protocol code being implemented on the host is compatible with the firmware on the NCP. Use this transaction to verify the connection with the NCP during the host's boot sequence.

Before worrying about creating a generic EZSP-SPI Protocol module or handling error cases, it is best to get a feel for a transaction in the simplest way possible. The following steps should result in your first transaction and can be explicitly coded in a test function for reference.

EZSP-SPI Protocol Version Transaction with an NCP Reset

Note: The following steps begin by resetting the NCP to guarantee that it is in a known state. The NCP resetting is an error and results in the first transaction performed after a reset returning the reset error. These steps describe receiving this reset error instead of the EZSP-SPI Protocol Version.

1. Assert nRESET and release to reset the NCP and guarantee it is in a known state.
2. Wait for nHOST_INT to assert, which indicates that the NCP is active.
3. Assert nSSEL to begin a transaction.
4. Transmit 0x0A.
5. Transmit 0xA7.
6. Continually transmit 0xFF until the byte received is not 0xFF. The first byte received that is not 0xFF will be 0x00.
7. Transmit 0xFF while receiving 0x02.
8. Transmit 0xFF while receiving 0xA7.
9. Deassert nSSEL to finish the transaction.

EZSP-SPI Protocol Version Transaction without an NCP Reset

1. Assert nSSEL to begin a transaction.
2. Transmit 0x0A.
3. Transmit 0xA7.

4. Continually transmit 0xFF until the byte received is not 0xFF. The first byte received that is not 0xFF will be 0x82.
5. Transmit 0xFF while receiving 0xA7.
6. Deassert nSSEL to finish the transaction.

Second Transaction: EZSP-SPI Status

The EZSP-SPI Status transaction is very similar to the EZSP-SPI Protocol Version transaction (detailed in the previous section). Like the EZSP-SPI Protocol Version transaction, this transaction provides a simple example of interaction with the NCP. Ember recommends this as a test transaction to verify the connection with the NCP during the host's boot sequence.

EZSP-SPI Status Transaction

1. Assert nSSEL to begin a transaction.
2. Transmit 0x0B.
3. Transmit 0xA7.
4. Continually transmit 0xFF until the byte received is not 0xFF. The first byte received that is not 0xFF will be 0xC1.
5. Transmit 0xFF while receiving 0xA7.
6. Deassert nSSEL to finish the transaction.

Performing a Hard Reset

When the host resets, it is far simpler to reset the NCP and begin from a known state as opposed to trying to recover and resync with the previous (unknown) state of the NCP. The recommended procedure when the host resets is to perform a Hard Reset of the NCP during bootup. A Hard Reset is defined as the following sequence:

1. Toggle nRESET (active low) to reset the NCP.
2. Wait for nHOST_INT to assert, which indicates that the NCP is active.
3. Perform an EZSP-SPI Protocol Version transaction and verify that the Response from the NCP is the NCP Reset error condition.
4. Perform an EZSP-SPI Protocol Version transaction and verify that the EZSP-SPI Protocol Version number is as expected.
5. Perform an EZSP-SPI Status transaction and verify that the NCP is "Alive" and ready to accept commands.

The purpose of performing this Hard Reset on bootup is threefold.

- By guaranteeing that the NCP is freshly booted, just like the host, the host can proceed with standard node and network initialization instead of consuming extra code space just trying to determine what state the NCP was left in.

- Because the NCP generates the NCP Reset error, which will override any legitimate transaction Response, the Hard Reset can acknowledge this planned and expected error condition so that the EZSP or full application does not have to implement special handling. Therefore, whenever an NCP Reset error is experienced outside of a Hard Reset, it can be treated as a true unexpected error condition.
- The EZSP-SPI Protocol Version and EZSP-SPI Status transactions are specialized transactions not implemented or used by the normal EZSP. These transactions are intended to be utility devices that allow the host to perform a simple "handshake" with the NCP. This handshake not only verifies that the NCP is alive and available to the EZSP, but also that the EZSP-SPI Protocol implemented in the NCP is compatible with the EZSP-SPI Protocol implemented on the host.

Third Transaction: EZSP Version Command

Before implementing a generic EZSP-SPI Protocol on the host, Ember recommends explicitly coding a third transaction for providing exposure to an EZSP Frame and the format of the data involved with an EZSP Frame. The EZSP Frame used in this transaction is the VERSION command. The VERSION command is required to be the first EZSP command issued to the NCP. It exercises the code path all the way through the NCP firmware. Therefore, this command is useful not only for verifying that the EZSP is active, but also for illustrating the implementation of an EZSP transaction.

Note: This section assumes you are using EmberZNet 3.0 or later. Previous versions of EmberZNet used a different transaction sequence using a NOP command for this example.

EZSP Version Command Transaction

1. Assert nSSEL to begin a transaction.
2. Transmit 0xFE.
3. Transmit 0x04.
4. Transmit 0x00.
5. Transmit 0x00.
6. Transmit 0x00.
7. Transmit 0x02.
8. Transmit 0xA7.
9. Continually transmit 0xFF until the byte received is not 0xFF. The first byte received that is not 0xFF will be 0xFE.
10. Transmit 0xFF while receiving 0x07.
11. Transmit 0xFF while receiving 0x00.
12. Transmit 0xFF while receiving 0x80.
13. Transmit 0xFF while receiving 0x00.
14. Transmit 0xFF while receiving 0x02.

15. Transmit 0xFF while receiving 0x02.
16. Transmit 0xFF while receiving 0x11. (Note that this value is the build number and may vary.)
17. Transmit 0xFF while receiving 0x30.
18. Transmit 0xFF while receiving 0xA7.
19. Deassert nSSEL to finish the transaction.

Wait Section

Transmitting a command is a basic operation that simply requires asserting Slave Select and "dumping" the command bytes on the SPI in the most convenient method available (such as using a `for()` loop over a manual write, an interrupt-driven write, or a DMA). Once the first byte of the Response is received and the transaction has moved into the Response Section, receiving a Response is a basic, three-step operation: decode the first two bytes to determine the length of the Response, receive that precise number of bytes, and then deassert Slave Select.

How the Wait Section is implemented and handled requires some careful consideration of the two techniques available: clock the SPI (also known as polling on the SPI or polling for data) and interrupt on the falling edge of nHOST_INT.

Clock the SPI (Polling for Data)

The simplest and most straightforward method for determining when a Response is ready is to continually clock the SPI until the NCP transmits a byte other than 0xFF. When the host "clocks the SPI," the host should simply transmit 0xFF, because transmitting 0xFF is considered an idle line. The major advantage of polling for data is that the simplicity of polling requires very little code space, and in most cases this can be implemented using either a `while()` or a `do{}while` loop. The disadvantage of polling for data is the blocking nature of polling. Because transactions must occur serially (meaning a transaction must complete before another transaction can begin), the blocking nature of polling for data is usually only an issue if the host needs to perform tasks not related to EmberZNet.

For example, if the host captures a button press and must send a message over the network in response to the button press, blocking in a polling loop is not a critical issue because of the serial nature of the transaction. Conversely, if the host must periodically take an ADC measurement and perform calculations based on the measurement, then blocking in a polling loop might not be desirable.

Because the host is the SPI Master, there are essentially no timing requirements dictating when or how often the host should clock the SPI (the most important requirement is to keep transactions moving quickly so that messages do not back up in the NCP's buffers). Therefore, the host can clock the SPI at its convenience, which means that a developer can choose to implement the simplest solution possible and sit in a `while()` loop waiting for a response. The developer can also choose a more advanced solution: for the host to poll periodically for a response while allowing other tasks to execute on the host. Knowing that the Wait Sections of many transactions can

be milliseconds long, the developer may decide to clock the SPI and check for a response only once every millisecond.

Ember recommends choosing the simplest solution possible in the context of the host's resources and other requirements. During development, starting with the simplest blocking `while()` loop is an easy solution that can be expanded and customized as development progresses.

Interrupt on the Falling Edge of nHOST_INT

As detailed elsewhere in this application note, the falling edge of the signal nHOST_INT indicates that a Response is ready when the falling edge occurs while Slave Select is asserted. Instead of clocking the SPI (either by completely blocking or periodically polling) and waiting for a response, the host can be configured to interrupt on the falling edge of nHOST_INT. Once the host sees a falling edge on nHOST_INT, it must still clock the SPI until data other than 0xFF is received. The major advantage to interrupting on nHOST_INT is the ability of the host to perform other tasks while waiting for a response. The major disadvantage to interrupting on nHOST_INT is the potential for accidentally starting a new transaction before the previous transaction has completed. Remember, because a new transaction cannot begin until the previous transaction has completed, be careful not to accidentally overlap transactions.

Note: The host should not poll on the level of the nHOST_INT signal. Despite nHOST_INT remaining low until the host performs an action, only the falling edge of nHOST_INT can be trusted to properly indicate data. The NCP will carefully schedule the falling edge of nHOST_INT, but due to latency it cannot guarantee exactly when the nHOST_INT signal will return to idle after the host performs an action.

Inter-Command Spacing

The inter-command spacing is a simple time requirement needed to guarantee that the NCP has finished processing a transaction and is ready to accept a new transaction. The inter-command spacing is currently defined as at least 1ms between the rising edge of Slave Select (ending transaction) and the falling edge of Slave Select (starting transaction). If the host is capable of blocking for 1ms, the simplest solution is to simply burn CPU cycles for 1ms after deasserting Slave Select. Since burning CPU cycles for 1ms is often undesirable, Ember recommends using a simple timer. By setting or starting a timer when Slave Select is deasserted, the host can perform other tasks during the inter-command spacing. If a timer is used, the host must guarantee that any and all attempts at starting a new transaction are either blocked or stalled until the timer has expired. Once the timer has expired, the host may assert Slave Select and begin a new transaction.

Asynchronous Signaling

As discussed in the "Interrupt on the Falling Edge of nHOST_INT" section of this application note, this falling edge is used to indicate data availability. When nHOST_INT is asserted outside of a transaction (Slave Select is idle), the assertion means there is

asynchronous data waiting in the NCP for the host. Remember, the host should *not* poll on the level of the nHOST_INT signal. Instead, the host should assign an interrupt to nHOST_INT and use the falling edge (the interrupt) to set a flag or some similar marker. This way, the EZSP implementation on the host can regularly poll on the flag outside of the interrupt context and trigger the EZSP Callback command.

For more advanced functionality, you can connect nHOST_INT to a pin that is capable of waking the host from sleep, and therefore enter a low power mode, while waiting for any incoming data, like a normal asynchronous callback.

Note: Care must be taken when enabling an interrupt on nHOST_INT so that the proper piece of code is executed. nHOST_INT is capable of indicating three different situations (wake, callback, and response), and these situations are best indicated by the current state of the nSSEL and nWAKE pins.

Waking the NCP

Waking the NCP should be a straightforward implementation that only requires you to choose between a polling or an interrupt mechanism for knowing when the NCP is ready (much like the rest of the EZSP-SPI Protocol). After asserting the nWAKE signal, the host should either poll for a falling edge of nHOST_INT or set up for an interrupt on the falling edge. As soon as the edge is seen, the host should deassert nWAKE and continue operating the EZSP as desired.

The only major caveat, as mentioned earlier about interrupting on nHOST_INT, is to make sure the proper piece of code gets triggered in response and to not perform further EZSP operations inside of interrupt context.

Error Conditions

The error conditions encountered by the host are exactly that: errors. These errors are not meant to be encountered in a mature product and are primarily used as development and debugging aids. If the host experiences an error condition, chances are the host and the NCP are out of sync, and the code needed to recover would be exceptionally error prone. Therefore, it is reasonable for the host to treat all error conditions or timeouts in the same way as asserts, and simply reset both the host and the NCP.

There is one common exception to this rule: When the host *intentionally* resets the NCP (for example, as described in the "Performing a Hard Reset" section), the host must expect the NCP Reset error condition to occur on the next transaction. This error condition should be observed and discarded as expected and normal.

Note: The application must be careful not to interfere with any operation that loads firmware onto the NCP (e.g., bootloading). The recommended practice is for the host to have access to and control of the NCP's nRESET signal, and to toggle nRESET if an error condition occurs. When the NCP is being loaded with new firmware, it will not be capable of responding to the host; the host may think the NCP is unresponsive and attempt to reset it, which will disrupt the loading of new

firmware. You should consider the best method to avoid resetting the NCP in this situation. Some options include:

- Putting the application in some mode where it leaves the NCP alone.
- Holding the host in reset, bootloader, or some other innocuous mode.
- Disabling the host's access to the nRESET line on the NCP.
- Physically disconnecting nRESET.

Error Bytes

As described in the "Primary SPI Bytes" section of this application note, there are four SPI Bytes that indicate error conditions. When implementing the code to receive a Response from the NCP, the host must be capable of parsing the SPI Byte as soon as possible for any of these error conditions. The host must continue to receive the entire error before deasserting Slave Select and processing the error. With the exception of an *intentional* NCP Reset error condition, the host should report, through a `printf` or other simple method, these four errors to the developer for debugging purposes, but should ultimately result in an assert or similar reset mechanism.

Timeouts

There are only two timeouts the host can experience: Wait Section and Wake Handshake. Just like the Error Bytes, if either of these timeouts occurs, the application should report them to the developer for debugging purposes, but should ultimately result in an assert or similar reset mechanism.

The timeouts are best measured using a timer, but if necessary the host can simply burn a known amount of CPU cycles while waiting for either normal operation to resume or the limit of allowable CPU cycles. For the Wait Section Timeout, the time is measured from the end of the last byte transmitted in the Command to the start of the first byte received that is not 0xFF. For the Wake Handshake Timeout, the time is measured from the falling edge of nWAKE to the falling edge of nHOST_INT.

Interfacing EZSP to the EZSP-SPI Protocol

Due to the serial nature of the EZSP (that is, transactions must occur in sequence instead of overlapping), Ember recommends that the EZSP interface into the SPI Protocol through a polling driven mechanism. For example, after calling a function `sendCommand()`, the EZSP could continually call a function `pollForResponse()`. Otherwise, the EZSP implementation should be carefully coded to prevent the host from accidentally overlapping transactions.

If the host's EZSP-SPI Protocol is implemented using interrupts, the host should be careful to never perform a transaction inside of an interrupt context. This is especially important because a transaction or a wake handshake could require up to 200ms or 10ms respectively.

After Reading This Document

If you have questions or require assistance with the procedures described in this document, contact Ember Customer Support. The Ember Customer Support portal provides a wide array of hardware and software documentation such as FAQ's,

reference designs, user guides, application notes, and the latest software available to download. To obtain support on all Ember products and to gain access to the Ember Customer Support portal, visit http://www.ember.com/support_index.html.