Ethernet Bootloader

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The Brush Electronics Ethernet Bootloaders have been developed to deliver a rapid development environment for an Ethernet enabled Microchip Flash Memory based PIC Microcontroller and to support remote firmware upgrade for these systems deployed in the field. Figure 1 outlines the Ethernet Bootloader's conceptional system elements. The LAN Interface Adapter (LIA) is the target device containing the bootloader image.

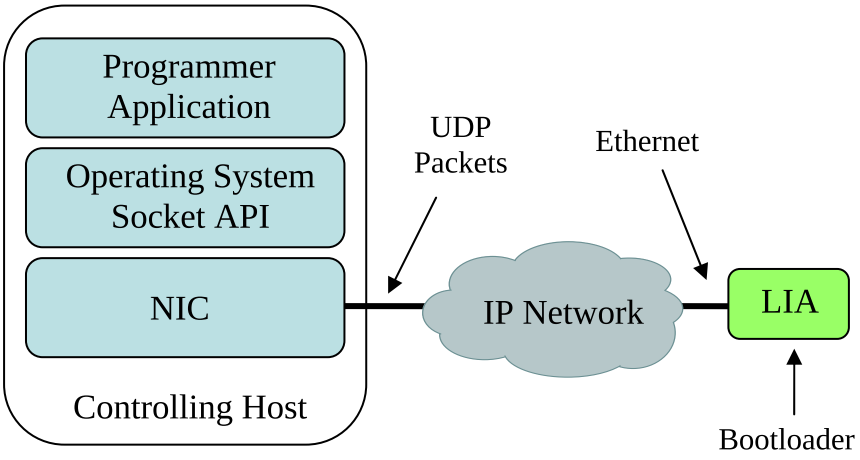


Figure 1: Ethernet Bootloader System

The Bootloader solution includes the bootloader code resident in the target PIC, the controlling host (the host running the programming application) and an Ethernet connection. For the sake of subsequent explanation, the term Bootloader refers to the code executing in the LIA's PIC microprocessor and the Programmer refers to the programming application running on the controlling host.

The Brush Electronics Ethernet Bootloader supports Microchips PIC18F family of Microcontrollers with implementations s the Microchip ENC28J60 Ethernet controller and the RealTek RTL8019AS Ethernet controller.

Key attributes of Brush Electronic's family of Ethernet Bootloaders:

- Plug and Play operation – the ability to use the bootloader without previously having to configured it with an IP address
- Ability to bootload a remote system
- Incremental bootloader. As little as a single byte can be modified

- No resources are required on the target PIC other than the flash memory holding the boot code

- Transparent to the user’s code. The bootloader is located in high program memory and automatically intercepts the application programs reset vectors.

- Report status to the programming application used for implementing a “reliable service”

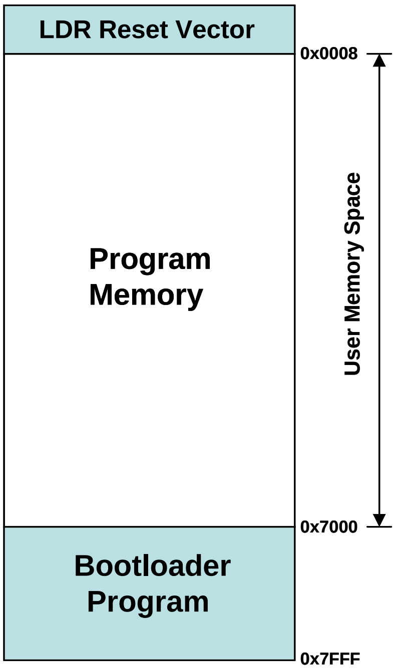
- Uses standard Intel Hex Files

- Is capable of uploading and downloading program and EEPROM data

Plug and Play operation over Ethernet is achieved via the use of multicast IP operation enabling the dynamic discovery and operation of a LIA on a local network segment. No “gleaming” is required to talk to the Bootloader. Remote support is achieved via Unicast IP operation enabling a LIA on the other side of the world to be remotely programmed. Flexible operating modes, embedded diagnostics and reliable service challenge the third requirement, the need to minimise the memory footprint of the loader to maximise the available user code space.

Bootloader Memory MAP

The Bootloader code resides in the upper portion of the program memory space. Because this program memory is flash memory based, user configurable optional parameters are also stored in this space. The EEPROM memory space internal to the PIC is preserved unchanged by the Bootloader. The Bootloader transparently uses the PIC’s reset vector, that is, the lower 8 bytes of program memory. The user’s reset vector is transparently mapped into an 8 byte block within the Bootloader’s code space. The user’s code MUST implement a GOTO instruction (a long jump) in the first 4 instructions. The Bootloader code includes a RESET instruction immediately following the remapped vector block. If the user’s program fails to implement a GOTO instruction in the first 4 instructions, then the RESET instruction is executed. The following diagram shows s typical bootloader’s memory MAP. The actual address ranges in use will depend on the program memory space size of the specific PIC.



MEMORY MAP

Basic Operation
The Bootloader code in the PIC and PC based programmer application use flags to control the boot load process. Two of these flags determine the boot up behaviour of the PIC:

- The PENDING RESET VECTOR is used to indicate that the user's RESET vector has not yet been received.
- The INVALID USER CODE SPACE flag indicates that an Intel End-of-File hex record has not yet been received.

The LIA's Bootloader code is executed automatically as a result of a power on reset, a reset command or a jump to absolute address 0000h. The Bootloader is now in BOOTLOADER DISCOVERY MODE. If either of the two critical flags is set the programmer will automatically enter LOADER COMMAND MODE. This generally indicates the user code space is empty or has previously been invalidated.

If neither of the critical flags has been set, the loader will wait for five seconds looking for a command from the Programmer via the Ethernet interface to put the LIA into LOADER COMMAND MODE. If no command is received the Bootloader passes control to the user's application code via the remapped reset vector. Note that the Bootloader and the user's code do not operate concurrently – this explains why the loader does not require any of the PICs resources other than the consumed program memory.

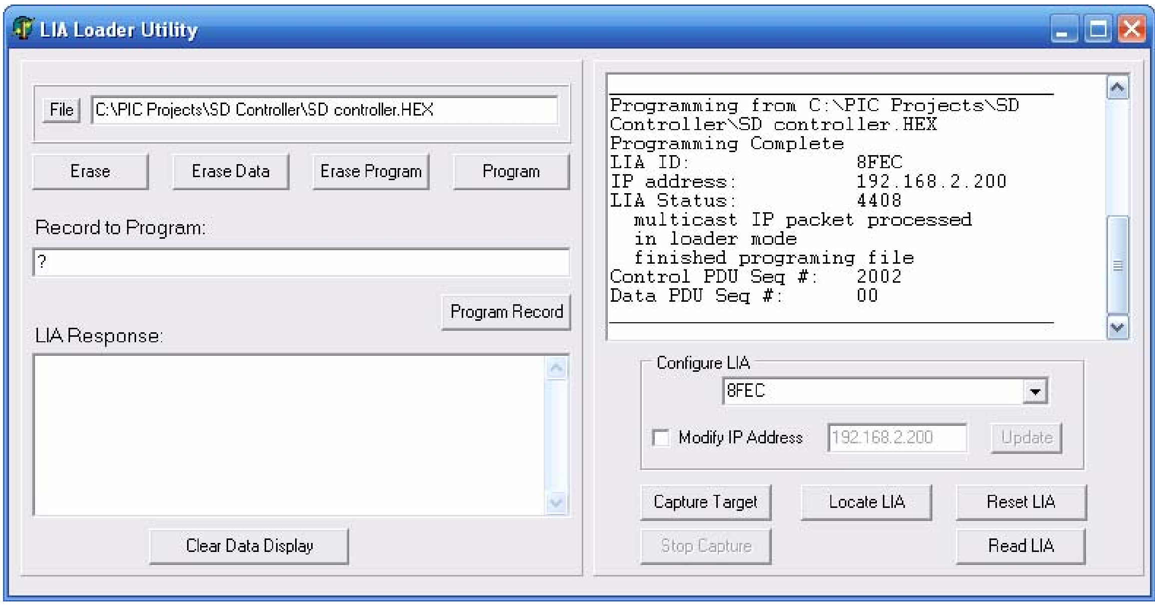
The Bootloader accepts commands from the Programmer using multicast and / or unicast IP packets. UDP (User Datagram Protocol) is used between the Bootloader and the programmer. The IP datagram service provides a good fit for exchanging Intel Hex File records (lines in the hex file) however UDP is an unreliable service which means that the application (both the Bootloader and the programmer) must implement their own error detection, reporting and, where applicable, retransmission.

The Bootloader implements an incremental programming mechanism. This means that it will program only the bytes specifically contained in the record to be programmed. Code changes down to a single byte granularity are supported and the remaining program memory space contents are preserved.

Using the programming application

The following diagram is a screenshot of the LIA Loader Utility. The LIA's Bootloader has been captured and the hex file HEAD.ASM has been programmed into the LIA via the Bootloader. The Status information is displayed in the right hand memo pane. Note the LIA_ID in the Configure LIA drop down menu box. This selects the target Bootloader (which LIA is to be programmed).

The LIA Response memo pane will usually be empty. This pane is used to display error messages. The bootloader will use either multicast or unicast IP depending on the settings contained in the configuration INI file located in the same directory as the programming application.



File: C:\PIC Projects\SD Controller\SD controller.HEX

Record to Program: ?

LIA Response:

```
Programming from C:\PIC Projects\SD
Controller\SD controller.HEX
Programming Complete
LIA ID:               8FEC
IP address:           192.168.2.200
LIA Status:           4408
  multicast IP packet processed
  in loader mode
  finished programing file
Control PDU Seq #:    2002
Data PDU Seq #:       00
```

Configure LIA: 8FEC

☐ Modify IP Address 192.168.2.200

There are two alternatives for downloading code to a LIA (target system). The manual method is used to identify the specific LIA to be programmed. The automatic method is used to perform automatic discovery. If there are multiple LIA devices in bootloader mode on the network then the first method would be used, otherwise the latter is a more user friendly method.

Automatic Method - steps for downloading code to a LIA via the Bootloader and Programmer Application:

> Step 1 – Click "Capture Target" to initiate device discovery and capture. If the "Configure LIA" drop down box is empty, the Capture Target button will

initiate a LIA discovery packet and start a retry timer. If the drop down box is not empty than a LOADER COMMAND MODE command packet will be sent to the LIA matching the ID in the drop down box. This process will repeat every 500ms (retry interval) until the LIA responds to the command or until the “Stop Capture” button is operated. Once a LIA has responded to the discovery packet, its ID will be added to the “Configure LIA” drop down box and, as a result, the next time the retry timer expires a LOADER COMMAND MODE command packet will be sent to the LIA.

Step 2 – Power cycle or reset the target device to be programmed. This will put the Bootloader into BOOTLOADER DISCOVERY MODE and enable the Bootloader to respond to discovery packets from the programming application. As a result of the “Capture Target” sequence initialised in step 1, the LIA should respond and be captured within seconds. Once captured, the target device remains in LOADER COMMAND MODE. In this mode the flash and EEPROM memory of the target device can be read, erased and programmed.

Step 3 – Select the desired read, erase or program operation. Note that to program the Bootloader from a hex file, you must first select the source file using the “File” button. The identified file and path will be displayed in the file window. The hex file is opened when the Program button is clicked and close at completion of the programming cycle. The next time the Program button is clicked the source file is again opened. This is important because it means that the Bootloader is always being programmed with the current contents of the source file. The edit control Record to Program can be used for sending individual records to the Bootloader. The Overwrite LIA button is used to invalidate the user’s program memory space without erasing the user’s program. A LIA in this mode will stay in BOOTLOADER DISCOVERY MODE after being reset without passing control to the user’s program.

Step 4 – Once the LIA has been successfully programmed or read, click the Reset LIA button which will issue a LOADER RESET COMMAND to the Bootloader.

Manual Method - steps for downloading code to a LIA via the Bootloader and Programmer Application:

Step 1 – Power cycle or reset the target device to be programmed. This will put the Bootloader into BOOTLOADER DISCOVERY MODE and enable the Bootloader to respond to discovery packets from the programming application.

Step 2 – Click “Locate LIA” to initiate device discovery to find all devices currently in BOOTLOADER DISCOVERY MODE. The first device to be discovery will have it’s LIA_ID displayed in the Configure LIA drop down control. If multiple devices were discovered then the target device can be selected in the Configure LIA drop down box.

Step 3 – Within 5 seconds of Step 1, click the “Capture Target” button. This will send the LOADER COMMAND MODE command to the LIA, identified in the Configure LIA control, to ***Capture*** the Bootloader. Once captured, the target device remains in LOADER COMMAND MODE. In this mode the flash and EEPROM memory of the target device can be read, erased and programmed.

Step 4 – Select the desired read, erase or program operation. Note that to program the Bootloader from a hex file, you must first select the source file using the "File" button. The identified file and path will be displayed in the file window. The hex file is opened when the Program button is clicked and close at completion of the programming cycle. The next time the Program button is clicked the source file is again opened. This is important because it means that the Bootloader is always being programmed with the current contents of the source file. The edit control Record to Program can be used for sending individual records to the Bootloader. The Overwrite LIA button is used to invalidate the user's program memory space without erasing the user's program. A LIA in this mode will stay in BOOTLOADER DISCOVERY MODE after being reset without passing control to the user's program.

Step 5 – Once the LIA has been successfully programmed or read, click the Reset LIA button which will issue a LOADER RESET COMMAND to the Bootloader.

When the LOADER RESET COMMAND is executed the LIA executes the Bootloader code and waits for 5 seconds to receive the LOADER COMMAND MODE command. If this command is not received and the critical flags are clear then the loader passes control to the user's application program.

Programmer Application - Under the Hood

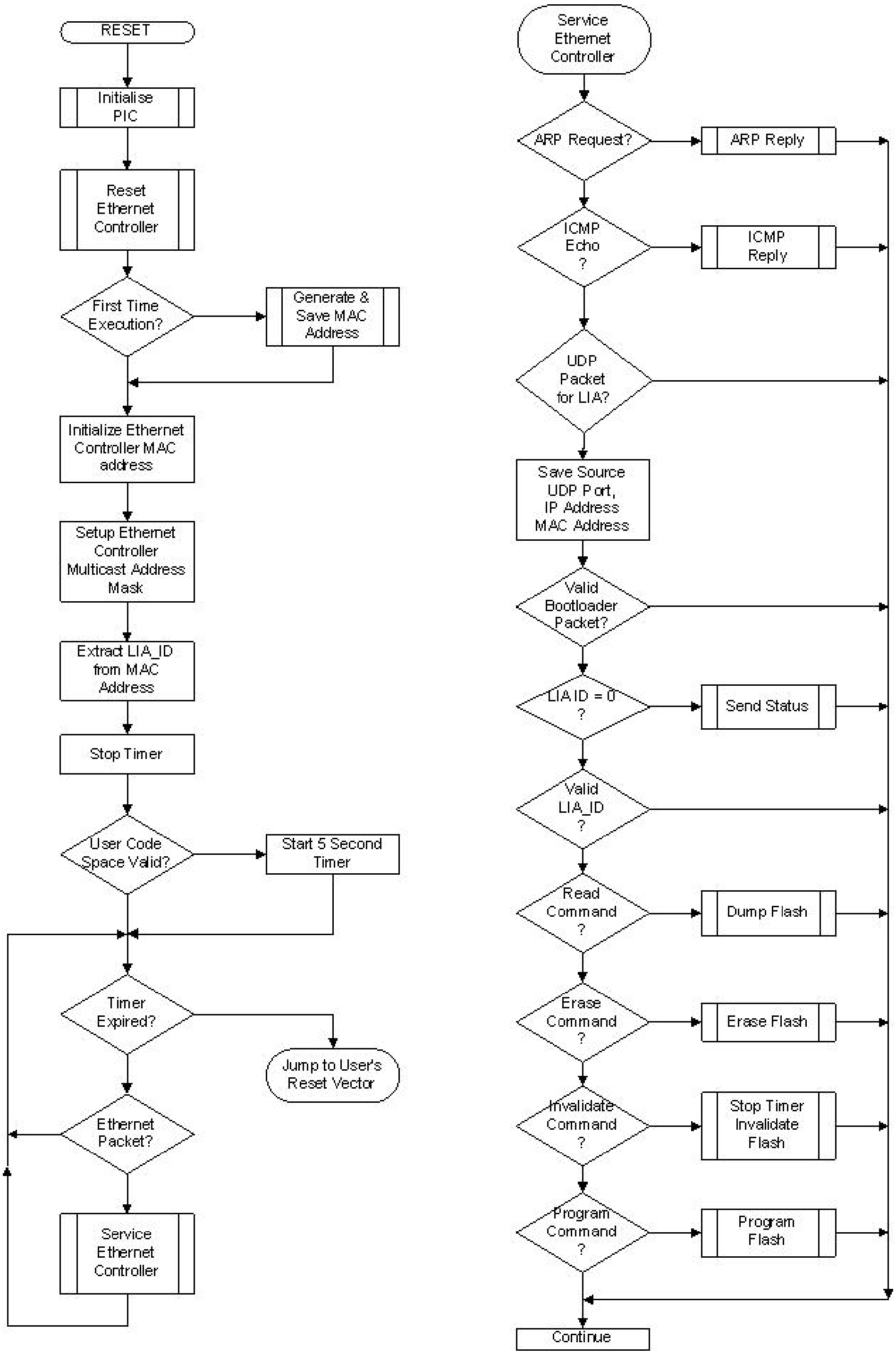
The Programmer Application is written in Delphi for the windows environment. The application should compile unchanged with Kylix for Linux but I have not tested this. The application uses the freeware INDY control TIdUDPClient for reading and writing packets to the network. The Indy software is licensed under the Indy Modified BSD License which is included in the files for this project. The Indy package is installed as standard in Delphi Enterprise addition 6 and 7. Indy versions 8 and 9 are compatible with this application. For Personal Delphi or Delphi 2005 you will need to download install one of these compatible versions from http://www.nevrona.com/indy

The Programmer and Bootloader are implemented in a client / server arrangement. The Programmer (client) issues commands to the Bootloader (server) which executes the commands and returns status information for each command. The Programmer application is multithreaded, implementing a read thread for processing packets received from the Bootloader. Packets sent to the Bootloader are handled by the main thread. The Programmer Application uses a timer control as part of the error detection and processing mechanism for the READ, ERASE and PROGRAM commands.

In the event that no status is returned for the current record, the timer will expire and a consecutive error counter variable will be incremented. If this is CEC value below the maximum consecutive error threshold then the timer is restarted and the previously saved current record is retransmitted.

LIA Bootloader - Under the Hood

The following diagram is a simplified representation of the Bootloader code operation:



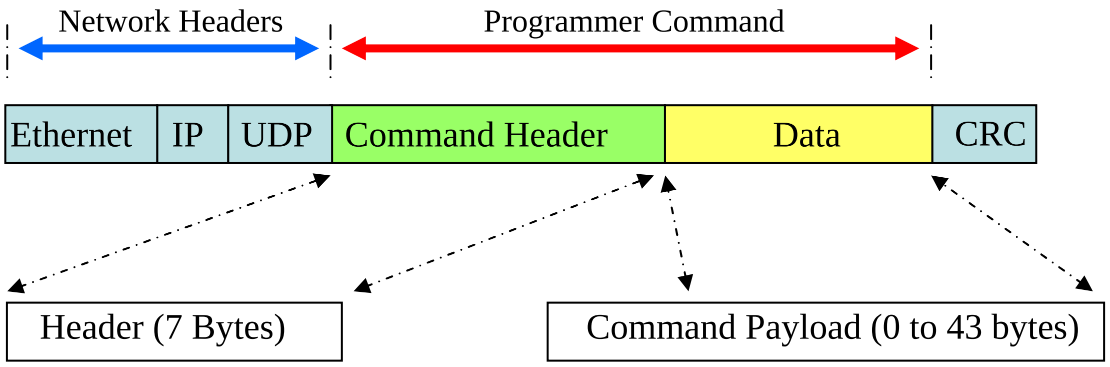
Packet Formats

Packets sent from the bootloader to the programmer can be sent to the Unicast Address of the Bootloader or the Multicast Address. IP packets can be Unicast for point to point communications, Broadcast to all devices on a subnet, or Multicast to a targeted subset of devices. Devices interested in receiving multicast packets will configure the network interfaces to accept specific multicast MAC layer addresses. These MAC layer addresses map to corresponding IP multicast addresses. The Bootloader configures the Ethernet Controller chip with a multicast filter mask in order to accept multicast packets destined for the multicast address 230.10.10.11

Unicast packets sent by the Application Programmer will have the TTL (Time-to-Live) field set to 255. Network routers along the path between the Source and Destination decrement this value by 1. If as a result of decrementing the TTL field, the result is zero, then instead of forwarding the packet out of the destination interface the router will discard the packet. This is the mechanism IP networks use to prevent packets looping for ever in the network. For Unicast packets this means the packet can traverse up to 254 routers.

For Multicast packets, the Programmer Application sets the TTL field to 1. The first time a router tries to forward the packet, the TTL field is decremented to zero and the router discards the packet. This mechanism limits Bootloader multicast packets to the local IP network segment. Multicast therefore provides us a mechanism to support plug and play operation. We do not need to assign an IP address to the Bootloader to be able to communicate with it over an IP network and we use the TTL limited to limit the traffic to the local segment. The multicast mechanism allows us to operate multiple bootloaders on the same network segment. This is accomplished using the LIA_ID which is derived from the MAC address of the Bootloader.

Programmer to LIA Communications



The Network Header portion is a convention UDP packet structure. The destination IP address is either the Unicast IP Address of the LIA or the Multicast IP address 230.10.10.11 The destination UDP port number for the Bootloader is 0x4000.

The Programmer Command is carried in the data portion of the UDP packet. This comprises a 7 byte command header and an optional variable length payload.

PROGRAMMER PAYLOAD STRUCTURE

Field	Length	Description
LIA_TAG	2 bytes	5AA5
LIA_ID	2 bytes	Unique 2 byte LIA identifier
Sequence	2 bytes	Incremental Sequence Number
Command	1 byte	
Command Payload	0 to 36 bytes	

LIA_TAG: a fixed pattern used to protect against the remote possibility that another device on the network is using the same IP address and port number. If the Key field of the incoming packet does not match then the record is discarded. The bootloader also checks to ensure all command structures are valid.

LIA_ID: the last two byes of the Bootloader's MAC address. The Bootloader generates a pseudo unique MAC address the very first time it is powered up. This MAC address is subsequently stored in the Bootloader's program memory space. Subsequent powering up of the LIA will use the MAC address stored in the Bootloader's program memory space. This LIA ID mechanism enables multiple LIAs to share a common network segment and still enable each LIA to be uniquely programmed by the Programmer application. All Bootloaders will respond to a status request if the target LIA_ID field is set to 0000. When the Bootloader responds it puts it's LIA_ID into the corresponding field. This is the mechanism used by the Programmer Application to discover all Bootloaders on the network segment. Other than the Status Command, the Bootloader will ignore all commands that do not specifically match the Bootloader's LIA_ID

Sequence: This field is incremented by the Programmer application. It is used by the Bootloader to detect lost command packets. Sequence numbers and acknowledgement timers are used to detect and recover from lost packets.

Command: Command issued by the Programming Application to the Bootloader. The commands are discussed later in this section.

Payload: Two commands use the optional payload field, the
Set_IP address command contains a four byte IP address to be assigned to the Bootloader. This IP address is stored in the Bootloader Program Memory space and permanently overwrites the default IP address.
New_Code: This contains an Intel INHX32 record – that is, a line from the hex file produced by an assembler and will be a type 0, type 1, or type 4 record.

The following diagram shows the Programmer Payload structure for packets send from the programmer to the Bootloader. Each command comprises of a seven byte command header.

The following figure gives a breakdown of the ten commands supported by the bootloader and the length of the optional payload field.

COMMAND FORMAT – Programmer to Bootloader

```
Command       Value Payload  Comment
*************************************************************
CP_Status       0     0      Show status
CP_SetIP        1     4      Set IP address
CP_Invalidate   2     0      Invalidate User Program Area
CP_LDR_Mode     3     0      Put LIA into Loader State
CP_New_Code     4   7 - 36   New code to store
CP_Dump         5     0      Dump user memory and EEPROM
CP_Erase        6     0      Erase Program Memory and EEPROM
CP_Erase_PGM    7     0      Erase Program Memory only
CP_Erase_EE     8     0      Erase EEPROM only
CP_Reset        9     0      Reboot the LIA
```

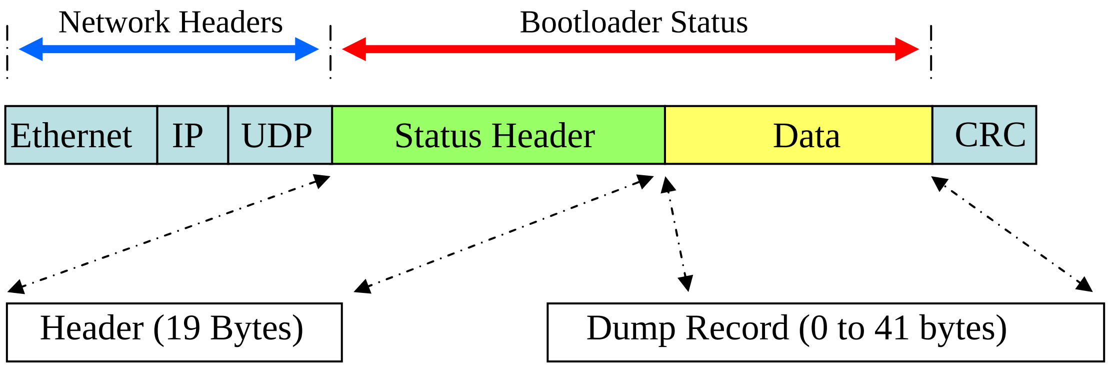
Most commands are self explanatory and further information can be found in the source code for the Programmer Application. The Invalidate command sets a flag in the Bootloader code which prevents the bootloader from passing control to the user’s program. Effectively the user’s program space has been invalidated but it has not been erased. It is possible to reverse the Invalidate status by sending a single type 1 (end-of-file) record to the Bootloader with the New_Code command.

The LDR_Mode command (Loader Mode) captures the Bootloader to prevent the Bootloader passing control to the user’s application program at the end of the initial 5 second period from reset. In this mode the Bootloader is under the control of the Programmer application. The user’s code is not invalidated – if the LIA is reset while in this mode then after 5 seconds control will once again be passed to the user’s program provided the user’s code space is valid.

The Dump command will upload the contents of the User’s program memory and EEPROM memory space to the Programmer Application. The Bootloader uses the same INHX32 Intel Hex record format.

All commands will result in a status packet being sent to the Programmer Application indicating the success or otherwise of the command. Lack of status information is interpreted by the programmer as a lost or missing command acknowledgement and will result in the application programming reissuing the previous command. In the worst case scenario this means the bootloader may program the same record (line of the Hex file) twice.

Bootloader to Programmer Communications



BOOTLOADER STATUS STRUCTURE

Field	Length	Description
LIA_TAG	2 bytes	5AA5
Target_ID	2	0x0000
Sequence	2 bytes	Command sequence number
Command	1	LIA command byte
Product_ID	1	LIA product identifier - 0x01
HW_version	1	Major / Minor 4 bits each
SW_Version	1	Major / Minor 4 bits each
LIA_ID	2 bytes	Unique 2 byte LIA identifier
IP_addr	4	User configurable IP address
LIA_State	2	LIA status Word
Data_Seq	1	Next Data Sequence Number to be used for data traffic
INHX32 record	0..41	Variable command payload

The status record reflects the command status header information to the Programmer Application as well as some additional fields. The Data sequence number is used for lost packet detection for the dump command. The Application program currently uses this information to report error status and terminate the dump command but it does not automatically issue another dump command.

Structure of Intel HEX file records

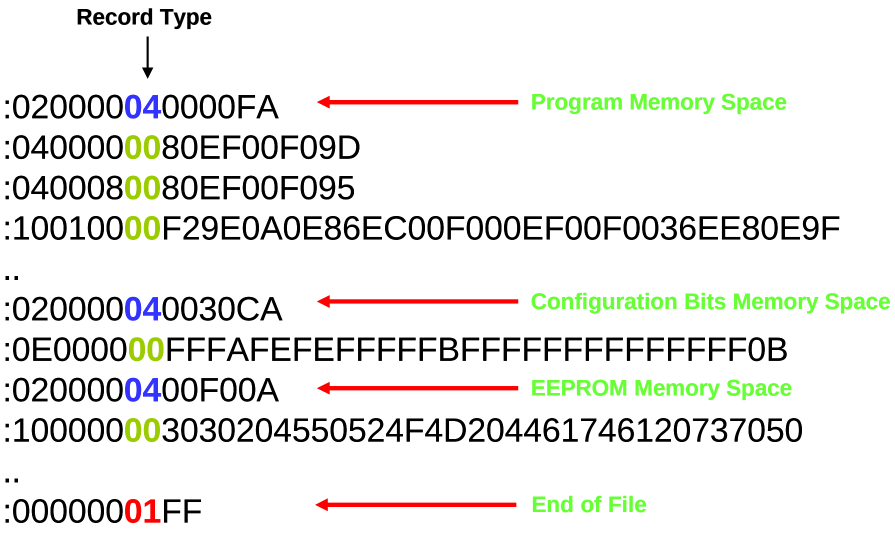
:AABBBBCCDDDD..EE

Where

: indicates the start of the current record
AA number of data bytes in the record
BBBB target address of the first byte in this record.
CC record Type
00 Data Record
01 End of File Record
04 Linear Address Record
DD.. data
EE checksum calculated across the record. Excludes the **:** character

Extract from INHX32 (Intel 32 bit hex file) produced by Microchip MPASM.

This figure show the use of type 4 records in the hex file which identifies the target memory page used by the bootloader to determine the target for subsequent data (type 0) records. The Bootloader ignores data records targeted to the configuration bits. The first record of the file is a type 4 record identifying the target for subsequent data records in the Program Memory Space until the receipt of a subsequent type 4 record or an EOF record.



```
:020000040000FA
:04000000080EF00F09D
:040008000080EF00F095
:10010000F29E0A0E86EC00F000EF00F0036EE80E9F
..
:020000040030CA
:0E000000FFFAFEFEFFFFFBFFFFFFFFFFFFFF0B
:0200000400F00A
:10000000303020455052 4F4D20446174612073705 0
..
:00000001FF
```

Unicast – directed traffic between two devices
Broadcast – flooding from a device to all other devices in a common broadcast domains - typically to all devices in a subnet
Multicast – Subset of broadcast, packets are sent to a common community. IP 224.0.0.0 to 239.255.255.255 CLASS D
This address range is only for the group address or destination address of IP multicast traffic. The source address for multicast datagrams is always the unicast source address. RFC1112

Limitations of the Bootloader

The following limitations of the Bootloader must be taken into account:

- The LIA registers are not preserved by a RESET
- No support for WDT fuse bit. WDT support if required must be implemented by the software enabled WDT feature
- User’s program must execute a GOTO instruction within the first four instructions
- The Bootloader ignores Configuration Records and ID records

Final Thoughts

The Ethernet Bootloader is a great tool for developing those “wouldn’t it be great to reach this over the network” projects. Developing Ethernet enabled Microcontroller projects is much easier today than when I started with the LIA. Microchip offers a free IP stack for use with Microchip PICs and they have a number of good proof of concept kits with the PICDEM.NET and the ENC28J60 Ethernet PigTail board. The LIA Bootloader does not use any of the Microchip stack, this is because the Bootloader is optimised for space, while the stack is optimised for performance. For this reason I did not open any of the Bootloader APIs for use by target applications.

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