

RAM loader program for 80C51 family applications

AN440

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The following program allows an 80C51 family microcontroller to load most of its code into a RAM over a serial link after power up and execute out of the RAM for normal operation. This can allow a final product to have firmware updates done by a simple diskette mailing. Such a program is often called a "bootstrap loader".

For this example, it is assumed that the code download is done via a serial communication

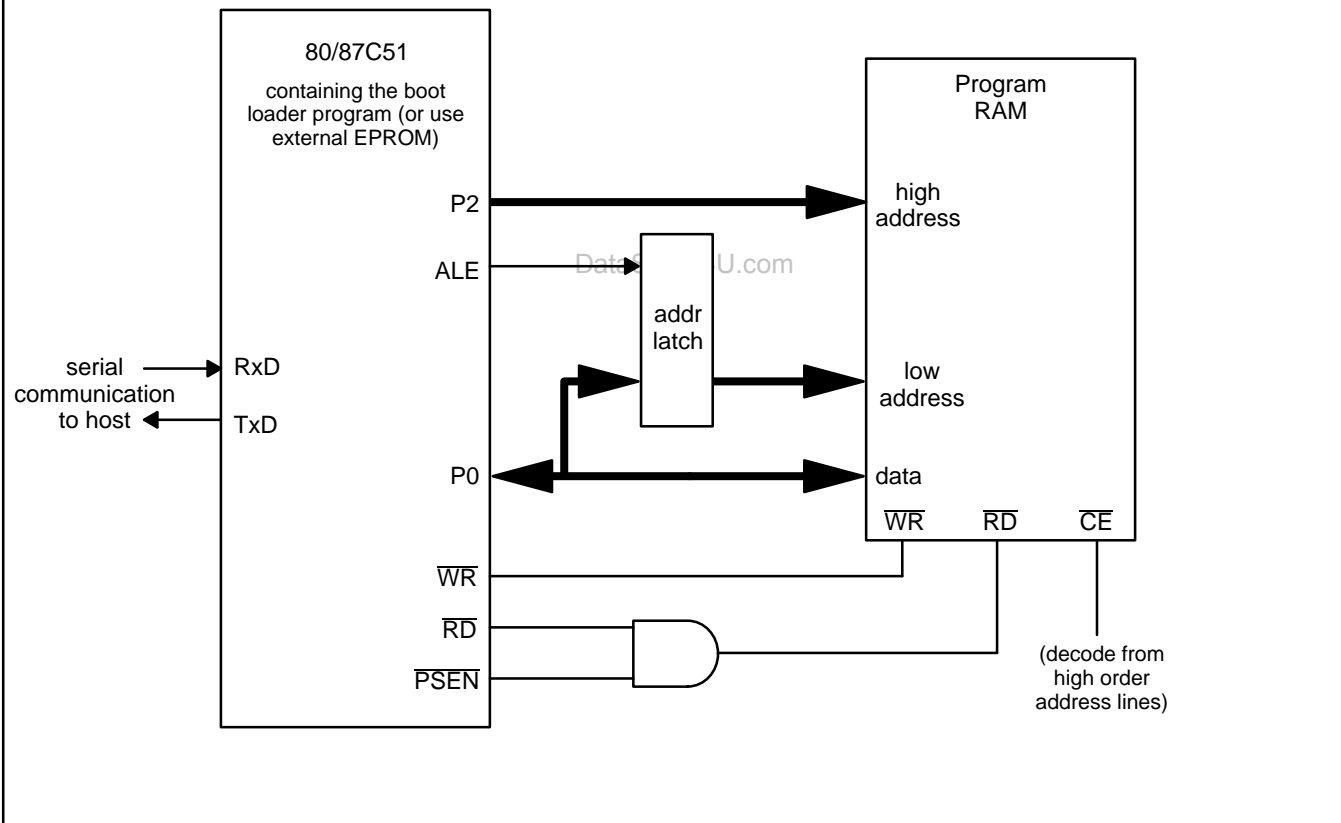
link, although the program could be adapted to other forms of download. The comments at the beginning of the listing are intended to document the program and its use completely.

An additional comment would be that any static routines (low level routines that are unlikely to change over time) can probably be put into the permanent program memory (on-chip or off-chip ROM or EPROM) along

with the bootstrap loader to save program RAM space for other things.

The source code file for this program is available for downloading from the Philips computer bulletin board system. This system is open to all callers, operates 24 hours a day, and can be accessed with modems at 2400, 1200, and 300 baud. The telephone numbers for the BBS are: (800) 451-6644 (in the U.S. only) or (408) 991-2406.

Basic Diagram of RAM Connections for the Boot Loader



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;=====
;
;           Bootstrap Loader for Hexadecimal Files
;           written by G. Goodhue, Philips Electronics
;
; This program allows downloading a hexadecimal program file over an
; asynchronous serial link to a code RAM in an 80C51 system. The downloaded
; code may then be executed as the main program for the system. This technique
; may be used in a system that normally connects to a host PC so that the code
; may come from a disk and thus be easily updated. The system RAM must be
; wired to the 80C51 system so that it appears as both data and program memory
; (wire the RAM normally, but use the logical AND of RD and PSEN for the
; output enable.)
;
; To use the bootstrap program, an Intel Hex file is sent through the serial
; port in 8-N-1 format at 9600 baud. The baud rate and format may be altered
; by making small changes in the serial port setup routine (SerStart).
;
; Note that there is no hardware handshaking (e.g. RTS/CTS or XON/XOFF)
; implemented between the host and the bootstrap system. This was done to keep
; the protocol between the two systems as simple as possible.
;
; Since the bootstrap program does not echo the data file, there is no chance
; of an overrun unless the 80C51 is running very slowly and/or the
; communication is very fast. An 80C51 running at 11.0592 MHz (the most
; commonly used frequency in systems with serial communication) will be able
; to easily keep up with 38.4K baud communication without handshaking.
;=====
; The download protocol for this program is as follows:
;
; - When the bootstrap program starts up, it sends a prompt character ("=")
;   up the serial link to the host.
;
; - The host may then send the hexadecimal program file down the serial link.
;   At any time, the host may send an escape character (1B hex) to abort and
;   restart the download process from scratch, beginning from the "=" prompt.
;   This procedure may be used to restart if a download error occurs.
;
; - At the end of a hex file download, a colon (":") prompt is returned. If
;   an error or other suspicious circumstance occurred, a flag value will
;   also be returned as shown below. The flag is a bit map of possible
;   conditions and so may represent more than one problem. If an error
;   occurs, the bootstrap program will refuse to execute the downloaded
;   program.
;
; Exception codes:
;   01 - non-hexadecimal characters found embedded in a data line.
;   02 - bad record type found.
;   04 - incorrect line checksum found.
;   08 - no data found.
;   10 - incremented address overflowed back to zero.
;   20 - RAM data write did not verify correctly.
;
; - If a download error occurs, the download may be retried by first sending
;   an escape character. Until the escape is received, the bootstrap program
;   will refuse to accept any data and will echo a question mark ("?") for
;   any character sent.
;
; - After a valid file download, the bootstrap program will send a message
;   containing the file checksum. This is the arithmetic sum of all of the
;   DATA bytes (not addresses, record types, etc.) in the file, truncated to
;   16 bits. This checksum appears in parentheses: "(abcd)". Program
;   execution may then be started by telling the bootstrap program the
;   correct starting address. The format for this is to send a slash ("/")
;   followed by the address in ASCII hexadecimal, followed by a carriage
;   return. Example: "/8A31<CR>"

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; - If the address is accepted, an at sign ("@" ) is returned before executing
; the jump to the downloaded file.
```

```
; The bootstrap loader can be configured to re-map interrupt vectors to the
; downloaded program if jumps to the correct addresses are set up. For
; instance, if the program RAM in the system where this program is to be used
; starts at 8000 hexadecimal, the re-mapped interrupts may begin at 8003 for
; external interrupt 0, etc.
```

```
;=====
```

```
$Title(Bootstrap Loader for Hexadecimal Files)
```

```
$Date(04-13-92)
```

```
$MOD51
```

```
;=====
```

```
; Definitions
```

```
;=====
```

LF	EQU	0Ah	; Line Feed character.
CR	EQU	0Dh	; Carriage Return character.
ESC	EQU	1Bh	; Escape character.
StartChar	EQU	':'	; Line start character for hex file.
Slash	EQU	'/'	; Go command character.
Skip	EQU	13	; Value for "Skip" state.
Ch	DATA	0Fh	; Last character received.
State	DATA	10h	; Identifies the state in process.
DataByte	DATA	11h	; Last data byte received.
ByteCount	DATA	12h	; Data byte count from current line.
HighAddr	DATA	13h	; High and low address bytes from the
LowAddr	DATA	14h	; current data line.
RecType	DATA	15h	; Line record type for this line.
ChkSum	DATA	16h	; Calculated checksum received.
HASave	DATA	17h	; Saves the high and low address bytes
LASave	DATA	18h	; from the last data line.
FilChkHi	DATA	19h	; File checksum high byte.
FilChkLo	DATA	1Ah	; File checksum low byte.
Flags	DATA	20h	; State condition flags.
HexFlag	BIT	Flags.0	; Hex character found.
EndFlag	BIT	Flags.1	; End record found.
DoneFlag	BIT	Flags.2	; Processing done (end record or some
			; kind of error.
EFlags	DATA	21h	; Exception flags.
ErrFlag1	BIT	EFlags.0	; Non-hex character embedded in data.
ErrFlag2	BIT	EFlags.1	; Bad record type.
ErrFlag3	BIT	EFlags.2	; Bad line checksum.
ErrFlag4	BIT	EFlags.3	; No data found.
ErrFlag5	BIT	EFlags.4	; Incremented address overflow.
ErrFlag6	BIT	EFlags.5	; Data storage verify error.
DatSkipFlag	BIT	Flags.3	; Any data found should be ignored.

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;=====
;                               Reset and Interrupt Vectors
;=====
; The following are dummy labels for re-mapped interrupt vectors. The
; addresses should be changed to match the memory map of the target system.
ExInt0    EQU    8003h           ; Remap address for ext interrupt 0.
T0Int     EQU    800Bh           ; Timer 0 interrupt.
ExInt1    EQU    8013h           ; External interrupt 1.
T1Int     EQU    801Bh           ; Timer 1 interrupt.
SerInt    EQU    8023h           ; Serial port interrupt.

        ORG     0000h
        LJMP    Start           ; Go to the downloader program.

; The following are intended to allow re-mapping the interrupt vectors to the
; users downloaded program. The jump addresses should be adjusted to reflect
; the memory mapping used in the actual application.

; Other (or different) interrupt vectors may need to be added if the target
; processor is not an 80C51.

        ORG     0003h
;       LJMP    ExInt0           ; External interrupt 0.
        RETI

        ORG     000Bh
;       LJMP    T0Int            ; Timer 0 interrupt.
        RETI

;       ORG     0013h
;       LJMP    ExInt1           ; External interrupt 1.
        RETI

        ORG     001Bh
;       LJMP    T1Int            ; Timer 1 interrupt.
        RETI

        ORG     0023h
;       LJMP    SerInt          ; Serial port interrupt.
        RETI

;=====
;                               Reset and Interrupt Vectors
;=====

Start:    MOV     IE,#0           ; Turn off all interrupts.
          MOV     SP,#5Fh         ; Start stack near top of '51 RAM.
          ACALL  SerStart        ; Setup and start serial port.
          ACALL  CRLF            ; Send a prompt that we are here.
          MOV     A,#'='         ; "<CRLF> ="
          ACALL  PutChar         ;
          ACALL  HexIn           ; Try to read hex file from serial port.
          ACALL  ErrPrt         ; Send a message for any errors or
          ; warnings that were noted.
          MOV     A,EFlags        ; We want to get stuck if a fatal
          JZ     HexOK           ; error occurred.

ErrLoop:  MOV     A,#'?'         ; Send a prompt to confirm that we
          ACALL  PutChar         ; are 'stuck'. " ? "
          ACALL  GetChar         ; Wait for escape char to flag reload.
          SJMP  ErrLoop

HexOK:    MOV     EFlags,#0       ; Clear errors flag in case we re-try.
          ACALL  GetChar         ; Look for GO command.
          CJNE   A,#Slash,HexOK  ; Ignore other characters received.

          ACALL  GetByte         ; Get the GO high address byte.
          JB     ErrFlag1,HexOK  ; If non-hex char found, try again.
          MOV    HighAddr,DataByte ; Save upper GO address byte.

          ACALL  GetByte         ; Get the GO low address byte.
          JB     ErrFlag1,HexOK  ; If non-hex char found, try again.
          MOV    LowAddr,DataByte ; Save the lower GO address byte.

          ACALL  GetChar         ; Look for CR.
          CJNE   A,#CR,HexOK    ; Re-try if CR not there.

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; All conditions are met, so hope the data file and the GO address are all
; correct, because now we're committed.

        MOV     A,#'@"'           ; Send confirmation to GO. " @ "
        ACALL  PutChar
        JNB   TI,$               ; Wait for completion before GOing.
        PUSH  LowAddr           ; Put the GO address on the stack,
        PUSH  HighAddr          ; so we can Return to it.
        RET                    ; Finally, go execute the user program!

;=====
;                               Hexadecimal File Input Routine
;=====

HexIn:   CLR     A               ; Clear out some variables.
        MOV     State,A
        MOV     Flags,A
        MOV     HighAddr,A
        MOV     LowAddr,A
        MOV     HASave,A
        MOV     LASave,A
        MOV     ChkSum,A
        MOV     FilChkHi,A
        MOV     FilChkLo,A
        MOV     EFlags,A
        SETB   ErrFlag4         ; Start with a 'no data' condition.

StateLoop: ACALL  GetChar        ; Get a character for processing.
          ACALL  AscHex          ; Convert ASCII-hex character to hex.
          MOV   Ch,A            ; Save result for later.
          ACALL  GoState         ; Go find the next state based on
          ; this char.
          JNB   DoneFlag,StateLoop ; Repeat until done or terminated.

          ACALL  PutChar        ; Send the file checksum back as
          MOV   A,#'('         ; confirmation. " (abcd) "
          ACALL  PutChar
          MOV   A,FilChkHi
          ACALL  PrByte
          MOV   A,FilChkLo
          ACALL  PrByte
          MOV   A,#')'
          ACALL  PutChar
          ACALL  CRLF
          RET                    ; Exit to main program.

; Find and execute the state routine pointed to by "State".

GoState: MOV     A,State         ; Get current state.
          ANL   A,#0Fh          ; Insure branch is within table range.
          RL   A                ; Adjust offset for 2 byte insts.
          MOV   DPTR,#StateTable
          JMP   @A+DPTR         ; Go to appropriate state.

StateTable: AJMP  StWait        ; 0 - Wait for start.
          AJMP  StLeft         ; 1 - First nibble of count.
          AJMP  StGetCnt       ; 2 - Get count.
          AJMP  StLeft         ; 3 - First nibble of address byte 1.
          AJMP  StGetAd1       ; 4 - Get address byte 1.
          AJMP  StLeft         ; 5 - First nibble of address byte 2.
          AJMP  StGetAd2       ; 6 - Get address byte 2.
          AJMP  StLeft         ; 7 - First nibble of record type.
          AJMP  StGetRec       ; 8 - Get record type.
          AJMP  StLeft         ; 9 - First nibble of data byte.
          AJMP  StGetDat       ; 10 - Get data byte.
          AJMP  StLeft         ; 11 - First nibble of checksum.
          AJMP  StGetChk       ; 12 - Get checksum.
          AJMP  StSkip         ; 13 - Skip data after error condition.
          AJMP  BadState       ; 14 - Should never get here.
          AJMP  BadState       ; 15 - " " " "

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; This state is used to wait for a line start character. Any other characters
; received prior to the line start are simply ignored.

StWait:    MOV     A,Ch           ; Retrieve input character.
           CJNE   A,#StartChar,SWEX ; Check for line start.
           INC   State         ; Received line start.
SWEX:     RET

; Process the first nibble of any hex byte.

StLeft:   MOV     A,Ch           ; Retrieve input character.
           JNB   HexFlag,SLERR   ; Check for hex character.
           ANL   A,#0Fh         ; Isolate one nibble.
           SWAP  A              ; Move nibble too upper location.
           MOV   DataByte,A      ; Save left/upper nibble.
           INC   State         ; Go to next state.
           RET   ; Return to state loop.

SLERR:    SETB   ErrFlag1       ; Error - non-hex character found.
           SETB   DoneFlag      ; File considered corrupt. Tell main.
           RET

; Process the second nibble of any hex byte.

StRight:  MOV     A,Ch           ; Retrieve input character.
           JNB   HexFlag,SRERR   ; Check for hex character.
           ANL   A,#0Fh         ; Isolate one nibble.
           ORL   A,DataByte     ; Complete one byte.
           MOV   DataByte,A      ; Save data byte.
           ADD   A,ChkSum       ; Update line checksum,
           MOV   ChkSum,A       ; and save.
           RET   ; Return to state loop.

SRERR:    SETB   ErrFlag1       ; Error - non-hex character found.
           SETB   DoneFlag      ; File considered corrupt. Tell main.
           RET

; Get data byte count for line.

StGetCnt: ACALL  StRight        ; Complete the data count byte.
           MOV   A,DataByte
           MOV   ByteCount,A
           INC   State         ; Go to next state.
           RET   ; Return to state loop.

; Get upper address byte for line.

StGetAd1: ACALL  StRight        ; Complete the upper address byte.
           MOV   A,DataByte
           MOV   HighAddr,A
           INC   State         ; Go to next state.
           RET   ; Return to state loop.

; Get lower address byte for line.

StGetAd2: ACALL  StRight        ; Complete the lower address byte.
           MOV   A,DataByte
           MOV   LowAddr,A
           INC   State         ; Go to next state.
           RET   ; Return to state loop.

; Get record type for line.

StGetRec: ACALL  StRight        ; Complete the record type byte.
           MOV   A,DataByte
           MOV   RecType,A
           JZ    SGRDat         ; This is a data record.
           CJNE A,#1,SGRErr     ; Check for end record.
           SETB EndFlag         ; This is an end record.
           SETB DatSkipFlag     ; Ignore data embedded in end record.
           MOV   State,#11      ; Go to checksum for end record.
           SJMP SGREX

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SGRDat:   INC      State           ; Go to next state.
SGREX:   RET                          ; Return to state loop.

SGRErr:   SETB    ErrFlag2         ; Error, bad record type.
          SETB    DoneFlag         ; File considered corrupt. Tell main.
          RET

; Get a data byte.

StGetDat: ACALL   StRight          ; Complete the data byte.
          JB     DatSkipFlag,SGD1  ; Don't process the data if the skip
          ; flag is on.
          ACALL  Store             ; Store data byte in memory.
          MOV    A,DataByte        ; Update the file checksum,
          ADD    A,FilChkLo        ; which is a two-byte summation of
          MOV    FilChkLo,A        ; all data bytes.
          CLR    A
          ADDC   A,FilChkHi
          MOV    FilChkHi,A
          MOV    A,DataByte
SGD1:    DJNZ   ByteCount,SGDEX    ; Last data byte?
          INC    State             ; Done with data, go to next state.
          SJMP  SGDEX2

SGDEX:   DEC     State            ; Set up state for next data byte.
SGDEX2:  RET                          ; Return to state loop.

; Get checksum.

StGetChk: ACALL   StRight          ; Complete the checksum byte.
          JNB    EndFlag,SGC1      ; Check for an end record.
          SETB   DoneFlag         ; If this was an end record,
          SJMP  SGCEX             ; we are done.

SGC1:    MOV    A,ChkSum           ; Get calculated checksum.
          JNZ    SGCErr           ; Result should be zero.
          MOV    ChkSum,#0        ; Preset checksum for next line.
          MOV    State,#0         ; Line done, go back to wait state.
          MOV    LASave,LowAddr    ; Save address byte from this line for
          MOV    HASave,HighAddr   ; later check.
SGCEX:   RET                          ; Return to state loop.

SGCErr:  SETB    ErrFlag3         ; Line checksum error.
          SETB    DoneFlag         ; File considered corrupt. Tell main.
          RET

; This state used to skip through any additional data sent, ignoring it.

StSkip:  RET                          ; Return to state loop.

; A place to go if an illegal state comes up somehow.

BadState: MOV     State,#Skip      ; If we get here, something very bad
          RET                          ; happened, so return to state loop.

; Store - Save data byte in external RAM at specified address.

Store:   MOV     DPH,HighAddr      ; Set up external RAM address in DPTR.
          MOV     DPL,LowAddr
          MOV     A,DataByte
          MOVX    @DPTR,A         ; Store the data.
          MOVX    A,@DPTR         ; Read back data for integrity check.
          CJNE   A,DataByte,StoreErr ; Is read back OK?

          CLR     ErrFlag4        ; Show that we've found some data.
          INC     DPTR            ; Advance to the next addr in sequence.
          MOV     HighAddr,DPH    ; Save the new address
          MOV     LowAddr,DPL
          CLR     A
          CJNE   A,HighAddr,StoreEx ; Check for address overflow
          CJNE   A,LowAddr,StoreEx ; (both bytes are 0).
          SETB    ErrFlag5        ; Set warning for address overflow.

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```

StoreEx:    RET

StoreErr:   SETB    ErrFlag6           ; Data storage verify error.
            SETB    DoneFlag          ; File considered corrupt. Tell main.
            RET

;=====
;                               Subroutines
;=====

; Subroutine summary:

; SerStart - Serial port setup and start.
; GetChar  - Get a character from the serial port for processing.
; GetByte  - Get a hex byte from the serial port for processing.
; PutChar  - Output a character to the serial port.
; AscHex   - See if char in ACC is ASCII-hex and if so convert to hex nibble.
; HexAsc   - Convert a hexadecimal nibble to its ASCII character equivalent.
; ErrPrt   - Return any error codes to our host.
; CRLF     - output a carriage return / line feed pair to the serial port.
; PrByte   - Send a byte out the serial port in ASCII hexadecimal format.

; SerStart - Serial port setup and start.
SerStart:   MOV     A,PCON             ; Make sure SMOD is off.
            CLR     ACC.7
            MOV     PCON,A
            MOV     TH1,#0FDh        ; Set up timer 1.
            MOV     TL0,#0FDh
            MOV     TMOD,#20h
            MOV     TCON,#40h
            MOV     SCON,#52h        ; Set up serial port.
            RET

; GetByte - Get a hex byte from the serial port for processing.
GetByte:    ACALL   GetChar           ; Get first character of byte.
            ACALL   AscHex           ; Convert to hex.
            MOV     Ch,A             ; Save result for later.
            ACALL   StLeft          ; Process as top nibble of a hex byte.
            ACALL   GetChar         ; Get second character of byte.
            ACALL   AscHex           ; Convert to hex.
            MOV     Ch,A             ; Save result for later.
            ACALL   StRight         ; Process as bottom nibble of hex byte.
            RET

; GetChar - Get a character from the serial port for processing.
GetChar:    JNB     RI,$             ; Wait for receiver flag.
            CLR     RI              ; Clear receiver flag.
            MOV     A,SBUF          ; Read character.
            CJNE   A,#ESC,GCEX      ; Re-start immediately if Escape char.
            LJMP   Start
GCEX:      RET

; PutChar - Output a character to the serial port.
PutChar:    JNB     TI,$             ; Wait for transmitter flag.
            CLR     TI              ; Clear transmitter flag.
            MOV     SBUF,A          ; Send character.
            RET

; AscHex - See if char in ACC is ASCII-hex and if so convert to a hex nibble.
; Returns nibble in A, HexFlag tells if char was really hex. The ACC is not
; altered if the character is not ASCII hex. Upper and lower case letters
; are recognized.

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```

AscHex:    CJNE    A,#'0',AH1      ; Test for ASCII numbers.
AH1:      JC      AHBad           ; Is character is less than a '0'?
          CJNE    A,#'9'+1,AH2     ; Test value range.
AH2:      JC      AHVal09        ; Is character is between '0' and '9'?

          CJNE    A,#'A',AH3       ; Test for upper case hex letters.
AH3:      JC      AHBad           ; Is character is less than an 'A'?
          CJNE    A,#'F'+1,AH4     ; Test value range.
AH4:      JC      AHValAF        ; Is character is between 'A' and 'F'?

          CJNE    A,#'a',AH5       ; Test for lower case hex letters.
AH5:      JC      AHBad           ; Is character is less than an 'a'?
          CJNE    A,#'f'+1,AH6     ; Test value range.
AH6:      JNC     AHBad           ; Is character is between 'a' and 'f'?
          CLR     C
          SUBB   A,#27h           ; Pre-adjust character to get a value.
          SJMP   AHVal09         ; Now treat as a number.

AHBad:    CLR     HexFlag        ; Flag char as non-hex, don't alter.
          SJMP   AHEX           ; Exit
AHValAF:  CLR     C
          SUBB   A,#7            ; Pre-adjust character to get a value.
AHVal09:  CLR     C
          SUBB   A,#'0'         ; Adjust character to get a value.
          SETB   HexFlag        ; Flag character as 'good' hex.
AHEX:    RET

```

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```

HexAsc:    ANL     A,#0Fh         ; Make sure we're working with only
          ; one nibble.
          CJNE    A,#0Ah,HA1      ; Test value range.
HA1:      JC      HAVal09        ; Value is 0 to 9.
          ADD     A,#7           ; Value is A to F, extra adjustment.
HAVal09:  ADD     A,#'0'         ; Adjust value to ASCII hex.
          RET

```

; ErrPrt - Return an error code to our host.

```

ErrPrt:    MOV     A,#':'        ; First, send a prompt that we are
          CALL   PutChar        ; still here.
          MOV     A,EFlags       ; Next, print the error flag value if
          JZ     ErrPrtEx       ; it is not 0.
          CALL   PrByte
ErrPrtEx:  RET

```

; CRLF - output a carriage return / line feed pair to the serial port.

```

CRLF:     MOV     A,#CR
          CALL   PutChar
          MOV     A,#LF
          CALL   PutChar
          RET

```

; PrByte - Send a byte out the serial port in ASCII hexadecimal format.

```

PrByte:   PUSH   ACC            ; Print ACC contents as ASCII hex.
          SWAP  A
          CALL   HexAsc         ; Print upper nibble.
          CALL   PutChar
          POP   ACC
          CALL   HexAsc         ; Print lower nibble.
          CALL   PutChar
          RET

```