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APPLICATION NOTE

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HC05 MCU Software-Driven Asynchronous Serial Communication Techniques Using the MC68HC705J1A

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INTRODUCTION

This application note describes a method for asynchronous serial communication with a microcontroller unit (MCU) using standard input/output (I/O) port pins and software which incorporate noise and frame-error detection. If error detection is not needed, the code size may be reduced for more efficient use of memory.

OVERVIEW

A serial communication interface (SCI) is a serial I/O sub system available with many Motorola MCUs. This hardware module provides full-duplex, universal asynchronous receiver/transmitter-type (UART) serial communication between the MCU and other UART-type devices, such as a cathode-ray-tube (CRT) terminal, personal computer, or other MCUs. The SCI handles all transmission and reception duties and by so doing off-loads the CPU to perform other functions simultaneously. The SCI is software programmable for many different baud rates. The receiver can detect error conditions automatically, such as framing, noise, and overrun.

Some Motorola MCUs do not include an SCI, specifically a low-cost, low-pin-count MCU such as the MC68HC705J1A. To perform asynchronous serial communication, software must be used to emulate an SCI. In this case, the CPU would control I/O port pins to perform the same functions as the receive data (RXD) and transmit data (TXD) pins of a true hardware-driven SCI.

This application's software solution requirements are:

- Speed optimization for maximum baud rate
- Minimal code size
- Easy configuration for different baud rates
- Ability to detect noise and framing errors while receiving.

Because the CPU is not as efficient as a dedicated hardware SCI, software emulation has limitations:

- Very fast baud rates are not attainable
- SCI software consumes memory space and CPU bandwidth
- Flexibility and features are reduced

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If a particular application cannot be limited by these restrictions, then using an MCU with an SCI would be appropriate. However, many applications do not need the performance or flexibility of an SCI, and, in those cases, software emulation is a cost-effective solution.

The above requirements would be jeopardized by software emulation of full-duplex transmission. This software solution only operates in half-duplex mode.

SERIAL COMMUNICATION TERMINOLOGY AND CONCEPTS

Several technical concepts and terms pertaining to SCI software operation are discussed here. Note that message protocol is not discussed, since it is assumed the reader is knowledgeable about effective SCI communication.

Half-Duplex Operation

In a half-duplex system, only one node transmits at any one time. The MCU cannot receive while it is transmitting, and it cannot transmit while it is receiving. This inability is in contrast to the hardware SCI, which can transmit and receive different information at the same time. This is known as a full-duplex system.

Transmission Format

The SCI uses the standard non-return-to-zero (NRZ) format consisting of one start bit followed by one byte (eight bits) of data and one stop bit. This is commonly referred to as an 8-N-1 format (8 data bits, no parity bit, 1 stop bit). Data is both transmitted and received least significant bit (LSB) first. Each bit has a duration, t_p, which defines the baud rate.

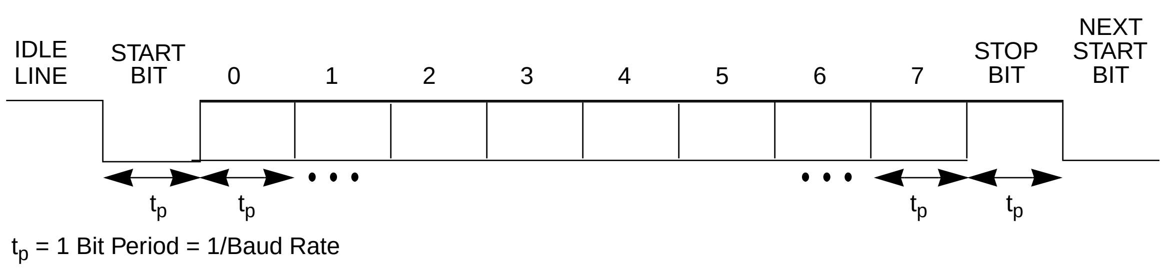


Figure 1. NRZ 8-N-1 Transmission Format

As shown in Figure 1, an idle line is high (logic one) prior to transmission or reception, and the start bit is low (logic zero). Each data bit is either high (logic one) or low (logic zero). The stop bit is high (logic one). The start bit, eight data bits, and stop bit constitute one frame of data.

Noise Detection

On an asynchronous serial network, data transmitted by one node may be received incorrectly by another node because of noise corruption along the data path. To minimize noise corruption, the SCI receiver software routine samples each bit three times in the middle of each bit period (see Figure 2).

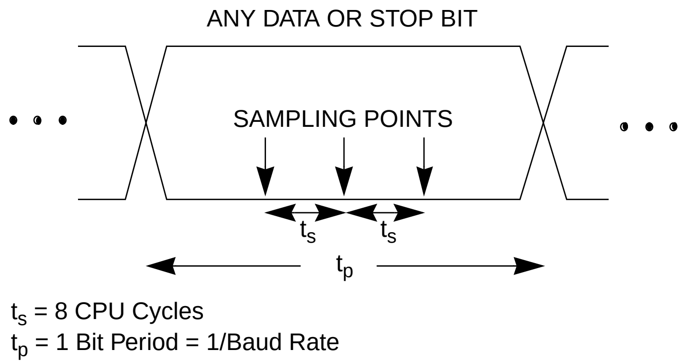


Figure 2. SCI Receiver Sample Points

The true bit data is derived by the receiver by using a majority rule of the three samples. A noise condition occurs when the three samples are not identical. The SCI receiver software routine sets the half-carry bit to signal a noise condition.

Frame Error Detection

The stop bit is defined as a logic one. If the stop bit is received as a logic zero, a frame error has occurred. The SCI receiver software routine uses the carry bit to signal a frame-error condition.

APPLICATION

System Overview

The application of the SCI software consists of an RS232-C physical interface connecting an MCU to a dumb terminal. As each character is typed on the terminal's keyboard, the ASCII-equivalent data is transmitted to the MCU. The MCU then transmits the ASCII character back to the dumb terminal. If a noise or frame error occurs during the reception of the character, the appropriate LEDs are lit to signal the error.

Hardware Description

The Motorola MC68HC705J1A MCU and the Motorola MC145407 RS232-C transmitter/receiver are used in this example (refer to Appendix A). The Motorola MC34064 low-voltage reset is connected to the reset pin to provide brown-out and slow supply power-on protection. A ribbon cable connects the MC145407 to the dumb terminal. A 4.0-MHz crystal oscillator clocks the MCU, and both the dumb terminal and the SCI receiver routine are configured for 9600 baud. Other selectable baud rates also may be used.

Software Description

The SCI software consists of two main subroutines to be called by the main program. The receive routine, **get_char**, receives one byte of data from the receive data pin (RXD) and places it into **char**, a variable in zero-page RAM. The **get_char** routine calls a subroutine, **get_bit**, which captures three samples of the state of RXD and adds them together to derive bit data and noise information. Upon exiting **get_char**, the carry bit is set if a noise condition occurred; otherwise, it is cleared. The half-carry bit is set if a frame error occurred; otherwise, it is cleared. **Char** contains the received data.

The transmit routine, **put_char**, transmits serially the contents of **char** using the transmit data pin (TXD).

Both **get_char** and **put_char** call **delay_13a**, a subroutine which produces a delay of 13*ACC + 12 CPU cycles, where ACC is the value in the accumulator at the time the subroutine is called. See Appendix B for flowcharts and Appendix C for the source code listing.

The baud rate for both the receiver and transmitter is selected by changing **BAUD_SEL** to 4, 8, 16, 32, 64, or 128 which, with a 4.0-MHz crystal oscillator, produces a baud rate of 19.2 k, 9600, 4800, 2400, 1200 or 600 respectively. The baud rate for the receiver and the transmitter will be the same. Appendix D specifies receiver tolerances and transmitter accuracies for each baud rate.

CUSTOMIZATION

This section introduces possible customization of the software SCI concept. Detailed description of these ideas is beyond the scope of this application note.

Wake-up and Time-out Features

Wake-up capability of the receiver routine allows the CPU to execute useful code while the RXD line is idle. Both the RXD pin and the $\overline{\text{IRQ}}$ pin are connected to the RXD line. A negative transition on the RXD line will cause an IRQ interrupt. The interrupt service routine can then call **get_char**. An excellent way to generate a negative transition on the RXD line is to transmit a zero ($00) immediately followed by the stream of data to be received. Note that the zero is not received, but the data following the zero is received.

Time-out capability of the receiver routine allows an interrupt to abort an idle line condition. Before the **get_char** routine is called, the multifunction timer (MFT) can be configured to interrupt after a time longer than the anticipated receive time. Care should be taken as to how the subroutine is entered and exited. Note that stack pointer housekeeping might be required.

Low Voltage Reset Circuitry

An MC34064 low-voltage reset device has been included to show the most robust reset circuit. This provides protection from slow-ramping power supplies. Many bench-type power supplies ramp slowly, causing faulty power-on of MCUs. The MC34064 holds the $\overline{\text{RESET}}$ pin low until the power supply is within a specified range. This also provides protection from brownout, when the MCUs minimum V_{DD} requirements are exceeded. If such robust protection is not required, engineering judgment may be used to design a more cost-effective circuit.

Code Minimization

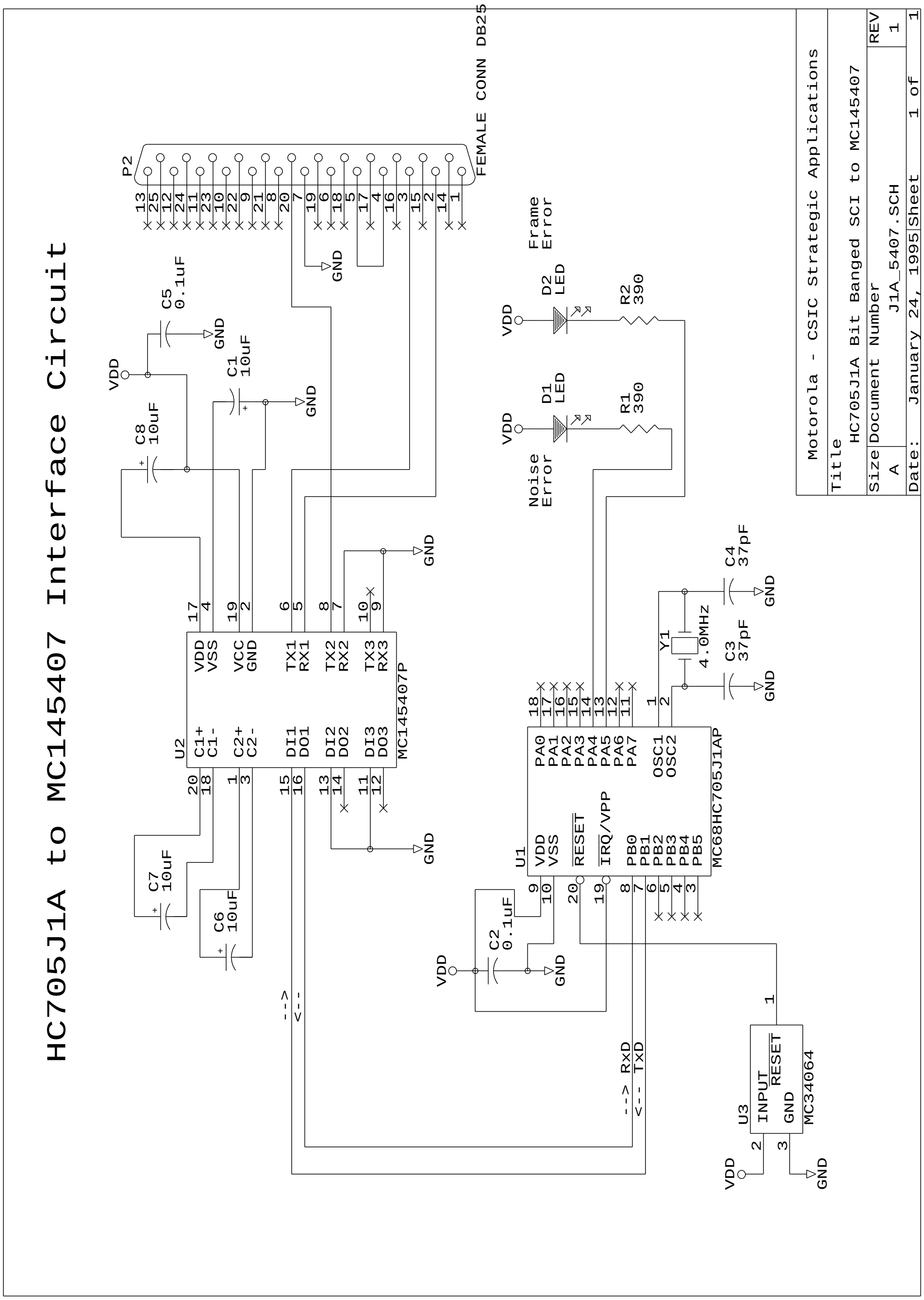
Code size may be minimized by eliminating code specific to noise detection if that feature is not needed in an application. This could result in up to a 30% reduction of code space.

CONCLUSION

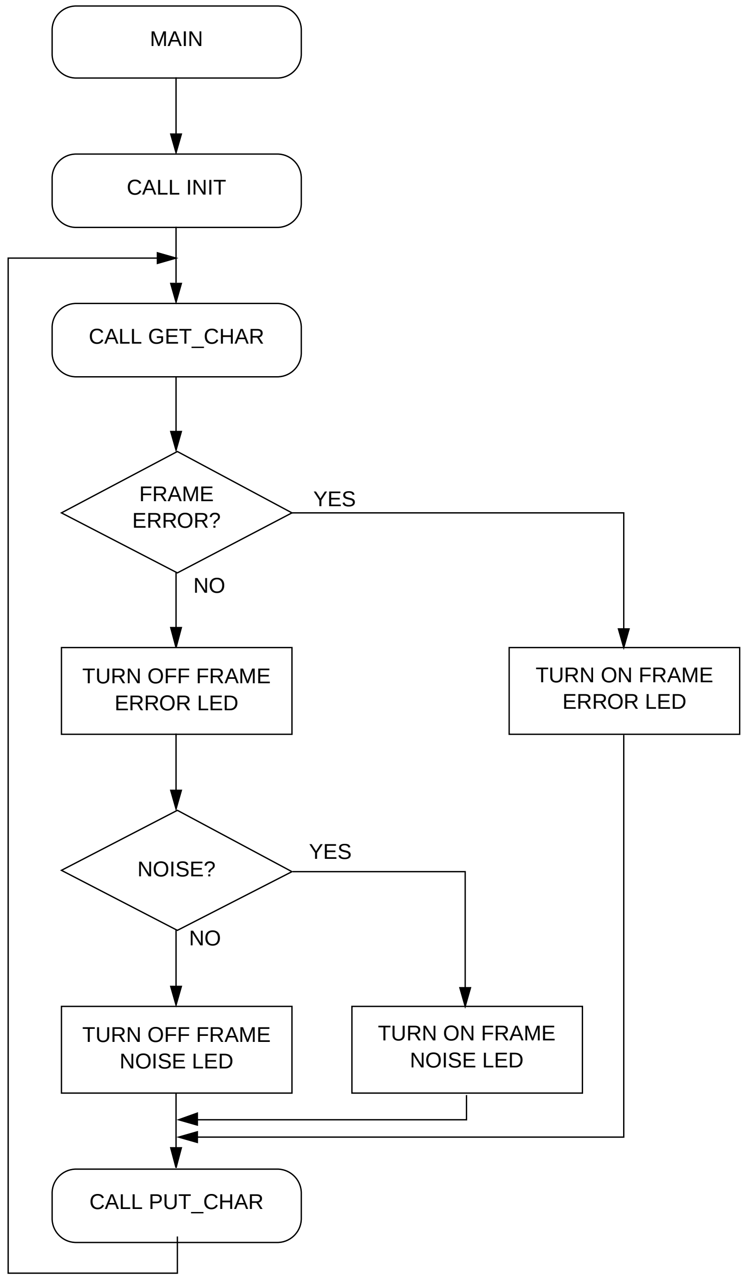
SCI receiver and transmitter software routines offer the application designer an alternative to using a hardware SCI. The software routine listings contain the operational details. The routines may be used as listed or customized as determined by engineering requirements.

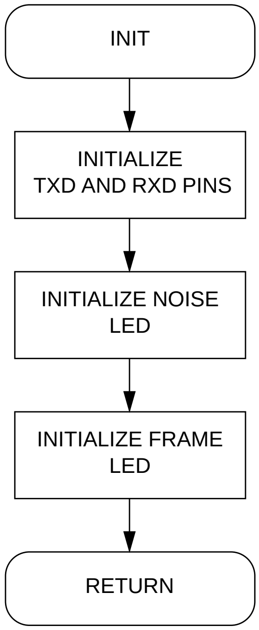
An electronic listing of the source code in Appendix C can be found on the Motorola MCU BBS. The BBS phone number is (512) 891-3733. The file name is J1A_5407.ARC and can be found on the CSIC BBS under the APPNOTES directory.

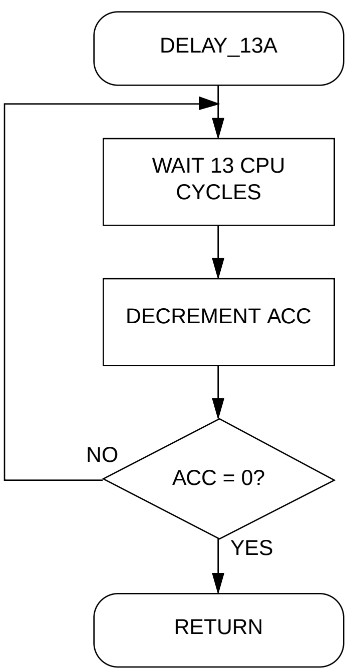
APPENDIX A

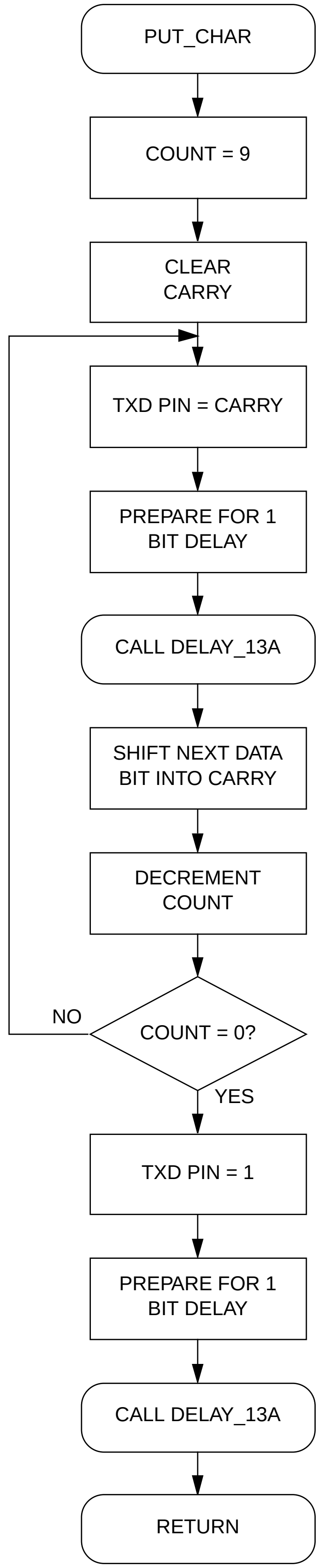

HC705J1A to MC145407 Interface Circuit
Motorola - CSIC Strategic Applications
Title
HC705J1A Bit Banged SCI to MC145407
Size Document Number REV
A J1A_5407.SCH 1
Date: January 24, 1995 Sheet 1 of 1
P2
FEMALE CONN DB25
U2
MC145407P
U1
MC68HC705J1AP
U3
MC34064
INPUT
RESET
GND
C1 10uF
C2 0.1uF
C3 37pF
C4 37pF
C5 0.1uF
C6 10uF
C7 10uF
C8 10uF
Y1 4.0MHz
D1 LED
D2 LED
R1 390
R2 390
Noise Error
Frame Error
--> RxD
<-- TxD
VDD
GND

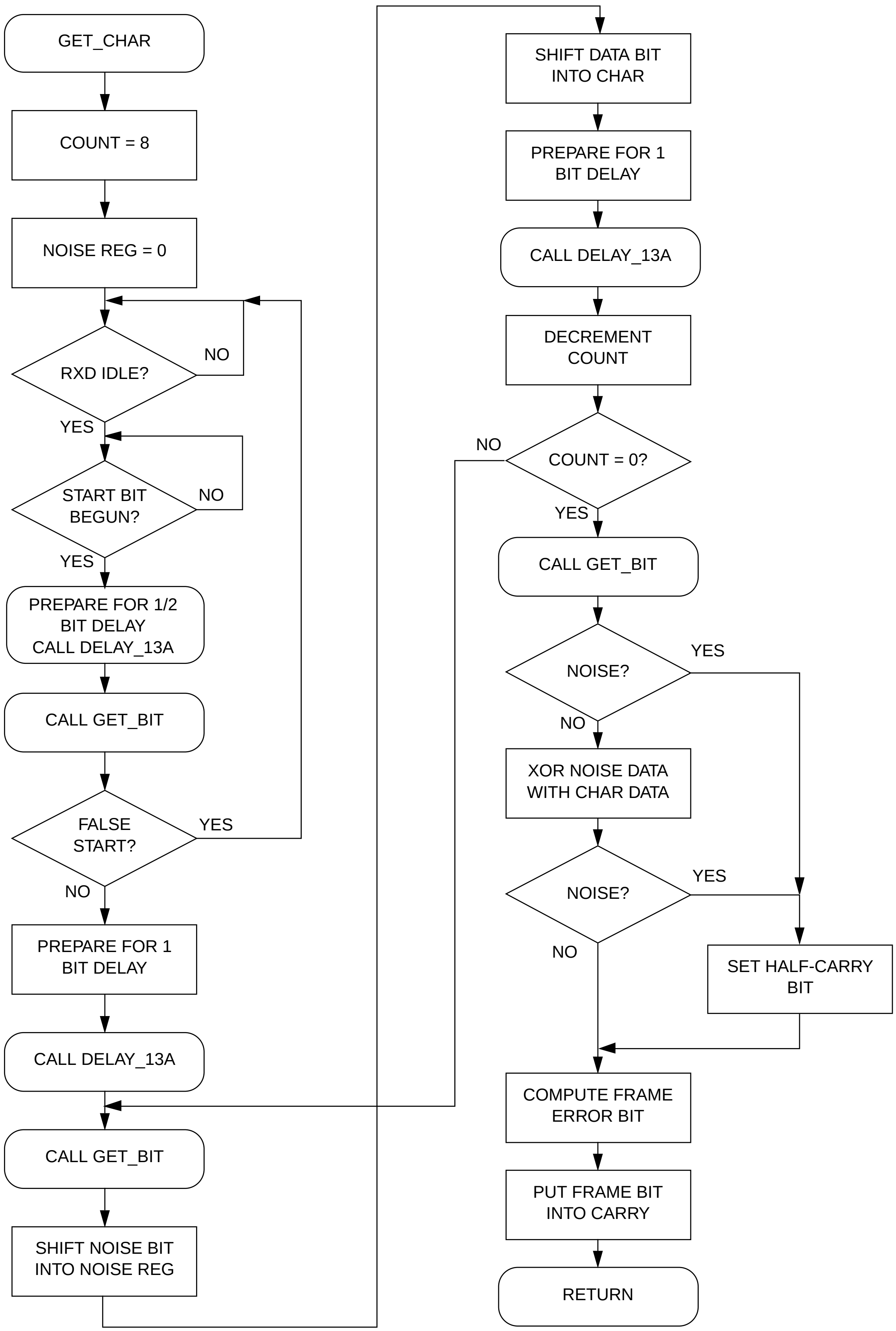
APPENDIX B

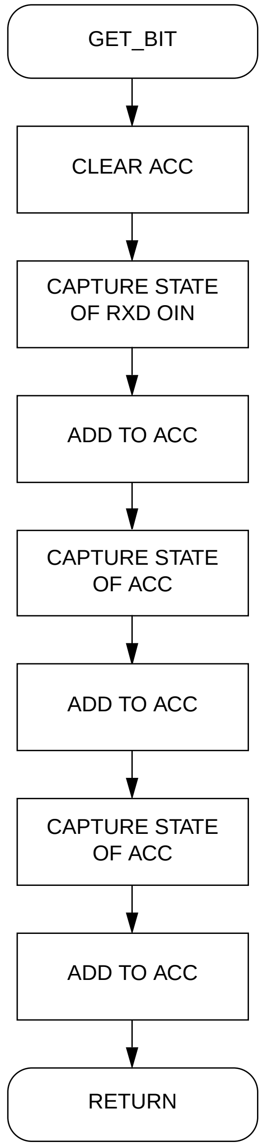

MAIN
CALL INIT
CALL GET_CHAR
FRAME ERROR?
YES
NO
TURN OFF FRAME ERROR LED
TURN ON FRAME ERROR LED
NOISE?
YES
NO
TURN OFF FRAME NOISE LED
TURN ON FRAME NOISE LED
CALL PUT_CHAR


INIT
INITIALIZE TXD AND RXD PINS
INITIALIZE NOISE LED
INITIALIZE FRAME LED
RETURN


DELAY_13A
WAIT 13 CPU CYCLES
DECREMENT ACC
ACC = 0?
NO
YES
RETURN


PUT_CHAR
COUNT = 9
CLEAR CARRY
TXD PIN = CARRY
PREPARE FOR 1 BIT DELAY
CALL DELAY_13A
SHIFT NEXT DATA BIT INTO CARRY
DECREMENT COUNT
COUNT = 0?
NO
YES
TXD PIN = 1
PREPARE FOR 1 BIT DELAY
CALL DELAY_13A
RETURN


GET_CHAR
COUNT = 8
NOISE REG = 0
RXD IDLE?
NO
YES
START BIT BEGUN?
NO
YES
PREPARE FOR 1/2 BIT DELAY CALL DELAY_13A
CALL GET_BIT
FALSE START?
YES
NO
PREPARE FOR 1 BIT DELAY
CALL DELAY_13A
CALL GET_BIT
SHIFT NOISE BIT INTO NOISE REG
SHIFT DATA BIT INTO CHAR
PREPARE FOR 1 BIT DELAY
CALL DELAY_13A
DECREMENT COUNT
COUNT = 0?
NO
YES
CALL GET_BIT
NOISE?
YES
NO
XOR NOISE DATA WITH CHAR DATA
NOISE?
YES
NO
SET HALF-CARRY BIT
COMPUTE FRAME ERROR BIT
PUT FRAME BIT INTO CARRY
RETURN


GET_BIT
CLEAR ACC
CAPTURE STATE OF RXD OIN
ADD TO ACC
CAPTURE STATE OF ACC
ADD TO ACC
CAPTURE STATE OF ACC
ADD TO ACC
RETURN

APPENDIX C

```
****************************************************************************
****************************************************************************
*                                                                          *
*  Main Routine SCI_01 - SCI Software Transmit/Receive Routines            *
*                                                                          *
****************************************************************************
*                                                                          *
* File Name: SCI_01.RTN                   Copyright (c) Motorola 1995      *
*                                                                          *
* Full Functional Description of Routine Design:                           *
*   Program flow:                                                          *
*       Reset:  Call init to initialize port pins                          *
*               Call get_char to receive a byte of data                    *
*               Light frame error LED if frame error occurred              *
*               Light noise LED if frame error occurred                    *
*               Call put_char to transmit the received byte of data        *
*               Loop back to get_char call (endless loop)                  *
*                                                                          *
****************************************************************************
*                                                                          *
*        Part Specific Framework Includes Section                          *
*                                                                          *
****************************************************************************
#INCLUDE 'H705J1A.FRK'                            ; Include the equates for the
                                                  ; HC705J1A so all labels can
                                                  ; be found.
```

```
****************************************************************************
*                                                                          *
*        MOR Bytes Definitions for the Main Routine                        *
*                                                                          *
****************************************************************************
                org     MOR
                fcb     $20

****************************************************************************
*                                                                          *
*        Equates and RAM Storage                                           *
*                                                                          *
****************************************************************************
*** I/O Pin Equates:
serial_port     equu    $01                     ; port used for serial port
                                                ;   pins
status_port     equ     $00                     ; port used for driving LED's.
noise           equ     4                       ; pin # for noise LED
frame           equ     5                       ; pin # for frame LED
rxd             equ     0                       ; pin # for receive data pin
txd             equ     1                       ; pin # for transmit data pin

*** Program Constant Equates:                   ; Baud rate select table:
BAUD_SEL        equ     $08                     ; BAUD_SEL   4MHz osc  2MHz osc
                                                ;    $04      19.2k      9600
                                                ;    $08       9600      4800
                                                ;    $10       4800      2400
                                                ;    $20       2400      1200
                                                ;    $40       1200       600
                                                ;    $80        600       300
*** RAM variable allocation:
                org     RAM
char            rmb     1                       ; data register for sci
count           rmb     1                       ; temp storage variable
```

```
****************************************************************************
* main - example program that continually echoes back received characters.   *
*                                                                            *
* input cond.     - reset                                                    *
* output cond.    - none (infinite loop)                                     *
* stack used      - 4 bytes                                                  *
* variables used  - none                                                     *
* ROM used        - 28 bytes                                                 *
****************************************************************************
                org     ROM                     ; start at the top of ROM
main            rsp                             ; reset the stack pointer
                jsr     init                    ; initialize port pins

main_loop       jsr     get_char                ; receive one byte of data
                                                ; from rxd pin

                bcc     no_frame_error          ; branch if no noise occured
                bclr    frame,status_port       ; turn on frame LED
                bra     continue                ; don't check for noise --
                                                ; it's undefined
no_frame_err    bset    frame,status_port       ; turn off frame LED

                bhcs    noise_error             ; branch if noise occured
                bset    noise,status_port       ; turn off noise LED
                bra     continue                ; skip next line of code
yes_noise_err   bclr    noise,status_port       ; turn on noise LED

continue        jsr     put_char                ; transmit the received byte
                bra     main_loop               ; and prepare for next
                                                ; reception.
```

```
******************************************************************************
* init - initialize port pins for sci operation and for driving LEDs;        *
*        called by main                                                      *
*                                                                            *
* input cond.     - none                                                     *
* output cond.    - TXD = output initialize to 1, RXD = input, noise LED =   *
*                   off, frame LED = off.                                    *
* stack used      - 0 bytes                                                  *
* variables used  - none                                                     *
* ROM used        - 15 bytes                                                 *
******************************************************************************
init            bset    txd,serial_port        ; init txd = 1
                bset    txd,serial_port+4      ; txd = output

                bclr    rxd,serial_port+4      ; rxd = input

                bset    noise,status_port      ; noise LED = off
                bset    noise,status_port+4    ; noise = output

                bset    frame,status_port      ; frame LED = off
                bset    frame,status_port+4    ; frame = output
                rts                            ; exit (init)

******************************************************************************
* get_char - receive one byte of data from RXD pin; called by main           *
*                                                                            *
* input cond.     - RXD pin defined as an input pin                          *
* output cond.    - char contains received data; X,ACC undefined;            *
*                   half carry = 1 (frame occured) or 0 (no frame error);    *
*                   carry = 1 (noise and/or frame error occured) or 0        *
*                   (no noise).                                              *
* stack used      - 2 bytes                                                  *
* variables used  - char: storage for received data (1 byte)                 *
*                   count: temporary storage (1 byte)                        *
* ROM used        - 63 bytes                                                 *
******************************************************************************
```

```
get_char        lda     #8                      ;[2] receiving 8 data bits
                sta     count                   ;[4] store value into RAM
                clrx                            ;[3] used to store noise data

get_start_bit   brclr   rxd,serial_port,*       ;[5] wait until rxd=1
                brset   rxd,serial_port,*       ;[5] wait for start bit

                lda     #BAUD_SEL-3             ;[2] prepare for 1/2 bit delay
                bsr     delay_13a               ;[13a+12] execute delay routine
                bsr     get_bit                 ;[39] sample start bit
                lsra                            ;[3] noise bit -> carry;
                                                ;    acc=filtered start bit
                bne     get_start_bit           ;[3] if false start, start over
                tsta                            ;[3] for timing purposes only
                tsta                            ;[3] for timing purposes only

                lda     #2*(BAUD_SEL-2)         ;[2] prepare for 1 bit delay
                bsr     delay_13a               ;[13a+12] execute delay routine

get_data_bits   bsr     get_bit                 ;[39] sample data bit
                rora                            ;[3] noise bit -> carry
                rorx                            ;[3] carry -> noise data reg
                rora                            ;[3] filtered data bit -> carry
                ror     char                    ;[5] carry -> char
                lda     #2*(BAUD_SEL-3)         ;[2] prepare for 1 bit delay
                bsr     delay_13a               ;[13a+12] execute delay routine
                tsta                            ;[3] for timing purposes only
                dec     count                   ;[5] bit received, dec count
                bne     get_data_bits           ;[3] loop if more bits to get

get_stop_bit    bsr     get_bit                 ;[39] sample stop bit
                lsra                            ;[3] noise bit -> carry
                                                ;    acc=filtered stop bit
                sta     count                   ;[4] store stop bit in count
                bcc     yes_noise               ;[3] if noise, then branch
```

```
                txa                             ;[2] noise data -> acc
                eor     char                    ;[3] XOR noise with char,
                beq     no_noise                ;[3] and if result=0,
                                                ;    then no noise in data
                                                ;    reception

yes_noise       lda     #$08                    ;[2] set noise bit (half carry)
                add     #$08                    ;[2] by adding $8 to $8

no_noise        lda     count                   ;[3] retrieve stop data bit,
                coma                            ;[3] complement it,
                lsra                            ;[3] and shift it into carry
                                                ;    for frame error bit
                rts                             ;[6] exit (get_char)

******************************************************************************
* get_bit - receive one bit of filtered data and noise info; called by       *
*             get_char                                                       *
*                                                                            *
* input cond.     - RXD pin defined as an input pin                          *
* output cond.    - ACC = 000000dn, where d = filtered data, n = noise info  *
* stack used      - 0 bytes                                                  *
* variables used  - none                                                     *
* ROM used        - 17 bytes                                                 *
******************************************************************************
get_bit         clra                            ;[3] used to add sampled bits
                brset   rxd,serial_port,samp_1 ;[5] sample 1st bit into carry
samp_1          adc     #0                      ;[3] add it to acc
                brset   rxd,serial_port,samp_2 ;[5] sample 2nd bit into carry
samp_2          adc     #0                      ;[3] add it to acc
                brset   rxd,serial_port,samp_3 ;[5] sample 3rd bit into carry
samp_3          adc     #0                      ;[3] add it to acc
                rts                             ;[6] exit (get_bit)
```

```
****************************************************************************
* put_char - transmit data byte in char out onto TXD pin; called by main     *
*                                                                            *
* input cond.     - TXD pin defined as an output pin and TXD = 1;            *
*                   char contains byte to be tranmitted.                     *
* output cond.    - X,ACC,char =  undefined;                                 *
* stack used      - 2 bytes                                                  *
* variables used  - char: storage for transmitted data (1 byte)              *
* ROM used        - 31 bytes (35 if sending two stop bits)                   *
****************************************************************************
put_char        ldx     #9                      ;[2] be sending 8 data bits
                clc                             ;[2] clear carry for start bit

put_data_bits   bcc     send_0                  ;[3] if carry<>0, then
                bset    txd,serial_port         ;[5]    send out a 1
                bra     jmp_bit                 ;[3]    finished sending a 1
send_0          bclr    txd,serial_port         ;[5] else send a 0
                bra     jmp_bit                 ;[3]    finished sending a 0
jmp_bit         lda     #2*(BAUD_SEL-1)-1       ;[2] prepare for a 1 bit delay
                bsr     delay_13a               ;[13a+12] execute delay routine
                tsta                            ;[3] for timing purposes only
                ror     char                    ;[5] get next data bit to send
                decx                            ;[3] one bit sent, so dec count
                bne     put_data_bits           ;[3] loop if more bits to send

put_stop_bit    nop                             ;[2] for timing purposes only
                bset    txd,serial_port         ;[5] send out a one
                lda     #2*(BAUD_SEL-1)         ;[2] prepare for a 1 bit delay
                bsr     delay_13a               ;[13a+12] execute delay routine

* add the next two lines to guarantee sending two stop bits:
*               lda     #2*(BAUD_SEL-1)+1       ;[2] prepare for a 1 bit delay
*               bsr     delay_13a               ;[13a+12] execute delay routine

                rts                             ;[6] exit (put_char)
```

```
******************************************************************************
* delay_13a - delay for 13*ACC + 12 cycles; called by get_char and put_char  *
*                                                                            *
* input cond.      - ACC set to appropriate value (13*ACC + 12 cycles)       *
* output cond.     - ACC = 0                                                 *
* stack used       - 0 bytes                                                 *
* variables used   - none                                                    *
* ROM used         - 7 bytes                                                 *
******************************************************************************
delay_13a       nop                             ;[2] this is a 13-cycle loop
                nop                             ;[2]
                tsta                            ;[3]
                deca                            ;[3] decrement loop count
                bne     delay_13a               ;[3] loop if count not zero
                rts                             ;[6] exit (delay_13a)


******************************************************************************
*                                                                            *
*        Interrupt and Reset vectors for Main Routine                        *
*                                                                            *
******************************************************************************
                org     RESET
                fdb     main
```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APPENDIX D

Receiver Tolerances

The following tolerances state the maximum variation of the average bit period allowable for accurate reception of data without noise or frame error conditions occurring.

Table 1 Receiver Tolerances

Baud Rate for 4 MHz clock (bits/sec)	Baud Rate for 2 MHz clock (bits/sec)	Bit Period t_p (µs)	Bit Period Tolerance
19.2k	n/a	52.08	+2.7%/-4.0%
9600	9600	104.2	+3.7%/-5.7%
4800	4800	208.3	+3.9%/-5.5%
2400	2400	416.7	+4.3%/-4.8%
1200	1200	833.3	+4.9%/-5.2%
600	600	1666.7	+4.9%/-5.4%
n/a	300	3333.3	+4.9%/-5.1%

Transmitter Accuracy

The following table states the percent accuracy of the transmitted bit period to the ideal bit period.

Table 2 Transmitter Accuracy

Baud Rate for 4 MHz clock (bits/sec)	Baud Rate for 2 MHz clock (bits/sec)	Ideal Bit Period t_p (µs)	Actual Bit Period t_p (µs)	% Accuracy
19.2k	n/a	52.08	52.0	0.16%
9600	9600	104.2	104.0	0.16%
4800	4800	208.3	208.0	0.16%
2400	2400	416.7	416.0	0.16%
1200	1200	833.3	832.0	0.16%
600	600	1666.7	1664.0	0.16%
n/a	300	3333.3	3328.0	0.16%

REFERENCES

1) Motorola, *M68HC11 Reference Manual*, Prentice Hall, Englewood Cliffs, New Jersey, 1989, Order no. M68HC11RM/AD.

2) Motorola, *M68HC05 Applications Guide*, Revision 1, Order no. M68HC05AG/AD.

3) Motorola, *MC68HC05J1A Technical Data*, Order no. M68HC05J1A/D

4) Steve Leibson, *The Handbook of Microcomputer Interfacing, Second Edition*, TAB Books, Inc., Blue Ridge Summit, Pennsylvania, 1989.