Serial Programming Guide for POSIX Operating Systems

5th Edition

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Table of Contents

Table of Contents

Introduction

The Serial Programming Guide for POSIX Operating Systems will teach you how to successfully, efficiently, and portably program the serial ports on your UNIX® workstation or PC. Each chapter provides programming examples that use the POSIX (Portable Standard for UNIX) terminal control functions and should work with very few modifications under IRIX®, HP−UX, SunOS®, Solaris®, Digital UNIX®, Linux®, and most other UNIX operating systems. The biggest difference between operating systems that you will find is the filenames used for serial port device and lock files.

This guide is organized into the following chapters and appendices:

Chapter 1, Basics of Serial Communications

This chapter introduces serial communications, RS−232 and other standards that are used on most computers as well as how to access a serial port from a C program.

What Are Serial Communications?

Computers transfer information (data) one or more bits at a time. Serial refers to the transfer of data one bit at a time. Serial communications include most network devices, keyboards, mice, MODEMs, and terminals.

When doing serial communications each word (i.e. byte or character) of data you send or receive is sent one bit at a time. Each bit is either *on* or *off.* The terms you'll hear sometimes are *mark* for the *on* state and *space* for the *off* state.

The speed of the serial data is most often expressed as bits−per−second ("bps") or baudot rate ("baud"). This just represents the number of ones and zeroes that can be sent in one second. Back at the dawn of the computer age, 300 baud was considered fast, but today computers can handle RS−232 speeds as high as 430,800 baud! When the baud rate exceeds 1,000, you'll usually see the rate shown in *kilo*baud, or kbps (e.g. 9.6k, 19.2k, etc). For rates above 1,000,000 that rate is shown in *mega*baud, or Mbps (e.g. 1.5Mbps).

When referring to serial devices or ports, they are either labeled as *Data Communications Equipment* ("DCE") or *Data Terminal Equipment* ("DTE"). The difference between these is simple − every signal pair, like transmit and receive, is swapped. When connecting two DTE or two DCE interfaces together, a serial *null−MODEM* cable or adapter is used that swaps the signal pairs.

What Is RS−232?

RS−232 is a standard electrical interface for serial communications defined by the Electronic Industries Association ("EIA"). RS−232 actually comes in 3 different flavors (A, B, and C) with each one defining a different voltage range for the *on* and *off* levels. The most commonly used variety is RS−232C, which defines a mark (on) bit as a voltage between −3V and −12V and a space (off) bit as a voltage between +3V and +12V. The RS−232C specification says these signals can go about 25 feet (8m) before they become unusable. You can usually send signals a bit farther than this as long as the baud is low enough.

Besides wires for incoming and outgoing data, there are others that provide timing, status, and handshaking:

Table 1 − RS−232 Pin Assignments

Pin	Description	Pin	Description	Pin	Description	Pin	Description	Pin	Description
1	Earth Ground	6	**DSR** − Data Set Ready	11	Unassigned	16	Secondary RXD	21	Signal Quality Detect
2	**TXD** − Transmitted Data	7	**GND** − Logic Ground	12	Secondary DCD	17	Receiver Clock	22	Ring Detect
3	**RXD** − Received Data	8	**DCD** − Data Carrier Detect	13	Secondary CTS	18	Unassigned	23	Data Rate Select
4	**RTS** − Request To Send	9	Reserved	14	Secondary TXD	19	Secondary RTS	24	Transmit Clock
5	**CTS** − Clear To Send	10	Reserved	15	Transmit Clock	20	**DTR** − Data Terminal Ready	25	Unassigned

Two standards for serial interfaces you may also see are RS−422 and RS−574. RS−422 uses lower voltages and *differential* signals to allow cable lengths up to about 1000ft (300m). RS−574 defines the 9−pin PC serial connector and voltages.

Signal Definitions

The RS−232 standard defines some 18 different signals for serial communications. Of these, only six are generally available in the UNIX environment.

GND − Logic Ground

Technically the logic ground is not a signal, but without it none of the other signals will operate. Basically, the logic ground acts as a reference voltage so that the electronics know which voltages are positive or negative.

TXD − Transmitted Data

The TXD signal carries data transmitted from your workstation to the computer or device on the other end (like a MODEM). A mark voltage is interpreted as a value of 1, while a space voltage is interpreted as a value of 0.

RXD − Received Data

The RXD signal carries data transmitted from the computer or device on the other end to your workstation. Like TXD, mark and space voltages are interpreted as 1 and 0, respectively.

DCD − Data Carrier Detect

The DCD signal is received from the computer or device on the other end of your serial cable. A space voltage on this signal line indicates that the computer or device is currently connected or on line. DCD is not always used or available.

DTR − Data Terminal Ready

The DTR signal is generated by your workstation and tells the computer or device on the other end that you are ready (a space voltage) or not−ready (a mark voltage). DTR is usually enabled automatically whenever you open the serial interface on the workstation.

CTS − Clear To Send

The CTS signal is received from the other end of the serial cable. A space voltage indicates that is alright to send more serial data from your workstation.

CTS is usually used to regulate the flow of serial data from your workstation to the other end.

RTS − Request To Send

The RTS signal is set to the *space* voltage by your workstation to indicate that more data is ready to be sent.

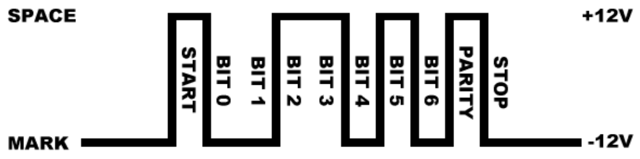
Like CTS, RTS helps to regulate the flow of data between your workstation and the computer or device on the other end of the serial cable. Most workstations leave this signal set to the space voltage all the time.

Asynchronous Communications

For the computer to understand the serial data coming into it, it needs some way to determine where one character ends and the next begins. This guide deals exclusively with *asynchronous* serial data.

In asynchronous mode the serial data line stays in the mark (1) state until a character is transmitted. A *start* bit preceeds each character and is followed immediately by each bit in the character, an optional parity bit, and one or more *stop* bits. The start bit is always a space (0) and tells the computer that new serial data is available. Data can be sent or received at any time, thus the name asynchronous.

Figure 1 − Asynchronous Data Transmission



The optional parity bit is a simple sum of the data bits indicating whether or not the data contains an even or odd number of 1 bits. With *even parity*, the parity bit is 0 if there is an even number of 1's in the character. With *odd parity*, the parity bit is 0 if there is an odd number of 1's in the data. You may also hear the terms *space parity*, *mark parity*, and *no parity*. Space parity means that the parity bit is always 0, while mark parity means the bit is always 1. No parity means that no parity bit is present or transmitted.

The remaining bits are called stop bits. There can be 1, 1.5, or 2 stop bits between characters and they always have a value of 1. Stop bits traditionally were used to give the computer time to process the previous character, but now only serve to synchronize the receiving computer to the incoming characters.

Asynchronous data formats are usually expressed as "8N1", "7E1", and so forth. These stand for "8 data bits, no parity, 1 stop bit" and "7 data bits, even parity, 1 stop bit" respectively.

What Are Full Duplex and Half Duplex?

Full duplex means that the computer can send and receive data simultaneously − there are two separate data channels (one coming in, one going out).

Half duplex means that the computer cannot send or receive data at the same time. Usually this means there is only a single data channel to talk over. This does not mean that any of the RS−232 signals are not used. Rather, it usually means that the communications link uses some standard other than RS−232 that does not support full duplex operation.

Flow Control

It is often necessary to regulate the flow of data when transferring data between two serial interfaces. This can be due to limitations in an intermediate serial communications link, one of the serial interfaces, or some storage media. Two methods are commonly used for asynchronous data.

The first method is often called "software" flow control and uses special characters to start (XON or DC1, 021 octal) or stop (XOFF or DC3, 023 octal) the flow of data. These characters are defined in the American Standard Code for Information Interchange ("ASCII"). While these codes are useful when transferring textual information, they cannot be used when transferring other types of information without special programming.

The second method is called "hardware" flow control and uses the RS−232 CTS and RTS signals instead of special characters. The receiver sets CTS to the space voltage when it is ready to receive more data and to the mark voltage when it is not ready. Likewise, the sender sets RTS to the space voltage when it is ready to send more data. Because hardware flow control uses a separate set of signals, it is much faster than software flow control which needs to send or receive multiple bits of information to do the same thing. CTS/RTS flow control is not supported by all hardware or operating systems.

What Is a Break?

Normally a receive or transmit data signal stays at the mark voltage until a new character is transferred. If the signal is dropped to the space voltage for a long period of time, usually 1/4 to 1/2 second, then a break condition is said to exist.

A break is sometimes used to reset a communications line or change the operating mode of communications hardware like a MODEM. Chapter 3, Talking to MODEMs covers these applications in more depth.

Synchronous Communications

Unlike asynchronous data, synchronous data appears as a constant stream of bits. To read the data on the line, the computer must provide or receive a common bit clock so that both the sender and receiver are synchronized.

Even with this synchronization, the computer must mark the beginning of the data somehow. The most common way of doing this is to use a data packet protocol like Serial Data Link Control ("SDLC") or High−Speed Data Link Control ("HDLC").

Each protocol defines certain bit sequences to represent the beginning and end of a data packet. Each also defines a bit sequence that is used when there is no data. These bit sequences allow the computer see the beginning of a data packet.

Because synchronous protocols do not use per−character synchronization bits they typically provide at least a 25% improvement in performance over asynchronous communications and are suitable for remote networking and configurations with more than two serial interfaces.

Despite the speed advantages of synchronous communications, most RS−232 hardware does not support it due to the extra hardware and software required.

Accessing Serial Ports

Like all devices, UNIX provides access to serial ports via *device files*. To access a serial port you simply open the corresponding device file.

Serial Port Files

Each serial port on a UNIX system has one or more device files (files in the `/dev` directory) associated with it:

Table 2 − Serial Port Device Files

System	Port 1	Port 2
IRIX®	/dev/ttyf1	/dev/ttyf2
HP−UX	/dev/tty1p0	/dev/tty2p0
Solaris®/SunOS®	/dev/ttya	/dev/ttyb
Linux®	/dev/ttyS0	/dev/ttyS1

Digital UNIX®	/dev/tty01	/dev/tty02

Opening a Serial Port

Since a serial port is a file, the *open(2)* function is used to access it. The one hitch with UNIX is that device files are usually not accessable by normal users. Workarounds include changing the access permissions to the file(s) in question, running your program as the super−user (root), or making your program set−userid so that it runs as the owner of the device file.

For now we'll assume that the file is accessable by all users. The code to open serial port 1 on an `sgi`® workstation running IRIX is:

Listing 1 − Opening a serial port.

```
#include <stdio.h>   /* Standard input/output definitions */
#include <string.h>  /* String function definitions */
#include <unistd.h>  /* UNIX standard function definitions */
#include <fcntl.h>   /* File control definitions */
#include <errno.h>   /* Error number definitions */
#include <termios.h> /* POSIX terminal control definitions */

/*
 * 'open_port()' − Open serial port 1.
 *
 * Returns the file descriptor on success or −1 on error.
 */

int
open_port(void)
{
  int fd; /* File descriptor for the port */


  fd = open("/dev/ttyf1", O_RDWR | O_NOCTTY | O_NDELAY);
  if (fd == −1)
  {
   /*
    * Could not open the port.
    */

    perror("open_port: Unable to open /dev/ttyf1 − ");
  }
  else
    fcntl(fd, F_SETFL, 0);

  return (fd);
}
```

Other systems would require the corresponding device file name, but otherwise the code is the same.

Open Options

You'll notice that when we opened the device file we used two other flags along with the read+write mode:

```
fd = open("/dev/ttyf1", O_RDWR | O_NOCTTY | O_NDELAY);
```

The *O_NOCTTY* flag tells UNIX that this program doesn't want to be the "controlling terminal" for that port. If you don't specify this then any input (such as keyboard abort signals and so forth) will affect your process. Programs like *getty(1M/8)* use this feature when starting the login process, but normally a user program does not want this behavior.

The *O_NDELAY* flag tells UNIX that this program doesn't care what state the DCD signal line is in − whether the other end of the port is up and running. If you do not specify this flag, your process will be put to sleep until the DCD signal line is the space voltage.

Writing Data to the Port

Writing data to the port is easy − just use the *write(2)* system call to send data it:

```
n = write(fd, "ATZ\r", 4);
if (n < 0)
  fputs("write() of 4 bytes failed!\n", stderr);
```

The *write* function returns the number of bytes sent or −1 if an error occurred. Usually the only error you'll run into is *EIO* when a MODEM or data link drops the Data Carrier Detect (DCD) line. This condition will persist until you close the port.

Reading Data from the Port

Reading data from a port is a little trickier. When you operate the port in raw data mode, each *read(2)* system call will return however many characters are actually available in the serial input buffers. If no characters are available, the call will block (wait) until characters come in, an interval timer expires, or an error occurs. The *read* function can be made to return immediately by doing the following:

```
fcntl(fd, F_SETFL, FNDELAY);
```

The *FNDELAY* option causes the *read* function to return 0 if no characters are available on the port. To restore normal (blocking) behavior, call *fcntl()* without the *FNDELAY* option:

```
fcntl(fd, F_SETFL, 0);
```

This is also used after opening a serial port with the O_NDELAY option.

Closing a Serial Port

To close the serial port, just use the *close* system call:

```
close(fd);
```

Closing a serial port will also usually set the DTR signal low which causes most MODEMs to hang up.

Chapter 2, Configuring the Serial Port

This chapter discusses how to configure a serial port from C using the POSIX termios interface.

The POSIX Terminal Interface

Most systems support the POSIX terminal (serial) interface for changing parameters such as baud rate, character size, and so on. The first thing you need to do is include the file `<termios.h>`; this defines the terminal control structure as well as the POSIX control functions.

The two most important POSIX functions are *tcgetattr(3)* and *tcsetattr(3)*. These get and set terminal attributes, respectively; you provide a pointer to a *termios* structure that contains all of the serial options available:

Table 3 − Termios Structure Members

Member	Description
c_cflag	Control options
c_lflag	Line options
c_iflag	Input options
c_oflag	Output options
c_cc	Control characters
c_ispeed	Input baud (new interface)

c_ospeed	Output baud (new interface)

Control Options

The *c_cflag* member controls the baud rate, number of data bits, parity, stop bits, and hardware flow control. There are constants for all of the supported configurations.

Table 4 − Constants for the c_cflag Member

Constant	Description
CBAUD	Bit mask for baud rate
B0	0 baud (drop DTR)
B50	50 baud
B75	75 baud
B110	110 baud
B134	134.5 baud
B150	150 baud
B200	200 baud
B300	300 baud
B600	600 baud
B1200	1200 baud
B1800	1800 baud
B2400	2400 baud
B4800	4800 baud
B9600	9600 baud
B19200	19200 baud
B38400	38400 baud
B57600	57,600 baud
B76800	76,800 baud
B115200	115,200 baud
EXTA	External rate clock
EXTB	External rate clock
CSIZE	Bit mask for data bits
CS5	5 data bits
CS6	6 data bits

CS7	7 data bits
CS8	8 data bits
CSTOPB	2 stop bits (1 otherwise)
CREAD	Enable receiver
PARENB	Enable parity bit
PARODD	Use odd parity instead of even
HUPCL	Hangup (drop DTR) on last close
CLOCAL	Local line − do not change "owner" of port
LOBLK	Block job control output
CNEW_RTSCTS CRTSCTS	Enable hardware flow control (not supported on all platforms)

The *c_cflag* member contains two options that should always be enabled, *CLOCAL* and *CREAD*. These will ensure that your program does not become the 'owner' of the port subject to sporatic job control and hangup signals, and also that the serial interface driver will read incoming data bytes.

The baud rate constants (*CBAUD*, *B9600*, etc.) are used for older interfaces that lack the *c_ispeed* and *c_ospeed* members. See the next section for information on the POSIX functions used to set the baud rate.

Never initialize the *c_cflag* (or any other flag) member directly; you should always use the bitwise AND, OR, and NOT operators to set or clear bits in the members. Different operating system versions (and even patches) can and do use the bits differently, so using the bitwise operators will prevent you from clobbering a bit flag that is needed in a newer serial driver.

Setting the Baud Rate

The baud rate is stored in different places depending on the operating system. Older interfaces store the baud rate in the *c_cflag* member using one of the baud rate constants in table 4, while newer implementations provide the *c_ispeed* and *c_ospeed* members that contain the actual baud rate value.

The *cfsetospeed(3)* and *cfsetispeed(3)* functions are provided to set the baud rate in the *termios* structure regardless of the underlying operating system interface. Typically you'd use the following code to set the baud rate:

Listing 2 − Setting the baud rate.

```
struct termios options;

/*
 * Get the current options for the port...
 */

tcgetattr(fd, &options);
```

```
        /*
         * Set the baud rates to 19200...
         */

        cfsetispeed(&options, B19200);
        cfsetospeed(&options, B19200);

        /*
         * Enable the receiver and set local mode...
         */

        options.c_cflag |= (CLOCAL | CREAD);

        /*
         * Set the new options for the port...
         */

        tcsetattr(fd, TCSANOW, &options);
```

The *tcgetattr(3)* function fills the termios structure you provide with the current serial port configuration. After we set the baud rates and enable local mode and serial data receipt, we select the new configuration using *tcsetattr(3)*. The *TCSANOW* constant specifies that all changes should occur immediately without waiting for output data to finish sending or input data to finish receiving. There are other constants to wait for input and output to finish or to flush the input and output buffers.

Most systems do not support different input and output speeds, so be sure to set both to the same value for maximum portability.

Table 5 − Constants for tcsetattr

Constant	Description
TCSANOW	Make changes now without waiting for data to complete
TCSADRAIN	Wait until everything has been transmitted
TCSAFLUSH	Flush input and output buffers and make the change

Setting the Character Size

Unlike the baud rate, there is no convienience function to set the character size. Instead you must do a little bitmasking to set things up. The character size is specified in bits:

```
        options.c_cflag &= ~CSIZE; /* Mask the character size bits */
        options.c_cflag |= CS8;    /* Select 8 data bits */
```

Setting Parity Checking

Like the character size you must manually set the parity enable and parity type bits. UNIX serial drivers support even, odd, and no parity bit generation. Space parity can be simulated with clever coding.

- No parity (8N1):

```
options.c_cflag &= ~PARENB
options.c_cflag &= ~CSTOPB
options.c_cflag &= ~CSIZE;
options.c_cflag |= CS8;
```

- Even parity (7E1):

```
options.c_cflag |= PARENB
options.c_cflag &= ~PARODD
options.c_cflag &= ~CSTOPB
options.c_cflag &= ~CSIZE;
options.c_cflag |= CS7;
```

- Odd parity (7O1):

```
options.c_cflag |= PARENB
options.c_cflag |= PARODD
options.c_cflag &= ~CSTOPB
options.c_cflag &= ~CSIZE;
options.c_cflag |= CS7;
```

- Space parity is setup the same as no parity (7S1):

```
options.c_cflag &= ~PARENB
options.c_cflag &= ~CSTOPB
options.c_cflag &= ~CSIZE;
options.c_cflag |= CS8;
```

Setting Hardware Flow Control

Some versions of UNIX support hardware flow control using the CTS (Clear To Send) and RTS (Request To Send) signal lines. If the *CNEW_RTSCTS* or *CRTSCTS* constants are defined on your system then hardware flow control is probably supported. Do the following to enable hardware flow control:

```
options.c_cflag |= CNEW_RTSCTS;    /* Also called CRTSCTS */
```

Similarly, to disable hardware flow control:

```
options.c_cflag &= ~CNEW_RTSCTS;
```

Local Options

The local modes member *c_lflag* controls how input characters are managed by the serial driver. In general you will configure the *c_lflag* member for *canonical* or *raw* input.

Table 6 − Constants for the c_lflag Member

Constant	Description
ISIG	Enable SIGINTR, SIGSUSP, SIGDSUSP, and SIGQUIT signals
ICANON	Enable canonical input (else raw)

XCASE	Map uppercase \lowercase (obsolete)
ECHO	Enable echoing of input characters
ECHOE	Echo erase character as BS−SP−BS
ECHOK	Echo NL after kill character
ECHONL	Echo NL
NOFLSH	Disable flushing of input buffers after interrupt or quit characters
IEXTEN	Enable extended functions
ECHOCTL	Echo control characters as ^char and delete as ~?
ECHOPRT	Echo erased character as character erased
ECHOKE	BS−SP−BS entire line on line kill
FLUSHO	Output being flushed
PENDIN	Retype pending input at next read or input char
TOSTOP	Send SIGTTOU for background output

Choosing Canonical Input

Canonical input is line−oriented. Input characters are put into a buffer which can be edited interactively by the user until a CR (carriage return) or LF (line feed) character is received.

When selecting this mode you normally select the *ICANON*, *ECHO*, and *ECHOE* options:

```
options.c_lflag |= (ICANON | ECHO | ECHOE);
```

Choosing Raw Input

Raw input is unprocessed. Input characters are passed through exactly as they are received, when they are received. Generally you'll deselect the *ICANON*, *ECHO*, *ECHOE*, and *ISIG* options when using raw input:

```
options.c_lflag &= ~(ICANON | ECHO | ECHOE | ISIG);
```

A Note About Input Echo

Never enable input echo (*ECHO*, *ECHOE*) when sending commands to a MODEM or other computer that is echoing characters, as you will generate a feedback loop between the two serial interfaces!

Input Options

The input modes member *c_iflag* controls any input processing that is done to characters received on the port. Like the *c_cflag* field, the final value stored in *c_iflag* is the bitwise OR of the desired options.

Table 7 − Constants for the c_iflag Member

Constant	Description
INPCK	Enable parity check
IGNPAR	Ignore parity errors
PARMRK	Mark parity errors
ISTRIP	Strip parity bits
IXON	Enable software flow control (outgoing)
IXOFF	Enable software flow control (incoming)
IXANY	Allow any character to start flow again
IGNBRK	Ignore break condition
BRKINT	Send a SIGINT when a break condition is detected
INLCR	Map NL to CR
IGNCR	Ignore CR
ICRNL	Map CR to NL
IUCLC	Map uppercase to lowercase
IMAXBEL	Echo BEL on input line too long

Setting Input Parity Options

You should enable input parity checking when you have enabled parity in the *c_cflag* member (*PARENB*). The revelant constants for input parity checking are *INPCK*, *IGNPAR*, *PARMRK*, and *ISTRIP*. Generally you will select *INPCK* and *ISTRIP* to enable checking and stripping of the parity bit:

```
options.c_iflag |= (INPCK | ISTRIP);
```

IGNPAR is a somewhat dangerous option that tells the serial driver to ignore parity errors and pass the incoming data through as if no errors had occurred. This can be useful for testing the quality of a communications link, but in general is not used for practical reasons.

PARMRK causes parity errors to be 'marked' in the input stream using special characters. If *IGNPAR* is enabled, a NUL character (000 octal) is sent to your program before every character with a parity error. Otherwise, a DEL (177 octal) and NUL character is sent along with the bad character.

Setting Software Flow Control

Software flow control is enabled using the *IXON*, *IXOFF*, and *IXANY* constants:

```
        options.c_iflag |= (IXON | IXOFF | IXANY);
```

To disable software flow control simply mask those bits:

```
        options.c_iflag &= ~(IXON | IXOFF | IXANY);
```

The XON (start data) and XOFF (stop data) characters are defined in the *c_cc* array described below.

Output Options

The *c_oflag* member contains output filtering options. Like the input modes, you can select processed or raw data output.

Table 8 − Constants for the c_oflag Member

Constant	**Description**
OPOST	Postprocess output (not set = raw output)
OLCUC	Map lowercase to uppercase
ONLCR	Map NL to CR−NL
OCRNL	Map CR to NL
NOCR	No CR output at column 0
ONLRET	NL performs CR function
OFILL	Use fill characters for delay
OFDEL	Fill character is DEL
NLDLY	Mask for delay time needed between lines
NL0	No delay for NLs
NL1	Delay further output after newline for 100 milliseconds
CRDLY	Mask for delay time needed to return carriage to left column
CR0	No delay for CRs
CR1	Delay after CRs depending on current column position
CR2	Delay 100 milliseconds after sending CRs
CR3	Delay 150 milliseconds after sending CRs
TABDLY	Mask for delay time needed after TABs
TAB0	No delay for TABs

TAB1	Delay after TABs depending on current column position
TAB2	Delay 100 milliseconds after sending TABs
TAB3	Expand TAB characters to spaces
BSDLY	Mask for delay time needed after BSs
BS0	No delay for BSs
BS1	Delay 50 milliseconds after sending BSs
VTDLY	Mask for delay time needed after VTs
VT0	No delay for VTs
VT1	Delay 2 seconds after sending VTs
FFDLY	Mask for delay time needed after FFs
FF0	No delay for FFs
FF1	Delay 2 seconds after sending FFs

Choosing Processed Output

Processed output is selected by setting the *OPOST* option in the *c_oflag* member:

```
options.c_oflag |= OPOST;
```

Of all the different options, you will only probably use the *ONLCR* option which maps newlines into CR−LF pairs. The rest of the output options are primarily historic and date back to the time when line printers and terminals could not keep up with the serial data stream!

Choosing Raw Output

Raw output is selected by resetting the *OPOST* option in the *c_oflag* member:

```
options.c_oflag &= ~OPOST;
```

When the *OPOST* option is disabled, all other option bits in *c_oflag* are ignored.

Control Characters

The *c_cc* character array contains control character definitions as well as timeout parameters. Constants are defined for every element of this array.

Table 9 − Control Characters in the c_cc Member

Constant	Description	Key
VINTR	Interrupt	CTRL−C

VQUIT	Quit	CTRL−Z
VERASE	Erase	Backspace (BS)
VKILL	Kill−line	CTRL−U
VEOF	End−of−file	CTRL−D
VEOL	End−of−line	Carriage return (CR)
VEOL2	Second end−of−line	Line feed (LF)
VMIN	Minimum number of characters to read	
VTIME	Time to wait for data (tenths of seconds)	

Setting Software Flow Control Characters

The *VSTART* and *VSTOP* elements of the *c_cc* array contain the characters used for software flow control. Normally they should be set to DC1 (021 octal) and DC3 (023 octal) which represent the ASCII standard XON and XOFF characters.

Setting Read Timeouts

UNIX serial interface drivers provide the ability to specify character and packet timeouts. Two elements of the *c_cc* array are used for timeouts: *VMIN* and *VTIME*. **Timeouts are ignored in canonical input mode or when the *NDELAY* option is set on the file via *open* or *fcntl*.**

VMIN specifies the minimum number of characters to read. If it is set to 0, then the *VTIME* value specifies the time to wait for every character read. Note that this does not mean that a *read* call for N bytes will wait for N characters to come in. Rather, the timeout will apply to the first character and the *read* call will return the number of characters immediately available (up to the number you request).

If *VMIN* is non−zero, *VTIME* specifies the time to wait for the first character read. If a character is read within the time given, any read will block (wait) until all *VMIN* characters are read. That is, once the first character is read, the serial interface driver expects to receive an entire packet of characters (*VMIN* bytes total). If no character is read within the time allowed, then the call to *read* returns 0. This method allows you to tell the serial driver you need exactly N bytes and any *read* call will return 0 or N bytes. However, the timeout only applies to the first character read, so if for some reason the driver misses one character inside the N byte packet then the *read* call could block forever waiting for additional input characters.

VTIME specifies the amount of time to wait for incoming characters in tenths of seconds. If *VTIME* is set to 0 (the default), reads will block (wait) indefinitely unless the *NDELAY* option is set on the port with *open* or *fcntl*.

Chapter 3, MODEM Communications

This chapter covers the basics of dialup telephone Modulator/Demodulator (MODEM) communications. Examples are provided for MODEMs that use the defacto standard "AT" command set.

What Is a MODEM?

MODEMs are devices that modulate serial data into frequencies that can be transferred over an analog data link such as a telephone line or cable TV connection. A standard telephone MODEM converts serial data into tones that can be passed over the phone lines; because of the speed and complexity of the conversion these tones sound more like loud screeching if you listen to them.

Telephone MODEMs are available today that can transfer data across a telephone line at nearly 53,000 bits per second, or 53kbps. In addition, most MODEMs use data compression technology that can increase the bit rate to well over 100kbps on some types of data.

Communicating With a MODEM

The first step in communicating with a MODEM is to open and configure the port for *raw* input:

Listing 3 − Configuring the port for raw input.

```
int            fd;
struct termios options;

/* open the port */
```

```
fd = open("/dev/ttyf1", O_RDWR | O_NOCTTY | O_NDELAY);
fcntl(fd, F_SETFL, 0);

/* get the current options */
tcgetattr(fd, &options);

/* set raw input, 1 second timeout */
options.c_cflag     |= (CLOCAL | CREAD);
options.c_lflag     &= ~(ICANON | ECHO | ECHOE | ISIG);
options.c_oflag     &= ~OPOST;
options.c_cc[VMIN]  = 0;
options.c_cc[VTIME] = 10;

/* set the options */
tcsetattr(fd, TCSANOW, &options);
```

Next you need to establish communications with the MODEM. The best way to do this is by sending the "AT" command to the MODEM. This also allows smart MODEMs to detect the baud you are using. When the MODEM is connected correctly and powered on it will respond with the response "OK".

Listing 4 − Initializing the MODEM.

```
int                  /* O − 0 = MODEM ok, −1 = MODEM bad */
init_modem(int fd)   /* I − Serial port file */
{
  char buffer[255];  /* Input buffer */
  char *bufptr;      /* Current char in buffer */
  int  nbytes;       /* Number of bytes read */
  int  tries;        /* Number of tries so far */

  for (tries = 0; tries < 3; tries ++)
  {
   /* send an AT command followed by a CR */
    if (write(fd, "AT\r", 3) < 3)
      continue;

   /* read characters into our string buffer until we get a CR or NL */
    bufptr = buffer;
    while ((nbytes = read(fd, bufptr, buffer + sizeof(buffer) − bufptr − 1)) > 0)
    {
      bufptr += nbytes;
      if (bufptr[−1] == '\n' || bufptr[−1] == '\r')
        break;
    }

   /* nul terminate the string and see if we got an OK response */
    *bufptr = '\0';

    if (strncmp(buffer, "OK", 2) == 0)
      return (0);
  }

  return (−1);
}
```

Standard MODEM Commands

Most MODEMs support the "AT" command set, so called because each command starts with the "AT" characters. Each command is sent with the "AT" characters starting in the first column followed by the specific command and a carriage return (CR, 015 octal). After processing the command the MODEM will reply with one of several textual messages depending on the command.

ATD − Dial A Number

The *ATD* command dials the specified number. In addition to numbers and dashes you can specify tone ("T") or pulse ("P") dialing, pause for one second (","), and wait for a dialtone ("W"):

```
ATDT 555−1212
ATDT 18008008008W1234,1,1234
ATD T555−1212WP1234
```

The MODEM will reply with one of the following messages:

```
NO DIALTONE
BUSY
NO CARRIER
CONNECT
CONNECT baud
```

ATH − Hang Up

The *ATH* command causes the MODEM to hang up. Since the MODEM must be in "command" mode you probably won't use it during a normal phone call.

Most MODEMs will also hang up if DTR is dropped; you can do this by setting the baud to 0 for at least 1 second. Dropping DTR also returns the MODEM to command mode.

After a successful hang up the MODEM will reply with "NO CARRIER". If the MODEM is still connected the "CONNECT" or "CONNECT baud" message will be sent.

ATZ − Reset MODEM

The *ATZ* command resets the MODEM. The MODEM will reply with the string "OK".

Common MODEM Communication Problems

First and foremost, *don't forget to disable input echoing*. Input echoing will cause a feedback loop between the MODEM and computer.

Second, when sending MODEM commands you must terminate them with a carriage return (CR) and not a newline (NL). The C character constant for CR is "\r".

Finally, when dealing with a MODEM make sure you use a baud that the MODEM supports. While many MODEMs do auto−baud detection, some have limits (19.2kbps is common) that you must observe.

Chapter 4, Advanced Serial Programming

This chapter covers advanced serial programming techniques using the *ioctl(2)* and *select(2)* system calls.

Serial Port IOCTLs

In Chapter 2, Configuring the Serial Port we used the *tcgetattr* and *tcsetattr* functions to configure the serial port. Under UNIX these functions use the *ioctl(2)* system call to do their magic.

The *ioctl* system call takes three arguments:

```
int ioctl(int fd, int request, ...);
```

The *fd* argument specifies the serial port file descriptor. The *request* argument is a constant defined in the `<termios.h>` header file and is typically one of the following:

Table 10 − IOCTL Requests for Serial Ports

Request	Description	POSIX Function
TCGETS	Gets the current serial port settings.	tcgetattr
TCSETS	Sets the serial port settings immediately.	tcsetattr(fd, TCSANOW, &options)
TCSETSF	Sets the serial port	tcsetattr(fd, TCSANOW, &options)

	settings after flushing the input and output buffers.	
TCSETSW	Sets the serial port settings after allowing the input and output buffers to drain/empty.	tcsetattr(fd, TCSANOW, &options)
TCSBRK	Sends a break for the given time.	tcsendbreak, tcdrain
TCXONC	Controls software flow control.	tcflow
TCFLSH	Flushes the input and/or output queue.	tcflush
TIOCMGET	Returns the state of the "MODEM" bits.	None
TIOCMSET	Sets the state of the "MODEM" bits.	None
FIONREAD	Returns the number of bytes in the input buffer.	None

Getting the Control Signals

The `TIOCMGET` *ioctl* gets the current "MODEM" status bits, which consist of all of the RS−232 signal lines except **RXD** and **TXD**:

Table 11 − Control Signal Constants

Constant	Description
TIOCM_LE	DSR (data set ready/line enable)
TIOCM_DTR	DTR (data terminal ready)
TIOCM_RTS	RTS (request to send)
TIOCM_ST	Secondary TXD (transmit)
TIOCM_SR	Secondary RXD (receive)
TIOCM_CTS	CTS (clear to send)
TIOCM_CAR	DCD (data carrier detect)
TIOCM_CD	Synonym for TIOCM_CAR
TIOCM_RNG	RNG (ring)

TIOCM_RI	Synonym for TIOCM_RNG
TIOCM_DSR	DSR (data set ready)

To get the status bits, call *ioctl* with a pointer to an integer to hold the bits:

Listing 5 − Getting the MODEM status bits.

```
#include <unistd.h>
#include <termios.h>

int fd;
int status;

ioctl(fd, TIOCMGET, &status);
```

Setting the Control Signals

The `TIOCMSET` *ioctl* sets the "MODEM" status bits defined above. To drop the DTR signal you can do:

Listing 6 − Dropping DTR with the TIOCMSET ioctl.

```
#include <unistd.h>
#include <termios.h>

int fd;
int status;

ioctl(fd, TIOCMGET, &status);

status &= ~TIOCM_DTR;

ioctl(fd, TIOCMSET, status);
```

The bits that can be set depend on the operating system, driver, and modes in use. Consult your operating system documentation for more information.

Getting the Number of Bytes Available

The `FIONREAD` *ioctl* gets the number of bytes in the serial port input buffer. As with `TIOCMGET` you pass in a pointer to an integer to hold the number of bytes:

Listing 7 − Getting the number of bytes in the input buffer.

```
#include <unistd.h>
#include <termios.h>

int fd;
int bytes;

ioctl(fd, FIONREAD, &bytes);
```

This can be useful when polling a serial port for data, as your program can determine the number of bytes in the input buffer before attempting a read.

Selecting Input from a Serial Port

While simple applications can poll or wait on data coming from the serial port, most applications are not simple and need to handle input from multiple sources.

UNIX provides this capability through the *select(2)* system call. This system call allows your program to check for input, output, or error conditions on one or more file descriptors. The file descriptors can point to serial ports, regular files, other devices, pipes, or sockets. You can poll to check for pending input, wait for input indefinitely, or timeout after a specific amount of time, making the *select* system call extremely flexible.

Most GUI Toolkits provide an interface to *select*; we will discuss the X Intrinsics ("Xt") library later in this chapter.

The SELECT System Call

The *select* system call accepts 5 arguments:

```
int select(int max_fd, fd_set *input, fd_set *output, fd_set *error,
           struct timeval *timeout);
```

The *max_fd* argument specifies the highest numbered file descriptor in the *input*, *output*, and *error* sets. The *input*, *output*, and *error* arguments specify sets of file descriptors for pending input, output, or error conditions; specify `NULL` to disable monitoring for the corresponding condition. These sets are initialized using three macros:

```
FD_ZERO(fd_set);
FD_SET(fd, fd_set);
FD_CLR(fd, fd_set);
```

The *FD_ZERO* macro clears the set entirely. The *FD_SET* and *FD_CLR* macros add and remove a file descriptor from the set, respectively.

The *timeout* argument specifies a timeout value which consists of seconds (*timeout.tv_sec*) and microseconds (*timeout.tv_usec*). To poll one or more file descriptors, set the seconds and microseconds to zero. To wait indefinitely specify `NULL` for the timeout pointer.

The *select* system call returns the number of file descriptors that have a pending condition, or −1 if there was an error.

Using the SELECT System Call

Suppose we are reading data from a serial port and a socket. We want to check for input from either file descriptor, but want to notify the user if no data is seen within 10 seconds. To do this we'll need to use the *select* system call:

Listing 8 − Using SELECT to process input from more than one source.

```
#include <unistd.h>
#include <sys/types.h>
#include <sys/time.h>
#include <sys/select.h>

int            n;
int            socket;
int            fd;
int            max_fd;
fd_set         input;
struct timeval timeout;

/* Initialize the input set */
FD_ZERO(input);
FD_SET(fd, input);
FD_SET(socket, input);

max_fd = (socket > fd ? socket : fd) + 1;

/* Initialize the timeout structure */
timeout.tv_sec  = 10;
timeout.tv_usec = 0;

/* Do the select */
n = select(max_fd,  NULL, NULL, ;

/* See if there was an error */
if (n 0)
  perror("select failed");
else if (n == 0)
  puts("TIMEOUT");
else
{
  /* We have input */
  if (FD_ISSET(fd, input))
    process_fd();
  if (FD_ISSET(socket, input))
    process_socket();
}
```

You'll notice that we first check the return value of the *select* system call. Values of 0 and −1 yield the appropriate warning and error messages. Values greater than 0 mean that we have data pending on one or more file descriptors.

To determine which file descriptor(s) have pending input, we use the *FD_ISSET* macro to test the input set for each file descriptor. If the file descriptor flag is set then the condition exists (input pending in this case) and we need to do something.

Using SELECT with the X Intrinsics Library

The X Intrinsics library provides an interface to the *select* system call via the *XtAppAddInput(3x)* and *XtAppRemoveInput(3x)* functions:

```
int XtAppAddInput(XtAppContext context, int fd, int mask,
                  XtInputProc proc, XtPointer data);
```

```
        void XtAppRemoveInput(XtAppContext context, int input);
```

The *select* system call is used internally to implement timeouts, work procedures, and check for input from the X server. These functions can be used with any Xt−based toolkit including Xaw, Lesstif, and Motif.

The *proc* argument to *XtAppAddInput* specifies the function to call when the selected condition (e.g. input available) exists on the file descriptor. In the previous example you could specify the *process_fd* or *process_socket* functions.

Because Xt limits your access to the *select* system call, you'll need to implement timeouts through another mechanism, probably via *XtAppAddTimeout(3x)*.

Appendix A, Pinouts

This appendix provides pinout information for many of the common serial ports you will find.

RS−232 Pinouts

RS−232 comes in three flavors (A, B, C) and uses a 25−pin D−Sub connector:

Figure 2 − RS−232 Connector

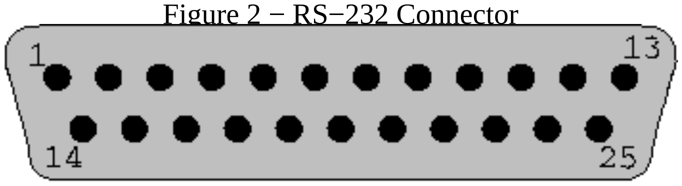


Table 12 − RS−232 Signals

Pin	Description	Pin	Description
1	Earth Ground	14	Secondary TXD
2	**TXD** − Transmitted Data	15	Transmit Clock
3	**RXD** − Received Data	16	Secondary RXD
4	**RTS** − Request To Send	17	Receiver Clock
5	**CTS** − Clear To Send	18	Unassigned
6	**DSR** − Data Set Ready	19	Secondary RTS

7	**GND** − Logic Ground	20	**DTR** − Data Terminal Ready
8	**DCD** − Data Carrier Detect	21	Signal Quality Detect
9	Reserved	22	Ring Detect
10	Reserved	23	Data Rate Select
11	Unassigned	24	Transmit Clock
12	Secondary DCD	25	Unassigned
13	Secondary CTS		

RS−422 Pinouts

RS−422 also uses a 25−pin D−Sub connector, but with differential signals:

Figure 3 − RS−422 Connector

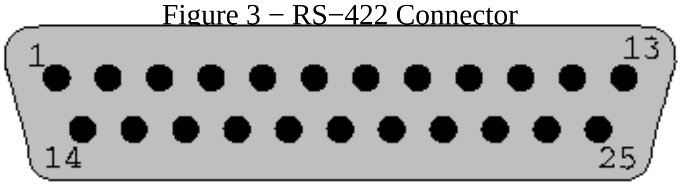


Table 13 − RS−422 Signals

Pin	Description	Pin	Description
1	Earth Ground	14	TXD+
2	**TXD−** − Transmitted Data	15	Transmit Clock−
3	**RXD−** − Received Data	16	RXD+
4	**RTS−** − Request To Send	17	Receiver Clock−
5	**CTS−** − Clear To Send	18	Unassigned
6	**DSR** − Data Set Ready	19	RTS+
7	**GND** − Logic Ground	20	**DTR−** − Data Terminal Ready
8	**DCD−** − Data Carrier Detect	21	Signal Quality Detect
9	Reserved	22	Unassigned
10	Reserved	23	**DTR+**
11	Unassigned	24	Transmit Clock+
12	DCD+	25	Receiver Clock+
13	CTS+		

RS−574 (IBM PC/AT) Pinouts

The RS−574 interface is used exclusively by PC manufacturers and uses a 9−pin male D−Sub connector:

Figure 4 − RS−574 Connector

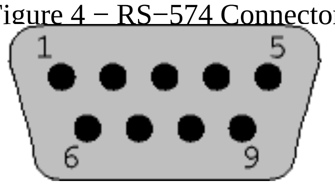


Table 14 − RS−574 (IBM PC/AT) Signals

Pin	Description	Pin	Description
1	**DCD** − Data Carrier Detect	6	Data Set Ready
2	**RXD** − Received Data	7	**RTS** − Request To Send
3	**TXD** − Transmitted Data	8	**CTS** − Clear To Send
4	**DTR** − Data Terminal Ready	9	Ring Detect
5	**GND** − Logic Ground		

SGI Pinouts

Older SGI equipment uses a 9−pin female D−Sub connector. Unlike RS−574, the SGI pinouts nearly match those of RS−232:

Figure 5 − SGI 9−Pin Connector

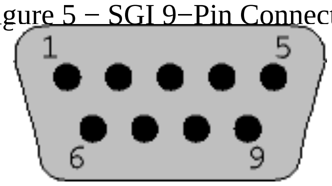


Table 15 − SGI 9−Pin DSUB Signals

Pin	Description	Pin	Description
1	Earth Ground	6	**DSR** − Data Set Ready
2	**TXD** − Transmitted Data	7	**GND** − Logic Ground
3	**RXD** − Received Data	8	**DCD** − Data Carrier Detect
4	**RTS** − Request To Send	9	**DTR** − Data Terminal Ready
5	**CTS** − Clear To Send		

The SGI Indigo, Indigo2, and Indy workstations use the Apple 8−pin MiniDIN connector for their serial ports:

Figure 6 − SGI 8−Pin Connector

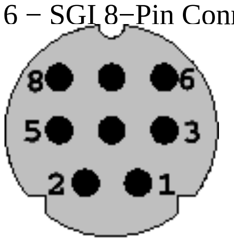


Table 16 − SGI 8−Pin MiniDIN Signals

Pin	Description	Pin	Description
1	**DTR** − Data Terminal Ready	5	**RXD** − Received Data
2	**CTS** − Clear To Send	6	**RTS** − Request To Send
3	**TXD** − Transmitted Data	7	**DCD** − Data Carrier Detect
4	**GND** − Logic Ground	8	**GND** − Logic Ground

Appendix B, ASCII Control Codes

This chapter lists the ASCII control codes and their names.

Control Codes

The following ASCII characters are used for control purposes:

Table 17 − ASCII Control Codes

Name	Binary	Octal	Decimal	Hexadecimal
NUL	00000000	000	0	00
SOH	00000001	001	1	01
STX	00000010	002	2	02
ETX	00000011	003	3	03
EOT	00000100	004	4	04
ENQ	00000101	005	5	05
ACK	00000110	006	6	06
BEL	00000111	007	7	07
BS	00001000	010	8	08
HT	00001001	011	9	09

NL	00001010	012	10	0A
VT	00001011	013	11	0B
NP, FF	00001100	014	12	0C
CR	00001101	015	13	0D
SO	00001110	016	14	0E
SI	00001111	017	15	0F
DLE	00010000	020	16	10
XON, DC1	00010001	021	17	11
DC2	00010010	022	18	12
XOFF, DC3	00010011	023	19	13
DC4	00010100	024	20	14
NAK	00010101	025	21	15
SYN	00010110	026	22	16
ETB	00010111	027	23	17
CAN	00011000	030	24	18
EM	00011001	031	25	19
SUB	00011010	032	26	1A
ESC	00011011	033	27	1B
FS	00011100	034	28	1C
GS	00011101	035	29	1D
RS	00011110	036	30	1E
US	00011111	037	31	1F