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Serial Programming

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Table of Contents

Introduction and OSI Model

Introduction

Welcome to the wonderful world of serial data communications. This is a part of a series of articles that will be cover many aspects of serial data communications. I am going to try and start from the beginning and follow a layered approach to working with serial data and by the time we are through we should be able to transfer just about any sort of data that you would care to send over wires between computers. Possibly even without wires (wireless data communication).

There are so many aspects about this subject that sometimes it is a very hard nut to crack. I'm going to dive down and try to start with the basics and introducing the RS-232 serial data communications standard.

Why Serial Communication?

First of all, the basic standards that I will be describing are from the perspective of computer technology, positively ancient. Some of you reading this could perhaps find your grandparents or even great-grandparents using this protocol when they were in College. At the same time, it is so solid in concept that the reason for abandoning it should always be questioned. Indeed, there have been several other data transmission methods that have been developed since the RS-232 serial data protocol was established, but this workhorse is still widely used and seems to go through a rebirth every once in a while.

When all else fails, RS-232 serial communication can be relied upon. When you are trying to get two pieces of computer equipment together, sometimes newer communications methods have hard limitations that can't be worked out due to number of connections, RF interference, distance limitations, being behind physical barriers, in sensitive areas like medical equipment where stray voltages can be a problem, or that you absolutely need to rely upon the data being transmitted. A sister protocol to RS-232, the RS-422 protocol, will even allow transmissions for several miles of cable.

Serial data communication is widely implemented. While it is sometimes presumed that a PC can deal with just about any problem you want to throw at it, there are a number of electronic devices that are full of data which needs to be recorded. In part because of the age of this protocol, there are many legacy devices that have RS-232 serial data as the only access to the outside world. But even many of the latest network devices have RS-232 "console" ports to facilitate initial configuration and provide a means of troubleshooting when the network itself is broken. Because the hardware is so widely implemented and available, together with many software tools, it is also relatively cheap to develop

equipment and software to be using this system. Particularly when transmission speed isn't particularly important, but it is necessary to send data on a regular basis, RS-232 serial data is a very reasonable solution instead of a more expensive 10BASE-T TCP/IP solution, or even high-speed fibre optics.

Serial data communication is also versatile. While the usual method of transmission is over copper wires between two fixed points, recently there have been some converters that transmit serial data over fibre optic lines, wireless transmitters, USB devices, and even being carried over TCP/IP networks. What is really surprising here is that all of these transmission methods are totally transparent to the device receiving or transmitting the serial data. It can also be a carrier for TCP/IP, and be used for private networks.

OSI Layered Network Communications Model

While serial data communication is not strictly a network communication protocol, it is still important to understand the layered communications model when dealing with any sort of communications protocols. Often people implementing serial data software have to build multiple layers of this model, even if they are not totally aware of it when they are doing it at the time.

Network Layers

- Application
- Presentation
- Session
- Transport
- Network
- Data-Link
- Physical

Often serial data communication does not implement all of these different layers, and even more often these different layers are combined in the same module or even the very same function. This model was originally developed by the International Organization for Standards (ISO) in 1984 to help give a good idea of where different networking structures could be separated and intermingled. The point here is to know that you can separate different parts of communications sub-systems to help with the debugging process, and to move structures from one sub-system to another.

If your software is well written using a model similar to this one, the software subroutines in layers above and below do not have to be rewritten if the module at a particular layer is changed. To achieve this you need to establish strong standards for the interface between the layers, which will be covered in other sections of these articles. For example, a web browser does not need to know if the HTML is being sent over fibre optic cables, wireless transmissions, or even over a serial data cable.

Serial Comm Layers

For serial data communication, I see this layer model as more common:

- Serial Data Applications
- Serial Networks
- Packet Challenge/Verification
- Basic Serial Packets
- 8250 UART processing
- Raw RS-232 Signals

In the case of many serial data applications, not all of these layers are implemented. Often it is just raw packets being transmitted in one direction, but sometimes even just a signal of any kind can indicate some action take place on a computer, regardless of content. It is possible to simply take the logic level of a raw RS-232 signal in your software, but at some point the data does need to be converted and the voltages involved with RS-232 can damage hardware, so this is very seldom done.

Software Examples

I don't want to get into a holy war over programming languages with this series of articles. For the moment, I'm going to be using Turbo Pascal and Delphi as the programming languages, if for no other reason then the fact that I am most comfortable programming in this development environment. If a good C/C++ guru would like to "translate" these routines, I would welcome that, as well as other programming languages where applicable. Serial communication is complicated enough that please avoid esoteric languages like Intercal or Malbrodge. A good BASIC implementation would be welcome, as would LISP. I'll try to avoid language-specific features and simply deal with functions in a generic sense, which a good programmer should be able to translate to the language of their choice.

These articles are meant to teach you the basics of serial data communication, not to be a functioning serial data driver. Still, all code examples will be checked and sent through an actual compiler before being listed in the articles, and hopefully fully debugged. There is no one single way to accomplish these steps and tasks, so I am going to encourage a hands-on approach to dealing with software and setting up networks.

While I've had quite a bit of experience in dealing with several serial data protocols (on the packet level), I am by no means the uberexpert at this. As I said earlier, I have considerable experience in dealing with communications at many levels, and I'd like to share some of my very hard-won knowledge.

Applications in Education

While I am only a Software Engineer and don't have the "formal" credentials necessary for making an educational textbook, I do believe that there is much that could be taught about computer networking by students experimenting with serial data communication. The audience that I am aiming for with these articles are the High School hackers/computer geeks and undergraduate CS majors. A High School teacher that wanted to tackle a subject like this, or if you wanted to cover a special topic course in a university setting where students could get some very hands-on experience with communications protocols. Every layer of the OSI model could be demonstrated in a manner that students would learn from first-hand experiences why certain rules/systems have been implemented on the Internet, what standards documents mean, and perhaps even participate in creating standards documents.

If you are a professor or High School instructor interested in using this text, I would be particularly interested in adapting this text to better suit your needs, or working with you in covering this subject.

From a professional **perspective**, this is a topic that is seldom taught at a university, and usually only in passing when they are rushing through a whole bunch of other protocol suites. Software developers are usually introduced to this topic by having their supervisor dump a bunch of specification documents on their desk, a driver disk with API documentation, and perhaps a typically short deadline in order to get something working that should have been working sometime last year. Software developers who really understand serial data communication are worth gold, and often even these developers only learn just enough to get the immediate job done.

I've also found that skills learned from developing serial data communications also translate into other projects and give a deeper understanding of just about any data transmission system. In addition to the other groups I mentioned, I am also aiming for those unfortunate software engineers who are trying to learn just about anything about this very difficult subject and don't know where to begin. Documentation about serial communication is sparse, and sometime contradictory.

This doesn't have to be that complicated of a subject, and it is possible for mere mortals to be able to understand how everything works.

External Links / References

- Cisco explanation of the OSI model
- University of Indiana / Unix Support Group explanation of OSI
- ISO catalog of OSI standards

RS-232 Connections

Introduction

The RS-232 standard is in fact really a collection of connection standards between different pieces of equipment. This is a rather old standard, and has been revised many times over the years to accommodate changes to communications technology. A bare-bones connection will have only one wire connected between two pieces of equipment, but usually there is more. Three wires (transmit, receive, and ground) are usually the minimum recommended. A fully implemented RS-232 connection can have as many as 25 wires between each end, so obviously the "standard" is really less than standardized. Still, there are some basic usually accepted connections. Some of the early RS-232 connections were also used to connect terminal equipment to modems, so you will see information about modems mixed with general serial data communication. Some documentation can even get confusing about which type of communication they are talking about, and often it really doesn't matter.

Data Terminal/Communications Equipment

In the world of serial communications, there are two different kinds of equipment:

- DTE - Data Terminal Equipment
- DCE - Data Communications Equipment

Straight Serial Connections

In practice the distinction between the two pieces of equipment is really a matter of function rather than any real difference. As mentioned earlier, modems and serial communication equipment have been mixed together, this is another case of that. In this situation, the modem can be thought of as the Data Communications Equipment (DCE) and the terminal that somebody is sitting down and using is the Data Terminal Equipment. In the older days when it was common to use a timeshare computer system (pre 1980s), you would dial up a telephone, stick the handset that you would normally talk with into an acoustical modem, and that modem would be connected to a simple dumb terminal with an RS-232 cable. When we get to baud rates this will make more sense, but the typical connection speed was usually either 50 baud or 110 baud, and really fast connections going at 300 baud.

As a side note, when the very first IMP's (Interconnection Message Processors) that formed the first nodes/routers of ARPAnet (the ancient predecessor of the internet), this was exactly the connection system they were using. This later gave way to other communication systems, but this was the beginning of the internet.

In a more modern setting, imagine a piece of equipment in a very dangerous place, like in a steel processing mill that measures the temperature of the rollers or other steel processing equipment. This would also be a form of what we now refer to as a piece of "Data Communication Equipment" that we would also want to be able to control remotely. The PC that is used in a control room of the mill would be the Data Terminal Equipment. There are many other similar kinds of devices, and RS-232 connections can be found on all kinds of equipment.

The reason this is called a "straight" connection is because when the cabling is put together, each wire on each end of the connection is put to the same pin. This wiring system will be explained further on.

Null Modems

Often you don't always want to connect a piece of equipment to a computer, but you would also like to connect two computers together. Unfortunately, when connecting two computers with a "straight" serial connection, the two computers are fighting each other on the same wires.

One way to make this work is to connect the two computers to each other with a pair of modems. As explained earlier, this is a very common task, and in the 1980's and early 1990's it was common to have "Bulletin Board Systems" (BBS) where computers would call each other up with modems and exchange all sorts of information.

Now imagine if these two computers are in the very same room. Instead of going through the physical modems, they go through a "null modem", or a modem that really doesn't exist. In order to make this work you have to "cross" some of the wires so when you transmit some information on one end, the other computer is able to detect and receive that same information.

In addition to simply allowing a computer to communicate and transmit data to another computer, a null modem connection can be used to "simulate" the behavior of DCE equipment. This will be particularly important later on with some of the discussion in this series of articles, where you can experiment with writing some of your own serial communication software. In my own experience, I've had to write these "emulators" in many instances, either because the equipment that I was trying to communicate with wasn't finished, or it was difficult to obtain a sample of that equipment and all that I had available to me was the communication protocol specification.

Loopback Connectors

Sometimes instead of trying to communicate with another computer, you would like to be able to test the transmission equipment itself. One practical way of doing this is to add a "loopback" connector to the terminal device, like a PC with a serial data connection. This connector has no cable attached, but loops the

transmit lines to the receive lines. By doing this, you can simulate both the transmission and receiving of data. Generally speaking, this is only done for actually testing the equipment, but can be used for testing software components as well. When this sort of connector is used, you will receive every byte that you transmit. If you separate out the transmission subroutines from the data capture subroutines, it can provide a controlled system for testing your application.

Protocol Analyser

General

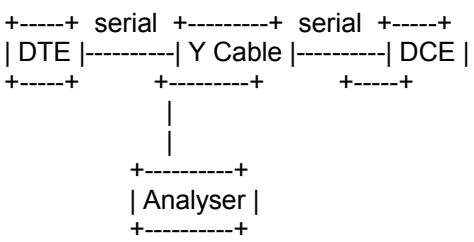
When it starts to get very difficult to examine the serial data being transmitted by the equipment, sometimes it is nice to be able to take a "snapshot" of the information being transmitted. This is done with a protocol analyser of one kind or another.

What is done is a modification of the cabling that allows for a third computer to be able to simply read the data as it is being transmitted. Sometimes the communication protocol can get so complicated that you need to see the whole exchange, and it needs to be examined in "real-time" rather than going through some sort of software debugger. Another purpose of this is to examine the data exchange for purposes of doing some reverse engineering if you are trying to discover how a piece of equipment works. Often, despite written specifications, the actual implementation of what is occurring when transmitting data can be quite a bit different than what was originally planned. Basically, this is a powerful tool for development of serial communications protocols and software, and should not be ignored.

There are common ways to connect a protocol analyser, which are discussed in the following sections.

Y "Cable"

A *Y "Cable"* is not just some cable, but also contains electronic - at least if it is not a cheap junk cable. It is supposed to be placed in between a serial line and it mirrors all signals on a third connector. This third connector can then be connected to a protocol analyser (e.g. a PC with some display software):



It is highly recommended to not use a passive Y cable. Such a cable overloads the transmitters at the DTE and DCE, which might result in the **destruction of the transmitters**.

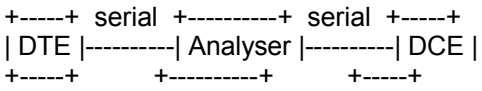
Often, the line going to the analyser is also just a serial line, and the Analyser is a PC with a serial interface and some display software. The disadvantage of such a simple Y cable solutions is that it only supports half-duplex communication. That is, only one site (DTE or DCE) can talk at any time. The reason for this is that the two TX lines from the DTE and DCE are combined into one TX line going to the analyser. If the DTE and the DCE both send at the same time, their signals get mixed up on the third line going to the analyser, and the analyser probably doesn't see any decodable signal at all.

See http://www.mmvisual.de/fbintermdspy.htm for an example of some simple circuitry for a Y cable.

More advanced Y cable solutions provide the TX data from the DTE and DCE separately to the analyser. Such analysers are capable of displaying full-duplex communication. Advanced professional systems not only display the decoded digital information, but also monitor the analog signal levels and timing.

Man-in-the-Middle

In this scenario the analyser sits in the middle between the DTE and DCE. It is basically some device (e.g. a PC) with two serial interfaces. The analyser mirrors each signal from one site to the other site, and also displays the traffic.



In principle, a simple version of such an analyser can be built with any PC with two serial interfaces. All that is needed is some software, which is not too difficult to write. Such a device will, however, lack a convenient feature. Professional analysers are able to auto-sense the speed of the serial communication. A home made solution needs to be configured to match the speed of the serial communication. Professional devices are also optimized to ensure minimal delay in the circuitry. Also, a simple homegrown, PC-based analyser can't be used to analyse faults due to signal voltage level problems. Nevertheless, any kind of protocol analyser is much better than nothing at all. Even the most simple analyser is very useful.

Others

See Setting up a Development Environment (for modem development) for some more information.

Breakout Box

An RS232 breakout box (a BOB) is a rather nifty piece of hardware which usually combines a number of functions into one. It basically consist of two RS232 connectors, and a patch field (or switches) which allows to change the wiring between the connectors. A patch field and small pieces of wires are preferable over (DIP) switches alone, since the patch field allows access to the signals for other purposes, too.

A breakout box is very useful if the pinout (DTE/DCE) of a particular device is not known. The patch field allows to quickly change the wiring from a straight connection to a null modem connection, or to set up a loopback connection.

Since the patch field provides access to all signals it also allows to use the breakout box to connect a protocol analyser. Better breakout boxes also provide some signal level information on their own, by having LEDs who inform about the signal voltage. This information is useful when trying to identify an unknown pinout. High-end BOBs contain circuitry to measure ground potential difference and pulse traps circuitry to find signal glitches.

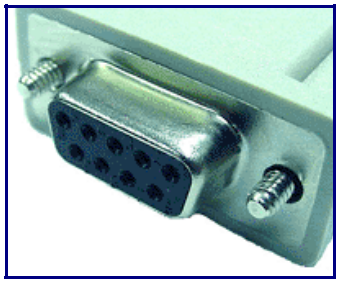
Commercial breakout boxes are available in many varieties. It is also possible to build a useful BOB from a handful of simple parts on a circuit board. The patch field can be made from DIL IC sockets, and the wiring of the LEDs is simple if 2-pin dual-color LEDs are used. Each signal line should be connected via such an LED and a 680 Ohm resistor in serial to GND (Signal Ground). The home-made breakout-box is completed with a couple of RS232 connectors, possibly also one to attach a protocol analyser and some simple metal or plastic case.

Connection Types

If you wanted to do a general RS-232 connection, you could take a bunch of long wires and solder them directly to the electronic circuits of the equipment you are using, but this tends to make a big mess and often those solder connections tend to break and other problems can develop. To deal with these issues, and to make it easier to setup or take down equipment, some standard connectors have been developed that is commonly found on most equipment using the RS-232 standards.

These connectors come in two forms: A male and a female connector. The female connector has holes that allow the pins on the male end to be inserted into the connector.

"DB-9"



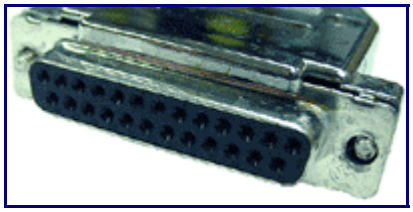
This is a female "DB-9" connector (properly known as DE9F):

The female DB-9 connector is typically used as the "plug" that goes into a typical PC. If you see one of these on the back of your computer, it is likely not to be used for serial communication, but rather for things like early VGA or CGA monitors (not SVGA) or for some special control/joystick equipment.

And this is a male "DB-9" connector (properly known as DE9M):

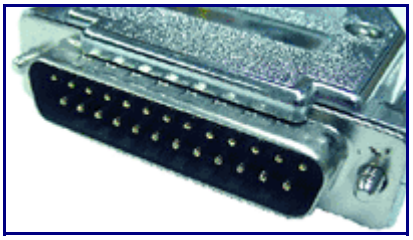
This is the connector that you are more likely to see for serial communications on a "generic" PC. Often you will see two of them side by side (for COM1 and COM2). Special equipment that you might communicate with would have either connector, or even one of the DB-25 connectors listed below.

DB-25



This is a female DB-25 connector (also known as DB25F):

This is what you normally find on the end of a traditional parallel printer cable on a PC. This connector type is also used frequently for equipment that conforms to RS-232 serial data communication as well, so don't always assume if you see one of these connectors that it is always parallel. When the original RS-232 specification was written, this was originally the kind of connector that was intended, but because many of the pins were seldom if ever used, it was switched to the DB-9 connectors on more recent equipment like the original IBM-PC (yes, that is comparatively recent equipment for this standard).



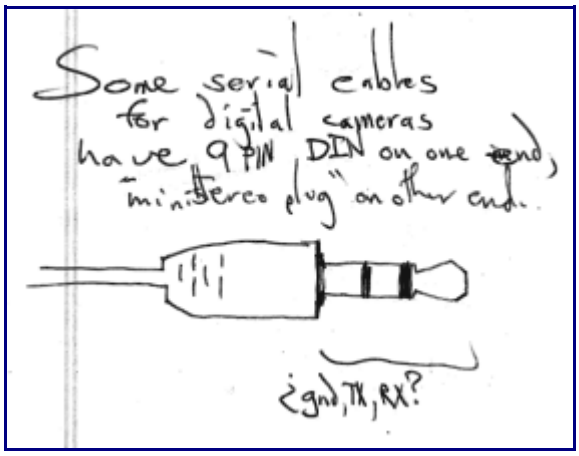
This is a male DB-25 connector (also known as DB25M):

Male DB-25 connectors are usually used on a PC for parallel data communication, which is beyond the scope of this series of articles. However, you should still be aware that this connector is also used for serial communications on many different types of equipment. In fact, if you have a random piece of equipment that you are trying to see how it works, you can presume that it is a piece of serial

equipment. Hacking random connectors is also beyond the scope of this document, but it can be an interesting hobby by itself.

mini-stereo plug connector

This is a male mini-stereo plug connector:

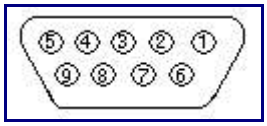


Some digital cameras come with a cable that has a mini-stereo plug connector on the end the plugs into the camera, and a DB-9 connector on the end that plugs into the PC.

See [1]

Wiring Pins Explained

The wiring of RS-232 devices involves first identifying the actual pins that are being used. Here is how a **female** DB-9 connector is numbered:



If the numbers are hard to read, it starts at the top-right corner as "1", and goes left until the end of the row and then starts again as pin 6 on the next row until you get to pin 9 on the bottom-left pin. "Top" is defined as the row with 5 pins.

The male connector (like what you have on your PC) is simply this same order, but reversed from right to left.

Here are what each pin is usually defined as:

9-pin	25-pin	pin definition
1	8	DCD (Data Carrier Detect)
2	3	RX (Receive Data)
3	2	TX (Transmit Data)
4	20	DTR (Data Terminal Ready)
5	7	GND (Signal Ground)
6	6	DSR (Data Set Ready)
7	4	RTS (Request To Send)
8	5	CTS (Clear To Send))
9	22	RI (Ring Indicator)

One thing to keep in mind when discussing these pins and their meaning, is that they are very closely tied together with modems and modem protocols. Often you don't have a modem attached in the loop, but you still treat the equipment as if it were a modem on a theoretical level.

The following are more formal explanations regarding each signal:

DCD (Data Carrier Detect)

This is a signal to indicate from the communications equipment (DCE) that the phone line is still "connected" and receiving a carrier signal from the modem at the other end. Presumably well-written software or serial equipment could detect from this logic state when the telephone has been "hung up" on the other end. Null-modems often tie DCD to DSR at each end since there is no carrier signal involved. This signal pin can be independently detected by software, and a "real" hacker could have some fun playing with this pin to add some sort of signal to increase bandwidth. Still, it isn't worth the effort, when there are much better ways to increase data throughput.

RX (Receive Data)

This is the "heart" of serial data communications. This wire will have a series of alternating +15V and -15V signals that determine what the actual data is that is coming over the wire. This is the data that is incoming from the data communications equipment (or being transmitted by the DCE). Remember, when you are making devices that attach to a serial comm port, the thinking is somewhat reversed. Think more along the lines of "Terminal Receive" and it helps to keep things in the proper frame of mind.

TX (Transmit Data)

The reverse of RX, this is where the terminal equipment (DTE) is transmitting serial data, using the same format and protocol that the receiver is expecting...usually. More on the exact protocol further below. Like RX, think along the lines of "Terminal Transmit" when designing equipment that will be using this pin.

DTR (Data Terminal Ready)

Basically a signal from the DTE that says "Hello!, I'm ready if you are". This is a general indicator to the DCE that the terminal is ready to start sending and receiving data. If there is some initialization that needs to happen in the communications equipment, this is a way for the terminal equipment to "boot" the receiving equipment.

GND (Signal Ground)

This is an interesting pin to look at. What it does is try to make a common "ground" reference between the equipment that is being connected to compare the voltages for the other signals. Normally this is a good thing, because sometimes different pieces of equipment have different power supplies and are some distance away. The not so pleasant thing about this wire is that it usually is a physical piece of copper that can conduct electricity that is not normally supposed to go down the wire, like a short-circuit or worse yet a bolt of lightning (it happens far more often that you would normally think for this sort of equipment). That can fry both the DCE as well as the DTE. Things like fiber converters and ground isolators can help prevent this from happening, but can still be something to worry about. Over short distances this is generally not a problem.

DSR (Data Set Ready)

This is the counterpart to DTR with the communications equipment (or computer peripheral on the serial line). When the DTR is sent as a signal, the communications equipment should change this signal to -15V to indicate that it is ready to communicate as well. If the DCE goes through a "boot" sequence when the DTR gets signaled, it should not signal DSR until it is complete. But many connectors "hard wire" this pin to be directly connected to the DTR pin at each end to reduce the number of wires needed in the cable. This can be useful for connecting devices using existing telephone wires, but prevents applications from using the DTR and DSR for handshaking.

RTS (Request To Send)

This is a part of the "Hardware" flow control protocol that will be explained below. Basically, when this pin has a -15V signal (logical "1"), it indicates to the DCE that the terminal is ready to receive more data. When it has a +15V (logical "0") signal, it indicates that the DCE should stop sending data temporarily until the buffer can be cleared.

CTS (Clear To Send)

This is the response signal from the DCE regarding if the terminal equipment should be transmitting any data. When this signal is -15V the terminal is "permitted" to transmit data. Like the DTR/DSR pins, this one can be directly connected to the RTS pin to reduce the number of wires needed, but this eliminates the possibility of hardware flow control. Some software ignores this pin and the RTS pin, so other flow control systems are also used. That will be explained when we get to actual software.

RI (Ring Indicator)

Again, thinking back to a telephone modem, this is a signal that indicates that the telephone is "ringing". Generally, even on a real telephone modem, this is only occasionally set to -15V for the signal. Basically, when you would normally be hearing a "ring" on your telephone, this pin would be signaled. On Null-modems, often this wire isn't even connected to anything. If you really are connected to a real modem, this does have some strong uses, although there are other ways to have the terminal equipment (like a PC connected to an external modem) be informed that there are ways to communicate this information through the data pins as well. This will be covered lightly in the software section.

Other RS-232 Pins

There are other pins that the DB-25 has implemented that the DB-9 doesn't normally use, such as a secondary transmit and receive pin, Secondary CTS/RTS for those alternate pins, a -15V signal for power, a clock, and a couple of other good ideas as well. The problem with implementing all of these pins is that you also need to run separate wires, and a full set of DB-25 connectors would also mean having 25 physical wires going the full distance between the DTE and DCE. If this is more than a foot or so, it gets to be a big hassle, particularly if you are going through walls or in a more permanent setting. If the wrong wire gets clipped in the bundle, the whole thing must be restrung again, or you must go through wire testing like the old-fashioned telephone linemen used to have to do when fixing a phone distribution box. Often only three physical copper lines are used to connect the DTE to DCE, and that is simply RX, TX, and GND. The rest can be easily "faked" on the connector end in a manner

sufficient for most software and hardware applications.

Baud Rates Explained

I'm going to go on a bit of a rant here. Baud and BPS (Bits Per Second) are usually the same thing, and originally it really did mean that. There are several ways to determine what the actual data rate of a particular piece of equipment is, but in popular marketing literature, or even general reference texts, they will almost always refer to "Baud Rate", even if they are referring to bits per second.

Language purists will go into a more literal definition of baud meaning a clump of data that is transmitted in one time unit. More on that in a bit.

Baud is actually a shortened term named in honor of Émile Baudot, a French inventor of early teleprinter machines that replaced the telegraph key using Morse Code. Basically two typewriters that could be connected to each other with some wires. He came up with some of the first digital character encoding schemes, and the character codes were transmitted with a serial data connection. Keep in mind this was being done largely before computers were invented. Indeed, some of these early teleprinter devices were connected to the very first computers like the ENIAC or UNIVAC, simply because they were relatively cheap and mass produced at that point.

In order for serial data communication to happen, you need to agree on a clock signal, or baud rate, in order to get everything to be both transmitted and received properly. This is where the language purists get into it, because it is this clock signal that actually drives the "baud rate". Let's start more at the beginning with Émile Baudot's teleprinters to explain baud rate.

Émile's early teleprinters used 5 data bits and 1 stop bit to transmit a character. We will go onto formatting issues in a second, but what is important is that six signals are sent through a wire in some fashion that would indicate that a character is transmitted. Typically the equipment was designed to run at 50 baud, or in other words the equipment would transmit or receive a "bit" of data 50 times per second. Not coincidentally, French power systems also ran on an alternating current system of 50 Hz, so this was an easy thing to grab to determine when a new character should be transmitted.

Teleprinters evolved, and eventually you have Western Union sending teleprinter "cablegrams" all around the world. If you hear of a TELEX number, this is the relic of this system, which is still in use at the present time, even with the internet. By rapidly glossing over a whole bunch of interesting history, you end up with the United States Department of Justice (DOJ) in a lawsuit with AT&T. Mind you this was an earlier anti-trust lawsuit prior to the famous/infamous 1982 settlement. The reason this is important is because the DOJ insisted that Western Union got all of the digital business (cable grams... and unfortunately this got to be read as computer equipment as well), and AT&T got modulated frequencies, or in other words, you could talk to your mother on Mother's Day on

their equipment. When computers were being built in the 1950s, people wanted some way to connect different pieces of computer equipment together to "talk" to each other. This finally resulted in the RS-232 standard that we are discussing on this page.

While Western Union was permitted to carry digital traffic, often the connections weren't in or near computer centers. At this time AT&T found a loophole in the anti-trust settlement that could help get them into the business of being a "carrier" of computer data. They were also offering to transmit computer data at rates considerably cheaper than Western Union was going to charge. Hence, the modem was born.

Modems Explained

The long description of a modem is a "Modulator/Demodulator", and this description is important. Since AT&T could only carry "tones", like music from a radio network or the voice of your mother, they created a device that would electronically create "music" or "tones" that could be carried on their network. They would then take a computer "1" or "0" and "modulate" the bit to a frequency, like say 2600 Hz. (The exact tones varied based on baud rate and other factors, but there were exact frequency specs here.) A matching device would be able to look for that "note" or "tone" in the "music" and be able to convert that back to a computer "1" or "0", or in other words, demodulate the music. Since all you and your buddy on each end of the telephone are only playing music to each other, it was legal for AT&T to have that music on their network. That only computers could possibly understand this music is besides the point, and the DOJ turned a blind eye on the whole practice, despite objections from Western Union.

The original modems you could buy were AT&T Bell 103 modems. These were clunky boxes about the size of a shoe box that had a bunch of switches on the outside and an RS-232 cable that connected to the computer equipment you were using. See, the RS-232 keeps coming back, so we are making some progress here. These boxes were designed for the old-fashioned handset telephones and had pieces of rubber that would go around the "speaker" and "mike" portion of the telephone (no direct copper connection to the telephone equipment back then). If you wanted to dial the telephone, you had to use the rotary dial on the phone itself... the computer didn't have access to that sort of equipment. Keep in mind that the FCC regulated just about everything that happened with phone equipment, and AT&T owned everything related to telephones. You even had to "rent" the modem from AT&T, and that rental charge was on your monthly phone bill.

The Bell 103 was originally 110 baud, although it eventually had a switch to "move up" to 220 baud. 300 baud modems were also fairly common throughout the 1960's and 1970's. Keep in mind that AT&T (or your local phone company) was the only company you could even rent a modem from, whether you wanted

one or not. By 1982, modems were so commonly used and the POTS telephone network so widespread that this same system of sending "music" over the telephone has been preserved, even though the legal reasons for doing it are no longer valid. With the advent of ISDN and DSL lines, this is no longer the case and the phone companies are now sending pure digital signals instead. This is also why DSL lines can carry much more data than an ordinary phone line, even though it is the same pair of copper wires going into your home.

When modems started going to very high speeds, they hit a brick wall of sorts. It was decided back in the 1950's that telephone equipment would only have to carry tone signals going to about 10kHz. For normal voice conversations this is sufficient, and you can even tell the difference between a man and a woman on the telephone. The problem comes in that this means the highest normal "baud rate" that you can send over a home telephone network is about 9600 baud, usually about 4800 baud, because the telephone equipment itself is going to be dropping "bits" as you switch from one tone to another. Without going into the heavy math, you need to have at least one full "sound wave" in order to be able to distinguish one tone or note from another. Modem manufacturers did think of something else that could be done to overcome this limitation, however. Instead of just sending one tone at a time, you could play a whole "chord", or several distinct tones at the same time. Finally back to baud vs. bits per second. With higher speeds, instead of simply sending only one bit, you are sending two or as many as sixteen bits at the same time with varying "chords" of "music". This is how you get a 56K BPS modem, even though it is still only transmitting at 9600 baud. Get it now?

Signal Bits

There are four sets of transmission bits that are used in the RS-232 standard. The positioning of these bits in the RS-232 data stream is all that distinguishes one bit from the other. This is also where serial communication really hits the "metal", because each bit follows in a sequence, or in a serial fashion. All of the other wires, pins, baud rate, and everything else is to make sure that these bits can be understood. Keep in mind that at this point the entire protocol is based on the transmission of a single character. Multiple characters can be sent, but they are a sequence of single character transmission events. How the characters relate is based on what the software does with the data on the next protocol "layer".

Start Bit

When a transmission line is not sending anything, it remains in a logical state of "1", or -15V on the wire. When you want to send a character, you start by changing the voltage to +15V, indicating a logical "0" state. Each subsequent bit is based on the baud rate that is established for communication between each

device. This bit signals that the receiving device should start scanning for subsequent bits to form the character.

Data Bits

This is the primary purpose of serial communications, where the data actually gets sent. The number of bits here can vary quite a bit, although in current practice the number of bits typically transmitted is eight bits. Originally this was five bits, which was all that the early teleprinters really used to make the letters of the Alphabet and a few special characters. This has implications for internet protocols as well, because early e-mail systems transmitted with only seven bits when they were connected over some RS-232 links. This worked because the early character encoding schemes, mainly ASCII, only used seven bits to encode all characters commonly used for the English language. Because computer components work best on powers of 2 (2,4,8,16,32, etc.), eight bits became more commonly used for data storage of individual characters. Unicode and other coding schemes have moved this concept forward for languages other than English, but eight bits still is a very common unit for transmitting data, and the most common setting for RS-232 devices today.

The least significant bit (LSB) is transmitted first in this sequence of bits to form a character.

Parity Bit

To help perform a limited error check on the characters being transmitted, the parity bit has been introduced. It is useful, but you must understand that there are limits to what information can be stored in a single bit. The "formula" that is used to determine the value of the parity bit is to add up the number of bits sent as a "1" in the string of data bits.

There are four different kinds of parity configuration to consider:

Odd Parity

When the sum of bits ends up coming up with an odd number (like the sequence 01110110), this bit will be set to a logical state of "1".

Even Parity

This uses the formula of trying to determine if there are an even number of bits set to "1". In this regard, it is the exact opposite state of the Odd Parity.

Mark Parity

Using this concept, the transmission protocol is essentially ignoring the parity bit entirely. Instead, the transmission configuration is sending a logical "1" at the

point that a parity bit should be sent, regardless of if the sequence should have an odd or even count. This configuration mode is useful for equipment that may want to be testing parity checking software or firmware in the receiving equipment.

Space Parity

The opposite of Mark parity, this sends a logical "0" for the parity checksum. Again, very useful for equipment diagnostics.

Parity None

This isn't really a parity formula, but rather an acknowledgement that parity really doesn't work, so the equipment doesn't even check for it. This means the parity bit isn't even used. This can cause, in some circumstances, a slight increase in the total data throughput. More on that below.

Stop Bits

This really isn't a bit at all, but an agreement that once the character is sent that the transmitting equipment will return to a logical "1" state. The RS-232 specification requires this logical state of "1" to remain for at least one whole clock cycle, indicating that the character transmission is complete. Sometimes the protocol will specify two stop bits. One reason that this might be done is because the clock frequencies being used by the equipment might have slightly different timing, and over the course of hundreds or thousands of characters being transmitted the difference between two clocks on the two different pieces of equipment will cause the expected bits to be shifted slightly, causing errors. By having two stop bits the transmission is slightly slower, but the clock signals between the two pieces of equipment can be coordinated better. Equipment expecting one stop bit can accept data transmitted by equipment sending two stop bits. It won't work the other way around, however. This is something to try if you are having problems trying to get two pieces of equipment to communicate at a given baud rate, to add the second stop bit to the transmitter.

Data Transmission Rates

We got into a discussion of baud rate vs. bits per second. Here is where baud as the number of bits being transmitted is still off, even if the nominal bits per second is also the same as the baud rate. By adding start bits, stop bits, and parity bits, that is going to add overhead to the transmission protocol. All digital transmission protocols have some sort of overhead on them, so this shouldn't be that much of a surprise. As we get more into data packets and other issues, the actual amount of data being transmitted will drop even further.

Keep in mind that if you are transmitting with 6 data bits, 2 Stop bits, and Even

Parity, you are transmitting only six bits of data and four other bits of data. That means that even with 9600 baud, you are only transmitting 5,760 bits of data per second. That really is a big difference, and that is still only raw bits once it gets through the actual serial communications channel. A more typical 8 data bits, 1 Stop Bit, No Parity will be a little bit better at 9600 baud, with eight bits of data and only two bits used for overhead. That gives a total throughput of 7,680 bits per second. A little bit better, but you can't simply presume that the baud rate indicates how much data is going to be transmitted.

Relationship of Baud Rate to Maximum Distance

There is one final topic that you should keep in mind when you are doing serial communication over RS-232. There are some hard physical limits to how far serial data communication can occur over a piece of wire. When you apply a voltage onto a wire it takes some time for that voltage to go down the full length of the wire and there are other unstable conditions that happen when you send a "pulse" down the wire and change voltages too quickly. This problem is worse as wires become longer and the frequency (i.e. baud rate) increases. This distance can vary based on a number of factor, including the thickness of the wires involved, RF interference on the wires, quality of the wires during the manufacturing process, how well they were installed... e.g., are there any "kinks" in the wires that force it into a sharp bend, and finally the baud rate that you are transmitting the data.

This table presumes a fairly straight and uniform cable that is typical for most low-voltage applications (i.e., not a power circuit that uses 110V to run your refrigerator, toaster, and television). Typically something like a CAT-5 cable (also used for local networks or phone lines) should be more than sufficient for this purpose.

Baud Rate	Maximum Distance (in feet)
2400	3000
4800	1000
9600	500
19200	50

You should also be aware that there are ways to get around this limitation. There are "short haul modems" that can extend this distance to several miles of cable. There are also telephone lines, or conventional modems, and other long-distance communications techniques. I am not going to cover any details beyond simply letting you know that there are other ways to handle data in situations like this, and that those signals can be converted to simple RS-232 data formats that a typical home computer can interpret. Distance still can be a limiting factor for

communication, although when you are talking about distances like to Saturn for the Cassini mission, serial data communication has other issues involved than just data loss due to cable length. And yes, NASA/ESA is using serial data communication for transmitting those stunning images back to Earth.

External References

- TIA-574 Specification
- RS-232 wiring standards explained
- RS-232 connection types explained
- Wikipedia article on RS-232
- RS-232 standards explained by HW-Server
- Serial Pinouts (D25 and D9 Connectors) (also has more technical information about the UARTs used in PCs)
- RS232 Connections, and wiring up serial device has several diagrams, including one showing how to let one PC monitor the serial communication between 2 other RS232 devices.
- Lammert Bies, RS232 Specifications and standard Includes technical specs on RS-232 signals and more detailed information about parity checking.

8250 UART Programming

Introduction

Finally we are moving away from wires and voltages and hard-core electrical engineering applications, although we still need to know quite a bit regarding computer chip architectures at this level. While the primary focus of this section will concentrate on the 8250 UART, there are really three computer chips that we will be working with here:

- 8250 UART
- 8259 PIC (Programmable Interrupt Controller)
- 8086 CPU (Central Processing Unit)

Keep in mind that these are chip families, not simply the chip part number itself. Computer designs have evolved quite a bit over the years, and often all three chips are put onto the same piece of silicon because they are tied together so much, and to reduce overall costs of the equipment. So when I say 8086, I also mean the successor chips including the 80286, 80386, Pentium, and compatible chips made by manufacturers other than Intel. There are some subtle differences and things you need to worry about for serial data communication between the different chips other than the 8086, but in many cases you could in theory write software for the original IBM PC doing serial communication and it should run just fine on a modern computer you just bought that is running the latest version of Linux or Windows XP.

Modern operating systems handle most of the details that we will be covering here through low-level drivers, so this should be more of a quick understanding for how this works rather than something you might implement yourself, unless you are writing your own operating system. For people who are designing small embedded computer devices, it does become quite a bit more important to understand the 8250 at this level.

Just like the 8086, the 8250 has evolved quite a bit as well, e.g. into the 16550 UART. Further down I will go into how to detect many of the different UART chips on PCs, and some quirks or changes that affect each one. The differences really aren't as significant as the changes to CPU architecture, and the primary reason for updating the UART chip was to make it work with the considerably faster CPUs that are around right now. The 8250 itself simply can't keep up with a Pentium chip.

Remember as well that this is trying to build a foundation for serial programming on the software side. While this can be useful for hardware design as well, quite a bit will be missing from the descriptions here to implement a full system.

8086 I/O ports

We actually have to go back in time even further than the 8086 chips. Let's go back to the original Intel CPU, the 4004, then one step forward to the 8008, the next CPU design Intel made. FYI, all of the computer instructions, or opcodes, for the 8008 chip can still be used with the most recent Pentium II chip, so Port I/O tutorials written back 30 years ago still are valid today. The newer CPU chips just have enhanced instructions for dealing with more data simultaneously or in some cases can process data more efficiently.

When this chip was put out, Intel tried to come up with a method for having the CPU be able to communicate with outside devices. The direction they chose to go was call I/O port architecture. This means that the CPU has a special set of wires that are dedicated to communicating to external devices. In the 8008, this meant that there were a total of sixteen (16) wires that were dedicated for communicating with the chip. The exact details varied based on chip design and other factors, and they may have used a serial transmitter or multiplexed data input, but let's not get picky here. I'm going to keep this simple for now to explain the theory.

Eight of the wires represented an I/O code that signaled a specific device. This is known as the I/O port. Since this is just a binary code, it represents the potential to hook up 256 different devices to the CPU. It gets a little more complicated than that, but still you can think of it from software like a small-town post-office that has a bank of 256 P.O. boxes for its customers.

The next set of wires represent the actual data that is being exchanged. You can think of this as a postcard that is either being taken by the CPU from the P.O. boxes or being put into one.

All the external device has to do is look for its I/O code, and then when it matches what it is "assigned" to look for, it has control over the I/O port. An additional wire signals if the data is being sent by the CPU, or if the CPU wants the device to send a piece of data to the CPU. For those familiar with setting up early PC's, this is also where I/O conflicts happen: when two or more devices try to access the same I/O port at the same time. This was a source of heartburn on those early systems, particularly when adding new equipment.

Just in case you are wondering, this is very similar to how conventional RAM also works, and some CPU designs simply do this whole process straight in RAM as well, reserving a block of memory for I/O control. This has some problems, including the fact that it chews up a portion of potential memory that could be used for software instead. It ends up that with the IBM PC and later PC systems, both I/O methods are used extensively, so it really gets complicated. For serial communication, however, we are going to stick with the port I/O method, as that is how the 8250 chip works.

Software I/O access

When you get down to actually using this in your software, the assembly language instruction to send or receive data to port 9 looks something like this:

```
out 9, ah ; sending data from register ah out to port 9
in 9, ah ; getting data from port 9 and putting it in register ah
```

When programing in higher level languages, it gets a bit simpler. A typical C language Port I/O library is usually written like this:

```
char test;

test = 255;
outp(9,test);
inp(9,*test);
```

For many versions of Pascal, it treats the I/O ports like a massive array that you can access, that is simply named Port:

```
procedure PortIO(var Test: Byte);
begin
  Port[9] := Test;
  Test := Port[9];
end;
```

Warning!! And this really is a warning. By randomly accessing I/O ports in your computer without really knowing what it is connected to can really mess up your computer. At the minimum, it will crash the operating system and cause the computer to not work. Writing to some I/O ports can permanently change the internal configuration of your computer, making a trip to the repair shop necessary just to undo the damage you've done through software. Worse yet, in some cases it can cause actual damage to the computer. This means that some chips inside the computer will no longer work and those components would have to be replaced in order for the computer to work again. Damaged chips are an indication of lousy engineering on the part of the computer, but unfortunately it does happen and you should be aware of it.

Don't be afraid to use the I/O ports, just make sure you know what you are writing to, and you know what equipment is "mapped" to for each I/O port if you intend to use a particular I/O port. We will get into more of the specifics for how to identify the I/O ports for serial communication in a bit. Finally we are starting to write a little bit of software, and there is more to come.

x86 port I/O extensions

There are a few differences between the 8008 CPU and the 8086. The most notable that affects software development is that instead of just 256 port I/O addresses, the 8086 can access 65536 different I/O ports. In addition, besides

simply sending a single character in or out, the 8086 will let you send and receive 16 bits at once. The Pentium chips will even let you send and receive 32-bits simultaneously. The need for more than 65536 different I/O ports has never been a serious problem, and if a device needed a larger piece of memory, the Direct Memory Access (DMA) methods are available. This is where the device writes and reads the RAM of the computer directly instead of going through the CPU. We will not cover that topic here.

Also, while the 8086 CPU was able to address 65536 different I/O ports, in actual practice it didn't. The chip designers at Intel got cheap and only had address lines for 10 bits, which has implications for software designers having to work with legacy systems. This also meant that I/O port address $1E8 and $19E8 (and others... this is just an example) would resolve to the same I/O port for those early PCs. The Pentium CPUs don't have this limitation, but software written for some of that early hardware sometimes wrote to I/O port addresses that were "aliased" because those upper bits were ignored. There are other legacy issues that show up, but fortunately for the 8250 chip and serial communications in general this isn't a concern, unless you happen to have a serial driver that "took advantage" of this aliasing situation. This issue would generally only show up when you are using more than the typical 2 or 4 serial COM ports on a PC.

x86 Processor Interrupts

The 8086 CPU and compatible chips have what is known as an interrupt line. This is literally a wire to the rest of the computer that can be turned on to let the CPU know that it is time to stop whatever it is doing and pay attention to some I/O situations.

Within the 8086, there are two kinds of interrupts: Hardware interrupts and Software interrupts. There are some interesting quirks that are different from each kind, but from a software perspective they are essentially the same thing. The 8086 CPU allows for 256 interrupts, but the number available for equipment to perform a Hardware interrupt is considerably restricted.

IRQs Explained

Hardware interrupts are numbered IRQ 0 through IRQ 15. IRQ means Interrupt Request. There are a total of fifteen different hardware interrupts. Before you think I don't know how to count or do math, we need to do a little bit of a history lesson here, which we will finish when we move on to the 8259 chip. When the original IBM-PC was built, it only had eight IRQs, labeled IRQ 0 through IRQ 7. At the time it was felt that was sufficient for almost everything that would ever be put on a PC, but very soon it became apparent it wasn't nearly enough for everything that was being added. When the IBM-PC/AT was made (the first one with the 80286 CPU, and a number of enhancements that are commonly found

on PCs today), it was decided that instead of a single 8259 chip, they would use two of these same chips, and "chain" them to one another in order to expand the number of interrupts from 8 to 15. One IRQ had to be sacrificed in order to accomplish this task, and that was IRQ 2.

The point here is that if a device wants to notify the CPU that it has some data ready for the CPU, it sends a signal that it wants to stop whatever software is currently running on the computer and instead run a special "little" program called an interrupt handler. Once the interrupt handler is finished, the computer can go back to whatever it was doing before. If the interrupt handler is fast enough, you wouldn't even notice that the handler has even been used.

In fact, if you are reading this text on a PC, in the time that it takes for you to read this sentence several interrupt handlers have already been used by your computer. Every time that you use a keyboard or a mouse, or receive some data over the internet, an interrupt handler has been used at some point in your computer to retrieve that information.

Interrupt handlers

We will be getting into specific details of interrupt handlers in a little bit, but now I want to explain just what they are. Interrupt handlers are a method of showing the CPU exactly what piece of software should be running when the interrupt is triggered.

The 8086 CPU has a portion of RAM that has been established that "points" to where the interrupt software is located elsewhere in RAM. The advantage of going this route is that the CPU only has to do a simple look-up to find just where the software is, and then transfers software execution to that point in RAM. This also allows you as a programmer to change where the CPU is "pointing" to in RAM, and instead of going to something in the operating system, you can customize the interrupt handler and put something else there yourself.

How this is best done depends largely on your operating system. For a simple operating system like MS-DOS, it actually encourages you to directly write these interrupt handlers, particularly when you are working with external peripherals. Other operating systems like Linux or MS-Windows use the approach of having a "driver" that hooks into these interrupt handlers or service routines, and then the application software deals with the drivers rather than dealing directly with the equipment. How a program actually does this is very dependent on the specific operating system you would be using. If you are instead trying to write your own operating system, you would have to write these interrupt handlers directly, and establish the protocol on how you access these handlers to send and retrieve data.

Software interrupts

Before we move on, I want to hit very briefly on software interrupts. Software interrupts are invoked with the 8086 assembly instruction "int", as in:

int $21

From the perspective of a software application, this is really just another way to call a subroutine, but with a twist. The "software" that is running in the interrupt handler doesn't have to be from the same application, or even made from the same compiler. Indeed, often these subroutines are written directly in assembly language. In the above example, this interrupt actually calls a "DOS" subroutine that will allow you to perform some sort of I/O access that is directly related to DOS. Depending on the values of the registers, usually the AX register in the 8086 in this case, it can determine just what information you want to get from DOS, such as the current time, date, disk size, and just about everything that normally you would associate with DOS. Compilers often hide these details, because setting up these interrupt routines can be a little tricky.

Now to really make a mess of things. "Hardware interrupts" can also be called from "software interrupts", and indeed this is a reasonable way to make sure you have written your software correctly. The difference here is that software interrupts will only be invoked, or have their portion of software code running in the CPU, if it has been explicitly called through this assembly opcode.

8259 PIC (Programmable Interrupt Controller)

The 8259 chip is the "heart" of the whole process of doing a hardware interrupt. External devices are directly connected to this chip, or in the case of the PC-AT compatibles (most likely what you are most familiar with for a modern PC) it will have two of these devices that are connected together. Literally fifteen wires come into this pair of chips, each wire labeled IRQ-0 through IRQ-15.

The purpose of these chips is to help "prioritize" the interrupt signals and organize them in some orderly fashion. There is no way to predict when a certain device is going to "request" an interrupt, so often multiple devices can be competing for attention from the CPU.

Generally speaking, the lower numbered IRQ gets priority. In other words, if both IRQ-1 and IRQ-4 are requesting attention at the same time, IRQ-1 gets priority and will be triggered first as far as the CPU is concerned. IRQ-4 has to wait until after IRQ-1 has completed its "Interrupt Service Routine" or ISR.

If the opposite happens however, with IRQ-4 doing its ISR (remember, this is software, just like any computer program you might normally write as a computer application), IRQ-1 will "interrupt" the ISR for IRQ-4 and push through its own ISR to be run instead, returning to the IRQ-4 ISR when it has finished. There are exceptions to this as well, but let's keep things simple at the moment.

Let's return for a minute to the original IBM-PC. When it was built, there was only one 8259 chip on the motherboard. When the IBM-AT came out the engineers at IBM decided to add a second 8259 chip to add some additional IRQ signals. Since there was still only 1 pin on the CPU (at this point the 80286) that could receive notification of an interrupt, it was decided to grab IRQ-2 from the original 8259 chip and use that to chain onto the next chip. IRQ-2 was re-routed to IRQ-10 as far as any devices that depended on IRQ-2. The nice thing about going with this scheme was that software that planned on something using IRQ-2 would still be "notified" when that device was used, even though seven other devices were now "sharing" this interrupt. These are IRQ-8 through IRQ-15.

What this means in terms of priorities, however, is that IRQ-8 through IRQ-15 have a higher priority than IRQ-3. This is mainly of concern when you are trying to sort out which device can take precedence over another, and how important it would be to notified when a piece of equipment is trying to get your attention. If you are dealing with software running a specific computer configuration, this priority level is very important.

It should be noted here that COM1 (serial communication channel one) usually uses IRQ-4, and COM2 uses IRQ-3, which has the net effect of making COM2 to be a higher priority for receiving data over COM1. Usually the software really doesn't care, but on some rare occasions you really need to know this fact.

8259 Registers

The 8259 has several "registers" that are associated with I/O port addresses. We will visit this concept a little bit more when we get to the 8250 chip. For a typical PC Computer system, the following are typical primary port addresses associated with the 8259:

Interrupt Controller Port I/O Addresses

Register Name	I/O Port
Master Interrupt Controller	$0020
Slave Interrupt Controller	$00A0

This primary port address is what we will use to directly communicate with the 8259 chip in our software. There are a number of commands that can be sent to this chip through these I/O port addresses, but for our purposes we really don't need to deal with them. Most of these are used to do the initial setup and configuration of the computer equipment by the Basic Input Output System (BIOS) of the computer, and unless you are rewriting the BIOS from scratch, you really don't have to worry about this. Also, each computer is a little different in its behavior when you are dealing with equipment at this level, so this is something more for a computer manufacturer to worry about rather than something an application programmer should have to deal with, which is exactly why BIOS

software is written at all.

Keep in mind that this is the "typical" Port I/O address for most PC-compatable type computer systems, and can vary depending on what the manufacturer is trying to accomplish. Generally you don't have to worry about incompatibility at this level, but when we get to Port I/O addresses for the serial ports this will become a much larger issue.

Device Registers

I'm going to spend a little time here to explain the meaning of the word register. When you are working with equipment at this level, the electrical engineers who designed the equipment refer to registers that change the configuration of the equipment. This can happen at several levels of abstraction, so I want to clear up some of the confusion.

A register is simply a small piece of RAM that is available for a device to directly manipulate. In a CPU like the 8086 or a Pentium, these are the memory areas that are used to directly perform mathematical operations like adding two numbers together. These usually go by names like AX, SP, etc. There are very few registers on a typical CPU because access to these registers are encoded directly into the basic machine-level instructions.

When we are talking about device register, keep in mind these are not the CPU registers, but instead memory areas on the devices themselves. These are often designed so they are connected to the Port I/O memory, so when you write to or read from the Port I/O addresses, you are directly accessing the device registers. Sometimes there will be a further level of abstraction, where you will have one Port I/O address that will indicate which register you are changing, and another Port I/O address that has the data you are sending to that register. How you deal with the device is based on how complex it is and what you are going to be doing.

In a real sense, they are registers, but keep in mind that often each of these devices can be considered a full computer in its own right, and all you are doing is establishing how it will be communicating with the main CPU. Don't get hung up here and get these confused with the CPU registers.

ISR Cleanup

One area that you have to interact on a regular basis when using interrupt controllers is to inform the 8259 PIC controller that the interrupt service routine is completed. When your software is performing an interrupt handler, there is no automated method for the CPU to signal to the 8259 chip that you have finished, so a specific "register" in the PIC needs to be set to let the next interrupt handler be able to access the computer system. Typical software to accomplish this is like the following:

```
Port[$20] := $20;
```

This is sending the command called "End of Interrupt" or often written as an abbreviation simply "EOI". There are other commands that can be sent to this register, but for our purposes this is the only one that we need to concern ourselves with.

Now this will clear the "master" PIC, but if you are using a device that is triggered on the "slave" PIC, you also need to inform that chip as well that the interrupt service has been completed. This means you need to send "EOI" to that chip as well in a manner like this:

```
Port[$A0] := $20;
Port[$20] := $20;
```

There are other things you can do to make your computer system work smoothly, but let's keep things simple for now.

PIC Device Masking

Before we leave the subject of the 8259 PIC, I'd like to cover the concept of device masking. Each one of the devices that are attached to the PIC can be "turned on" or "turned off" from the viewpoint of how they can interrupt the CPU through the PIC chip. Usually as an application developer all we really care about is if the device is turned on, although if you are trying to isolate performance issues you might turn off some other devices. Keep in mind that if you turn a device "off", the interrupt will not work until it is turned back on. That can include the keyboard or other critical devices you may need to operate your computer.

The register to set this mask is called "Operation Control Word 1" or "OCW1". This is located at the PIC base address + 1, or for the "Master" PIC at Port I/O Address $21. This is where you need to go over bit manipulation, which I won't cover in detail here. The following tables show the related bits to change in order to enable or disable each of the hardware interrupt devices:

Master OCW1 ($21)

Bit	IRQ Enabled	Device Function
7	IRQ7	Parallel Port (LPT1)
6	IRQ6	Floppy Disk Controller
5	IRQ5	Reserved/Sound Card
4	IRQ4	Serial Port (COM1)
3	IRQ3	Serial Port (COM2)
2	IRQ2	Slave PIC
1	IRQ1	Keyboard
0	IRQ0	System Timer

Slave OCW1 ($A1)

Bit	IRQ Enabled	Device Function
7	IRQ15	Reserved
6	IRQ14	Hard Disk Drive
5	IRQ13	Math Co-Processor
4	IRQ12	PS/2 Mouse
3	IRQ11	PCI Devices
2	IRQ10	PCI Devices
1	IRQ9	Redirected IRQ2 Devices
0	IRQ8	Real Time Clock

Assuming that we want to turn on IRQ3 (typical for the serial port COM2), we would use the following software:

```
Port[$21] := Port[$21] and $F7; {Clearing bit 3 for enabling IRQ3}
```

And to turn it off we would use the following software:

```
Port[$21] := Port[$21] or $08; {Setting bit 3 for disabling IRQ3}
```

If you are having problems getting anything to work, you can simply send this command in your software:

```
Port[$21] := 0;
```

which will simply enable everything. This may not be a good thing to do, but will have to be something for you to experiment with depending on what you are working with. Try not to take short cuts like this as not only is it a sign of a lazy

programmer, but it can have side effects that your computer may behave different than you intended. If you are working with the computer at this level, the goal is to change as little as possible so you don't cause damage to any other software you are using.

Serial COM Port Memory and I/O Allocation

Now that we have pushed through the 8259 chip, lets move on to the UART itself. While the Port I/O addresses for the PICs are fairly standard, it is common for computer manufacturers to move stuff around for the serial ports themselves. Also, if you have serial port devices that are part of an add-in card (like an ISA or PCI card in the expansion slots of your computer), these will usually have different settings than something built into the main motherboard of your computer. It may take some time to hunt down these settings, and it is important to know what these values are when you are trying to write your software. Often these values can be found in the BIOS setup screens of your computer, or if you can pause the messages when your computer turns on, they can be found as a part of the boot process of your computer.

For a "typical" PC system, the following are the Port I/O addresses and IRQs for each serial COM port:

Common UART IRQ and I/O Port Addresses

COM Port	IRQ	Base Port I/O address
COM1	IRQ4	$3F8
COM2	IRQ3	$2F8
COM3	IRQ4	$3E8
COM4	IRQ3	$2E8

If you notice something interesting here, you can see that COM3 and COM1 share the same interrupt. This is not a mistake but something you need to keep in mind when you are writing an interrupt service routine. The 15 interrupts that were made available through the 8259 PIC chips still have not been enough to allow all of the devices that are found on a modern computer to have their own separate hardware interrupt, so in this case you will need to learn how to share the interrupt with other devices. I'll cover more of that later when we get into the actual software to access the serial data ports, but for now remember not to write your software strictly for one device.

The Base Port I/O address is important for the next topic we will cover, which is directly accessing the UART registers.

UART Registers

The UART chip has a total of 12 different registers that are mapped into 8 different Port I/O locations. Yes, you read that correct, 12 registers in 8 locations. Obviously that means there is more than one register that uses the same Port I/O location, and affects how the UART can be configured. In reality, two of the registers are really the same one but in a different context, as the Port I/O address that you transmit the characters to be sent out of the serial data port is the same address that you can read in the characters that are sent to the computer. Another I/O port address has a different context when you write data to it than when you read data from it... and the number will be different after writing the data to it than when you read data from it. More on that in a little bit.

One of the issues that came up when this chip was originally being designed was that the designer needed to be able to send information about the baud rate of the serial data with 16 bits. This actually takes up two different "registers" and is toggled by what is called the "Divisor Latch Access Bit" or "DLAB". When the DLAB is set to "1", the baud rate registers can be set and when it is "0" the registers have a different context.

Does all this sound confusing? It can be, but lets take it one simple little piece at a time. The following is a table of each of the registers that can be found in a typical UART chip:

UART Registers

Base Address	DLAB	I/O Access	Abbrv.	Register Name
+0	0	Write	THR	Transmitter Holding Buffer
+0	0	Read	RBR	Receiver Buffer
+0	1	Read/Write	DLL	Divisor Latch Low Byte
+1	0	Read/Write	IER	Interrupt Enable Register
+1	1	Read/Write	DLM	Divisor Latch High Byte
+2	x	Read	IIR	Interrupt Identification Register
+2	x	Write	FCR	FIFO Control Register
+3	x	Read/Write	LCR	Line Control Register
+4	x	Read/Write	MCR	Modem Control Register
+5	x	Read	LSR	Line Status Register
+6	x	Read	MSR	Modem Status Register
+7	x	Read/Write	SR	Scratch Register

The "x" in the DLAB column means that the status of the DLAB has no effect on what register is going to be accessed for that offset range. Notice also that some

registers are Read only. If you attempt to write data to them, you may end up with either some problems with the modem (worst case), or the data will simply be ignored (typically the result). As mentioned earlier, some registers share a Port I/O address where one register will be used when you write data to it and another register will be used to retrieve data from the same address.

Each serial communication port will have its own set of these registers. For example, if you wanted to access the Line Status Register (LSR) for COM1, and assuming the base I/O Port address of $3F8, the I/O Port address to get the information in this register would be found at $3F8 + $05 or $3FD. Some example code would be like this:

```
const
  COM1_Base = $3F8;
  COM2_Base = $2F8;
  LSR_Offset = $05;

function LSR_Value: Byte;
begin
  Result := Port[COM1_Base+LSR_Offset];
end;
```

There is quite a bit of information packed into each of these registers, and the following is an explanation for the meaning of each register and the information it contains.

Transmitter Holding Buffer/Receiver Buffer

The Transmit and Receive buffers are related, and often even use the very same memory. This is also one of the areas where later versions of the 8250 chip have a significant impact, as the later models incorporate some internal buffering of the data within the chip before it gets transmitted as serial data. The base 8250 chip can only receive one byte at a time, while later chips like the 16550 chip will hold up to 16 bytes either to transmit or to receive (sometimes both... depending on the manufacturer) before you have to wait for the character to be sent. This can be useful in multi-tasking environments where you have a computer doing many things, and it may be a couple of milliseconds before you get back to dealing with serial data flow.

These registers really are the "heart" of serial data communication, and how data is transferred from your software to another computer and how it gets data from other devices. Reading and Writing to these registers is simply a matter of accessing the Port I/O address for the respective UART.

Divisor Latch Bytes

The Divisor Latch Bytes are what control the baud rate of the modem. As you might guess from the name of this register, it is used as a divisor to determine what baud rate that the chip is going to be transmitting at.

In reality, it is even simpler than that. This is really a count-down clock that is used each time a bit is transmitted by the UART. Each time a bit is sent, a count-down register is reset to this value and then counts down to zero. This clock is running typically at 115.2 KHz. In other words, at 115 thousand times per second a counter is going down to determine when to send the next bit. At one time during the design process it was anticipated that some other frequencies might be used to get a UART working, but with the large amount of software already written for this chip this frequency is pretty much standard for almost all UART chips used on a PC platform. They may use a faster clock in some portion (like a 1.843 MHz clock), but some fraction of that will then be used to scale down to a 115.2 KHz clock.

Some more on UART clock speeds (advanced coverage): For many UART chips, the clock frequency that is driving the UART is 1.8432 MHz. This frequency is then put through a divider circuit that drops the frequency down by a factor of 16, giving us the 115.2 KHz frequency mentioned above. If you are doing some custom equipment using this chip, the National Semiconductor spec sheets allow for a 3.072 MHz clock and 18.432 MHz clock. These higher frequencies will allow you to communicate at higher baud rates, but require custom circuits on the motherboard and often new drivers in order to deal with these new frequencies. What is interesting is that you can still operate at 50 baud with these higher clock frequencies, but at the time the original IBM-PC/XT was manufactured this wasn't a big concern as it is now for higher data throughput.

If you use the following mathematical formula, you can determine what numbers you need to put into the Divisor Latch Bytes:

$$DivisorLatchValue = \frac{115200}{BaudRate}$$

That gives you the following table that can be used to determine common baud rates for serial communication:

Divisor Latch Byte Values (common baud rates)

Baud Rate	Divisor (in decimal)	Divisor Latch High Byte	Divisor Latch Low Byte
50	2304	$09	$00
110	1047	$04	$17
220	524	$02	$0C
300	384	$01	$80
600	192	$00	$C0
1200	96	$00	$60
2400	48	$00	$30
4800	24	$00	$18
9600	12	$00	$0C
19200	6	$00	$06
38400	3	$00	$03
57600	2	$00	$02
115200	1	$00	$01

One thing to keep in mind when looking at the table is that baud rates 600 and above all set the Divisor Latch High Byte to zero. A sloppy programmer might try to skip setting the high byte, assuming that nobody would deal with such low baud rates, but this is not something to always presume. Good programming habits suggest you should still try to set this to zero even if all you are doing is running at higher baud rates.

Another thing to notice is that there are other potential baud rates other than the standard ones listed above. While this is not encouraged for a typical application, it would be something fun to experiment with. Also, you can attempt to communicate with older equipment in this fashion where a standard API library might not allow a specific baud rate that should be compatible. This should demonstrate why knowledge of these chips at this level is still very useful.

When working with these registers, also remember that these are the only ones that require the Divisor Latch Access Bit to be set to "1". More on that below, but I'd like to mention that it would be useful for application software setting the baud rate to set the DLAB to "1" just for the immediate operation of changing the baud rate, then putting it back to "0" as the very next step before you do any more I/O access to the modem. This is just a good working habit, and keeps the rest of the software you need to write for accessing the UART much cleaner and easier.

One word of caution: Do not set the value "0" for both Divisor Latch bytes. While it will not (likely) damage the UART chip, the behavior on how the UART will be

transmitting serial data will be unpredictable, and will change from one computer to the next, or even from one time you boot the computer to the next. This is an error condition, and if you are writing software that works with baud rate settings on this level you should catch potential "0" values for the Divisor Latch.

Here is some sample software to set and retrieve the baud rate for COM1:

```
const
  COM1_Base = $3F8;
  COM2_Base = $2F8;
  LCR_Offset = $03;
  Latch_Low = $00;
  Latch_High = $01;

procedure SetBaudRate(NewRate: Word);
var
  DivisorLatch: Word;
begin
  DivisorLatch := 115200 div NewRate;
  Port[COM1_Base + LCR_Offset] := Port[COM1_Base + LCR_Offset] or $80; {Set DLAB}
  Port[COM1_Base + Latch_High] := DivisorLatch shr 8;
  Port[COM1_Base + Latch_Low] := DivisorLatch and $FF;
  Port[COM1_Base + LCR_Offset] := Port[COM1_Base + LCR_Offset] and $7F; {Clear DLAB}
end;
```

```
function GetBaudRate: Integer;
var
  DivisorLatch: Word;
begin
  Port[COM1_Base + LCR_Offset] := Port[COM1_Base + LCR_Offset] or $80; {Set DLAB}
  DivisorLatch := (Port[COM1_Base + Latch_High] shl 8) + Port[COM1_Base + Latch_Low];
  Port[COM1_Base + LCR_Offset] := Port[COM1_Base + LCR_Offset] and $7F; {Clear DLAB}
  Result := 115200 div DivisorLatch;
end;
```

Interrupt Enable Register

This register allows you to control when and how the UART is going to trigger an interrupt event with the hardware interrupt associated with the serial COM port. If used properly, this can enable an efficient use of system resources and allow you to react to information being sent across a serial data line in essentially real-time conditions. Some more on that will be covered later, but the point here is that you can use the UART to let you know exactly when you need to extract some data. This register has both read and write access.

The following is a table showing each bit in this register and what events that it will enable to allow you check on the status of this chip:

Interrupt Enable Register (IER)

Bit	Notes
7	Reserved
6	Reserved
5	Enables Low Power Mode (16750)
4	Enables Sleep Mode (16750)
3	Enable Modem Status Interrupt
2	Enable Receiver Line Status Interrupt
1	Enable Transmitter Holding Register Empty Interrupt
0	Enable Received Data Available Interrupt

The Received Data interrupt is a way to let you know that there is some data waiting for you to pull off of the UART. This is probably the one bit that you will use more than the rest, and has more use.

The Transmitter Holding Register Empty Interrupt is to let you know that the output buffer (on more advanced models of the chip like the 16550) has finished sending everything that you pushed into the buffer. This is a way to streamline the data transmission routines so they take up less CPU time.

The Receiver Line Status Interrupt indicates that something in the LSR register has probably changed. This is usually an error condition, and if you are going to

write an efficient error handler for the UART that will give plain text descriptions to the end user of your application, this is something you should consider. Certainly something that takes a bit more advanced knowledge of programming.

The Modem Status Interrupt is to notify you when something changes with an external modem connected to your computer. This can include things like the telephone "bell" ringing (you can simulate this in your software), that you have successfully connected to another modem (Carrier Detect has been turned on), or that somebody has "hung up" the telephone (Carrier Detect has turned off). It can also help you to know if the external modem or data equipment can continue to receive data (Clear to Send). Essentially this deals with the other wires in the RS-232 standard other than strictly the transmit and receive wires.

The other two modes are strictly for the 16750 chip, and help put the chip into a "low power" state for use on things like a laptop computer or an embedded controller that has a very limited power source like a battery. On earlier chips you should treat these bits as "Reserved", and only put a "0" into them.

Interrupt Identification Register

This register is to be used to help identify what the unique characteristics of the UART chip that you are using has. This chip has two uses:

- Identification of why the UART triggered an interrupt.
- Identification of the UART chip itself.

Of these, identification of why the interrupt service routine has been invoked is perhaps the most important.

The following table explains some of the details of this register, and what each bit on it represents:

Interrupt Identification Register (IIR)

Bit	Notes				
7 and 6	**Bit 6**	**Bit 7**			
	0	0	No FIFO on chip		
	0	1	FIFO enabled, but not functioning		
	1	0	Reserved condition		
	1	1	FIFO enabled		
5	64 Byte FIFO Enabled (16750 only)				
4	Reserved				
3, 2 and 1	**Bit 3**	**Bit 2**	**Bit 1**		**Reset Method**
	0	0	0	Modem Status Interrupt	Reading Modem Status Register(MSR)
	0	0	1	Transmitter Holding Register Empty Interrupt	Reading Interrupt Identification Register(IIR) or Writing to Transmit Holding Buffer(THR)
	0	1	0	Received Data Available Interrupt	Reading Receive Buffer Register(RBR)
	0	1	1	Receiver Line Status Interrupt	Reading Line Status Register (LSR)
	1	0	0	Reserved	N/A
	1	0	1	Reserved	N/A
	1	1	0	Time-out Interrupt Pending (16550 & later)	Reading Receive Buffer Register(RBR)
	1	1	1	Reserved	N/A
0	Interrupt Pending Flag				

When you are writing an interrupt handler for the 8250 chip (and later), this is the register that you need to look at in order to determine what exactly was the trigger for the interrupt.

As explained earlier, multiple serial communication devices can share the same hardware interrupt. The use of "Bit 0" of this register will let you know (or confirm) that this was indeed the device that caused the interrupt. What you need to do is check on all serial devices (that are in separate port I/O address spaces), and get the contents of this register. Keep in mind that it is at least possible for more than one device to trigger an interrupt at the same time, so when you are doing

this scanning of serial devices, make sure you examine all of them, even one of the first devices did in fact need to be processed. Some computer systems may not require this to occur, but this is a good programming practice anyway. It is also possible that due to how you processed the UARTs earlier, that you have already dealt with all of the UARTs for a given interrupt. When this bit is a "0", it identifies that the UART is triggering an interrupt. When it is "1", that means the interrupt has already been processed or this particular UART was not the triggering device. I know that this seems a little bit backward for a typical bit-flag used in computers, but this is called digital logic being asserted low, and is fairly common with electrical circuit design. This is a bit more unusual through for this logic pattern to go into the software domain.

Bits 1, 2 & 3 help to identify exactly what sort of interrupt event was used within the UART to invoke the hardware interrupt. These are the same interrupts that were earlier enabled with the IER register. In this case, however, each time you process the registers and deal with the interrupt it will be unique. If multiple "triggers" occur for the UART due to many things happening at the same time, this will be invoked through multiple hardware interrupts. Earlier chip sets don't use bit 3, but this is a reserved bit on those UART systems and always set to logic state "0", so programming logic doesn't have to be different when trying to decipher which interrupt has been used.

To explain the FIFO timeout Interrupt, this is a way to check for the end of a packet or if the incoming data stream has stopped. Generally the following conditions must exist for this interrupt to be triggered: Some data needs to be in the incoming FIFO and has not been read by the computer. Data transmissions being sent to the UART via serial data link must have ended with no new characters being received. The CPU processing incoming data must not have retrieved any data from the FIFO before the timeout has occurred. The timeout will occur usually after the period it would take to transmit or receive at least 4 characters. If you are talking about data sent at 1200 baud, 8 data bits, 2 stop bits, odd parity, that would take about 40 milliseconds, which is almost an eternity in terms of things that your computer can accomplish on a 4 GHz Pentium CPU.

The "Reset Method" listed above describes how the UART is notified that a given interrupt has been processed. When you access the register mentioned under the reset method, this will clear the interrupt condition for that UART. If multiple interrupts for the same UART have been triggered, either it won't clear the interrupt signal on the CPU (triggering a new hardware interrupt when you are done), or if you check back to this register (IIR) and query the Interrupt Pending Flag to see if there are more interrupts to process, you can move on and attempt to resolve any new interrupt issue that you may have to deal with, using appropriate application code.

Bits 5, 6 & 7 are reporting the current status of FIFO buffers being used for transmitting and receiving characters. There was a bug in the original 16550 chip design when it was first released that had a serious flaw in the FIFO, causing the

FIFO to report that it was working but in fact it wasn't. Because some software had already been written to work with the FIFO, this bit (Bit 7 of this register) was kept, but Bit 6 was added to confirm that the FIFO was in fact working correctly, in case some new software wanted to ignore the hardware FIFO on the earlier versions of the 16550 chip. This pattern has been kept on future versions of this chip as well. On the 16750 chip an added 64-byte FIFO has been implemented, and Bit 5 is used to designate the presence of this extended buffer. These FIFO buffers can be turned on and off using registers listed below.

FIFO Control Register

This is a relatively "new" register that was not a part of the original 8520 UART implementation. The purpose of this register is to control how the First In/First Out (FIFO) buffers will behave on the chip and to help you fine-tune their performance in your application. This even gives you the ability to "turn on" or "turn off" the FIFO.

Keep in mind that this is a "write only" register. Attempting to read in the contents will only give you the Interrupt Identification Register (IIR), which has a totally different context.

FIFO Control Register (FCR)

Bit	Notes			
7 & 6	**Bit 7**	**Bit 6**	**Interrupt Trigger Level (16 byte)**	**Trigger Level (64 byte)**
	0	0	1 Byte	1 Byte
	0	1	4 Bytes	16 Bytes
	1	0	8 Bytes	32 Bytes
	1	1	14 Bytes	56 Bytes
5	Enable 64 Byte FIFO (16750)			
4	Reserved			
3	DMA Mode Select			
2	Clear Transmit FIFO			
1	Clear Receive FIFO			
0	Enable FIFOs			

Writing a "0" to bit 0 will disable the FIFOs, in essence turning the UART into 8250 compatibility mode. In effect this also renders the rest of the settings in this register to become useless. If you write a "0" here it will also stop the FIFOs from sending or receiving data, so any data that is sent through the serial data port may be scrambled after this setting has been changed. It would be recommended to disable FIFOs only if you are trying to reset the serial

communication protocol and clearing any working buffers you may have in your application software. Some documentation suggests that setting this bit to "0" also clears the FIFO buffers, but I would recommend explicit buffer clearing instead using bits 1 and 2.

Bits 1 and 2 are used to clear the internal FIFO buffers. This is useful when you are first starting up an application where you might want to clear out any data that may have been "left behind" by a previous piece of software using the UART, or if you want to reset a communications connection. These bits are "automatically" reset, so if you set either of these to a logical "1" state you will not have to go and put them back to "0" later. Sending a logical "0" only tells the UART not to reset the FIFO buffers, even if other aspects of FIFO control are going to be changed.

Bit 3 is in reference to how the DMA (Direct Memory Access) takes place, primarily when you are trying to retrieve data from the FIFO. This would be useful primarily to a chip designer who is trying to directly access the serial data, and store this data in an internal buffer. There are two digital logic pins on the UART chip itself labeled RXRDY and TXRDY. If you are trying to design a computer circuit with the UART chip this may be useful or even important, but for the purposes of an application developer on a PC system it is of little use and you can safely ignore it.

Bit 5 allows the 16750 UART chip to expand the buffers from 16 bytes to 64 bytes. Not only does this affect the size of the buffer, but it also controls the size of the trigger threshold, as described next. On earlier chip types this is a reserved bit and should be kept in a logical "0" state. On the 16750 it make that UART perform more like the 16550 with only a 16 byte FIFO.

Bits 6 and 7 Describe the trigger threshold value. This is the number of characters that would be stored in the FIFO before an interrupt is triggered that will let you know data should be removed from the FIFO. If you anticipate that large amounts of data will be sent over the serial data link, you might want to increase the size of the buffer. The reason why the maximum value for the trigger is less than the size of the FIFO buffer is because it may take a little while for some software to access the UART and retrieve the data. Remember that when the FIFO is full, you will start to lose data from the FIFO, so it is important to make sure you have retrieved the data once this threshold has been reached. If you are encountering software timing problems in trying to retrieve the UART data, you might want to lower the threshold value. At the extreme end where the threshold is set to 1 byte, it will act essentially like the basic 8250, but with the added reliability that some characters may get caught in the buffer in situations where you don't have a chance to get all of them immediately.

Line Control Register

This register has two major purposes:

- Setting the Divisor Latch Access Bit (DLAB), allowing you to set the values of the Divisor Latch Bytes.
- Setting the bit patterns that will be used for both receiving and transmitting the serial data. In other words, the serial data protocol you will be using (8-1-None, 5-2-Even, etc.).

Line Control Register (LCR)

Bit	Notes			
7	Divisor Latch Access Bit			
6	Set Break Enable			
3, 4 & 5	**Bit 3**	**Bit 4**	**Bit 5**	**Parity Select**
	x	x	0	No Parity
	0	0	1	Odd Parity
	0	1	1	Even Parity
	1	0	1	Mark
	1	1	1	Space
2	0	One Stop Bit		
	1	1.5 Stop Bits or 2 Stop Bits		
0 & 1	**Bit 1**	**Bit 0**	**Word Length**	
	0	0	5 Bits	
	0	1	6 Bits	
	1	0	7 Bits	
	1	1	8 Bits	

The first two bits (Bit 0 and Bit 1) control how many data bits are sent for each data "word" that is transmitted via serial protocol. For most serial data transmission, this will be 8 bits, but you will find some of the earlier protocols and older equipment that will require fewer data bits. For example, some military encryption equipment only uses 5 data bits per serial "word", as did some TELEX equipment. Early ASCII teletype terminals only used 7 data bits, and indeed this heritage has been preserved with SMTP format that only uses 7-bit ASCII for e-mail messages. Clearly this is something that needs to be established before you are able to successfully complete message transmission using RS-232 protocol.

Bit 2 controls how many stop bits are transmitted by the UART to the receiving device. This is selectable as either one or two stop bits, with a logical "0" representing 1 stop bit and "1" representing 2 stop bits. In the case of 5 data bits, the RS-232 protocol instead sends out "1.5 stop bits". What this means is that

one serial data "word" is transmitted with only 1 stop bit, and then the next one is transmitted with 2 stop bits.

Another thing to keep in mind is that the RS-232 standard only specifies that at least one data bit cycle will be kept a logical "1" at the end of each serial data word (in other words, a complete character from start bit, data bits, parity bits, and stop bits). If you are having timing problems between the two computers but are able to in general get the character sent across one at a time, you might want to add a second stop bit instead of reducing baud rate. This adds a one-bit penalty to the transmission speed per character instead of halving the transmission speed by dropping the baud rate (usually).

Bits 3, 4, and 5 control how each serial word responds to parity information. When Bit 5 is a logical "0", this causes no parity bits to be sent out with the serial data word. Instead it moves on immediately to the stop bits, and is an admission that parity checking at this level is really useless. You might still gain a little more reliability with data transmission by including the parity bits, but there are other more reliable and practical ways that will be discussed in other chapters in this book. If you want to include parity checking, the following explains each parity method other than "none" parity:

Odd Parity
: Each bit the data portion of the serial word is added as a simple count of the number of logical "1" bits. If this is an odd number of bits, the parity bit will be transmitted as a logical "1".

Even Parity
: Like Odd Parity, the bits are added together. In this case, however, if the number of bits end up as an even number it will display as a logical "1", which is the exact opposite of odd parity.

Mark Parity
: In this case the parity bit will always be a logical "1". While this may seem a little unusual, this is put in for testing and diagnostics purposes. If you want to make sure that the software on the receiving end of the serial connection is responding correctly to a parity error, you can send a Mark or a Space parity, and send characters that don't meet what the receiving UART or device is expecting for parity. In addition for Mark Parity only, you can use this bit as an extra "stop bit". Keep in mind that RS-232 standards are expecting a logical "1" to end a serial data word, so a receiving computer will not be able to tell the difference between a "Mark" parity bit and a stop bit. In essence, you can have 3 or 2.5 stop bits through the use of this setting and by appropriate use of the stop bit portion of this register as well. This is a way to "tweak" the settings on your computer in a way that typical applications don't allow you to do, or at least gain a deeper insight into serial data settings.

Space Parity

Like the Mark parity, this makes the parity bit "sticky", so it doesn't change. In this case it puts in a logical "0" for the parity bit every time you transmit a character. There are not many practical uses for doing this other than a crude way to put in 9 data bits for each serial word, or for diagnostics purposes.

Modem Control Register

This register allows you to do "hardware" flow control, under software control. Or in a more practical manner, it allows direct manipulation of four different wires on the UART that you can set to any series of independent logical states, and be able to offer control of the modem. It should also be noted that most UARTs need Auxiliary Output 2 set to a logical "1" to enable interrupts.

Modem Control Register (MCR)

Bit	Notes
7	Reserved
6	Reserved
5	Autoflow Control Enabled (16750)
4	Loopback Mode
3	Auxiliary Output 2
2	Auxiliary Output 1
1	Request To Send
0	Data Terminal Ready

Of these outputs on a typical PC platform, only the Request to Send (RTS) and Data Terminal Ready (DTR) are actually connected to the output of the PC on the DB-9 connector. If you are fortunate to have a DB-25 serial connector (more commonly used for parallel communications on a PC platform), or if you have a custom UART on an expansion card, the auxiliary outputs might be connected to the RS-232 connection. If you are using this chip as a component on a custom circuit, this would give you some "free" extra output signals you can use in your chip design to signal anything you might want to have triggered by a TTL output, and would be under software control. There are easier ways to do this, but in this case it might save you an extra chip on your layout.

The "loopback" mode is primarily a way to test the UART to verify that the circuits are working between your main CPU and the UART. This seldom, if ever, needs to be tested by an end user, but might be useful for some initial testing of some software that uses the UART. When this is set to a logical state of "1", any character that gets put into the transmit register will immediately be found in the

receive register of the UART. Other logical signals like the RTS and DTS listed above will show up in the modem status register just as if you had put a loopback RS-232 device on the end of your serial communication port. In short, this allows you to do a loopback test using just software. Except for these diagnostics purposes and for some early development testing of software using the UART, this will never be used.

On the 16750 there is a special mode that can be invoked using the Modem Control Register. Basically this allows the UART to directly control the state of the RTS and DTS for hardware character flow control, depending on the current state of the FIFO. This behavior is also affected by the status of Bit 5 of the FIFO Control Register (FCR). While this is useful, and can change some of the logic on how you would write UART control software, the 16750 is comparatively new as a chip and not commonly found on many computer systems. If you know your computer has a 16750 UART, have fun taking advantage of this increased functionality.

Line Status Register

This register is used primarily to give you information on possible error conditions that may exist within the UART, based on the data that has been received. Keep in mind that this is a "read only" register, and any data written to this register is likely to be ignored or worse, cause different behavior in the UART. There are several uses for this information, and some information will be given below on how it can be useful for diagnosing problems with your serial data connection:

Line Status Register (LSR)

Bit	Notes
7	Error in Received FIFO
6	Empty Data Holding Registers
5	Empty Transmitter Holding Register
4	Break Interrupt
3	Framing Error
2	Parity Error
1	Overrun Error
0	Data Ready

Bit 7 refers to errors that are with characters in the FIFO. If any character that is currently in the FIFO has had one of the other error messages listed here (like a framing error, parity error, etc.), this is reminding you that the FIFO needs to be cleared as the character data in the FIFO is unreliable and has one or more errors. On UART chips without a FIFO this is a reserved bit field.

Bits 5 and 6 refers to the condition of the character transmitter circuits and can help you to identify if the UART is ready to accept another character. Bit 6 is set to a logical "1" if all characters have been transmitted (including the FIFO, if active), and the "shift register" is done transmitting as well. This shift register is an internal memory block within the UART that grabs data from the Transmitter Holding Buffer (THB) or the FIFO and is the circuitry that does the actual transformation of the data to a serial format, sending out one bit of the data at a time and "shifting" the contents of the shift register down one bit to get the value of the next bit. Bit 5 merely tells you that the UART is capable of receiving more characters, including into the FIFO for transmitting.

The Break Interrupt (Bit 4) gets to a logical state of "1" when the serial data input line has not received any new bits for a period of time that is at least as long as an entire serial data "word", including the start bit, data bits, parity bit, and stop bits, for the given baud rate in the Divisor Latch Bytes. Usually this means that the device that is sending serial data to your computer has stopped for some reason. Often with serial communications this is a normal condition, but in this way you have a way to monitor just how the other device is functioning.

Framing errors (Bit 3) occur when the last bit is not a stop bit. Or to be more precise the stop bit is a logical "0". There are several causes for this, including that you have the timing between the two computer mismatched. This is usually caused by a mismatch in baud rate, although other causes might be involved as well, including problems in the physical cabling between the devices or that the cable is too long. You may even have the number of data bits off, so when errors like this are encountered, check the serial data protocol very closely to make sure that all of the settings for the UART (data bit length, parity, and stop bit count) are what should be expected.

Parity errors (Bit 2) can also indicate a mismatched baud rate like the framing errors (particularly if both errors are occurring at the same time). This bit is raised when the parity algorithm that is expected (odd, even, mark, or space) has not been found. If you are using "no parity" in the setup of the UART, this bit should always be a logical "0". When framing errors are not occurring, this is a way to identify that there are some problems with the cabling, although there are other issues you may have to deal with as well.

Overrun errors (Bit 1) is a sign of poor programming or an operating system that is not giving you proper access to the UART. This error condition occurs when there is a character waiting to be read, and the incoming shift register is attempting to move the contents of the next character into the Receiver Buffer (RBR). On UARTs with a FIFO, this also indicates that the FIFO is full as well.

Some things you can do to help get rid of this error including looking at how efficient your software is that is accessing the UART, particularly the part that is monitoring and reading incoming data. On multi-tasking operating systems, you might want to make sure that the portion of the software that reads incoming data is on a separate thread, and that the thread priority is high or time-critical,

as this is a very important operation for software that uses serial communications data. A good software practice for applications also includes adding in an application specific "buffer" that is done through software, giving your application more opportunity to be able to deal with the incoming data as necessary, and away from the time critical subroutines needed to get the data off of the UART. This buffer can be as small as 1KB to as large as 1MB, and depends substantially on the kind of data that you are working with. There are other more exotic buffering techniques as well that apply to the realm of application development, and that will be covered in later modules.

If you are working with simpler operating systems like MS-DOS or a real-time operating system, there is a distinction between a poll-driven access to the UART vs. interrupt driven software. Writing an interrupt driver is much more efficient, and there will be a whole section of this book that will go into details of how to write software for UART access.

Finally, when you can't seem to solve the problems of trying to prevent overrun errors from showing up, you might want to think about reducing the baud rate for the serial transmission. This is not always an option, and really should be the option of last choice when trying to resolve this issue in your software. As a quick test to simply verify that the fundamental algorithms are working, you can start with a slower baud rate and gradually go to higher speeds, but that should only be done during the initial development of the software, and not something that gets released to a customer or placed as publicly distributed software.

The Data Ready Bit (Bit 0) is really the most simple part here. This is a way to simply inform you that there is data available for your software to extract from the UART. When this bit is a logical "1", it is time to read the Receiver Buffer (RBR). On UARTs with a FIFO that is active, this bit will remain in a logical "1" state until you have read all of the contents of the FIFO.

Modem Status Register

This register is another read-only register that is here to inform your software about the current status of the modem. The modem accessed in this manner can either be an external modem, or an internal modem that uses a UART as an interface to the computer.

Modem Status Register (MSR)

Bit	Notes
7	Carrier Detect
6	Ring Indicator
5	Data Set Ready
4	Clear To Send
3	Delta Data Carrier Detect
2	Trailing Edge Ring Indicator
1	Delta Data Set Ready
0	Delta Clear To Send

Bits 7 and 6 are directly related to modem activity. Carrier Detect will stay in a logical state of "1" while the modem is "connect" to another modem. When this goes to a logical state of "0", you can assume that the phone connection has been lost. The Ring Indicator bit is directly tied to the RS-232 wire also labeled "RI" or Ring Indicator. Usually this bit goes to a logical state of "1" as a result of the "ring voltage" on the telephone line is detected, like when a conventional telephone will be ringing to inform you that somebody is trying to call you.

When we get to the section of AT modem commands, there will be other methods that can be shown to inform you about this and other information regarding the status of a modem, and instead this information will be sent as characters in the normal serial data stream instead of special wires. In truth, these extra bits are pretty worthless, but have been a part of the specification from the beginning and comparatively easy for UART designers to implement. It may, however, be a way to efficiently send some additional information or allow a software designer using the UART to get some logical bit signals from other devices for other purposes.

The "Data Set Ready" and "Clear To Send" bits (Bits 4 and 5) are found directly on an RS-232 cable, and are matching wires to "Request To Send" and "Data Terminal Ready" that are transmitted with the "Modem Control Register (MCR). With these four bits in two registers, you can perform "hardware flow control", where you can signal to the other device that it is time to send more data, or to hold back and stop sending data while you are trying to process the information. More will be written about this subject in another module when we get to data flow control.

A note regarding the "delta" bits (Bits 0, 1, 2, and 3). In this case the word "delta" means change, as in a change in the status of one of the bits. This comes from other scientific areas like rocket science where delta-vee means a change in

velocity. For the purposes of this register, each of these bits will be a logical "1" the next time you access this Modem Status register if the bit it is associated with (like Delta Data Carrier Detect with Carrier Detect) has changed its logical state from the previous time you accessed this register. The Trailing Edge Ring Indicator is pretty much like the rest, except it is in a logical "1" state only if the "Ring Indicator" bit went from a logical "1" to a logical "0" condition. There really isn't much practical use for this knowledge, but there is some software that tries to take advantage of these bits and perform some manipulation of the data received from the UART based on these bits. If you ignore these 4 bits you can still make a very robust serial communications software.

Scratch Register

The Scratch Register is an interesting enigma. So much effort was done to try and squeeze a whole bunch of registers into all of the other I/O port addresses that the designers had an extra "register" that they didn't know what to do with. Keep in mind that when dealing with computer architecture, it is easier when dealing with powers of 2, so they were "stuck" with having to address 8 I/O ports. Allowing another device to use this extra I/O port would make the motherboard design far too complicated.

On some variants of the 8250 UART, any data written to this scratch register will be available to software when you read the I/O port for this register. In effect, this gives you one extra byte of "memory" that you can use in your applications in any way that you find useful. Other than a virus author (maybe I shouldn't give any ideas), there isn't really a good use for this register. Of limited use is the fact that you can use this register to identify specific variations of the UART because the original 8250 did not store the data sent to it through this register. As that chip is hardly ever used anymore on a PC design (those companies are using more advanced chips like the 16550), you will not find that "bug" in most modern PC-type platforms. More details will be given below on how to identify through software which UART chip is being used in your computer, and for each serial port.

Software Identification of the UART

Just as it is possible to identify many of the components on a computer system through just software routines, it is also possible to detect which version or variant of the UART that is found on your computer as well. The reason this is possible is because each different version of the UART chip has some unique qualities that if you do a process of elimination you can identify which version you are dealing with. This can be useful information if you are trying to improve performance of the serial I/O routines, know if there are buffers available for transmitting and sending information, as well as simply getting to know the equipment on your PC better.

One example of how you can determine the version of the UART is if the Scratch Register is working or not. On the first 8250 and 8250A chips, there was a flaw in the design of those chip models where the Scratch Register didn't work. If you write some data to this register and it comes back changed, you know that the UART in your computer is one of these two chip models.

Another place to look is with the FIFO control registers. If you set bit "0" of this register to a logical **1**, you are trying to enable the FIFOs on the UART, which are only found in the more recent version of this chip. Reading bits "6" and "7" will help you to determine if you are using either the 16550 or 16550A chip. Bit "5" will help you determine if the chip is the 16750.

Below is a full psuedo code algorithm to help you determine the type of chip you are using:

```
Set the value "0xE7" to the FCR to test the status of the FIFO flags.
Read the value of the IIR to test for what flags actually got set.
If Bit 6 is set Then
  If Bit 7 is set Then
    If Bit 5 is set Then
      UART is 16750
    Else
      UART is 16550A
    End If
  Else
    UART is 16550
  End If
Else you know the chip doesn't use FIFO, so we need to check the scratch register
  Set some arbitrary value like 0x2A to the Scratch Register.
  You don't want to use 0xFF or 0x00 as those might be returned by the Scratch Register instead
for a false postive result.
  Read the value of the Scratch Register
  If the arbitrary value comes back identical
    UART is 16450
  Else
    UART is 8250
  End If
End If
```

when written in Pascal, the above algorithm ends up looking like this:

```
const
  COM1_Addr = $3F8;
  FCR = 2;
  IIR = 2;
  SCR = 7;

function IdentifyUART: String;
var
  Test: Byte;
begin
  Port[COM1_Addr + FCR] := $E7;
  Test := Port[COM1_Addr + IIR];
  if (Test and $40) > 0 then
    if (Test and $80) > 0 then
      if (Test and $20) > 0 then
        IdentifyUART := '16750'
      else
        IdentifyUART := '16550A'
    else
      IdentifyUART := '16550'
  else begin
    Port[COM1_Addr + SCR] := $2A;
    if Port[COM1_Addr + SCR] = $2A then
      IdentifyUART := '16450'
    else
      IdentifyUART := '8250';
  end;
end;
```

We still havn't identified between the 8250, 8250A, or 8250B; but that is rather pointless anyway on most current computers as it is very unlikely to even find one of those chips because of their age.

A very similar procedure can be used to determine the CPU of a computer, but that is beyond the scope of this book.

External References

- History of Interrupt Programming
- 8259 Chip Information with other registers explained
- Interfacing the Serial / RS232 Port

Serial DOS

Introduction

It is now time to build on everything that has been establshed so far. While it is unlikely that you are going to be using MS-DOS for a major application, it is a good operating system to demonstrate a number of ideas related to software access of the 8250 UART and driver development. Compared to modern operating systems like Linux, OS-X, or Windows, MS-DOS can hardly be called an operating system at all. All it really offers is basic access to the hard drive and a few minor utilities. That really doesn't matter so much for what we are dealing with here, and it is a good chance to see how we can directly manipulate the UART to get the full functionality of all aspects of the computer. The tools I'm using are all available for free (as in beer) and can be used in emulator software (like VMware or Bochs) to try these ideas out as well. Emulation of serial devices is generally a weak point for these programs, so it may work easier if you work from a floppy boot of DOS, or on an older computer that is otherwise destined for the trash can because it is obsolete.

For Pascal, you can look here:

- http://bdn.borland.com/article/0,1410,20803,00.html Turbo Pascal version 5.5 - This is the software I'm actually using for these examples, and the compiler that most older documentation on the web will also support (generally).
- http://www.freepascal.org/ Free Pascal - *note* this is a 32-bit version, although there is a port for DOS development. Unlike Turbo Pascal, it also has ongoing development and is more valuable for serious projects running in DOS.

For MS-DOS substitution (if you don't happen to have MS-DOS 6.22 somewhere):

- http://www.freedos.org/ FreeDOS Project - Now that Microsoft has abandoned development of DOS, this is pretty much the only OS left that is pure command line driven and following the DOS architecture.

Hello World, Serial Data Version

In the introduction, I mentioned that it was very difficult to write computer software that implements RS-232 serial communications. A very short program shows that at least a basic program really isn't that hard at all. In fact, just three more lines than a typical "Hello World" program.

```
program HelloSerial;
var
  DataFile: Text;
begin
  Assign(DataFile,'COM1');
  Rewrite(DataFile);
  Writeln(DataFile,'Hello World');
  Close(DataFile);
end.
```

All of this works because in DOS (and all version of Windows as well... on this particular point) has a "reserved" file name called COM1 that is the operating system hooks into the serial communications ports. While this seems simple, it is deceptively simple. You still don't have access to being able to control the baud rate or any of the other settings for the modem. That is a fairly simple thing to add, however, using the knowledge of the UART discussed in the previous chapter.

To try something even easier, you don't even need a compiler at all. This takes advantage of the reserved "device names" in DOS and can be done from the command prompt.

```
C:\>COPY CON COM1
```

What you are doing here is taking input from *CON* (the console or the standard keyboard you use on your computer) and it "copies" the data to *COM1*. You can also use variations of this to do some interesting file transfers, but it has some important limitations. Most importantly, you don't have access to the UART settings, and this simply uses whatever the default settings of the UART might be, or what you used last time you changes the settings to become with a serial terminal program.

Finding the Port I/O Address for the UART

The next big task that we have to work with is trying to find the base "address" of the Port I/O so that we can communicate with the UART chip directly. For a "typical" PC system, the following are usually the addresses that you need to work with:

Serial Port Name	Base I/O Port Address	IRQ Number
COM1	3F8	4
COM2	2F8	3
COM3	3E8	4
COM4	2E8	3

Looking up UART Base Address in RAM

We will get back to the issue of the IRQ Number in a little bit, but for now we need to know where to start accessing information about each UART. As demonstrated previously, DOS also keeps track of where the UART IO ports are located at for its own purpose, so you can try to "look up" within the memory tables that DOS uses to try and find the correct address as well. This doesn't always work, because we are going outside of the normal DOS API structure. Alternative operating systems like FreeDOS that are otherwise compatable with MS-DOS may not work in this manner, so take note that this may simply give you a wrong result altogether.

The addresses for the serial I/O Ports can be found at the following locations in RAM:

Port	Segment	Offset
COM1	$0040	$0000
COM2	$0040	$0002
COM3	$0040	$0004
COM4	$0040	$0006

Those addresses are written to memory by the BIOS when it boots. If one of the ports doesn't exist, the BIOS writes zero to the respective address. Note that the addresses are given in segment:offset format and that you have to multiply the address of the segment with 16 and add the offset to get to the pysical address in memory. This is where DOS "finds" the port addresses so you can run the first sample program in this chapter.

In assembler you can get the addresses like this:

```
; Data Segment
.data
Port  dw 0
...

; Code Segment
.code
mov ax,40h
mov es,ax
mov si,0
mov bx,Port ; 0 - COM1 , 1 - COM2 ...
shl bx,1
mov Port, es:[si+bx]
```

In Turbo Pascal, you can get at these addresses almost the same way, and in some ways even easier because it is a "high level language". All you have to do

is add the following line to access the COM Port location as a simple array:

```
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
```

The reserved word **absolute** is a flag to the compiler that instead of "allocating" memory, that you already have a place in mind to have the computer look instead. This is something that should seldom be done by a programmer unless you are accessing things like these I/O port addresses that are always stored in this memory location.

For a complete program that simply prints out a table of the I/O port addresses for all four standard COM ports, you can use this simple program:

```
program UARTLook;
const
  HexDigits: array [$0..$F] of Char = '0123456789ABCDEF';
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
  Index: Integer;
function HexWord(Number:Word):String;
begin
  HexWord := '$' + HexDigits[Hi(Number) shr 4] +
                   HexDigits[Hi(Number) and $F] +
                   HexDigits[Lo(Number) shr 4] +
                   HexDigits[Lo(Number) and $F];
end;
begin
  writeln('Serial COMport I/O Port addresses:');
  for Index := 1 to 4 do begin
    writeln('COM',Index,' is located at ',HexWord(ComPort[Index]));
  end;
end.
```

Searching BIOS Setup

Assuming that the standard I/O addresses don't seem to be working for your computer, and you havn't been able to find the correct I/O Port offset addresses through searching RAM either, all hope is still not lost. Assuming that you have not accedently changed these settings earlier, you can also try to look up these numbers in the BIOS setup page for your computer. It may take some pushing around to find this information, but if you have a conventional serial data port on your computer, it will be there.

If you are using a serial data port that is connected via USB (common on more recent computers), you are simply not going to be (easily) able to do direct serial data communications in DOS. Instead, you need to use more advanced operating systems like Windows or Linux that is beyond the scope of this chapter. We will cover how to access the serial communications routines in those operating systems in subsequent chapters. The basic principles we are discussing here would still be useful to review because it goes into the basic

UART structure.

Making modifications to UART Registers

Now that we know where to look in memory to modify the UART registers, lets put that knowledge to work. We are also now going to do some practical application of the tables listed earlier in the chapter 8250 UART Programming.

To start with, lets redo the previous "Hello World" application, but this time we are going to set the RS-232 transmission parameters to 1200 baud, 7 databits, even parity, and 2 stop bits. I'm choosing this setting parameter because it is not standard for most modem applications, as a demonstration. If you can change these settings, then other transmission settings are going to be trivial.

First, we need to set up some software constants to keep track of locations in memory. This is mainly to keep things clear to somebody trying to make changes to our software in the future, not because the complier needs it.

```
const
  LCR = 3;
  Latch_Low = $00;
  Latch_High = $01;
```

Next, we need to set the DLAB to a logical "1" so we can set the baud rate:

```
Port[ComPort[1] + LCR] := $80;
```

In this case, we are ignoring the rest of the settings for the Line Control Register (LCR) because we will be setting them up in a little bit. Remember this is just a "quick and dirty" way to get this done for now. A more "formal" way to set up things like baud rate will be demonstrated later on with this module.

Following this, we need to put in the baud rate for the modem. Looking up 1200 baud on the Divisor Latch Bytes table gives us the following values:

```
Port[ComPort[1] + Latch_High] := $00;
Port[ComPort[1] + Latch_Low] := $60;
```

Now we need to set the values for the LCR based on our desired setting of 7-2-E for the communication setttings. We also need to "clear" the DLAB which we can also do at the same time.

```
Clearing DLAB = 0 * 128
Clearing "Set Break" flag = 0 * 64
Even Parity = 2 * 8
Two Stop bits = 1 * 4
7 Data bits = 2 * 1

Port[ComPort[1] + LCR] := $16  {8*2 + 4 + 2 = 22 or $16 in hex}
```

Are things clear so far? What we have just done is some bit-wise arithmetic, and

I'm trying to keep things very simple here and to try and explain each step in detail. Let's just put the whole thing together as the quick and dirty "Hello World", but with adjustment of the transmission settings as well:

```
program HelloSerial;
const
  LCR = 3;
  Latch_Low = $00;
  Latch_High = $01;
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
  DataFile: Text;
begin
  Assign(DataFile,'COM1');
  Rewrite(DataFile);
  {Change UART Settings}
  Port[ComPort[1] + LCR] := $80;
  Port[ComPort[1] + Latch_High] := $00;
  Port[ComPort[1] + Latch_Low] := $60;
  Port[ComPort[1] + LCR] := $16
  Writeln(DataFile,'Hello World');
  Close(DataFile);
end.
```

This is getting a little more complicated, but not too much. Still, all we have done so far is just write data out to the serial port. Reading data from the serial data port is going to be a little bit trickier.

Basic Serial Input

In theory, you could use a standard I/O library and simply read data from the COM port like you would be reading from a file on your hard drive. Something like this:

```
Readln(DataFile,SomeSerialData);
```

There are some problems with doing that with most software, however. One thing to keep in mind is that using a standard input routine will stop your software until the input is finished ending with a "Enter" character (ASCII code 13 or in hex $0D).

Usually what you want to do with a program that recieves serial data is to allow the user to do other things while the software is waiting for the data input. In a multi-tasking operating system, this would simply be put on another "thread", but with this being DOS, we don't (usually) have threading capabilities, nor is it necessary. There are some other alternatives that we do in order to get the serial data brought into your software.

Polling the UART

Perhaps the easiest to do besides simply letting the standard I/O routines grab the input is to do software polling of the UART. One of the reasons why this works is because serial communications is generally so slow compared to the CPU speed that you can perform many tasks in between each character being transmitted to your computer. Also, we are trying to do practical applications using the UART chip, so this is a good way to demonstrate some of the capabilities of the chip beyond simple output of data.

Serial Echo Program

Looking at the Line Status Register (LSR), there is a bit called **Data Ready** that indicates there is some data available to your software in the UART. We are going to take advantage of that bit, and start to do data access directly from the UART instead of relying on the standard I/O library. This program we are going to demonstrate here is going to be called *Echo* because all it does is take whatever data is sent to the computer through the serial data port and display it on your screen. We are also going to be configuring the RS-232 settings to a more normal 9600 baud, 8 data bits, 1 stop bit, and no parity. To quit the program, all you have to do is press any key on your keyboard.

```
program SerialEcho;
uses
  Crt;
const
  RBR = 0;
  LCR = 3;
  LSR = 5;
  Latch_Low = $00;
  Latch_High = $01;
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
  InputLetter: Char;
begin
  Writeln('Serial Data Terminal Character Echo Program.  Press any key on the keyboard to quit.');
  {Change UART Settings}
  Port[ComPort[1] + LCR] := $80;
  Port[ComPort[1] + Latch_High] := $00;
  Port[ComPort[1] + Latch_Low] := $0C;
  Port[ComPort[1] + LCR] := $03;
  {Scan for serial data}
  while not KeyPressed do begin
    if (Port[ComPort[1] + LSR] and $01) > 0 then begin
      InputLetter := Chr(Port[ComPort[1] + RBR]);
      Write(InputLetter);
    end; {if}
  end; {while}
end.
```

Simple Terminal

This program really isn't that complicated. In fact, a very simple "terminal" program can be adapted from this to allow both sending and recieving characters. In this case, the *Escape* key will be used to quit the program, which will in fact be where most of the changes to the program will happen. We are also introducing for the first time direct output into the UART instead of going through the standard I/O libraries with this line:

```
Port[ComPort[1] + THR] := Ord(OutputLetter);
```

The Transmit Holding Register (THR) is how data you want to transmit gets into the UART in the first place. DOS just took care of the details earlier, so now we don't need to open a "file" in order to send data. We are going to assume, to keep things very simple, that you can't type at 9600 baud, or roughly 11,000 words per minute. Only if you are dealing with very slow baud rates like 110 baud is that going to be an issue anyway (still at over 130 words per minute of typing... a very fast typist indeed).

```
program SimpleTerminal;
uses
  Crt;
const
  THR = 0;
  RBR = 0;
  LCR = 3;
  LSR = 5;
  Latch_Low = $00;
  Latch_High = $01;
  {Character Constants}
  NullLetter = #0;
  EscapeKey = #27;
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
  InputLetter: Char;
  OutputLetter: Char;
begin
  Writeln('Simple Serial Data Terminal Program.  Press "Esc" to quit.');
  {Change UART Settings}
  Port[ComPort[1] + LCR] := $80;
  Port[ComPort[1] + Latch_High] := $00;
  Port[ComPort[1] + Latch_Low] := $0C;
  Port[ComPort[1] + LCR] := $03;
  {Scan for serial data}
  OutputLetter := NullLetter;
  repeat
    if (Port[ComPort[1] + LSR] and $01) > 0 then begin
      InputLetter := Chr(Port[ComPort[1] + RBR]);
      Write(InputLetter);
    end; {if}
    if KeyPressed then begin
      OutputLetter := ReadKey;
      Port[ComPort[1] + THR] := Ord(OutputLetter);
    end; {if}
  until OutputLetter = EscapeKey;
end.
```

Interrupt Drivers in DOS

The software polling method may be adequate for most simple tasks, and if you want to test some serial data concepts without writing a lot of software, it may be sufficient. Quite a bit can be done with just that method of data input.

When you are writing a more complete piece of software, however, it becomes important to worry about the efficiency of your software. While the computer is "polling" the UART to see if a character has been sent through the serial communications port, it spends quite a few CPU cycles doing absolutely nothing at all. It also get very difficult to expand a program like the one demonstrated above to become a small section of a very large program. If you want to get that last little bit of CPU performance out of your software, we need to turn to interrupt drivers and how you can write them.

I'll openly admit that this is a tough leap in complexity from a simple polling application listed above, but it is an important programming topic in general. We are also going to expose a little bit about the low-level behavior of the 8086 chip family, which is knowledge you can use in newer operating systems as well, at least for background information.

Going back to earlier discussions about the 8259 Programmable Interrupt Controller (PIC) chip, external devices like the UART can "signal" the 8086 that an important task needs to occur that **interrupts** the flow of the software currently running on the computer. Not all computers do this, however, and sometimes the software polling of devices is the only way to get data input from other devices. The real advantage of interrupt events is that you can process data aquisition from devices like the UART very quickly, and CPU time spent trying to test if there is data available can instead be used for other tasks. It is also useful when designing operating systems that are *event driven*.

Interrupt Requests (IRQs) are labeled with the names IRQ0 to IRQ15. UART chips typically use either IRQ 3 or IRQ 4. When the PIC signals to the CPU that an interrupt has occured, the CPU automatically start to run a very small subroutine that has been previously setup in the **Interrupt Table** in RAM. The exact routine that is started depends on which IRQ has been triggered. What we are going to demonstrate here is the ability to write our own software that "takes over" from the operating system what should occur when the interrupt occurs. In effect, writing our own "operating system" instead, at least for those parts we are rewriting.

Indeed, this is exactly what operating system authors do when they try to make a new OS... deal with the interrupts and write the subroutines necessary to control the devices connected to the computer.

The following is a very simple program that captures the keyboard interrupt and produces a "clicking" sound in the speaker as you type each key. One interesting thing about this whole section, while it is moving slightly off topic, this is communicating with a serial device. The keyboard on a typical PC transmits the information about each key that you press through a RS-232 serial protocol that operates usually between 300 and 1200 baud and has its own custom UART chip. Normally this isn't something you are going to address, and seldom are you going to have another kind of device connected to the keyboard port, but it is interesting that you can "hack" into the functions of your keyboard by understanding serial data programming.

```
program KeyboardDemo;
uses
  Dos, Crt;
const
  EscapeKey = #27;
var
  OldKeybrdVector: Procedure;
{$F+}
procedure Keyclick; interrupt;
begin
  if Port[$60] < $80 then begin
    Sound(5000);
    Delay(1);
    Nosound;
  end;
  inline($9C) { PUSHF - Push the flags onto the stack }
  OldKeybrdVector;
end;
{$F-}
begin
  GetIntVec($9,@OldKeybrdVector);
  SetIntVec($9,Addr(Keyclick));
  repeat
   if KeyPressed then begin
     OutputLetter := ReadKey;
     Write(OutputLetter);
   end; {if}
  until OutputLetter = EscapeKey;
  SetIntVec($9,@OldKeybrdVector);
end.
```

There are a number of things that this program does, and we need to explore the realm of 16-bit DOS software as well. The 8086 chip designers had to make quite a few compromises in order to work with the computer technology that was available at the time it was designed. Computer memory was quite expensive compared to the overall cost of the computer. Most of the early microcomputers that the IBM-PC was competing against only had 64K or 128K of main CPU RAM anyway, so huge programs were not considered important. In fact, the original IBM-PC was designed to operate on only 128K of RAM although it did come standard with generally up to 640K of main RAM, especially by the time the IBM PC-XT was relesed and the market for PC "clones" turned out what is generally considered the "standard PC" computer today.

The design came up with what is called **segmented memory**, where the CPU address is made up of a memory "segment" pointer and a 64K block of memory. That is why some early software on these computers could only run in 64K of memory, and created nightmares for compiler authors on the 8086. Pentium computers don't generally have this issue, as the memory model in "protected mode" doesn't use this segmented design methodology.

Far Procedure Calls

```
{$F+}
{$F-}
```

This program has to "compiler switches" that inform the compiler of the need to use what are called far procedure calls. Normally for small programs and simple subroutines, you are able to use what is called relative indexing with the software so the CPU "jumps" to the portion of RAM with the procedure by doing a bit of simple math and "adding" a number to the current CPU address in order to find the correct instructions. This is done especially because it uses quite a bit less memory to store all of these instructions.

Sometimes, however, a procedure must be accessed from somewhere in RAM that is quite different from the current CPU memory address "instruction pointer". Interrupt procedures are one of these, because it doesn't even have to be the same program that is stored in the interrupt vector table. That brings up the next part to discuss:

Interrupt Procedures

```
procedure Keyclick; interrupt;
```

The word "interrupt" after this procedure name is a key item here. This tells the compiler that it must do something a little bit different when organizing this function than how a normal function call behaves. Typically for most software on the computer, you have a bunch of simple instructions that are then followed by (in assembler) an instruction called:

```
RET
```

This is the memonic assembly instruction for return from procedure call. Interrupts are handled a little bit differently and should normally end with a different CPU instruction that in assembly is called:

```
IRET
```

or Interrupt return for short. One of the things that should also happen with any interrupt service routine is to "preserve" the CPU information before doing anything else. Each "command" that you write in your software will modify the internal registers of the CPU. Keep in mind that an interrupt can occur right in the middle of doing some calculations for another program, like rendering a graphic image or making payroll calculations. We need to hand onto that information and "restore" those values on all of the CPU registers at the end of our subroutine. This is usually done by "pushing" all of the register values onto the CPU stack, performing the ISR, and then restoring the CPU regsiters afterward.

In this case, Turbo Pascal (and other well-written compilers having a compiler

flag like this) takes care of these low-level details for you with this simple flag. If the compiler you are using doesn't have this feature, you will have to add these features "by hand" and explicitly put them into your software. That doesn't mean the compiler will do everything for you to make an interrupt procedure. There are more steps to getting this to work still.

Procedure Variables

```
var
  OldKeybrdVector: Procedure;
```

These instructions are using what is called a procedure variable. Keep in mind that all software is located in the same memory as variables and other information your software is using. Essentially, a variable procedure where you don't need to worry about what it does until the software is running, and you can change this variable while your program is running. This is a powerful concept that is not often used, but it can be used for a number of different things. In this case we are keeping track of the previous interrupt service routine and "chaining" these routines together.

There are programs called Terminate and Stay Resident (TSRs) that are loaded into your computer. Some of these are called drivers, and the operating system itself also puts in subroutines to do basic functions. If you want to "play nice" with all of this other software, the established protocol for making sure everybody gets a chance to review the data in an interrupt is to link each new interrupt subroutine to the previously stored interrupt vector. When we are done with whatever we want to do with the interrupt, we then let all of the other programs get a chance to used the interrupt as well. It is also possible that the Interrupt Service Routine (ISR) that we just wrote is not the first one in the chain, but instead one that is being called by another ISR.

Getting/Setting Interrupt Vectors

```
 GetIntVec($9,@OldKeybrdVector);
 SetIntVec($9,Addr(Keyclick));
 SetIntVec($9,@OldKeybrdVector);
```

Again, this is Turbo Pascal "hiding" the details in a convienient way. There is a "vector table" that you can directly access, but this vector table is not always in the same location in RAM. If instead you go through the BIOS with a software interrupt, you are "guarenteed" that the interrupt vector will be correctly replaced.

Hardware Interrupt Table

Interrupt	Hardware IRQ	Purpose
$00	CPU	Divide by Zero
$01	CPU	Single Step Instruction Processing
$02	CPU	Non-maskable Interrupts
$03	CPU	Breakpoint Instruction
$04	CPU	Overflow Instruction
$05	CPU	Bounds Exception
$06	CPU	Invalid Op Code
$07	CPU	Math Co-processor not found
$08	IRQ0	System Timer
$09	IRQ1	Keyboard
$0A	IRQ2	Cascade from IRQ8 - IRQ15
$0B	IRQ3	Serial Port (COM2)
$0C	IRQ4	Serial Port (COM1)
$0D	IRQ5	Sound Card
$0E	IRQ6	Floppy Disk Controller
$0F	IRQ7	Parallel Port (LPT1)
$10 - $6F		Software Interrupts
$70	IRQ8	Real-time Clock
$71	IRQ9	Legacy IRQ2 Devices
$72	IRQ10	Reserved (often PCI devices)
$73	IRQ11	Reserved (often PCI devices)
$74	IRQ12	PS/2 Mouse
$75	IRQ13	Math Co-Processor Results
$76	IRQ14	Hard Disk Drive
$77	IRQ15	Reserved
$78 - $FF		Software Interrupts

This table gives you a quick glance at some of the things that interrupts are used for, and the interrupt numbers associated with them. Keep in mind that the IRQ

numbers are mainly reference numbers, and that the CPU uses a different set of numbers. The keyboard IRQ, for example, is IRQ1, but it is numbered as interrupt $09 inside the CPU.

There are also several interrupts that are "generated" by the CPU itself. While technically hardware interrupts, these are generated by conditions *within* the CPU, sometimes based on conditions setup by your software or the operating system. When we start writing the interrupt service routine for the serial communication ports, we will be using interrupts 11 and 12 ($0B and $0C in hex). As can be seen, most interrupts are assigned for specific tasks. I've ommitted the software interrupts mainly to keep this on topic regarding serial programming and hardware interrupts.

Other features

There are several other parts to this program that don't need too much more explaination. Remember, we are talking about serial programming, not interrupt drivers. I/O Port $60 is interesting as this is the Reciever Buffer (RBR) for the keyboard UART. This returns the keyboard "scan code", not the actual character pressed. In fact, when you use a keyboard on a PC, the keyboard actually transmits two characters for each key that you use. One character is transmitted when you press the key down, and another character when the key is "released" to go back up. In this case, the interrupt service routine in DOS normally converts the scan codes into ASCII codes that your software can use. In fact, simple keys like the shift key are treated as just another scan code.

The sound routines access the internal PC speaker, not something on a sound card. About the only thing that uses this speaker any more is the BIOS "beep codes" that you hear only when there is a hardware failure to your computer, or the quick "beep" when you start or reboot the computer. It was never designed for doing things like speech synthisis or music playback, and driver attempts to use if for those purposes sound awful. Still, it is something neat to experiment with and a legacy computer part that is surprisingly still used on many current computers.

Terminal Program Revisited

I'm going to go back to the serial terminal program for a bit and this time redo the application by using an interrupt service routine. There are a few other concepts I'd like to introduce as well so I'll try to put them in with this example program. From the user perspective, I would like to add the ability to change the terminal characteristics from the command line and allow an "end-user" the ability to change things like the baud rate, stop bits, and parity checking, and allow these to be variables instead of hard-coded constants. I'll explain each section and then put it all together when we are through.

Serial ISR

This is an example of a serial ISR we can use:

```
{$F+}
procedure SerialDataIn; interrupt;
var
 InputLetter: Char;
begin
  if (Port[ComPort[1] + LSR] and $01) > 0 then begin
    InputLetter := Chr(Port[ComPort[1] + RBR]);
    Write(InputLetter);
  end; {if}
end;
{$F-}
```

This isn't that much different from the polling method that we used earlier, but keep in mind that by placing the checking inside an ISR that the CPU is only doing the check when there is a piece of data available. Why even check the LSR to see if there is a data byte available? Reading data sent to the UART is not the only reason why the UART will invoke an interrupt. We will go over that in detail in a later section, but for now this is good programming practice as well, to confirm that the data is in there.

By moving this checking to the ISR, more CPU time is available for performing other tasks. We could even put the keyboard polling into an ISR as well, but we are going to keep things very simple for now.

Fifo disabling

There is one minor problem with the way we have written this ISR. We are assuming that there is no FIFO in the UART. The "bug" that could happen with this ISR as it is currently written is that multiple characters can be in the FIFO buffer. Normally when this happens, the UART only sends a single interrupt, and it is up to the ISR to "empty" the FIFO buffer completely.

Instead, all we are going to do is simply disable the FIFO completely. This can be done using the FCR (FIFO Control Register) and explicitly disabling the FIFO. As an added precaution, we are also going to "clear" the FIFO buffers in the UART as a part of the initialization portion of the program. Clearling the FIFOs look like this:

```
 Port[ComPort[1] + FCR] := $07; {clearing the FIFOs}
```

Disabling the FIFOs look like this:

```
 Port[ComPort[1] + FCR] := $00; {disabling FIFOs}
```

We will be using the FIFOs in the next section, so this is more a brief introduction to this register so far.

Working with the PIC

Up until this point, we didn't have to worry about working with the Programmable Interrupt Controller (the PIC). Now we need to. There isn't the need to do all of the potential instructions for the PIC, but we do need to enable and disable the interrupts that are used by the UART. There are two PICs typically on each PC, but due to the typical UART IRQ vector, we really only have to deal with the master PIC.

Pic Function	I/O Port Address
PIC Commands	0x20
Interrupt Flags	0x21

This adds the following two constants into the software:

```
{PIC Constants}
MasterPIC = $20;
MasterOCW1 = $21;
```

After consulting the PIC IRQ table we need to add the following line to the software in order to enable IRQ4 (used for COM1 typically):

```
Port[MasterOCW1] := Port[MasterOCW1] and $EF;
```

When we do the "cleanup" when the program finishes, we also need to disable this IRQ as well with this line of software:

```
Port[MasterOCW1] := Port[MasterOCW1] or $10;
```

Remember that COM2 is on another IRQ vector, so you will have to use different constants for that IRQ. That will be demonstrated a little bit later. We are using a logical and/or with the existing value in this PIC register because we don't want to change the values for the other interrupt vectors that other software and drivers may be using on your PC.

We also need to modify the Interrupt Service Routine (ISR) a little bit to work with the PIC. There is a command you can send to the PIC that is simply called End of Interrupt (EOI). This signals to the PIC that it can clear this interrupt signal and process lower-priority interrupts. If you fail to clear the PIC, the interrupt signal will remain and none of the other interrupts that are "lower priority" can be processed by the CPU. This is how the CPU communicates back to the PIC to end the interrupt cycle.

The following line is added to the ISR to make this happen:

```
Port[MasterPIC] := EOI;
```

Modem Control Register

This is perhaps the most non-obvious little mistake you can make when trying to get the UART interrupt. The Modem Control register is really the way for the UART to communicate to the rest of the PC. Because of the way the circuity on the motherboards of most computers are design, you usually have to turn on the Auxiliary Output 2 signal in order for interrupts to "connect" to the CPU. In addition, here we are going to turn on the RTS and DTS signals on the serial data cable to make sure the equipment is going to transmit. We will cover software and hardware flow control in a later section.

To turn on these values in the MCR, we need to add the following line in the software:

```
Port[ComPort[1] + MCR] := $0B;
```

Interrupt Enable Register

We are still not home free yet. We still need to enable interrupts on the UART itself. This is very simple, and for now all we want to trigger an interrupt from the UART is just when data is recieved by the UART. This is a very simple line to add here:

```
Port[ComPort[1] + IER] := $01;
```

Putting this together so far

Here is the complete program using ISR input:

```
program ISRTerminal;
uses
  Crt, Dos;
const
  {UART Constants}
  THR = 0;
  RBR = 0;
  IER = 1;
  FCR = 2;
  LCR = 3;
  MCR = 4;
  LSR = 5;
  Latch_Low = $00;
  Latch_High = $01;
  {PIC Constants}
  MasterPIC = $20;
  MasterOCW1 = $21;
  {Character Constants}
  NullLetter = #0;
  EscapeKey = #27;
var
  ComPort: array [1..4] of Word absolute $0040:$0000;
```

```
  OldSerialVector: procedure;
  OutputLetter: Char;
{$F+}
procedure SerialDataIn; interrupt;
var
  InputLetter: Char;
begin
  if (Port[ComPort[1] + LSR] and $01) > 0 then begin
    InputLetter := Chr(Port[ComPort[1] + RBR]);
    Write(InputLetter);
  end; {if}
  Port[MasterPIC] := EOI;
end;
{$F-}
begin
  Writeln('Simple Serial ISR Data Terminal Program.  Press "Esc" to quit.');
  {Change UART Settings}
  Port[ComPort[1] + LCR] := $80;
  Port[ComPort[1] + Latch_High] := $00;
  Port[ComPort[1] + Latch_Low] := $0C;
  Port[ComPort[1] + LCR] := $03;
  Port[ComPort[1] + FCR] := $07; {clearing the FIFOs}
  Port[ComPort[1] + FCR] := $00; {disabling FIFOs}
  Port[ComPort[1] + MCR] := $0B;
  {Setup ISR vectors}
  GetIntVec($0C,@OldSerialVector);
  SetIntVec($0C,Addr(SerialDataIn));
  Port[MasterOCW1] := Port[MasterOCW1] and $EF;
  Port[ComPort[1] + IER] := $01;
  {Scan for keyboard data}
  OutputLetter := NullLetter;
  repeat
    if KeyPressed then begin
      OutputLetter := ReadKey;
      Port[ComPort[1] + THR] := Ord(OutputLetter);
    end; {if}
  until OutputLetter = EscapeKey;
  {Put the old ISR vector back in}
  SetIntVec($0C,@OldSerialVector);
  Port[MasterOCW1] := Port[MasterOCW1] or $10;
end.
```

At this point you start to grasp how complex serial data programming can get. We are not finished yet, but if you have made it this far you hopfully understand each part of the program listed above. We are going to try and stay with this one step at a time, but at this point you should be able to write some simple custom software that uses serial I/O.

Command Line Input

There are a number of different ways that you can "scan" the parameters that start the program. For example, if you start a simple terminal program in DOS, you can use this command to begin:

```
C:> terminal COM1 9600 8 1 None
```

or perhaps

```
C:> terminal COM4 1200 7 2 Even
```

Obviously there should not be a need to have the end-user recompile the software if they want to change something simple like the baud rate. What we are trying to accomplish here is to grab those other items that were used to start the program. In Turbo Pascal, there is function that returns a string

```
ParamStr(index)
```

which contain each item of the command line. These are passed to the program through strings. A quick sample program on how to extract these parameters can be found here:

```
program ParamTst;
var
  Index: Integer;
begin
  writeln('Parameter Test -- displays all command line parameters of this program');
  writeln('Parameter Count = ',ParamCount);
  for Index := 0 to ParamCount do begin
    writeln('Param # ',Index,' - ',ParamStr(Index));
  end;
end.
```

One interesting "parameter" is parameter number 0, which is the name of the program that is processing the commands. We will not be using this parameter, but it is something useful in many other programming situations.

Grabbing Terminal Parameters

For the sake of simplicity, we are going to require that either all of the parameters are going to be in that format of baud rate, bit size, stop bits, parity; or there will be no parameters at all. This example is giong to be mainly to demonstrate how to use variables to change the settings of the UART by the software user rather than the programmer. Since the added sections are self-explainitory, I'm just going to give you the complete program. There will be some string manipulation going on here that is beyond the scope of this book, but that is going to be used only for parsing the commands. To keep the user interface simple, we are using the command line arguments alone for changing the UART parameters. We could build a fancy interface to allow these settings to be changed while the program is running, but that is an exercise that is left to the reader.

Serial Linux

The Classic Unix C APIs for Serial Communication

Here are just some remarks and buzzwords:

Introduction

Scope

This module talks about the classic Unix C APIs for controlling serial devices. Languages other than C might provide appropriate wrappers to these APIs which look similar, or come with their own abstraction (e.g.Java). Nevertheless, these APIs are the lowest level of abstraction one can find for serial I/O in Unix. And, in fact they are also the highest abstraction in C on standard Unix. Some Unix versions ship additional vendor-specific proprietary high-level APIs. These APIs are not discussed here.

Actual implementations of classic Unix serial APIs do vary in practice, due to the different versions of Unix and its clones, like Linux. Therefore, this module just provides a general outline. It is highly recommended that you study a particular Unix version's manual (man pages) when programming for a serial device in Unix. The relevant man pages are not too great a read, but they are usually complete in their listing of options and parameters. Together with this overview it should be possible to implement programs doing serial I/O under Unix.

Basics

Linux, or any Unix, is a multi-user, multi-tasking operating system. As such, programs usually don't, and are usually not allowed to, access hardware resources like serial UARTs directly. Instead, the operating system provides

1. low-level drivers for mapping the device into the file system (/dev and/or /device/ file system entries),
2. the standard system calls for opening, reading, writing, and closing the device, and
3. the standard system call for controlling a device, and/or
4. high-level C libraries for controlling the device.

The low-level driver not only maps the device into the file system with the help of the kernel, it also encapsulates the particular hardware. The user often does not even know or care what type of UART is in use.

Classic Unix systems often provide two different device nodes (or minor

numbers) for serial I/O hardware. These provide access to the same physical device via two different names in the /dev hierarchy. Which node is used affects how certain serial control signals, such as CD (carrier detect), are handled when the device is opened. In some cases this can be changed programmatically, making the difference largely irrelevant. As a consequence, Linux only provides the different devices for legacy programs.

Device names in the file system can vary, even on the same Unix system, as they are simply aliases. The important parts of a device name (such as in /dev) are the major and minor numbers. The major number distinguishes a serial port, for example, from a keyboard driver, and is used to select the correct driver in the kernel. Note that the major number differs between different Unix systems. The minor number is interpreted by the device driver itself. For serial device drivers, it is typically used to detect which physical interface to use. Sometimes, the minor number will also be used by the device driver to determine the CD behaviour or the hardware flow control signals to be used.

The typical (but not standardised, see above) device names under Unix for serial interfaces are:

/dev/tty*xxx*
: Normal, generic access to the device. Used for terminal and other serial communication. More recently, they are also used in modem communication, for example, whereas the /dev/cua*xxx* was used on older systems.
See the following module on how terminal I/O and serial I/O relate on Unix.

/dev/cua*xxx*
: Legacy device driver with special CD handling. Typically this was used for accessing a modem on old Unix systems, such as running the UUCP communication protocol over the serial line and the modem.

The **xxx** part is typically a one or two digit number, or a lowercase letter, starting at 'a' for the first interface.

PC-based Unix systems often mimic the DOS/Windows naming for the devices and call them /dev/com*xxx*.

To summarise, when programming for the serial interface of a Unix system it is **highly advisable** to provide complete configuration for the device name. Not even the typical /dev path should be hard coded.

Note, devices with the name /dev/pty*xxx* are pseudo terminal devices, typically used by a graphical user interface to provide a terminal emulator like *xterm* or *dtterm* with a "terminal" device, and to provide a terminal device for network logins. There is no serial hardware behind these device drivers.

Serial I/O via Terminal I/O

Serial I/O under Unix is implemented as part of the terminal I/O capabilities of Unix. It is not limited to terminals, though. The terminal I/O API is used for communication with many serial devices other than terminals, such as modems and printers.

Three terminal interfaces that are commonly found in Unix:

1. V7, 4BSD, XENIX style device-specific Serial_Programming:Serial_Linux#V7 / ioctl(2),
2. An old one called termio
3. A newer one (although still already a few decades old), which is called termios (note the additional 's').

The newer termios API is based on the older termio API, and so the two termio... APIs share a lot of similarities. The termios API has also undergone changes since inception. For example, the method of specifying the baud rate has changed from using pre-defined constants to a more relaxed schema (the constants can still be used as well on most implementations).

Some systems provide other, similar APIs, either in addition or as a replacement. termiox is such an API, which is largely compatible with termio and adds some extensions to it taken from termios.

Systems that support the newer termios often also support the older termio API, either by providing it in addition, or by providing a termios implementation with data structures which can be used in place of the termio data structures and work as termio. These systems also often just provide one man page under the older name **termio***(7)* which is then in fact the termios man page, too.

Unfortunately, whichever of the two standard APIs is used, one fact holds for both: They are a slight mess. Well, not really. Communication with terminals was and is a difficult issue, and the APIs reflect these difficulties. But due to the fact that one can do "everything" with the APIs, it is overwhelming when one "just" wants to do some serial communication. So why is there no separate serial-I/O-only API in Unix? There are probably two reasons for this:

1. Terminals were the first, and apparently very important, serial devices which were connected to Unix. Once the API was there, there was no need to create a separate one for serial I/O only.
2. A large part of terminal I/O is serial I/O, even if a lot of these features are not used when e.g. communicating with a modem instead of a terminal.

The terminal I/O APIs rely on the standard system calls for reading and writing data. They don't provide their own reading/writing functions. Reading and writing data is done via the **read***(2)* and **write***(2)* system calls. The terminal I/O APIs just add functions for controlling and configuring the device. Most of this happens via the **ioctl***(2)* system call.

So which API should one use? In general, the newer termios API makes the most sense. Only if compatibility with old Unix systems is an issue does it make sense to consider termio.

V7 / ioctl(2)

{stub}<sys/ttold.h> TIOCGETP TIOCEXCL TIOCNXCL TIOCSETP TIOCSETN TIOCHPCL TIOCFLUSH TIOCSBRK TIOCCBRK TIOCSDTR TIOCCDTR TIOCSTOP TIOCSTART TIOCGETC TIOCSETC TIOCLGET TIOCLBIS TIOCLBIC TIOCLSET TIOCGLTC TIOCSLTC FIORDCHK FIONREAD

termios

Introduction

Termios is the newer Unix API for terminal I/O. The necessary declarations and constants can be found in the header file <termios.h>. So code for serial or terminal I/O will usually start with

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

Some additional functions can also be found in the <stdio.h>, and <unistd.h> header files.

The termios I/O API supports two different modes: *doesn't old termio do this too? if yes, move paragraphs up to the general section about serial and terminal I/O in Unix)*.

1. Canonical mode.
   This is most useful when dealing with real terminals, or devices which provide line-by-line communication. The terminal driver returns data line-by-line.
2. Non-canonical mode.
   In this mode, no special processing is done, and the terminal driver returns individual characters.

On BSD-like systems, there are three modes:

1. Cooked Mode.
   Input is assembled into lines and special characters are processed.
2. Raw mode.
   Input is not assembled into lines and special characters are not processed.
3. Cbreak mode.
   Input is not assembled into lines but some special characters are processed.

Unless set otherwise, canonical (or cooked mode under BSD) is the default. The special characters which are processed in the corresponding modes are control

characters, such as end-of-line or backspace. The full list for a particular Unix flavour can be found in the corresponding termios *man page*. For serial communication it is often advisable to use non-canonical, (raw or cbreak mode under BSD) to ensure that transmitted data is not interpreted by the terminal driver. Therefore, when setting up the communication parameters, the device should also configured for raw/non-canonical mode by setting/clearing the corresponding termios flags. It is also possible to enable or disable the processing of the special characters on an individual basis.

This configuration is done by using the struct termios data structure, defined in the termios.h header. This structure is central to both the configuration of a serial device and querying its setup. It contains a minimum of the following fields:

```
struct termios {
  tcflag_t c_iflag;    /* input specific flags (bitmask) */
  tcflag_t c_oflag;    /* output specific flags (bitmask) */
  tcflag_t c_cflag;    /* control flags (bitmask) */
  tcflag_t c_lflag;    /* local flags (bitmask) */
  cc_t     c_cc[NCCS]; /* special characters */
};
```

It should be noted that real struct termios declarations are often much more complicated. This stems from the fact that Unix vendors implement termios so that it is backward compatible with termio and integrate termio and termios behavior in the same data structure so they can avoid to have to implement the same code twice. In such a case, an application programmer may be able to intermix termio and termios code.

There are more than 45 different flags which can be set (via tcsetattr()) or got (via tcgetattr()) with the help of the struct termios. The large number of flags, and their sometimes esoteric and pathologic meaning and behavior, is one of the reasons why serial programming under Unix can be hard. In the device configuration, once must be careful not to make a mistake.

Opening/Closing a Serial Device

- open(2)
- close(2)

Line-Control Functions

Termios contains a number of line-control functions. These allow a more fine-grained control over the serial line in certain special situations. They all work on a file descriptor *fildes*, returned by an **open**(2) call to open the serial device. In the case of an error, the detailed cause can be found in the global errno variable (see **errno**(2)).

```
#include <termios.h>
int tcdrain(int fildes);
```

Wait until all data previously written to the serial line indicated by fildes has been sent. This means, the function will return when the UART's send buffer has cleared.
If successful, the function returns 0. Otherwise it returns -1, and the global variable errno contains the exact reason for the error.

#include <termios.h>
int tcflow(int *fildes*, int *action*);
This function suspends/restarts transmission and/or reception of data on the serial device indicated by *fildes*. The exact function is controlled by the *action* argument. *action* should be one of the following constants:

TCOOFF
Suspend output.
TCOON
Restarts previously suspended output.
TCIOFF
Transmit a STOP (xoff) character. Remote devices are supposed to stop transmitting data if they receive this character. This requires the remote device on the other end of the serial line to support this software flow-control.
TCION
Transmit a START (xon) character. Remote devices should restart transmitting data if they receive this character. This requires the remote device on the other end of the serial line to support this software flow-control.
If successful, the function returns 0. Otherwise it returns -1, and the global variable errno contains the exact reason for the error.

#include <termios.h>
int tcflush(int *fildes*, int *queue_selector*);
Flushes (discards) not-send data (data still in the UART send buffer) and/or flushes (discards) received data (data already in the UART receive buffer). The exact operation is defined by the *queue_selector* argument. The possible constants for *queue_selector* are:

TCIFLUSH
Flush received, but unread data.
TCOFLUSH
Flush written, but not send data.
TCIOFLUSH
Flush both.
If successful, the function returns 0. Otherwise it returns -1, and the global variable errno contains the exact reason for the error.

#include <termios.h>
int tcsendbreak(int *fildes*, int *duration_flag*);

Sends a break for a certain duration. The *duration_flag* controls the duration of the break signal:

0
: Send a break of at least 0.25 seconds, and not more than 0.5 seconds.

any other value
: For other values than 0, the behavior is implementation defined. Some implementations interpret the value as some time specifications, others just let the function behave like *tcdrain()*.

A break is a deliberately generated framing (timing) error of the serial data – the signal's timing is violated by sending a series of zero bits, which also encompasses the start/stop bits, so the framing is explicitly gone.

If successful, the function returns 0. Otherwise it returns -1, and the global variable errno contains the exact reason for the error.

Reading and Setting Parameters

Attribute Changes

- tcgetattr()
- tcsetattr()

Baud-Rate Setting

- cfgetispeed()
- cfgetospeed()
- cfsetispeed()
- cfsetospeed()

Modes

Special Input Characters

Canonical Mode

Non-Canonical Mode

Misc.

There are a few C functions which can be useful for terminal and serial I/O programming and which are not part of the terminal I/O API. These are

#include <stdio.h>
char *ctermid(char *s);

This function returns the device name of the current controlling terminal of the process as a string (e.g. "/dev/tty01"). This is useful for programs who want to open that terminal device directly in order to communicate with it, even if the controlling terminal association is removed later (because, for example, the process forks/execs to become a daemon process).
s can either be NULL or should point to a character array of at least *L_ctermid* bytes (the constant is also defined in *stdio.h*). If *s* is NULL, then some internal static char array is used, otherwise the provided array is used. In both cases, a pointer to the char array is returned

#include <unistd.h>
int isatty(int *fildes*)

Checks if the provided file descriptor represents a terminal device. This can e.g. be used to figure out if a device will understand the commands send via the terminal I/O API.

#include <unistd.h>
char *ttyname (int *fildes*);

This function returns the device name of a terminal device represented by a file descriptor as a string.

#include <sys/ioctl.h>
ioctl(int *fildes*, TIOCGWINSZ, struct winsize *)
ioctl(int *fildes*, TIOCSWINSZ, struct winsize *)

These I/O controls allow to get and set the window size of a terminal emulation, e.g. an *xterm* in pixel and character sizes. Typically the get variant (TIOCGWINSZ) is used in combination with a SIGWINCH signal handler. The signal handler gets called when the size has changed (e.g. because the user has resized the terminal emulation window), and the application uses the I/O control to get the new size.

termio / ioctl(2)

<termio.h> (note the missing 's') is the older Unix Version 7 and System V terminal I/O API. It has been replaced by <termios.h> on modern systems. It is still in use on many systems, e.g. on embedded Unix systems or those based on Unix System V. Often modern systems still also provide the old API, too.

All settings to a serial device are done via the ioctl*(2)* system call, as opposite to the special functions as provided by <termios.h>.

Special Characters

- INTR (default Ctrl-C or ASCII ETX)
- QUIT (default Ctrl-\, or ASCII ES)
- ERASE (default backspace or ASCII BS)
- KILL (Ctrl-U, or ASCII NAK)
- EOF (Ctrl-D, or ASCII EOT)
- NL (ASCII LF)
- EOL (ASCII LF)
- STOP (Ctrl-S, or ASCII DC3)
- START (Ctrl-Q, or ASCII DC1)

Setting and Getting Parameters via Termio

Primary commands

The main commands for controlling serial (terminal) I/O with termio all use an ioctl() call of the form

```
ioctl(int fileDescriptor, int termioCommand, struct termio *arg);
```

The following commands use this ioctl() form:

TCGETA
: Get current parameters

```
#include <termio.h>
   :
   .
struct termio params;
ioctl(fileDescriptor, TCGETA, &params);
```

TCSETA
: Set parameters immediately

TCSETAW
: Set parameters when output is empty (waits with change until all buffered data has been sent).

TCSETAF
: Wait until output is empty, then flush input, then set parameters.

The struct termio argument as used in all the above *ioctl*(2) command looks as it follows:

struct termio

```
/*
 * Classic struct termio. More modern Unix versions
 * contain additional information. Unix versions who
 * support termio and termios often use the same
 * structure for termio and termios, so termio
 * contains the full termios data on this systems.
 */
#define NCC 8
struct termio {
    int c_iflag;        /* input modes   */
    int c_oflag;         /* output modes  */
    int c_cflag;         /* control modes */
    int c_lflag;        /* local modes   */
    char c_cc[NCC];      /* control chars */
};
```

- c_cc array in struct termio
- c_iflag input mode flag in struct termio
    - IGNBRK
    - BRKINT
    - IGNPAR
    - PARMRK
    - INPCK
    - ISTRIP
    - INLCR
    - IGNCR
    - ICRNL
    - IUCLC
    - IXON
    - IXANY
    - IXOFF
- c_oflag output mode flag in struct termio
    - OPOST
    - OLCUC
    - ONLCR
    - OCRNL
    - ONOCR
    - ONLRET
    - OFILL
    - OFDEL
    - NLDLY
    - NL0
    - NL1
    - CRDLY
    - CR0
    - CR1

        - CR2
        - CR3
        - TABDLY
        - TAB0
        - TAB1
        - TAB2
        - TAB3
        - BSDLY
        - BS0
        - BS1
        - VTDLY
        - VT0
        - VT1
        - FFDLY
        - FF0
        - FF1
- c_cflag in struct termio
    - B0, B50, B75, B110, B134, B150, B300, B600, B1200, B1800, B2400, B4800, B9600, B19200, B38400 This are to select baud rate
    - CSIZE
    - CS5, CS6, CS7, CS8 These are for setting data bit length, between 5..8
    - CSTOPB
    - CREAD
    - PARENB This is for enabling parity check
    - PARODD This is to select odd parity
    - HUPCL
    - CLOCAL
- c_lflag in struct termio
    - ISIG
    - ICANON
    - XCASE
    - ECHO
    - ECHOE
    - ECHOK
    - ECHONL
    - NOFLSH

Additional Commands

The additional commands use the following form of ioctl() calls:

```
ioctl(int fileDescriptor, int termioCommand, int arg);
```

The following termio commands use this form:

TCSBRK

Wait until output is empty (drain). Optionally, a break can be sent when this happens. In fact, this is the most common application

```
#include <termio.h>

/* Convenience macros for the waitBreak cmd argument */
#define WAIT_N_BREAK  0
#define WAIT_ONLY     1

/*
 * Function for waiting until output is empty and opt. sending a break
 */
tcWaitBreak(int fileDescriptor, int cmd) {
    ioctl(fileDescriptor, TCSBRK, cmd);
}

/*
 * Send break when output is empty
 */
tcBreak(int fileDescriptor) {
     tcWaitBreak(fileDescriptor, WAIT_N_BREAK);
}
```

TCXONC

Start or stop the output.

```
#include <termio.h>

/* Convenience macros for the start/stop cmd argument */
#define STOP  0
#define START 1

/*
 * Function for starting /stopping output
 */
tcStartStop(int fileDescriptor, int cmd) {
    ioctl(fileDescriptor, TCXONC, cmd);
}

/*
 * stop output
 */
tcStop(int fileDescriptor) {
    tcStartStop(fileDescriptor, STOP);
}

/*
 * start output
 */
tcStart(int fileDescriptor) {
    tcStartStop(fileDescriptor, START);
}
```

TCFLSH
Flush the input, output, or both queues.

```
#include <termio.h>

/* Convenience macros for the flush cmd argument */
#define FLUSH_IN   0
#define FLUSH_OUT  1
#define FLUSH_BOTH 2

/*
 * Function for flushing a terminal/serial device
 */
tcFlush(int fileDescriptor, int cmd) {
   ioctl(fileDescriptor, TCFLSH, cmd);
}
```

Serial I/O on the Shell Command Line

Introduction

It is possible to do serial I/O on the Unix command line. However, the available control is limited. Reading and writing data can be done with the shell I/O redirections like **<**, **>**, and **|**. Setting basic configuration, like the baud rate, can be done with the stty (set terminal type) command.

Configuration with stty

The Unix command stty allows one to configure a "terminal". Since all serial I/O under Unix is done via terminal I/O, it should be no surprise that stty can also be used to configure serial lines. Indeed, the options and parameters which can be set via stty often have a 1:1 mapping to termio/termios. If the explanations regarding an option in the **stty***(1)* man page is not sufficient, looking up the option in the termio/termios man page can often help.

On "modern" (System V) Unix versions, stty changes the parameters of its current **standard input**. On older systems, stty changes the parameters of its current **standard output**. We assume a modern Unix is in use here. So, to change the settings of a particular serial interface, its device name must be provided to stty via an I/O redirect:

```
stty parameters < /dev/com0  # change setting of /dev/com0
```

On some systems, the settings done by stty are reverted to system defaults as soon as the device is closed again. This closing is done by the shell as soon as the stty *parameters* < /dev/com0 command has finished. So when using the

above command, the changes will only be in effect for a few milliseconds.

One way to keep the device open for the duration of the communication is to start the whole communication in a sub shell (using, for example, '(...)'), and redirecting that input. So to send the string "ATI0" over the serial line, one could use:

```
( stty parameters
  echo "ATI0"
) < /dev/com0 > /dev/com0
```

Interweaving sending and receiving data is difficult from the command line. Two processes are needed; one reading from the device, and the other writing to the device. This makes it difficult to coordinate commands sent with the responses received. Some extensive shell scripting might be needed to manage this.

A common way to organise the two processes is to put the reading process in the background, and let the writing process continue to run in the foreground. For example, the following script configures the device and starts a background process for copying all received data from the serial device to standard output. Then it starts writing commands to the device:

```
# set up device and read from it
# Capture PID of background process so
# terminate process once writing is done
# TODO: Also set up a trap in case script is killed
#       or crashes.
( stty parameters; cat; )& < /dev/com0
pid=$?

# Read commands from user, send them to device
while read cmd; do
   echo "$cmd"
done >/dev/com0

# Terminate background read process
kill $pid
```

If there is a chance that a response to some command might never come, and if there is no other way to terminate the process, it is advisable to set up a timeout by using the alarm signal.

Permanent Configuration

Overview

It is possible to provide a serial line with a default configuration. On classic Unix this is done with entries in the /etc/ttytab configuration file, on newer (System V R4) systems with /etc/ttydefs.

The default configurations make some sense when they are used for setting up terminal lines or dialup lines for a Unix system (and that's what they are for). However, such default configurations are not of much use when doing some serial communication with some other device. The correct function of the communication program should better not depend on some operating system configuration. Instead, the application should be self-contained and configure the device as needed by it.

/etc/ttytab

The ttytab format varies from Unix to Unix, so checking the corresponding man page is a good idea. If the device is not intended for a terminal (no login), then the *getty* field (sometimes also called the program field, usually the 3rd field) for the device entry should be empty. The init field (often the 4th field) can contain an initialization command. Using stty here is a good idea. So, a typical entry for a serial line might look like:

```
# Device    TermType    Getty   Init
tty0        unknown     ""      "stty parameters"
```

/etc/ttydefs

Just some hints:

/etc/ttydefs provides the configuration as used by the **ttymon** program. The settings are similar to the settings possible with stty.

ttymon is a program which is typically run under control of the Service Access Controller (SAC), as part of the Service Access Facility (SAF).

TODO: Provide info to set up all the sac/sacadm junk.

[edit]

/etc/serial.conf

Just some hints:

A Linux-specific way of configuring serial devices using the **setserial** program.

tty

tty with the **-s** option can be used to test if a device is a terminal (supports the termio/termios ioctl()'s). Therefore it can also be used to check if a given file name is indeed a device name of a serial line.

```
echo "Enter serial device name: \c"
read dev
if tty -s < "$dev"; then
```

```
  echo "$dev is indeed a serial device."
else
  echo "$dev is not a serial device."
fi
```

tip

It is a simple program for establishing a terminal connection with a remote system over a serial line. tip takes the necessary communication parameters, including the parameters for the serial communication, from a tip-specific configuration file. Details can be found in the tip*(1)* manual page.

uucp

Uucp (Unix-to-Unix-Copy) is a set of programs for moving data over serial lines/modems between Unix computers. Before the rise of the Internet uucp was the heart and foundation of services like e-mail and usenet (net news) between Unix computers. Today uucp is largely insignificant. However, it is still a good choice if two or more Unix systems should be connected via serial lines/modems.

System Configuration

inittab, ttytab, SAF configuration

Serial Java

Using Java for Serial Communication

Introduction

The Java programming language gained rapid usage in the last few years. So it is natural that people ask for being able do program serial interfaces in Java. Since Java is supposed to be platform-independent, and doesn't provide any facilities for system programming, serial programming in Java requires a standardised API with platform-specific implementations.

Unfortunately, Sun doesn't pay much attention to serial communication in Java. Sun has defined a serial communication API, called *JavaComm*, but an implementation of the API is not part of the Java standard edition. Sun provides a reference implementation for a few, but not all Java platforms. Third party implementations for some of the omitted platforms are available. *JavaComm* hasn't seen much maintenance activities, only the bare minimum maintenance is performed by Sun.

This situation, and the fact that Sun does not provide a *JavaComm* implementation for Linux led to the development of the free software *RxTx* library. *RxTx* is available for a number of platforms, not only Linux. It can be used in conjunction with *JavaComm* (*RxTx* providing the hardware-specific drivers), or it can be used stand-alone. When used as a *JavaComm* driver the bridging between the *JavaComm* API and *RxTx* is done by *JCL* (*JavaComm for Linux*). *JCL* is part of the *RxTx* distribution.

Sun's negligence of *JavaComm* and *JavaComm'*s particular programming model gained *JavaComm* the reputation of being unusable. Fortunately, this is not the case. Unfortunately, the reputation is further spread by people who don't know the basics of serial programming at all and make *JavaComm* responsible for their incompetence.

RxTx - if not used as a *JavaComm* driver - provides a richer interface, but one which is not standardised. *RxTx* supports more platforms than the existing *JavaComm* implementations.

So, which of the libraries should one use in an application? If maximum portability (for some value of "maximum") is desired, than *JavaComm* is a good choice. If there is no *JavaComm* implementation for a particular platform available, but an *RxTx* implementation is, then *RxTx* could be used as a driver on that platform for *JavaComm*. This way the application doesn't need to be changed, and can work against just one interface, the standardised *JavaComm* interface.

Installation

Both *JavaComm* and *RxTX* show some installation quirks. It is highly recommended to follow the installation instructions word-for-word. If they say that a jar file or a shared library has to go into a particular directory, then this is meant seriously! If the instructions say that a particular file or device needs to have a specific ownership or access rights, this is also meant seriously. Many installation troubles simply come from the fact that people are not able to read and follow the instructions.

It should especially be noted that some versions of *JavaComm* come with two installation instructions. One for Java 1.2 and newer, one for Java 1.1. Using the wrong one will result in a non-working installation. On the other hand, some versions/builds/packages of *RxTx* come with incomplete instructions. In such a case the corresponding source code distribution of *RxTx* needs to be obtained, which should contain complete instructions.

A general problem, both for *JavaComm* and *RxTx* is, that they resist installation via Java WebStart:

JavaComm is notorious, because it requires a file called *javax.comm.properties* to be placed in the JDK lib directory, something which can't be done with Java WebStart. This is particularly sad, because the need for that file is the result of some unnecessary design/decision in *JavaComm* and could have easily been avoided by the *JavaComm* designers.

RxTx on some platforms requires to change ownership and access rights of serial devices. This is also something which can't be done via WebStart.

JavaComm API

The official API for serial communication in Java is the JavaComm API. This API is not part of the standard Java 2 version. Instead, an implementation of the API has to be downloaded separately. Sun provides reference implementations for Windows and Solaris, which can be downloaded from Sun's JavaComm web page. For other operating systems one has to check the operating system vendor for JavaComm implementation or at least a JavaComm driver.

Unfortunately, JavaComm has not much attention from Sun, and hasn't been really maintained for a long time. From time to time Sun does trivial bug-fixes, but doesn't do the long overdue main overhaul.

The JavaComm download comes with several examples. These examples almost contain more information about using the API than the API documentation. Unfortunately, Sun does not provide any real tutorial or some introductory text. Therefore, it is worth to study the example code to understand the mechanisms of the API. Still, the API documentation should be studied, too. But the best way is to study the examples and play with them. Due to the lack of

easy-to-use application and people's difficulty to understand the API's programming model, the API is often bad-mouthed. The API is better than its reputation and functional. But not more.

The API uses a callback mechanism to inform the programmer about newly arriving data. It is also a good idea to study this mechanism instead of relying on polling the port. Unlike other callback interfaces in Java (e.g. in he GUI), this one only allows to have one listener listening to events. If multiple listeners should listen to serial events, the one primary listener has to be implemented in a way that it dispatches the information to other secondary listeners.

Insert simple read/write example here

SerialIO

Because of delays in Sun's releasing of JavaComm, SerialIO.com released their own drivers and APIs over a full year before Sun Microsystems announced the first *beta* of javax.comm.SerialPort. Their commercial product is the most widely used commercial serial port communications API, and offers native libraries for the following platforms: Windows, OS/2, Mac, Unix (Solaris, HP/UX, FreeBSD, SGI, AIX, SCO), Linux, Alpha and mobile devices (T-Mobile ARM, EPOC32 ARM, Sharp Zaurus and Palm OS 5.2)

RxTx

Due to the fact that Sun didn't provide a reference implementation of the JavaComm API for Linux, people developed RxTx for Java and Linux [2]. RxTx can be used independent of the JavaComm API, or can be used as a so called provider for the JavaComm API. In order to do the later, a wrapper called JCL is also needed [3]. JCL and RxTx are usually packaged together with Linux/Java distributions. So, before trying to get them separately, it is worth having a look at the Linux distribution CD.

The latest version of RxTx is known to work on Linux, Windows, Mac OS, Solaris and other operating systems.

There seems to be a trend to abandon the JavaComm API, and using RxTx directly instead of via the JCL wrapper, due to Sun's limited support and improper documentation for the JavaComm API.

See also

- Sun Java Communications API
- Java Comm Serial API How-To for Linux
- RxTx Home Page
- SerialIO Home Page

Forming Data Packets

Just about every idea for communicating between computers involves "data packets", especially when more than 2 computers are involved.

The idea is very similar to putting a check in an envelope to mail to the electricity company. We take the data (the "check") we want to send to a particular computer, and we place it inside an "envelope" that includes the address of that particular computer.

A packet of data starts with some address information, some other transmission-related information, followed by the raw data, and finishes up with a few more bytes of transmission-related data (often a Adler-32 checksum).

The accountant at the electricity company throws away the envelope when she gets the photo. She already knows the address of her own company. Does this mean the "overhead" of the envelope is useless ? No.

Unfortunately, there are dozens of slightly different, incompatible protocols for data packets, because people pick slightly different ways to represent the address information and the check data.

... gateways between incompatible protocols ...

external links

- http://intcomm.wiki.taoriver.net/moin.cgi/ProtocolMadness
- UDP
- TCP/IP
- ATM
- HTTP
- VSCP - Very Simple Control Protocol http://www.vscp.org/ "The protocol is free"
- "Protocol Design Folklore" by Radia Perlman. Jan 15, 2001. http://www.awprofessional.com/articles/article.asp?p=20482
- "Devices that play together, work together: UPnP defines common protocols and procedures to guarantee interoperability among network-enabled PCs, appliances, and wireless devices." article by Edward F Steinfeld, EDN, 9/13/2001 http://www.reed-electronics.com/ednmag/index.asp?layout=article&articleid=CA154802&spacedesc=readersChoice&rid=0&rme=0&cfd=1
- CAN bus http://computer-solutions.co.uk/ http://computer-solutions.co.uk/gendev/can-module.htm

  "CMX-MicroNet is the first system that allows TCP/IP
  and other protocols to be run natively on small processors
  ... [including] AVR, PIC 18, M16C."

- "byteflight is a high speed data bus protocol for automotive applications" http://byteflight.com/
- Nagle's rule ... The Nagle algorithm. "Nagle's rule is a heuristic to avoid sending particularly small IP packets, also called tinygrams. Tinygrams are usually created by interactive networking tools that transmit single keystrokes, such as telnet or rsh. Tinygrams can become particularly wasteful on low-bandwidth links like SLIP. The Nagle algorithm attempts to avoid them by holding back transmission of TCP data briefly under some circumstances." -- http://www.tldp.org/LDP/nag/node45.html
- ... other packet protocols ? ...

Error Correction Methods

Introduction

There are 3 main types of handling errors:

- acknowledge or retry (ACK-NAK).
- "Forward Error Correction" (FEC)
- Pretend It Never Happened

ACK-NAK

Each packet is checked by the receiver to make sure it is "good".

If it *is* good, the receiver (eventually) tells the sender that it came through OK -- it acknowledges (ACK) the packet.

All versions of ACK-NAK absolutely require Two Way Communication.

How does the receiver know it's good ?

The sender calculates a checksum or CRC for the entire packet (except for the footer), then appends it to the end of the packet (in the footer/trailer).

The typical CRC is 32 bits.

Whenever the receiver receives a packet, the receiver calculates exactly the same checksum or CRC, then compares it to the one in the footer/trailer. If they match, the entire packet is (almost certainly) good.

When there's even the slightest question that the packet has any sort of error (which could be *either* in the actual data *or* in the checksum bits -- there's no way for the receiver to tell), the receiver discards it completely and (in most cases) pretends it never saw it.

If it's not good, the *sender* sends it again.

How does the sender know it wasn't good ?

It never got the ACK. (So either the packet was corrupted, *or* the ACK was corrupted -- there's no way for the sender to know).

"Stop-and-wait ARQ"

The simplest version of ACK-NAK is "Stop-and-wait ARQ".

The sender sends a packet, then waits a little for an ACK. As soon as it gets the ACK, it immediately sends the next packet. If the sender doesn't hear the ACK in time, it starts over from the beginning, sending the same packet again, until it does get an ACK.

The receiver waits for a packet. If the packet passes all the error-detection tests perfectly, the receiver transmits an ACK (acknowledgement) to the sender.

Subtleties: Some early protocols had the receiver send a NAK (negative acknowledgement) to the sender whenever a bad packet was received, and the sender would wait indefinitely until it received *either* an ACK *or* a NAK. This is a bad idea. Imagine what happens when (a) a little bit of noise made a bad packet, so the receiver sends the NAK back to the sender, but then (b) a little bit of noise made that NAK unrecognizable. Alternatively, imagine a shared-medium network with 1 sender and 2 receivers. What happens when a little noise messes up the "destination" field of the packet ?

Note that the sender only needs to keep 1 packet in memory at a time.

streaming ARQ

The sender sends a packet, then the next packet, then the next, without waiting.

As it sends each packet, it puts a copy of that packet in a "window".

Each packet is consecutively numbered.

... turn-around time ... bouncing off geostationary satellites ...

The receiver occasionally transmits an acknowledgement ("I got all packets up to 8980", "I got all packets up to 8990").

If the receiver is expecting packet number 9007, but it receives a packet with an *earlier* number (that it had already received successfully), it transmits (or possibly re-transmits) a "I got all packets up to 9006" message.

When the sender receives an acknowledgement of any packet in the "window", it deletes that copy.

When the sender's window gets full, it waits a little, then tries re-sending the packets in the window starting with the oldest.

So when the sender suspects an error in some packet, it resend *all* packets starting with the erroneous packet. This guarantees that the receiver will (eventually) receive all packets in order.

Optionally, If the receiver is expecting packet number 9007, but it receives packet number 9008, it may transmit a negative acknowledge (NAK) for 9007, and ignores any higher packet numbers until it gets packet 9007.

When the sender receives a NAK for any packet in the window, it re-starts transmission with that packet (and keeps it in the window).

(There's a variant where the receiver tries to keep a copy of all packets it receives in a window of its own, and negotiates with the sender to try to resend *only* the erroneous packets).

Note that the sender needs to keep the entire window of packets in memory at a time.

(Some people think of "streaming" as one big packet the size of the window using "stop-and-wait" protocol, divided into smaller "sub-packets").

FEC

If you have only one-way communication, you are forced to use Forward Error Correction, sometimes called EDAC (Error Detection And Correction).

You transmit the data, then (instead of a CRC) you transmit "check bits" that are calculated from the data.

... NASA space probes ... compact disks ...

The simplest kind is "repeat the message".

If I send the same packet 2wice, and noise only corrupts one of them, *and* the receiver can tell which one was corrupted, then no data was lost. If I send the same packet 3 times, and noise corrupts any one of them, then the receiver can do "best 2 out of 3". The "check bits" are 2 copies of the data bits. In fact, noise could corrupt a little bit of *all three* of them, and you could still extract all the data -- align the 3 packets next to each other, and do "best 2 out of 3" for every bit. As long as there were only a few bits of noise in each packet, and the noise was in a different place in each packet, all the data can be recovered.

... (put picture here) ...

There are some very clever kinds of FEC (Hamming codes, Reed-Solomon codes) that can correct all kinds of common errors better than "best 2 out of 3", and only require the same number of "check bits" as there are data bits.

Pretend It Never Happened

A sender often streams audio and video live, in real-time.

What should a receiver do when a packet gets mangled ?

If it sends a message back to the sender, asking it to resend that packet, by the time the reply gets back, it's probably several video frames later. It's too late to use that information.

Rather than pausing the entire movie until the request makes a round-trip, it's far

less jarring to the audience if the receiver silently discards the mangled packet, fills in as best it can (filling in black pixels is less noticeable than filling in with a flash of white pixels), try not to draw attention to the error, and continue on as if nothing had happened.

combination

Even when they have 2-way communication, sometimes people use FEC anyway. That way small amounts of noise can be corrected at the receiver. If a packet is corrupted so badly that FEC cannot fix it, the protocol falls back on ACK-NAK retransmission (or on Pretend It Never Happened).

external links

a detailed description of one ACK-NAK protocol: "XModem / YModem Protocol Reference" by Chuck Forsberg 1988-10-14
http://www.commonsoftinc.com/Babylon_Cpp/Documentation/Res/yModem.htm

a detailed description of one streaming protocol: "The ZMODEM Inter Application File Transfer Protocol" by Chuck Forsberg 1988-10-14
http://www.commonsoftinc.com/Babylon_Cpp/Documentation/Res/zModem.htm

"Data Link Error Detection / Correction Methods"
http://techref.massmind.org/techref/method/errors.htm brief descriptions of several error correction methods: Hamming codes, Fire codes, Reed-Solomon codes, Viterbi decoding, etc.

Appendix A:Modems and AT Commands

Introduction

What is Hayes?

Hayes Microcomputer Products, Inc. was a modem manufacturer from the beginning of the 1980s until the end of the 1990s, with its heyday in the early '90s. The name *Hayes* still exists as a brand name, owned by *Zoom Telephonics, Inc.* (as of Fall 2004).

In 1981, Hayes developed the **Hayes Smartmodem**. This was a unique product at the time, because this modem was no longer simply a "dumb" device blindly converting serial data to and from audio tones, but contained some "intelligence". It was possible to send commands to the modem to configure it, to execute certain operations (such as dialing a number, quieting the speaker, hanging up, etc.), and to read the current status of the connection. Hayes developed and published a command set to control the modem over a serial line. This command set became popular among consumer modem manufacturers, and was cloned a thousand times. Known as both the "Hayes command set" and the "AT command set", it has long been the de-facto standard for controlling consumer modems. Modems which support this command set are called *Hayes-compatible*. Since the command set was never precisely standardized, the implementations in different modems vary slightly.

Over time, modem manufacturers enhanced the command set with their own commands and extensions. Some of these enhancements were required to support emerging features, such as data compression and FAX support. As a result, the command sets of modern modems are no longer fully compatible with each other. The original Hayes commands, however, should still work, and still form the core of almost all consumer modem command sets.

See Also: Wikipedia:Hayes_Communications

What are AT Commands?

Almost all of the Hayes modem commands start with the two letter sequence AT - for getting the modem's *attention*. Because of this, modem commands are often called *AT Commands*. This still holds for many of the manufacturer specific command set extensions. Most of them also start with AT, and are called *AT Commands*, too. Extension commands frequently have an ampersand ("&") after the AT; for example, AT&F will reset certain US Robotics modems to their factory defaults.

The exact usage of the term slightly varies from manufacturer to manufacturer, often subject to marketing blurbs. In general, it can be assumed that a modem with an *AT command set*

- uses commands mostly starting with AT,
- uses the original Hayes way of separating data and commands, and
- supports the original Hayes commands and register settings as a subset.

What is a Modem?

A modem in the classic sense is a **mo**dulator/**dem**odulator for transmitting digital information over analog wires, such as the analog telephone system's two-wire or four-wire lines. The term has come to be used as acceptable slang for many communication devices used to link a computer to either another computer, or a wide-area network (Wikipedia:WAN). For example, the Ricochet radio data transceivers were commonly known as "Ricochet modems".

This module deals with the classic type of *smart* modems, designed to convert data from/to a serial interface to/from an analog line. The module also applies to modems which provide the classic serial interface but connect over a different physical layer, such as a digital line, as well as devices providing a serial modem-like interface for other purposes. For our purpose, the modem is a classic DCE (data communications equipment) device, controlled via serial line by a classic DTE device (such as a computer).

Depending on the type of modem, the modem can use a number of different technologies and speeds to transmit the data over the analog line. The details of these technologies are of no particular interest here, other than to note that it is possible with most modems to specify these communication parameters (for example, to disable compression, or to change modulation techniques). The data this module deals with is not the data on the analog line, but the data as it appears on the serial interface between the DTE and DCE.

(*Smart*) Modems also provide auxiliary services, such as dialing a particular number to set up a connection. As a consequence, a modem can be in a number of different states and modes, which are not always orthogonal. It is possible, for example, for a modem to be in the command mode while still keeping a connection (see the +++ sequence for details).

For further details of low-level serial communications, please see Serial Data Communications and in the future the Serial communications bookshelf.

See Also: Wikipedia:Modem

Inband Signalling

The original RS232C/V.24 specification contained wiring for transmitting data, but also for transmitting control information between the DTE and DCE, the idea being to separate data and control information. In telecommunication jargon this

is called **outband signalling**.

Hayes-compatible modems use almost none of these RS232C/V.24 features. Instead, communication with the modem is done via the same RX/TX lines which are used for transferring the data. This mechanism is called **inband signalling**.

Inband signalling has significant disadvantages. At any point in time, both the DTE and DCE must know if information sent or received via the TX and RX lines is for signalling purposes, or if it is data, which should be handled transparently. Therefore, the DTE and DCE must operate in sync. If they get out of sync, either data will be lost, or signalling information will be interpreted as data, effectively destroying the original data.

Inband signalling has the advantage that the wiring between the DTE and DCE is simpler, and also that, at least at first glance, the communication software in the DTE is simpler.

See also the RS232 Technical Manual.

Command State / On-line State

With respect of controlling the modem a Hayes-compatible modem is one of two states:

Command State
: The modem interprets data from the DTE as modem commands. The modem can be in command state while still keeping a connection with a remote party.

On-line State
: The modem interprets data from the DTE as payload and transmits it to the other party. This state requires that a connection to the remote site has been established.

Originating Mode / Answer Mode

Originating mode
: A modem in originating mode is a modem which is setting up a connection, e.g. by dialing the number of a remote station and initiating the negotiation of protocols.

Answer Mode
: A modem in answer mode is a modem waiting to be contacted and ready to "answer the phone".

Command Responses

A modem is supposed to send a response for almost all commands it receives. These responses can either be in the form of ASCII strings, or numeric values. The response type can be switched with a command, but it is typical to use the ASCII responses.

Responses need to be tracked by the DTE with great care. Among other things they inform the DTE if the dialing of the remote site was successful or not, and if the modem switches from command state to on-line state or not.

Unfortunately, the set of response messages has been greatly enhanced since the original Hayes modems and are often configurable via additional AT commands. It is suggested to not strictly parse response messages but to forgivingly check if they contain interesting keywords, like CONNECT. It is also suggested to study the manual of a particular modem very carefully.

S-Registers

The so called S-registers are also a Hayes heritage which all Hayes-compatible modems support. They are registers in the modem which contain various settings. And like the AT commands, they have been extensively enhanced by different modem manufacturers.

The reason why they are called **S**-Registers is a little bit unclear. Some say the **S** stands for modem *settings*. Some say they are just called like this, because they are set and read with ATS... commands.

Several of the other AT commands also change values in a particular S-Register. There is usually no difference in setting a value directly via an S-Register or via another AT command. It depends on the particular situation which way of setting a register is better.

Modem Programming Basics

Command Reference

In order to program for an actual modem it is a rather good idea to obtain the command reference for that particular modem. Unfortunately, it has become quite common for no-name modems to ship without any kind of usable command reference. Thanks to Windows' Plug & Play feature it is no longer necessary on Windows to know the individual commands. Instead, all that is needed for a modem to run on Windows is to be shipped with the necessary .inf files (often hidden inside some "installer" software).

If the modem doesn't come with a command reference the next logical step is to search the Web. However, unfortunately, a lot of modem information has

vanished from the surface of the earth and the web in recent years. With the rise of broadband internet connections, Modems have become old fashioned devices and many sources are no longer available. It has become more and more difficult to find basic information about particular modem types.

There are an number of alternatives to obtain a command reference if one doesn't come with the modem:

- Maybe the distributor provides one on its website
- Maybe the OEM manufacturer provides one.
  This requires to identify the OEM manufacturer. A possible way is to use the FCC number of the device, and then looking the original manufacturer up on the FCC web site.
- Maybe the chipset manufacturer provides one.
  Consumer modems are often just build around "off-the-shelf" modem chipsets from larger hardware manufacturers. The cheaper the modem, the more likely it is that the modem manufacturer didn't change anything in the firmware and is using the original example software form the chipset manufacturer. Some chipset vendors provide command references for their modems.
- By looking into the corresponding Windows .inf files it is possible to at least obtain the basic commands
- By using the generic Hayes command reference in this Wikibook module.

Setting up a Development Environment

It is highly recommended to spend some preparation time setting up a suitable development environment before starting to write drivers or software for a modem. Most of this consists of hardware setup.

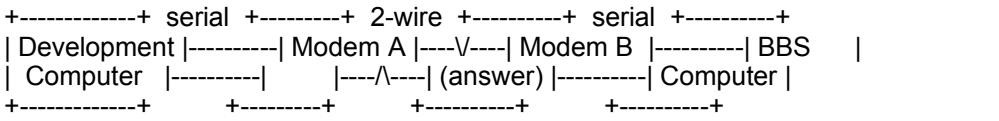
It is suggested to set up a small network with a "remote" computer and a second modem in answer mode. "Remote" computer in this case means a computer sitting right next to the development machine, but connected via the modems. If a **terminal program** is being developed, the "remote" computer should run some small BBS software (for example), so there is always someone ready to answer, and/or protocol analysis/data dump software. Developing modem software without such a setup can be extremely frustrating. Such a setup pays off a hundred times in reduced development time and lower stress. Likewise, the modems used should have real speakers, and support ATM*n* commands well enough that you can leave the speaker on for the entire connection process (and ideally have the option to leave it on, period). "Debugging by ear" can be a reality with modems, particularly during compatibility testing.

If possible, a hardware protocol analyzer, or at least an RS-232 breakout box, should be obtained. These can be placed between the computers and modems, if needed, to troubleshoot the serial link and ensure that data is, in fact, being transferred between the modem and the computer -- a sanity check which comes in handy far more often than you might expect. Actual hardware protocol

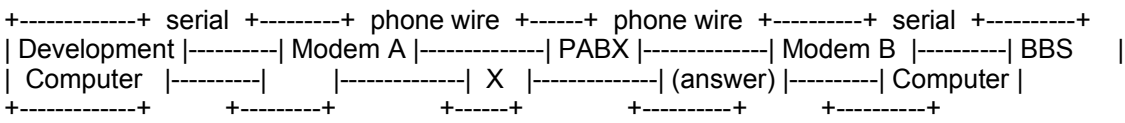
analyzers are surprisingly expensive, however; old Wyse terminals are not, and are almost as useful for this purpose. If you find one, pick it up. Terminals that support automatic baud-rate detection are particularly useful.

If dialing with the modem also needs to be tested, a small analog PABX for home usage is needed. These PABX units are dirt cheap; an analog PABX for four internal lines and one external line should cost no more than US$50. If dialing is not needed, then the modems should be capable of directly driving a two-wire or four-wire line in **leased-line** mode; otherwise, the PABX is still needed.

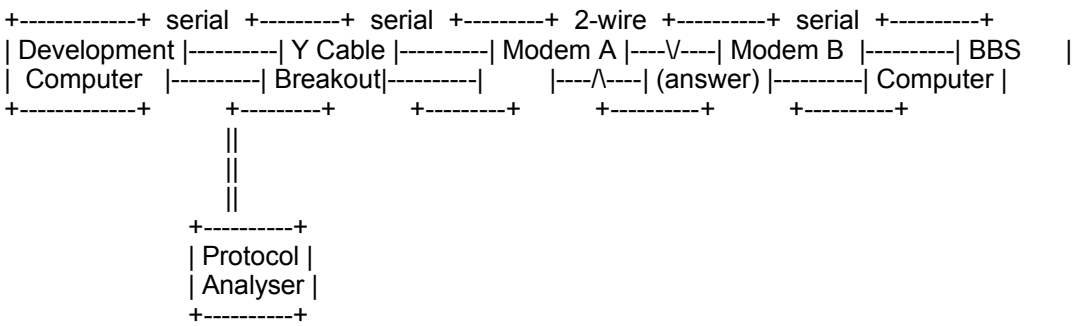
Possible setups are for example:



or



or



Operating System, Programming Language & Communication Basics

Before dealing with the details of handling a modem, a few basics should be in place. First of all, the communication with the serial interface should be in place. This includes that the APIs as provided by the particular operating system for serial communication - if any - should be understood. If the operating system doesn't provide such APIs, then it is recommended to first implement the UART access and wrap it into a library, if the serial UART in some hardware is supposed to be programmed directly. Alternatively, a programming language which provides convenient access to a serial interface can be used.

Whatever is used, it should be tested before starting to program for the modem.

There is nothing more annoying than not knowing if a particular misbehaviour is caused by a failure in the serial communication with the modem, or is a problem with the modem (usually with the commands sent to it).

Unless in the most simple case, it is suggested to use hardware handshaking with the modem - particularly for speeds greater then 2400 bps or 9600 bps. Therefore, the used low-level serial communication software and hardware should support hardware handshake. If the UART supports some FIFO, like the 16550 UART, the FIFO should be enabled (both for sending and receiving data).

It is undecided if data reception via polling or via interrupts is better. If every incoming byte raises an interrupt there are many interrupts at high communication speeds, and, as surprising as it might sound, polling the UART might be more efficient in such cases.

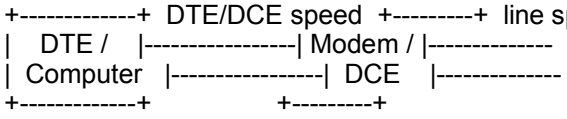
Communication as supported by a modem is usually half-duplex. Either the DTE or the DCE talks, the other side is supposed to listen. The communication with the modem should best be done with

- 8 Bit
- No parity
- 1 Stop bit

See the next section for speed information.

[edit]

Line Speed is not DTE/DCE Speed



An issue which can be very confusing is the difference between the line speed (the data transfer speed on the telephone line) and the speed on the serial line between the DTE (computer) and the DCE (modem).

First, there is always some general confusion about the line speed, because some line speed is given with taking compression into account, while other data is given without taking compression into account. Also, there is a difference between *bps* and *Baud* due to the modulation schema used on the line. In addition, marketing blurbs obscure the picture. We will not make any attempt to clean up the long-standing Baud vs. bps confusion here (it is hopeless :-)). It is just recommended that whenever the modem returns information about line speed the above mentioned differences are taken into account to avoid any misinterpretation.

Second, the speed on the telephone line does not necessarily have to be the same as the speed on the serial line. In fact, it usually isn't on modern modems.

It is recommended to set the DTE/DCE speed to a fixed speed instead of following the line speed. Logically, the fixed DTE/DCE speed should be large enough to cope with the highest expected line speed. V.90 modems should e.g. be accessed via 115200 bps or higher on the serial interface.

Setting the DTE/DCE speed on modern modems is quite simple. They all use autosensing on the serial interface. That is, they themselves detect the speed of data as received from the DTE and use the same speed to return data to the computer. They usually also autosense the parity, and 7 bit / 8 bit data length. Usually modems assume one stop bit when autosensing the serial interface.

When a modem sets up a connection with a remote party it can report the used speed. In fact, it can report the line speed or just the DTE speed (some modems can report both). The end user is most probably interested in the line speed, and not the DTE/DCE speed. So from this point of view, it is best to set the modem to report the line speed, and e.g. write the received information to a log file. However, some old communication software or modem drivers interpret the response from the modem as a request to change the DTE/DCE speed. In such cases the modem must be set to always return the DTE/DCE speed. Since this DTE/DCE speed will be the same as detected via autosensing there will be no speed change.

In the rare case that the DTE/DCE speed should indeed follow the line speed, the responses from the modem should of course be set to return the line speed. Then the DTE software has to evaluate the response, and change the DTE/DCE speed accordingly. This is really not recommended these days.

See the #W: Negotiation Progress Message Selection command for details on how to set which response to get.

Note: Some modem manufacturers call the DTE/DCE speed *DTE speed*, and the line speed *DCE speed*. Others distinguish between *DTE speed* (DTE/DCE speed on the serial interface), *DCE speed* (bps between the modems), and *line speed* (Baud rate between the modems).

Character Set and Character Case

Commands sent to the modem, and textual responses are supposed to be in the ISO 646 character set, which is just another name for the familiar 7-bit ASCII character set. Typically, modems chop off any 8th bit in commands they receive anyhow, and interpret the result as if the command has been sent using only 7-bit characters. However, it is not recommended to rely on this, but instead ensure that commands are only sent using 7-bit characters.

Commands are not case sensitive, assuming a modern modem. Some early modems insisted on uppercase-only commands. Still, a generic driver could do worse than ensuring that all commands are sent in uppercase, and all responses are interpreted case-independent. Typically, both letters of the AT command

prefix must be of the same case. So AT and at are acceptable, while At and aT are not.

Flow Control

A slow device needs a way to tell its peer that currently, it is busy, so further incoming data must be stopped until this slow device tells otherwise. This mechanism is provided by flow control. There are two ways of doing flow control: by hardware or software.

Hardware Flow Control

Hardware flow control is usually implemented using the CTS (Clear To Send) and RTS (Ready to Send) lines, which needs separate hardware data lines between devices. This is allocated in the RS-232 cable specification.

Software Flow Control

This kind of flow control doesn't need extra signal line(s) like hardware flow control, but instead uses special control characters within the data content. To stop further incoming data, the receiving device sends XOFF. To enable more data, an XON will be sent.

However, since the data being sent cannot contain these characters (unless you know that the receiving device ignores such information), binary (non-ASCII) data cannot be transmitted this way. Software flow control is typically used for communications to terminals and other character-based devices. Binary data should not be sent this way as it could, randomly, contain these characters. Hardware flow control using RTS/CTS is usually used.

Helpful Hint: Realizing that the Control Key is a special "shift" key that chops off the 100 bit (octal), it is easy to remember that the ASCII character used for sending XOFF is a Control-S (23 Octal) while the character for XON is a Control-Q (21 Octal). [Think of "S" for Stop and "Q" for Qontinue... don't you spell it that way?]

Changing State

General

Changing the state from command state to on-line state or vice versa is either straight forward or a great mystery. This module covers the more obscure ways.

On-line State to Command State

It is of course possible to switch from on-line state to command state by dropping the connection (going on-hook in modem terminology). It is also possible to temporarily switch into command state while keeping the connection.

Going on-hook programmatically (and not via dropping a modem control line) requires to first switch into command state while keeping the connection, too.

Switching into command state, while in fact in the middle of transferring data (nothing else is meant with on-line state) requires to send a certain escape sequence as part of the data. This escape sequence is detected by the modem and the modem changes state. Since this character sequence might also be part of the normal data, an additional mechanism is needed to separate the escape sequence from normal data. This is the curse of inband signalling.

The separation of the escape sequence is done by using a so called guard time. The escape sequence is only recognized by the modem when there was no other data from the DTE (terminal) for at least the duration of the guard time, and when there was no other data from the terminal after the escape sequence for at least the duration of the guard time, too.

An escape sequence consists of three times the same particular character. The character, as well as the guard time is configurable. By default, the character is +, and the guard time is one second. So, with the default configuration, a change to command state requires

<1 sec. nothing>+++*<1 sec. nothing>*

If the connection should be dropped, this escape sequence should be followed by the AT command to go on-hook, which is ATH0:

<1 sec. nothing>+++*<1 sec. nothing>*ATH0<*CR*>

Command State to On-line State

The usual way to go from command state to on-line state is via dialing the remote site (see D command). But if the connection already exists, and the modem has been switched to command mode via the escape sequence, the way is different.

If the connection should not be dropped, but instead data transmission should be continued, the ATO0 (letter o, digit zero) command is needed:

<1 sec. nothing>+++*<1 sec. nothing>*
send a few more modem commands, then go back on-line
ATO0<*CR*>

Sync. vs. Async. Interface

X.25 Interface

AT Commands

The following list is the list of the original Hayes commands. Different modems use slightly different commands. However, this list is supposed to be as "generic" as possible, and should not be extended with modem specific commands. Instead it is recommended to provide such command lists in an Appendix.

AT Command Format

Here is a summary of the format and syntax of AT commands. Please note that most of the control characters are configurable, and the summary only uses the default control characters.

- AT commands are accepted by the modem only when in command mode. The modem can be forced into command mode with the [[#+++: Escape Sequence]].
- Commands are grouped in command lines.
- Each command line must start with the #AT: Command Prefix and terminated with #<CR>: End-of-line Character. The only exception is the #A/: Repeat Last Command command.
- The body of a command line consists of visible ASCII characters (ASCII code 32 to 126). Space (ASCII code 32) and ASCII control characters (ASCII code 0 to 31) are ignored, with the exception of #<BS>: Backspace Character, #<CAN>: Cancel Character, and #<CR>: End-of-line Character.
- All characters preceding the #AT: Command Prefix are ignored.
- Interpretation / execution of the command line starts with the reception of the first (and also command-line terminating) #<CR>: End-of-line Character.
- Characters after the initial #AT: Command Prefix and before the #<CR>: End-of-line Character are interpreted as commands. With some exceptions, there can be many commands in one command line.
- Each of the basic commands consists of a single ASCII letter, or a single ASCII letter with a &prefix, followed by a numeric value. Missing numeric values are interpreted as 0 (zero).
- The following commands can't be followed by more commands on the command line. They must always be the last commands in a command

line. If they are followed by other commands, these other commands are ignored. However, some of these commands take command modifiers and it is possible that a following command is accidentally interpreted as a command modifier. Therefore, care should be taken to not follow these commands with any more commands on the same command line. Instead, they should be placed in an own command line.
    - #A: Answer Command
    - #D: Dial Command
    - #Z: Soft Reset Command
- A command line can be edited if the terminating #<CR>: End-of-line Character has not ben entered, using the #<BS>: Backspace Character to delete one command line character at a time. The initial #AT: Command Prefix can't be edited/deleted (it has already been processed, because upon reception of the #AT: Command Prefix the modem immediately starts command line parsing and editing, but not execution).
- The modem echoes command lines and edits when #E: Command State Character Echo Selection is on (surprise, surprise :-)).
- When echo is on, #<BS>: Backspace Characters are echoed with a sequence of <BS> <BS> (backspace, space, backspace) to erase the last character in e.g. a terminal program on the DTE.
- A command line can be canceled at any time before the terminating #<CR>: End-of-line Character by sending the #<CAN>: Cancel Character. No command in the command line is executed in this case.
- The #A: Answer Command and #D: Dial Command can also be canceled as long as the handshake with the remote site has not been completed. Cancelation is done by sending an additional character. In theory, it doesn't matter which character. But care has to be taken that cancelation is not attempted when the handshake has already completed. In this case the modem has switched to on-line state (#Command State to On-line State) and the character will be send to the remote side. A save way to avoid this problem is to always use the [[#+++: Escape Sequence]] followed by going on-hock with the #H: Hook Command Options. If the modem is already in the on-line state, this will drop the connection. If the modem is still in the handshake phase the first character of the [[#+++: Escape Sequence]] will cancel the command (and the rest will be interpreted as a normal command line, doing no harm).
- Command line execution stops when the first command in the command line fails, or the whole command line has been executed. Every command before the failed command has been executed. Every command after the failed command and the failed command in the command line has not been executed.
- There is no particular indication which command in a command line failed,

only that one failed. It is best to repeat the complete command line, or to first reset the modem to a defined state before recovering from a failure.

- A modem only accepts a new command line when the previous command line has been executed (half-duplex communication). Therefore, care should be taken to only send the next command line after the result code from the previous command line has been received.

Command Description Template

To be removed when all commands are documented

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

Special Commands and Character Sequences

AT: Command Prefix

Syntax:

AT<*command ...*><CR>

Description:

Almost every line with commands start with the AT prefix, followed by one or more commands, terminated with a Carriage Return character.

See the #AT Command Format section for details.

Related Commands and Registers:

- #<CR>: End-of-line Character
- #A/: Repeat Last Command

+++: Escape Sequence

Syntax:

<1 sec. nothing>+++<1sec. nothing>

Description:

See: #On-line State to Command State

Result Codes:

Result Codes

Code	Description
OK	Escape into command mode was successful

Related Commands and Registers:

- #O: On-Line Command
- #S2: Escape Sequence Character -- Register to change the character
- #S12: Escape Sequence Guard Time -- register to change the guard time

<CR>: End-of-line Character

Syntax:

AT command line<CR>

Description:

In command mode the end of line character (default ASCII 13, alias ASCII 0dH, alias <CR>, alias <Ctrl-M>, alias carriage return) marks the end of a command line. The modem starts to execute the command line after reception of the end-of-line character.

Result Codes:

Result Codes

Code	Description
OK	All commands in the command line were successfully executed.
ERROR	One command in the command line failed.

Related Commands and Registers:

- #AT Command Format
- #<BS>: Backspace Character
- #S3: Carriage Return Character -- Register to change the character.

<BS>: Backspace Character

Syntax:

AT command line<BS>*more command line*

Description:

In command mode the backspace character (default ASCII 8, alias ASCII 08H, alias <BS>, alias <Ctrl-H>, alias backspace) can be used to edit the command line.

Result Codes:

Result Codes

Code	Description
<none>	Does not generate a result code.

Related Commands and Registers:

- #AT Command Format
- #<CR>: End-of-line Character
- #S5: Backspace Character -- Register to change the character.

<CAN>: Cancel Character

Syntax:

AT command line<CAN>

Description:

In command mode the cancel character (default ASCII 24, aka ASCII 18H, aka <CAN>, aka <Ctrl-X>) cancels a command line as long as the command line has not been terminated with the #<CR>: End-of-line Character.

Result Codes:

Result Codes

Code	Description
<none>	No result code is returned.

Related Commands and Registers:

- #AT Command Format
- #<BS>: Backspace Character

A/: Repeat Last Command

Syntax:

A/

Description:

The command repeats the last command. It differs from other commands in two ways:

1. It is *not* prefixed with the AT command.
2. It should not be followed by the usual <CR>:

The most typical usage is to repeat a previous dialing command that failed because of a BUSY line.

Related Commands and Registers:

- #D: Dial Command

A: Answer Command

Syntax:

A

Description:

The command initiates handshake as answering side. No next commands in this command line are proceeded. If handshake succeeds, modem sends successful message ("CONNECT...") to serial line and serial line switches to data mode, otherwise failure message is sent and serial line remains in command mode.

Result Codes:

Result Codes

Code	Description
CONNECT	Handshaking succeeds
NO CARRIER	Handshake failed

CONNECT message usually contains speed, protocol and other details of succeeded connection and may be preceded with other messages of connection details.

Related Commands and Registers:

- #D: Dial
- #H: Hook Command Options
- #O: On-Line
- #S0: Register 0 - auto answer ring counter

B: Select Communication Standard

Syntax:

B[0|1] (original Hayes)
B[number] (extensions)

Description:

In original Hayes modems, it selects protocols for 300bps and 1200bps handshake: B0 selects CCITT protocols; B1 selects Bell protocols.

Some vendors (e.g. Rockwell) extends it to limit connection speed (e.g. B15 - no more than 28800 bps).

Result Codes:

Result Codes

Code	Description
OK	Speed/protocol selection succeeded
ERROR	Speed/protocol selection failed

Related Commands and Registers:

- A: Answer
- D: Dial
- +MS: Speed and protocol selection

C: Carrier Control Selection

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

D: Dial Command

Syntax:

D [T|P|digits|misc]

Description:

The command initiates dialing a number using pulse or tone.

Dial Modifiers:

- 0-9: Digits
- A-D, #, *: Characters for Dialing
- P: Pulse Dialing Modifier
- T: Tone Dialing Modifier
- W: Wait for Second Dial Tone
- ,: Delay
- @: Wait for Silence
- !: Flash
- ;: Return to Command State after Dialing
- DS=n: Dial Stored Telephone Number
- R: Originate Call in Answer Mode

E: Command State Character Echo Selection

Syntax:

E[0|1]

Description:

Switches character echo on (1) or off (0) when in the command state. Given no argument, assumes 0.

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid
ERROR	Bad number specified; must be either 0 or 1.

F: On-line State Character Echo Selection

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

H: Hook Command Options

Syntax:

H|H0|H1

Description:

As H or H0 ("hook on"), disconnects external line from modem and connects it to internal phone line, if any. If modem is connected, drop the connection.

As H1 ("hook off"), connects external line to modem and disconnects it from internal phone line, if any. Modem simulates hooking the phone off.

Result Codes:

Result Codes

Code	Description
OK	Command succeeded.
ERROR	Command failed.

Related Commands and Registers:

- A: Answer
- D: Dial

I: Internal Memory Tests

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

L: Speaker Volume Level Selection

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

M: Speaker On/Off Selection

Syntax:

M[0|1|2|3]

Description:

M0 switches the internal speaker always off.

M1 switches the internal speaker off when connected and on otherwise.

M2 switches the internal speaker always on.

M3 switches the internal speaker on when not connected or during retrains, and off during normal connection.

Some vendors add additional modes.

Result Codes:

Result Codes

Code	Description
OK	Speaker mode setting succeeded.
ERROR	Speaker mode setting failed.

Related Commands and Registers:

- L: Set internal speaker loudness

N: Negotiation of Handshake Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

O: On-Line Command

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

P: Select Pulse Dialing Method

Syntax:

P

Description:

Sets the default dialing method to pulse (rotary) dialing. The setting is valid until it is either changed by using the T command, or a T modifier with the D command.

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid

Related Commands and Registers:

- #D: Dial Command
  - #P: Pulse Dialing Modifier
  - #T: Tone Dialing Modifier
- #T: Select Tone Dialing Method
- #S14: General Bit Mapped Options Status Bit 5

Q: Result Code Display Options

Syntax:

Q[0|1]

Description:

The command allows to configure if result codes are supposed to be send to the DTE or not.

Q

or

Q0
: (default) Result codes are send to the DTE.

Q1
: No result codes are send (silent mode).

Result Codes:

Result codes are only send if the option is turned on.

Result Codes

Code	Description
OK	Parameter was valid
ERROR	Otherwise

Related Commands and Registers:'

- S14: General Bit Mapped Options Status Bit 2

Sr=: Write to an S-Register

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

Sr?: Read an S-Register

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

T: Select Tone Dialing Method

Syntax:

T

Description:

Sets the default dialing method to tone (DTFM) dialing. The setting is valid until it is either changed by using the P command, or a P modifier with the D command.

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid

Related Commands and Registers:

- #D: Dial Command
  - #P: Pulse Dialing Modifier
  - #T: Tone Dialing Modifier
- #P: Select Pulse Dialing Method
- #S14: General Bit Mapped Options Status Bit 5

V: Result Code Format Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

W: Negotiation Progress Message Selection

Syntax:

W[0|1|2]

Description:

The command controls the contents and format of the CONNECT message:

W

or

W0
(default). When connecting, the modem reports the DTE/DCE speed in the CONNECT message. The speed is reported only once, upon initial set up of the connection. Subsequent reports are disabled.

W1
When connecting, the modem reports the line speed, error correction protocol, and the DTE/DCE speed. The data is reported only once, upon initial set up of the connection. Subsequent reports are disabled.

W2
When connecting, the modem reports the line speed in the CONNECT message. The data is reported only once, upon initial set up of the connection. Subsequent reports are disabled.

Result Codes:

Result Codes

Code	Description
OK	if parameter was valid (0, 1, 2)
ERROR	Otherwise.

Related Commands and Registers:'

- #X: Call Progress Options for selecting the details of the reporting message.
- #S31: Bit Mapped Options Status Bits 2-3.

X: Call Progress Options

Syntax:

X[0|1|2|3|4]

Description:

The command governs the type and verbosity of connect message responses:

X

or

X0
: blind dial, no busy detect, CONNECT.

X1
: blind dial, no busy detect, CONNECT xxxx.

X2
: dial tone detect, no busy detect, CONNECT xxxx.

X3
: blind dial, busy detect, CONNECT xxxx.

X4
: full monitor, all messages, CONNECT xxxx.

where xxxx = DTE rate or DCE rate.

Note that the connect message response is a function of Wn, Xn and \Vn.

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid (0,1,2,3,4,5)
ERROR	Otherwise

Related Commands and Registers:

- W: Negotiation Progress Message Selection

Y: Long Space Disconnect Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

Z: Soft Reset Command

Syntax:

Z (common)
Z[0|1|2|3] (US Robotics)

Description:

Soft reset is started. If modem is connected, connection is dropped. Last saved profile is loaded from NVRAM to RAM. No more commands are read from the command line.

US Robotics modems allow to specify number of NVRAM profile to load as command parameter.

Result Codes:

Result Codes

Code	Description
OK	Soft reset succeeded.
ERROR	Command failed.

Related Commands and Registers:

- &F: load profile from ROM
- &V: show current profile or profile from NVRAM
- &W: save current profile to NVRAM

&B: V.32 Auto Retrain Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&C: Data Carrier Detect Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&D: Data Terminal Ready Options

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&F: Recall Factory Profile

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&G: Guard Tone Selection

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&J: Jack Type Selection (Auxiliary Relay Options)

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&K: Local Flow Control Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&L: Line Type Selection (Dialup/Leased)

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&O: PAD Channel Selection

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&Q: Communications Mode Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&R: RTS/CTS Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&S: Data Set Ready Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&T: Test Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&U: Trellis Coding Options

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&V: View Configuration Profiles

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&W: Write Active Profile to Memory

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&X: Synchronous Transmit Clock Source

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

[edit]

&Y: Select Stored Profile For Hard Reset

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

&Zn=x: Store Telephone Number

*This module is a **stub**. You can help Wikibooks by expanding it.*

Command Description Template

Syntax:

<The syntax of the command, when necessary in EBNF>

Description:

<Description of the command, including information about the purpose and effects>

Result Codes:

Result Codes

Code	Description
OK	Parameter was valid *<description of success>*
ERROR	Otherwise *<description of failure>*

Related Commands and Registers:

- *<Link list of related commands and registers>*

Result Codes

*This module is a **stub**. You can help Wikibooks by expanding it.*

[edit]

0: OK

[edit]

1: CONNECT

[edit]

2: RING

[edit]

3: NO CARRIER

[edit]

4: ERROR

[edit]

5: CONNECT 1200

[edit]

6: NO DIALTONE

[edit]

7: BUSY

[edit]

8: NO ANSWER

[edit]

10: CONNECT 2400

[edit]

11: CONNECT 4800

[edit]

12: CONNECT 9600

[edit]

14: CONNECT 19200

[edit]

22: CONNECT 1200/75

[edit]

23: CONNECT 75/1200

[edit]

28: CONNECT 38400

[edit]

40: CARRIER 300

[edit]

44: CARRIER 1200/75

[edit]

45: CARRIER 75/1200

[edit]

46: CARRIER 1200

[edit]

47: CARRIER 2400

[edit]

48: CARRIER 4800

[edit]

50: CARRIER 9600

[edit]

66: COMPRESSION: CLASS 5

[edit]

67: COMPRESSION: V.42BIS

[edit]

68: COMPRESSION: ADC

[edit]

69: COMPRESSION: NONE

[edit]

70: PROTOCOL: NONE

[edit]

71: PROTOCOL: ERROR-CONTROL/LAP-B

[edit]

72: PROTOCOL: ERROR-CONTROL/ LAP-B/HDX

[edit]

73: PROTOCOL: ERROR-CONTROL/LAP-B/AFT

[edit]

74: PROTOCOL: X.25/LAP-B

[edit]

75: PROTOCOL: X.25/LAP-B/HDX

[edit]

76: PROTOCOL: X.25/LAP-B/AFT

[edit]

77: PROTOCOL: LAP-M

[edit]

78: PROTOCOL: LAP-M/HDX V.42

[edit]

79: PROTOCOL: LAP-M/AFT

[edit]

80: PROTOCOL: ALT

[edit]

91: AUTOSTREAM: LEVEL 1

[edit]

92: AUTOSTREAM: LEVEL 2

[edit]

93: AUTOSTREAM: LEVEL 3

[edit]

S-Registers

*This module is a **stub**. You can help Wikibooks by expanding it.*

[edit]

S0: Ring to Answer After

[edit]

S1: Ring Count

[edit]

S2: Escape Sequence Character

[edit]

S3: Carriage Return Character

[edit]

S4: Line Feed Character

[edit]

S5: Backspace Character

[edit]

S6: Wait Before Blind Dialing

[edit]

S7: Wait for Carrier after Dialing

[edit]

S8: Duration of Delay for Comma Dial Modifier

[edit]

S9: Carrier Detect Response Time

[edit]

S10: Delay Between Lost Carrier and Hang Up

[edit]

S11: Multi-Frequency Tone Duration

[edit]

S12: Escape Sequence Guard Time

[edit]

S18: Modem Test Timer

[edit]

S25: DTR Detection

[edit]

S26: RTS to CTS Interval

[edit]

S30: Inactivity Time-out

[edit]

S33: AFT Options

[edit]

S36: Negotiation Failure Treatment

[edit]

S37: Desired DCE Line Speed

[edit]

S38: Delay Before Forced Hang up

[edit]

S44: Asynchronous Framing Technique Selection

[edit]

S46: Error-Control Protocol Selection

[edit]

S48: Enabling/Disabling Feature Negotiation

[edit]

S49: ASB buffer size lower limit

[edit]

S50: ASB buffer size upper limit

[edit]

S53: Global PAD Configuration

[edit]

S63: Leased line carrier level

[edit]

S69: Link Layer Window Size

[edit]

S70: Maximum Number of Retransmissions

[edit]

S71: Link Layer Time-out

[edit]

S72: Loss of Flag Idle Time-out

[edit]

S73: No Activity Time-out

[edit]

S74, S75: Minimum Incoming Logical Channel Number (LCN)

[edit]

S76, S77: Maximum Incoming Logical Channel Number (LCN)

[edit]

S78, S79: Outgoing Logical Channel Number (LCN)

[edit]

S80: Packet Layer N20 Parameter

[edit]

S81: Packet Layer T20 Parameter

[edit]

S82: Break Signaling Technique

[edit]

S84: Adaptive start up negotiation (ASU)

[edit]

S85: ASU Negotiation Report

[edit]

S86: Connection Failure Cause

[edit]

S92: MI/MIC Options

[edit]

S93: V.25bis DTE interface speed

[edit]

S94: Command Mode Selector

[edit]

S95: Negotiation Message Options

[edit]

S97: V.32 Automode V.22/V.22bis Probe Timing

[edit]

Advanced Features

Introduction

Modern consumer modems provide a number of additional features which were originally uncommon for a modem, but became standard features over time. This section provides an overview about how to program these features.

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