PART I

THE SERIAL INTERFACE

1

The RS-232 Standard

1.1 Introduction

The RS-232 serial interface is a so-called low-performance character interface, which converts digital information from the parallel format used within computers and peripherals to the serial format used when sending data from one device to another. It is intended for linking devices which handle data in units of characters, and was originally used to connect computer terminals to modems.

The Standard for the serial interface was established in 1960 by the Electronic Industries Association,† and published as their Recommended Standard 232, hence RS-232. However, in 1986 the prefix RS was superseded by the prefix EIA. This was purely to make clear the origin of their documents, there being no *technical* significance to the change. In 1988 the Telecommunications Industry Association (TIA) was formed by the merger of the US Telephone Suppliers Association and EIA/ITG, and subsequent documents are therefore prefixed by EIA/TIA.

Where an EIA Standard has been approved as an American National Standard this fact is indicated by the prefix ANSI, for example ANSI/EIA-232-D-87, where the last two digits indicate the year of approval as an ANSI Standard.

Over the years the RS-232 Standard has undergone a number of revisions; the third revision in 1969 being known as RS-232-C. This was revised in 1987 and called EIA-232-D. The most recent document at the time of writing is that of the fifth revision in July 1991, known as EIA/TIA-232-E (ANSI/EIA/TIA-232-E-91). However, in spite of the various names and revisions, the interface is still generally known as

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'RS-232', and for convenience will be referred to as such throughout this book.

Useful overviews of the RS-232 Standard are those by Maine (1986), Friend *et al.* (1988), Hughes (1989), and Honig & Hoover (1990). Details of all EIA standards can be found in the annual catalogue of a firm called Global Engineering Documents,† which is the primary distributor for all EIA standards and publications. Some of the documents which relate to the serial interface and connectors are as follows.

- EIA/TIA-232-E (ANSI/EIA/TIA-232-E-91).
  Interface between data terminal equipment and data circuit-terminating equipment employing serial binary data interchange. Electrical Industry Association, July 10th 1991.
- EIA/TIA-530.
  High speed 25-position interface for data terminal equipment and data circuit-terminating equipment. Electrical Industry Association, March 1987.
- Industrial Electronics Bulletin No. 12.
  Application notes on interconnection between interface circuits using EIA-449 and EIA-232-D. Electrical Industry Association, 1987.
- EIA/TIA-363.
  Standard for specifying signal quality for transmitting and receiving data-processing terminal equipment using serial data transmission at the interface with non-synchronous communication equipment. Electrical Industry Association.
- EIA/TIA-404.
  Standard for start-stop signal quality for non-synchronous data communication equipment. Electrical Industry Association.
- CCITT, Blue Book, Fascicle VIII.1, Recommendation V.24.
  List of definitions for interchange circuits between data terminal equipment (DTE) and data circuit-terminating equipment (DCE).
- ISO 2110.
  25-pole DTE/DCE interface connector and contact number assignments. International Standards Organisation.
- EIA/TIA-574.
  9-position non-synchronous interface between data terminal equipment and data circuit-terminating equipment employing serial binary data interchange. Electrical Industry Association.

† Global Engineering Documents, 1990 M Street N.W., Washington, DC 20036, USA. Tel: +1–202–429–2860. Fax: +1–202–331–0960.

The EIA/TIA-232-E revision is a 36-page document which includes a number of modifications to circuit definitions, a specification for an alternative 26-pin interface connector (EIA/TIA-232-E ALT A), a list of 'Recommendations and explanatory notes', and a Glossary. Four aspects of the communications interface are addressed, as follows.

- Functional characteristics of the three circuit groups (data, control, timing).
- Electrical and grounding characteristics of the signals.
- Mechanical characteristics of connectors and cables.
- Standard interfaces for selected communication system configurations.

1.2 Circuits

The RS-232 Standard allocates specific serial communications circuits to specific pins of 25/26-pin connectors, as shown in Table 1.1. Since the pin number of the various circuits varies with the connector (9, 15, and 25/26 pins), the standard three-letter function codes are always used when referring to the RS-232 circuits in order to avoid confusion.

The EIA-232-D revision gave two of the circuits new names (see Honig & Hoover, 1990). Thus the circuit previously known as Data Terminal Ready (DTR) was renamed DTE Ready. Similarly, Data Set Ready (DSR) was renamed DCE Ready. However, since virtually all books on the subject still use the old RS-232-C names, the function codes DTR and DSR will continue to be used throughout this book.

Note that in practice only 9 of the circuits shown in Table 1.1 are generally used by the PC's serial interface, hence the widespread use of the 9-pin interface connector. These circuits (Table 1.2) together with their direction (input or output) are shown in Figure 1.1.

The serial interface circuits running between the computer and the peripheral device can be classified into four groups as follows.

- Ground
- Data
- Control
- Timing

These will now be described in some detail with the exception of the timing circuits, since these are not used in the asynchronous form of data transmission employed by IBM compatible PCs.

Table 1.1. *EIA/TIA-232-E pin assignments for 25/26-pin connectors.*

Pin No.	Code	Descriptive name
1		Shield
2	TxD	Transmits data
3	RxD	Receives data
4	RTS	Request to send/ready for receiving
5	CTS	Clear to send
6	DSR	Data set ready (DCE ready)
7	GND	Signal ground
8	DCD	Data carrier detect (received line signal detector)
9		RESERVED FOR TESTING
10		RESERVED FOR TESTING
11		UNASSIGNED
12		Secondary received line signal detector
13		Secondary clear to send
14		Secondary transmitted data
15		Transmitter signal element timing—DCE source
16		Secondary received data
17		Receiver signal element timing
18		Local loopback
19		Secondary request to send
20	DTR	Data terminal ready (DTE ready)
21		Remote loopback/signal quality detector
22	RI	Ring indicator
23		Data signal rate selector
24		Transmitter signal element timing—DTE source
25		Test mode
26		Alt A connector only—not connected

Table 1.2. *Pin assignments for 9-pin serial port connectors.*

Pin No.	Code	Descriptive name
1	DCD	Data carrier detect
2	RxD	Receives data
3	TxD	Transmits data
4	DTR	Data terminal ready
5	GND	Signal ground
6	DSR	Data set ready
7	RTS	Request to send
8	CTS	Clear to send
9	RI	Ring indicator

1.2.1 Ground circuits

Two ground circuits exist, namely

- Shield (chassis ground)
- Signal ground (GND)

The shield pin, when available,† should be connected to the equipment chassis. Where a shielded cable is used, then the shield should be connected to the shield pin at one end only.‡ *Never* connect the shield at both ends of the cable (Friend *et al.*, 1988). Note that the protective ground is not used with 9-pin connectors.

Signal ground (GND) is the reference for all cables and must, therefore, be connected at both ends.

1.2.2 Data circuits

Two wires are assigned to carry data, one for each direction. The 25-pin connectors have the computer receiving data on pin-3 (Receives data; RxD), and transmitting data on pin-2 (Transmits data; TxD). Note that this order is reversed when using 9-pin connectors (see Tables 1.1 and 1.2).

When interfacing computers to other equipment, therefore, it is important to check that the pin receiving data at the computer (RxD) is connected to the pin used for transmitting data from the peripheral device (TxD), and vice versa.

1.2.3 Control circuits

Six control circuits are used by microcomputers, and are commonly known as 'handshaking' lines. The control circuits are used to enable the computer and the other device to communicate to each other such things as whether they are switched on or not, or whether they are ready to receive data or not. This is achieved very simply by setting the respective control line voltage either HIGH (positive) or LOW (negative).

For example, when a printer using hardware handshaking runs out of paper, it will set one of its control lines either HIGH or LOW depending on the particular code used. This voltage change will be sensed by the

† A pin is allocated for the shield only on 25-pin connectors, and on the new alternative (Alt A) 26-pin connector described in EIA/TIA-232-E.

‡ EIA/TIA-232-E indicates that *Normally the DCE should make no connection to the interface connector contact number 1.*

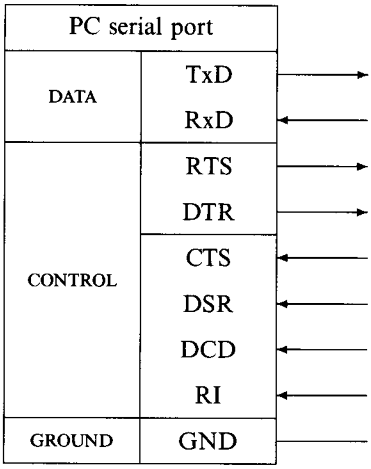

Fig. 1.1. Schematic diagram showing the 9 circuits used by the PC's serial port. Note that the PC has 4 *input* control lines, but only 2 *output* control lines.

computer and interpreted as a signal to stop sending data. When the paper tray has been reloaded the printer resets the control line, and the computer will resume sending data.

The six control circuits, together with their short codes, are as follows.

- Request to Send (RTS)
- Clear to Send (CTS)
- Data Set Ready (DSR)
- Data Carrier Detect (DCD)
- Data Terminal Ready (DTR)
- Ring Indicator (RI)

The curious names of the control circuits arise from the fact that the circuits were originally designed for connecting equipment to modems. Both the names and the number of circuits therefore reflect the fairly complex control-line signalling which modems use when synchronising the flow of data traffic in the two data lines RxD and TxD.

It is important to appreciate the *direction* of signalling in the various control lines—see Figure 1.1. The PC has two output control circuits (RTS, DTR) which it can use to communicate with the peripheral device. These two output control circuits are controlled by the computer's Modem Control Register (see Chapter 4). Conversely, the PC receives incoming control signals from the peripheral device via the remaining four control circuits (CTS, DSR, DCD, RI). The status of these four input control circuits is monitored by the computer's Modem Status Register (see Chapter 4).

1.3 Voltages

The RS-232 Standard specifies certain conditions as follows.

- Positive voltages should be in the range +3 to +15 volts; negative voltages should be in the range −3 to −15 volts.
- The interface should tolerate without damage up to ±25 volts at the input.
- It should be possible to short across any two lines without damage.

The transmission line voltages produced by RS-232 line-driver chips are usually within the range ±9 to ±15 volts depending on the particular line-driver chip used. The range of transmission line voltages is, therefore, considerably greater than that of the TTL (transistor-transistor logic) circuits used within the PC (0–5 volts). The reason for this difference is historical, since RS-232 predates modern chip technology.

The interpretation of the RS-232 transmission voltages is initially somewhat confusing, since those on the two *data* lines (TxD, RxD) are inverted relative to the TTL voltages used within the devices, while those on the six *control* lines (RTS, CTS, etc) are not inverted.

Thus a positive control line voltage is counted as HIGH (ON, TRUE, RAISED, ASSERTED), and a negative one as LOW (OFF, FALSE, LOWERED). However, for the data lines, logic 1 (Marking) is transmitted as a negative voltage, and logic 0 (Spacing) as a positive voltage.† The idle, or inactive, line state which exists on the data lines between data transmissions is a negative voltage.

1.4 Connectors

Although an interface connector was not defined in the original RS-232 Standard, the 25-pin D-shell connector has been generally adopted, and was incorporated into the EIA-232-D revision (Honig & Hoover, 1990). The mechanical aspects of the connector are detailed in the document EIA/TIA-530. The convention is that computers have male connectors and peripherals have female connectors, although not all manufacturers adhere to this.

† The terms Marking, Spacing are often contracted to Mark, Space.

A new aspect of the EIA/TIA-232-E revision is the inclusion of a specification for a smaller Alternative 26-pin D-shell interface connector (EIA/TIA-232-E Alt A). The 26-pin Alt A connector is about half the size of the usual 25-pin connector. Note that the Alt A connector has the *same* pin-outs as the 25-pin connector, with the addition of pin-26 which is unallocated.

Since IBM's implementation of RS-232 makes use of only nine channels, many devices and computers have adopted the 9-pin D-shell connector. However, a large number of peripheral devices still use either a 15 or 25-pin D-shell connector, and utilise either unassigned channels or those nominally reserved for testing, in order to transmit a number of useful signals. These are commonly additional power lines (either AC or DC or both), analog signals, or extra signal ground (GND) lines.

The D-shell connectors are sometimes named according to a 'DXn' convention, where D codes for the shape of the shell, X codes for the size, and n gives the number of pins (Honig & Hoover, 1990). Consequently, the 25-pin and 9-pin serial port connectors are occasionally referred to as DB25 and DE9 respectively.

1.5 Problems with RS-232

Although the RS-232 interface is widely used and works well, there are limitations, particularly with regard to the maximum bit rate (20 K bits/sec), transmission distance, and the use of a common signal ground (see Friend *et al.*, 1988). As a result of these and other problems, a number of different interface standards have been developed which are capable of much greater bit rates, e.g. RS-423 (100 K bits/sec), RS-422 (10 M bits/sec).

Of these newer interface standards, only the RS-423 interface (logic 1 +3.6 to +6 volts; logic 0 −3.6 to −6 volts) is compatible with RS-232. Note that since RS-232 signals are considerably greater than those for RS-423 circuits, any connection between the two circuits should use an appropriate attenuator circuit (see Maine, 1986).

A comparison of the electronic specifications of the various EIA standards (RS-232, RS-423, RS-422, RS-485) is given in the RS Data Sheet 6985.†

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1.5.1 Distance

The RS-232 Standard specifies maximum limits for the duration of the transition time from HIGH to LOW, and vice versa. For example, for data circuits the transition time must be less than 4% of the bit period. This therefore restricts the amount of stray capacitance allowed in a cable since the transition time is a function of capacitance. In addition, the Standard also specifies that the total cable capacitance should be less than 2500 picofarads (pF). Since the capacitance of cables used in data communications is in the range 40–200 pF/m† the maximum length can theoretically be as great as 62 m depending on the particular cable. In practice, such long lengths are not recommended since the likelihood of noise being picked up and causing data corruption increases with length. However, since the bit period is inversely related to the bit rate, even greater lengths (e.g. 1000 feet) can work satisfactorily providing slow bit rates are used (Campbell, 1989a).

1.5.2 Ground

Because the RS-232 interface is technically an 'unbalanced' system (i.e. all the control and data signals are referenced to a common signal ground), there is the possibility that transmission errors may arise if there is a significant difference in ground potential between the two ends of the cable. This is another reason for keeping the interface cable relatively short since the further the peripheral device is from the PC, the greater the likelihood that their GND pins will be at significantly different potentials (Friend *et al.*, 1988).

† The flat Speedbloc ribbon cable commonly used for serial interfacing has a nominal capacitance of 49 pF/m (RS Catalogue).