Basic Techniques in Data Communications

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Dedication

I had intended that my earlier book would be my last, but now that this volume is completed, I am sure I mean it. Thus, this is my final chance to write a dedication that will long survive the book, at least in the hearts of the dedicatees.

To Scarlatti, our cat, who regularly incubated the manuscript;

to my parents, in-laws, and other relatives, who have skeptically tolerated my neglect of them for the years it has taken me to produce the books;

to my daughter Kim, who perfected her typing skills on the typescript;

to my wife Linda, who, like Penelope, tactfully undid my daughter's typing every night;

to my daughter Rana, who fortunately was too young at the time to want to type the manuscript;

and finally, to my loyal customers in the New York metropolitan area, whose moral and financial support saves me from having to make a living as an author —

I dedicate this book with gratitude.

Foreword

With every day that passes, the need for swift, accurate digital data communications becomes more of a necessity in keeping the government and industry of a densely-populated, modern civilization functioning efficiently. Without the near-instantaneous availability via communication of such things as account balances, inventory status, stock prices, currency rates, and seat or room occupancy, to list just a few, our present economic system would quickly falter and our civilization would drift into disorder. Non-electronic methods of data transfer, such as mail, or analog methods, such as telephone conversations, are no longer adequate to sustain the economic activity of a modern industrial nation. There is every expectation that the growth in digital communications will accelerate, and that a sort of digital society eventually will evolve, in which private homes are equipped with two-way digital terminals receiving digitized television, music, news, credit, and messages broadcast from space stations.

In this book, the focus of the discussion is on the present-day, sophisticated hardware required to implement many different types of data communications links. After a brief investigation of fundamentals (which more knowledgeable readers may wish to skip over), an in-depth discussion of short- and long-haul data transmission using various types of drivers and modems is provided. Following are details about equipment that can be used to configure and control systems, and to diagnose specific network problems. The book concludes with a coverage of some devices that enhance the usefulness and versatility of modems. Other advanced systems equipment, such as multiplexers, concentrators, wideband interfaces, and other topics, are discussed in the author's preceding, complementary volume, Advanced Techniques in Data Communications, *also published by Artech House.*

March 1979

Ralph Glasgal
Harrington Park, New Jersey

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Baudy Bits

The Basics of Data Communications

A very basic data communications system is shown in Figure 1-1. Data to be transmitted is put into digital format by the source, presented to the interface, sent via the communications medium, received by the remote interface, and interpreted by the sink. Typical data sources that format or store data are teletypes, printers, cathode ray tube terminals, paper and magnetic tapes, disks, punched cards, and computers. Interface units (which convert the digital source data to a format suitable for transmission) include line drivers, modulators, modems, radio transmitters, microwave dishes, loudspeakers, flashlights, and even Boy Scouts using semaphore. The most common data communications medium is, of course, the telephone or telegraph line, but light beams, sound waves, and radio waves are also perfectly acceptable media. The remote interface is the receiver; it interprets and restores the data to a digital format that the sink can interpret. The most common data sink is a computer.

Bits vs. Bauds

Bits are the units of binary digital information. Bits may be combined to form characters, and characters may be grouped to form blocks. A bit of binary digital data may be a 1 or a 0 — no other state is possible. In contrast, the baud is the unit of signaling. One baud is the shortest signaling element in a given transmission channel. Signaling elements sometimes are restricted to 1 or 0 states (referred to as marks or spaces),

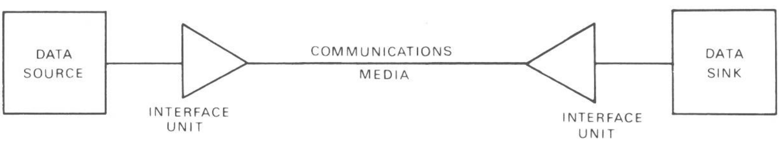

Figure 1-1/The Basic Elements of a Point-to-Point Data Communications Link but quite often signaling elements may have several positive or negative values other than 1 or 0. A baud may represent more or less than one bit in a given transmission system. For instance, if we say that two blinks of red light mean a 1 and two blinks of blue light are a 0, it takes two baud (blinks) to transmit one bit. On the other hand, if we say that one blink of red light means 00, one blink of blue light means 11, one blink of yellow light means 01, and one blink of green light means 10, then it takes only one baud (blink) to transmit two bits.

In this book we try to use the term "baud" when we mean the rate at which the transmission of signal elements is occurring, and "bits per second" when we refer to the amount of data passing through a channel.

Asynchronous Data Transmission

All data transmission is clocked in some manner and therefore is synchronous in a sense. However, for purposes of definition in this book, synchronous data is data found in systems in which all clocks are identical in rate over a long period of time. Thus, synchronous data is clocked out of the source at the same average rate it is clocked into the sink. How data clocks are kept synchronized over vast distances is discussed in Chapter 5. By contrast, in asynchronous transmission, the clock that clocks data from the source is nominally independent of the clock that clocks the received data into the sink. Obviously the two clocks must be related in some manner, or the data would be garbled. In most systems, the send and receive asynchronous data clocks originate in oscillators that generate clocks accurate to within approximately 1% of one another. If both clocks could be started simultaneously, they would remain in reasonable synchronism for many bits before the drift between them became noticeable. Indeed, since data bits almost always are grouped together to form characters, it is best to restart the oscillators each time a character is transmitted — which is what actually is done.

It is easy to synchronize transmitted data to a transmit clock since a data bit can be sent each time the clock cycles. At the receiving end, the problem is more difficult. Since an idle line in a binary system is by definition in the marking state, how do you detect the beginning of a character if its first baud is a mark? The answer is to preface each character with a non-data bit called a start bit (actually a start baud). The start bit is always a space, and its function is to tell the receiver that a character is starting. The transition from mark to space starts the receiver's clock and allows the receiver to count out the bits in the character. If the receiver oscillator is reasonably accurate and if the character is not too long, no timing errors occur. Thus asynchronous transmission essentially is accomplished one character at a time.

Suppose now that asynchronous characters are being sent continuously, without pause, and that the last bit of a character is a space. There then would be no mark-to-space transition between the end of one character and the start bit of the next to mark the moment at which the receive clock should be restarted to count out the next character. Therefore it is necessary to guarantee a minimum period of marking between asynchronous characters. This marking period is the rest or stop interval and is measured in rest bits or stop bits.

The start and stop bits limit the efficiency of asynchronous data transmission since, if a character has eight data bits, at least ten bits must be transmitted. In terms of signaling elements (baud) and information elements (bits), ten baud must be signaled for every eight bits of information transmitted.

Synchronous Data Transmission

Because of the inefficiency of asynchronous data transmission and the upper bound of about 1800 baud for asynchronous data transmission via phone lines (see Chapter 4), synchronous data transmission has come into widespread use. Synchronous transmission proceeds without start or stop bits and, instead of single characters, large blocks of characters can be transmitted without pause. In synchronous data transmission, a transmit clock sends out data to a receiver which clocks in the data at an identical rate; all bit intervals are equal, including idle bit intervals between blocks of data. Nevertheless, even synchronous data transmission has characteristics which lead to inefficiencies and which must be taken into account if a full understanding of synchronous systems is to be had.

The blocking of data in serial synchronous transmission systems is not just optional, it is mandatory in practical systems. First, each block of data must be prefaced with one or more synchronization characters so that the receiver can identify which groups of bits in the stream are characters. Remember that in the synchronous case there are no start bits to locate the first bit of a character for the receiver. The blocks also must be of finite size so that the receiver can periodically check its synchronization and recover from clock "glitches" or timing errors due to noise, Doppler shift, modem errors, etc. In essence, the synchronization characters and the idle characters between blocks constitute a more efficient form of the start and stop bits that were needed in asynchronous transmission. Other characters in synchronous transmission, such as "Start of Header," "Start of Text," "End of Text," "End of Transmission," and block error checks, are required to ensure that blocks of data are received in order and without error. Many block transmission protocols have been developed by the major computer manufacturers and, unfortunately, there is not the same standardization in this area as there has been in asynchronous data transmission.

Communication Links

While light blinkers, smoke signals, and drums were used in the past to transmit data characters, copper wire and microwave beams are the mainstays of today's data transmission systems, with optical fibers coming on strong. The most universal communications link for data is, of course, the switched or dial network, which was constructed originally for voice communication. Other examples of switched networks, however, such as Telex, TWX, and some specialized carrier networks, were designed specifically for data or for facsimile transmission.

For those who must transmit a lot of data to the same location, a private or leased line is desirable. Such lines may be analog or digital; two-wire or four-wire (see below); narrowband, voiceband, or wideband; and via satellite or terrestrial links. The properties of these different offerings are discussed in the following chapters of this book.

Full Duplex and Half Duplex

All elements in a data communications system can be defined in terms of their abilities to send and receive sequentially or simultaneously. A device or phone line that can only receive or only transmit is called simplex. Television networks are examples of simplex communications systems — TV sets are simplex receivers, TV cameras are simplex transmitters, and TV broadcast networks are simplex transmission media. By contrast, when you make a *local* phone call, it is possible to both speak and listen simultaneously or alternately. The former is called a full-duplex conversation, and it is difficult for most humans and data terminals as well. An alternating conversation is called half-duplex and usually is easier for persons and machines.

In brief, a full-duplex (FDX) device or line can send and receive simultaneously while a half-duplex (HDX) device or line can send and receive, but not simultaneously. In practice, applying these definitions is not as simple as it may seem. Terminals, modems, and lines each may be FDX or HDX. If an HDX terminal is used with FDX modem and line, the resulting system is still basically HDX. A modem that operates FDX on an FDX line may need to operate HDX on an FDX line to accommodate an HDX terminal. A line that is HDX with one type of modem may be capable of FDX operation with another. In the chapters that follow, these anomalies are explained.

In the case of the dial-up and leased lines with which we primarily are concerned here, we can define the common line offerings in terms of whether they are FDX or HDX. The four-wire leased line consists of a send pair and a receive pair; since these pairs are completely independent, four-wire lines are inherently full duplex, even if they are used with half-duplex modems or terminals. Two-wire leased lines are inherently half-duplex; their bandwidth, however, can be split to form what amounts to two or more channels, as in frequency-division multiplexing or with some low-speed modems. Similarly, two-wire dial network connections are inherently half-duplex unless frequency-division multiplexing techniques are used.

Echo Suppression

Two-wire dial network connections can be used only for FDX communication using multiplexing if the line has no echo suppressor. An echo suppressor is a switchable attenuator used on long-distance phone lines to prevent an echo on the line from confusing a speaker with a delayed replica of the speaker's own voice. The echo attenuator or suppressor switches rapidly in direction as each speaker becomes a listener. Therefore, this type of long-distance voice call is a half-duplex call. For HDX data calls, it is desirable to disable the echo suppressor since data signals often do not properly reverse the echo suppressor circuits which were, after all, designed to be triggered by speech; also, the reversing process is a slow one. The echo suppressors can be disabled by transmitting a single tone in the band 2000 to 2250 for slightly less than half a second. Once disabled, the echo suppressor remains disabled for the duration of the call, unless the signal on the line drops out for more than 50 ms. It should be mentioned that modems are designed to cope with the echoes that remain on the line once the suppressors are disabled. For FDX data calls, disabling the echo suppressors is mandatory since transmission must be possible in both directions simultaneously.

Line Conditioning

Phone lines are prone to such impairments as noise, distortion, and frequency translation, described in detail in Chapter 8. Some line impairments can be controlled on leased lines by means of special networks. Such arrangements are called "line conditioning" and the phone company offers several different types to control frequency response, phase response, signal-to-noise ratio, and harmonic distortion.

C1, C2, and C4 conditionings represent increasing degrees of perfection in regard to bandwidth and delay. Another form of conditioning, D1 (D2 for multipoint lines), guarantees a signal-to-noise ratio better than 28 dB, a second harmonic distortion down 35 dB, and a third harmonic distortion down 40 dB below the signal level. C2 conditioning is often required by modems operating at 9600 bps; it guarantees a frequency response of 300 to 3000 Hz + 2 dB, -6 dB and a difference in delay between 500 and 2800 Hz of less than 3 ms. By contrast, a C1 line has an upper limit of 2700 Hz; a C4 line, 3200 Hz. C3 conditioning is reserved for access lines and trunks in switching centers, and usually is not a factor in data transmission.

EIA RS-232 Interface

An entire book could be written on the ramifications of the Electronic Industries Association (EIA) specification RS-232, which governs the interface between data terminal equipment and data communications equipment. In this introductory chapter, we try to show why the signals in this interface are necessary and how they relate to the modes of transmission (HDX, FDX, Async, Sync, two-wire, four-wire, and dial-up).