

A definitive set of conventions has been established for the automatic, synchronous transmission of digital data over half-duplex (nonsimultaneous) communication links. Provision has been made for communication between different device types and between computer processing units. Although one transmission code must be used on a given data communication link, a special feature permits digital data in any form to be transmitted, including encrypted data and compiled computer programs.

This paper describes the Binary Synchronous Communication (BSC) conventions, which prescribe the encoding of data, the procedures for synchronizing stations, the methods for controlling the data links, transmission message formats, and error detection and correction methods. The presentation is sufficiently detailed to indicate the kinds of design decisions that are involved in setting up automatic data communication links.

Conventions for digital data communication link design

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Transmitting digital data over communication lines is a fundamental requirement in a growing variety of data processing applications. As the kinds of applications have grown, so has the variety of terminal devices, data codes, and communication facilities.

Binary data to be transmitted to a remote location may originate from any of a variety of input/output devices, including typewriters, card reader/punches, analog-to-digital converters, computers, and terminals for remote entry of jobs. The data may be transmitted over privately owned, leased, or public communication facilities, microwave relay links, or communication satellites. The data itself may be encoded in standard codes, it may be encrypted to provide data security, or it may be in the form of a compiled computer program. At the receiving end, the data may be fed to a computer, be displayed on a cathode-ray tube screen, be used to control a process, or simply be recorded or printed.

Existing data communication links use control procedures and formats that have been optimized for particular devices, systems, and applications. For example, different communication link control procedures are used in the IBM Synchronous Transmitter Receiver (STR) family of transmission devices, the IBM 1050 Communication System, and the various teletypewriter systems. Because these procedures were optimized for each system, their suitability to other devices and applications is limited. For example, the STR family of devices uses a transmission code limited to 64 data characters, so that it cannot easily accommodate the eight-bit data

byte used in SYSTEM/360.¹ In addition, STR systems have no provision for controlling operation of multipoint communication lines, which can often be used to reduce network costs in teleprocessing systems.² Most teletypewriter systems make no provision for error detection and correction by automatic retransmission, which is required in many other applications.

Special-purpose digital data communication systems have real advantages in terms of efficiency and cost. But the growth in kinds of applications and device types dictated a unified, consistent, and completely definitive set of conventions prescribing every aspect of a broad class of digital data communication. Binary Synchronous Communications (BSC) is a set of conventions developed to satisfy that need.

The principal design objective for BSC was versatility. By consolidating existing control procedures, transmission codes, and formats, and by extending them where necessary, BSC conventions prescribe every aspect of the data transmission operation necessary for carrying on communication between different devices. If message content is compatible, one type of device can communicate directly with a different type of device through the common language of BSC. Also, the BSC conventions are versatile enough to economically handle a wide range of applications. This flexibility, for example, permits a computer, with a single type of transmission control unit and a common set of subroutines for controlling the data link, to accommodate a variety of terminal devices and applications.

Of course, the BSC conventions are not completely general. Compromises had to be found to achieve a balance among simplicity (i.e., economy), functional capability, and transmission efficiency. Thus, the conventions apply to systems in which data are transmitted sequentially by bit and by character. Binary synchronous communication takes place in a two-way, half-duplex (nonsimultaneous) fashion, in which transmission can occur in either direction but never in both simultaneously. This design choice, made largely for economic reasons, permits BSC to be used with most existing communication facilities and equipment. BSC links are expected to operate at medium and high transmission rates (presently from 600 to 230,400 bits per second).

The BSC conventions are intended for systems that enable an entire transmission to take place automatically, including automatic recovery from certain types of transmission errors. Thus, BSC is suitable for operation of computer-controlled communication networks, including those involving direct communication between remotely located central processing units.

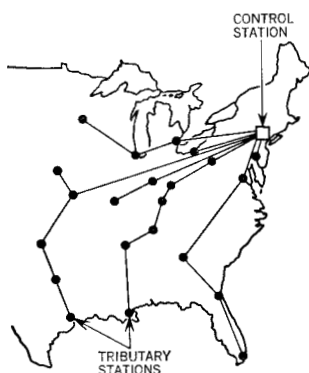
A particular transmission code must be selected as the basis for operation of a particular data communications link. However, a special message block format, called transparent text, permits transmission of data in other codes, including unrestricted binary data, such as in compiled computer programs (in machine language) and encrypted data.

The diagram illustrates a data communication system connecting two stations. Each station is enclosed in a dashed box and contains three main components: I/O units, a station communication interface, and a control unit. The I/O units are connected to the station communication interface. The control unit is connected to both the station communication interface and the modem. The station communication interface is connected to a modem. The two modems are connected via a communications channel, which is part of the data communication link. The data communication link also includes an interface between the station and communication facility, which connects the modem to the communications channel. The entire system is labeled 'DATA COMMUNICATION LINK'.

A station may act as a transmitter, a receiver, or both. The station equipment may include one or more input/output units (e.g., typewriter, card reader/punch, etc.); there are no limitations regarding the type or number of input/output units at a station. However, each station must operate through a single interface to the network in accordance with the BSC conventions. These conventions govern generating and responding to the various communication link control signals. The interface may be implemented through a combination of hardware and software. The interface function can have effects throughout the station; for example, a program that performs BSC-prescribed functions in the main storage of a computer would be considered part of the communication interface.

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Figure 2 A general communication network



Communication networks vary widely in size and complexity; a simple example is shown in Figure 2. Networks are made up of either dedicated or switched lines or both. Dedicated lines interconnect two or more stations on a permanent basis, whether or not the stations are active. A network may comprise a number of dedicated lines, all of which are connected to a central station that handles traffic between different lines; very large networks may have a number of such central stations that communicate among themselves through trunk lines. A station operating on a dedicated line communicates only with stations on the same line; communication with other stations is done indirectly, through the central station. Dedicated lines are termed *two-point* (sometimes called point-to-point) lines if they connect only two stations, and are termed *multipoint* lines if they connect three or more stations.

A switched network operates as does the public telephone network; in fact, the public telephone network is commonly used for data transmission. A connection can be made between any two stations operating in the network, but it is maintained only for the duration of a single "call"; the circuit is then disconnected and both stations are free to make connection with (call) any other stations in the network.

A modem, which includes a modulator-demodulator and its interface, must be provided for each station. The modulator-demodulator modulates a carrier signal using the binary d-c data signals presented through the interface to produce signals suitable for transmission on the communication line. It also demodulates received signals into d-c signals like those presented on the transmitting station's interface. When the modem equipment is provided by a common carrier, it is generally referred to as a data set and may include provision for additional functions, such as automatically controlled connection and disconnection of a call in a switched network.

Facilities used for BSC must provide for two-way communication. Since no transmissions can take place in two directions simultaneously, the communication facility can be half-duplex. However, the facility can also be full-duplex; although the simultaneous two-way capability of full-duplex is not used, certain delays encountered with half-duplex facilities can be eliminated. These delays are necessary after each change in the direction of transmission to permit the signals in the half-duplex channel and the demodulator to stabilize sufficiently for the reliable transmission of data. Such delays range typically from 10 to 200 milliseconds.

Communication link control

The BSC conventions apply to six basic aspects of digital data transmission:

- Encoding of data
- Synchronizing procedures

- Operational control functions
- Information formats
- Timeouts
- Error control

The functions performed in each of these areas are interdependent and must be coordinated to achieve reliable, efficient, and automatic operation of the data communication link.

bsc is oriented toward devices and systems in which data are encoded into discrete characters, defined in terms of a fixed number of binary digits (bits). Data are transmitted serially by bit and by character (i.e., both the characters and the bits of which they are comprised are sent sequentially). This is the most widely used format for transferring data on the interface between a station and its associated modem.

Only one transmission code is used on a given communication link, although a special message format called transparent text permits the transmission of data in other codes. Each combination of bits in a character is termed a code position. Each particular graphic and control character defined for the transmission code is assigned a unique code position. However, nine of the code positions must be reserved for assignment as BSC control characters and cannot be used for other than their assigned communication control functions except within transparent text.

The synchronizing procedure gets and keeps the receiving station in step with both the bits and characters sent by the transmitting station. Bit and character synchronization are separate but interdependent functions. Bit synchronization locates each bit in time so that its value can be determined correctly. Character synchronization marks the beginning of a transmission and establishes the frame of reference to determine the beginning and ending bits forming each character in the transmission.

The operational control functions form the structure of BSC operation, covering the procedures for sending messages and coordinating the operation of the stations in the link.

A number of information formats are used in BSC, including message formats and various signals used for controlling other stations and for replying and indicating status. The BSC control characters are used for achieving synchronism, for establishing the format of messages, and as the various control and reply signals.

Timeouts are used to supplement the transmission and recognition of control characters. By limiting the time for various operations, timeouts provide protection against false or garbled synchronizing patterns, message blocks, and control sequences, which could otherwise result in a permanent stoppage of operation. After such predetermined time intervals have elapsed, retry and recovery procedures are initiated.

Error control is the means for detection and recovery from error conditions that arise in the course of operation. The relatively high exposure to errors in transmission makes error control essential for

Table 1A Basic set of BSC control characters

<i>Abbreviation</i>	<i>Name</i>	<i>Purpose</i>
SYN	synchronous idle	Used to establish synchronism and, in the absence of any other character, to maintain synchronism.
STX	start of text	Precedes a block of characters (text) transmitted as an entity and terminates a heading.
ETX	end of text	Terminates a block of characters started with STX and transmitted as an entity. Block check character is sent immediately after ETX. ETX calls for a reply indicating receiving station status.
EOT	end of transmission	Indicates conclusion of a transmission (including text and associated headings) of one or more messages.
NAK	negative acknowledge	Reply indicating that previous block in the transmission was not accepted and receiver is ready for a retransmission. Is also "not ready" reply by station to its selection address.
ENQ	enquiry	Requests a response indicating identification, station status, and/or repeat of a reply.
DLE	data link escape	Provides additional BSC control signals by changing meaning of the character that follows it. In basic set, serves as leader (first character) of two-character alternating affirmative reply sequences, represented by: ACK0 even affirmative acknowledge ACK1 odd affirmative acknowledge
ACK0	even affirmative acknowledge	A reply indicating that receiver is ready to accept the next block and that either the previous block was accepted because no error was detected and the block count was even or that the station's selection address was received without error.
ACK1	odd affirmative acknowledge	A reply indicating that the receiver is ready to accept the next block, that the last block was accepted because no error was detected and the block count was odd.

reliable automatic operation. For this reason, error detection and recovery procedures permeate all of the areas of operation.

Encoding of data

BSC uses a fixed-length (in bits) character set, because it greatly simplifies the character synchronizing function. Due to the serial-by-bit, serial-by-character nature of BSC transmissions, both data and control signals must be interleaved and sent serially between stations. This adds significantly to the complexity of a station's internal data and line control paths, and it often imposes restrictions on input/output device operation (particularly when compared to their operation on parallel-path channels, which use separate data and control leads, such as in the SYSTEM/360 multiplexor channel).

The interleaved data and control signals must be easily identifiable and separable at a receiving station. It was therefore decided

Table 1B Extended set* of BSC control characters

<i>Abbreviation</i>	<i>Name</i>	<i>Purpose</i>
SOH	start of heading	Precedes a block of characters called a heading, which contains auxiliary information (such as routing, priority, etc.) needed to process the text message.
ETB	end of transmission block	Blocks data by indicating end of a block started by SOH or STX, where block structure is not necessarily related to processing format. Block check character immediately follows ETB. ETB calls for a reply, such as ACK or NAK, indicating receiver status.
ITB	intermediate block character	Blocks data by indicating end of intermediate text or heading block. Block check character immediately follows ITB. ITB, which does not call for a reply, is followed by next intermediate text block without changing direction of transmission or ending character phase.
DLE	data link escape	Used to form the transparent text formatting sequences DLE STX, DLE ETX, DLE ETB, DLE ITB, and DLE ENQ; the wait-before-transmit sequence (WABT); and the switched network disconnect sequence DLE EOT.
WABT	wait before transmit	Used as a reply indicating a temporary "not ready" condition.
DLE EOT	disconnect	Used in switched-network operation to indicate that a station is about to disconnect.

* These characters, even though their BSC function is not being used, cannot be used for any other purpose (except within transparent text).

to use a set of unique control characters that would be used only for its communication control function (except in transparent text). The control characters must frame data blocks and messages. In addition, they must signal control functions and indicate station status. With one exception (the intermediate block character), the set of control characters chosen for BSC operation are based on those defined in the United States of America Standard Code for Information Interchange (USASCII). This set was selected because it is a standard code that is suitable for a variety of devices and many different applications.

The basic set of control characters in Table 1A is used in BSC. It should be noted that, despite the multiple-letter abbreviations used in the table, the control characters actually transmitted are single eight-bit characters or, where noted, two-character sequences. The basic set is always required; certain optional functions also require use of the characters in the extended set in Table 1B.

All code positions other than those assigned as communication link control characters are available to encode data and to control functions other than the communications link. The latter are termed end-to-end controls, because their functions relate only to devices at the ends of the link and are independent of any BSC convention. The BSC conventions can be used in conjunction with

control
characters

any code that has a fixed-length character set and includes the required control characters. This characteristic permits using either EBCDIC or USASCII as the transmission code. Except for the encoding of data, the operation of the communication link is identical for either code.

It is appropriate to note here that a device conforming to BSC conventions by no means guarantees its operational compatibility with all other devices conforming to BSC conventions. Although the use of graphic characters is generally not a problem, because there is no question of interpretation, end-to-end controls are quite another matter. Different input/output devices generally require entirely different end-to-end control functions. For instance, a display's cursor control character would mean nothing to a printer. Device incompatibilities of this sort require special manipulation of the data to convert from an incompatible into a compatible format, before transfer to a particular output device. This function might be performed at either end of the link.

transparent
text

In transparent text mode, normal interpretation of the BSC control characters is inhibited, permitting their use as data characters. The transparent text feature permits the sending of data encoded in other than the transmission code used in the communications link. However, the transmission line format must still be based on the same fixed-length character size as that of the transmission code. Because both EBCDIC or USASCII have a total of eight bits per character, transparent text can provide for sending packed decimal or hexadecimal encoded data and unrestricted eight-bit binary bytes. During transparent text mode, the parity bit position in USASCII is used as an eighth data bit; no parity check is performed on transparent text. Codes with fewer than eight bits per character can also be transmitted in transparent text format within the eight-bit character frame of EBCDIC and USASCII.

Synchronization

The BSC conventions prescribe the synchronization procedure. The serial-by-bit, serial-by-character nature of BSC requires that two levels of synchronization be established and maintained throughout each transmission. Bit synchronization requires that the receiver determine the optimum time for sampling each received bit; character synchronization requires that the receiver determine which of the bits in the bit stream together form a character.

Bit and character synchronization are established at the beginning of each transmission by transmitting a synchronizing pattern. Bit and character synchronization (usually called character phase) is then maintained until that transmission stops, the end point being signaled by certain BSC line control characters. A transmission stops at a point where either there is to be a change of direction of transmission or the transmission is being terminated. Synchronizing each transmission independently permits multipoint line operation, with each station sending with its own bit and character phase. This approach also allows the transmitter and receiver portions of a

station to share common hardware (e.g., shift registers and synchronization circuitry), because there is no requirement to maintain simultaneously both transmit and receive character phase.

The mechanism that controls bit synchronism is generally called a clock. Depending on the type of modem used, the clock is located within either the BSC station or the modem. When in the station, the clock determines the time for sampling each bit from the transitions between bits of different value. When the clock is within the modem, it provides a separate bit timing signal to the station. When transmitting, a BSC station also establishes bit timing either from its internal clock or from the modem.

Character synchronization must be performed by all BSC stations. The maintenance of current character phase is necessary at all times, even when a station is passively monitoring on a multipoint line while others transmit and receive. Character phase is established at the beginning of each transmission, through a two-character synchronizing pattern. If the station is equipped with a bit synchronizing clock, the character synchronizing pattern is sent immediately after the bit synchronizing pattern. From that point until transmission stops, all characters are sent contiguously and in phase with each other. If not prepared to send one data character immediately after another, the station must insert one or more whole synchronous idle characters (SYN) to maintain character phase until the next data character can be sent (in transparent text, synchronous idle is signalled by the two-character sequence, DLE SYN). The receiver recognizes synchronous idle and deletes it from the received data.

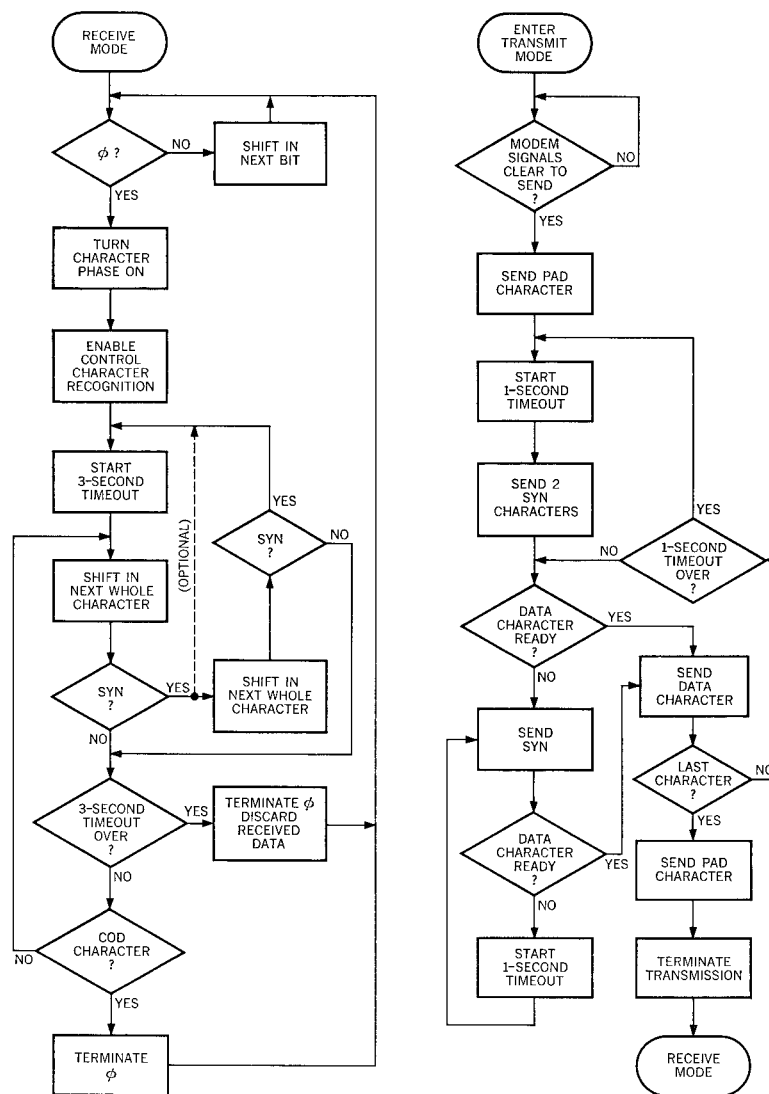
character
synchronization

Character phase is ended by those BSC control characters and sequences that signal either the termination of or a change of direction (COD) in transmission. In addition, while a station is receiving, character phase is terminated after an excessive time has elapsed (a timeout) without an appropriate control character being recognized. A flowchart of the basic character synchronizing procedure is shown in Figure 3.

A receiver achieves character phase by monitoring the communication line for the synchronizing pattern. This is called *hunt* mode, in which the station scans the received bit stream on a bit-by-bit basis for the character synchronizing pattern. At that point, the station turns on character phase and stops scanning for the synchronizing pattern; hunt mode is terminated, and the station enters *phase-lock* mode, so called because character phase is locked on. Received characters are formed by assembling the proper number of consecutive bits following the synchronizing pattern or the preceding character.

Once character synchronism has been achieved, hunt mode must be discontinued until the end of the transmission. Because of the lack of restrictions on the coding of data characters, sequences of normal characters can contain a false synchronizing pattern that could cause a receiver in hunt mode to achieve false character synchronism. Losing true character synchronism, in turn, can lead

Figure 3 Flowchart of character synchronization procedure



to recognizing false control sequences within a block of data.

Termination of character phase is coincident with ending transmission of the current block of data or sequence of control characters, as signaled through the line control characters. A receiving station must monitor for such end characters while in phase lock mode; when detected, it terminates phase lock mode and either sends a response, if appropriate, or returns immediately to hunt mode.

Timeouts are used to recover from becoming falsely synchronized while receiving, either because a false synchronizing pattern was recognized or because a phase-ending line control

character was garbled and not recognized during transmission, by returning the receiver to hunt mode. The procedure requires that the transmitting station insert the two-character sequence SYN SYN (DLE SYN in transparent text blocks) at nominal 1-second intervals in transmissions longer than 2.6 seconds. The inserted synchronous idle characters provide a receiving station with a pattern on which to scan to confirm that it is in true character phase. Once in phase lock mode, a receiving station will initiate a nominal 3-second (minimum, 2.6-second) timeout. If the SYN SYN sequence is not recognized before this timeout ends, the receiver assumes that it is falsely synchronized. It immediately terminates character phase and reverts to hunt mode. Should a synchronous idle sequence be recognized (in current character phase) before the timeout ends, the receiving station restarts its 3-second timeout, permitting data transmission to continue indefinitely.

Since the minimum receive timeout is 2.6 seconds, a transmitter whose transmissions can never exceed 2.6 seconds need not insert the synchronous idle sequence. But these signals must be inserted in all transmission blocks with a transmission time exceeding 2.6 seconds.

The inserted synchronous idle signals reduce slightly the effective data transmission rate but eliminate restrictions on block length. The insertion of two consecutive SYN characters also has the advantage of causing a receiver that is incorrectly in hunt mode (perhaps because it missed the synchronizing pattern) to become correctly synchronized by the inserted sequence. This limits the exposure of becoming falsely synchronized by bit patterns within data.

The BSC conventions permit a station to place constraints on block length. A station can apply reasonableness tests on record length wherever appropriate. For instance, it is not reasonable to transmit more characters in a block than a receiving station can handle at one time (the maximum block size for a particular receiver should be known at the transmitter); hence, a receiver may terminate synchronism whenever such limits are exceeded. However, limit checking is not always possible; even though used by a station while it is receiving, limit checks cannot generally be used when monitoring transmissions that are directed to other stations on a multipoint communication line.

Operational control

The operational control conventions cover the exchange of information between stations, for the purpose both of sending messages and of controlling and coordinating the operation of stations in the communication link. A BSC communication link can be in either of two states:

- *Message transfer state*, in which the principal function is the transmission of data.

- *Control state*, in which the direction of data transmission and the roles of the stations on the line during the forthcoming transmission are established (whether they transmit, receive, or monitor the transmission).

message
transfer
state

The message transfer state exists in the communication link while messages and the related reply signals (used to ensure that the transfer was successful and correct) are transmitted. This state is entered at the beginning of the first message in a transmission and is maintained throughout the last message and reply, until an end-of-transmission signal is sent.

In BSC, each message is treated as an entity that is independent of all other messages in the transmission. A BSC message need not coincide with what another part of the system treats as a message. Actual system messages may comprise one or more data communication link messages, or several actual messages may be sent in a single data communication link message. On the link, a message may be made up of one or more blocks of data, each block denoted by line control characters at its beginning and end; bits and characters for error checking purposes accompany each block. At the end of each block, the receiver replies indicating whether the transmission can continue or a retransmission is necessary.

Three message block formats are permitted—text, transparent text, and heading. Text blocks contain the data to be transmitted between stations. “Normal” text blocks can be used only to convey characters encoded in the communication link’s transmission code. Transparent text must be used for transmitting data encoded in any other (foreign) codes, such as unrestricted binary data or encrypted messages. The BSC system must deliver text (either normal or transparent) without adding, deleting, altering, or transforming the information content. However, re-establishing format, subdividing into blocks, translating code, inserting and deleting line control signals, etc., may be performed within the system. But to effect final delivery of the text data without alteration, a BSC device must restore or convert the message to its proper format prior to delivery to the ultimate destination. In this way, BSC is made independent of message content and format.

Heading is a special-purpose format, available to convey supplementary system control information separately from text data. A heading block is a sequence of transmission code data characters (noncommunication control) preceding a text or transparent text message. The supplementary information contained in a heading may relate to either or both the communication link or the ultimate destination devices or systems. For example, the heading may be used to indicate:

- Precedence or priority
- Security classification
- Date and time of origination
- Identity of originator
- Classification of data

- Addressee(s)
- Routing information
- Instructions related to processing of the associated text

An active BSC link operates in the control state whenever it is not operating in the message transfer state. Control state is entered when the end of a transmission is signaled with the end-of-transmission (EOT) control character.

control
state

The initialization of stations preparatory to transmission of text is carried out in the control state. The different types of communication networks, line configurations, and station types have differing control requirements. The BSC conventions provide two separate, basic modes of operation in the control state:

- Contention mode, which is restricted to operation on two-point communication lines (either switched or dedicated).
- Supervised mode, which is required to operate on dedicated, multipoint communication lines and may also be used on switched or dedicated two-point lines.

Two stations operating in contention mode are symmetrical, with neither station having general control over the link or the other station. Either station may initiate a transmission to the other when in the control state; since there is no control over this act, both can contend for the line simultaneously.

contention
mode

A station initiates a transmission by "bidding"; it signals its intention and requests permission to transmit by sending the enquiry (ENQ) character. The other station is then obliged to reply, indicating whether or not it is able to receive a transmission by using the affirmative (ACK) or negative (NAK) reply signals.

To provide for the situation in which both stations simultaneously bid to become the transmitter, one of the stations is denoted the primary station and the other, the secondary station. If both stations attempt to transmit simultaneously, the primary station will transmit first.

On long-distance communication lines, sufficient propagation delay can occur so that, above certain transmission rates, the entire enquiry signal and its synchronizing pattern are traveling along the line at one time. If two stations bid for the line at almost the same time and the channel is full-duplex (so that the two signals do not interfere with each other), both stations will receive the other's enquiry instead of the expected affirmative or negative reply. A similar situation occurs on both half- and full-duplex lines if one station's enquiry is garbled during transmission.

To overcome these contention situations, the primary station ignores an enquiry received after sending its initial bid enquiry and repeats the enquiry until an affirmative or negative reply is received. The secondary station, on the other hand, replies affirmatively to received enquiry signals if ready to receive and negatively otherwise. The primary station uses a nominal three-second timeout to limit the time that a reply is awaited before

supervised
mode

retransmitting the enquiry. The difference between the primary and secondary stations' timeouts forces them out of contention. In switched network circuits, by convention, the station that originates (dials) the connection acts as a primary station; the answering party as a secondary station.

In supervised mode, one station on the line, the control station, has the primary responsibility for controlling the communication link when in the control state; all other stations on the link are termed tributary stations. The control station polls each of the tributary stations, in turn, by sending their respective polling addresses, to give them an opportunity to transmit. A polled tributary station replies with its message if it is ready to transmit and negatively otherwise. After each negative reply or data transmission in response to a poll address, the control station may continue or resume polling.

The basic operation of supervised mode is "centralized"; that is, all transmissions are either to or from the control station. Messages between tributary stations on the same communication link must be transmitted to the control station, which retransmits them to the specified (addressee) tributary station.

If the control station desires to send to a tributary station, it must first select that station through a unique selection address, which is assigned to each tributary station. When addressed, the tributary station replies affirmatively (ACK0) if ready to receive and negatively (NAK) if not. The affirmative response permits the control station to send the message. A station is selected only if it replies affirmatively to its selection address. The negative reply to selection permits the control station to immediately poll or select other stations without special termination, because the communication link remains in the control state.

Noncentralized operation is a special-purpose extension of supervised mode that permits a tributary station to send directly to another tributary station on the same link. When polled, the tributary station that is ready to transmit must first select the station to which it desires to send by sending the selection address. Even the control station has a unique selection address and must be selected to receive a message. However, only the control station may perform polling.

Whether centralized or noncentralized, in the supervised mode, all stations not selected are required to monitor all transmissions on the communication link during the message transfer state, for the end-of-transmission signal that returns the link to the control state. While in the message transfer state, a station cannot be polled or selected, since it ignores addresses. The control station monitors the line using an idle line timeout. If, after a polled tributary station has started sending, there is a long idle period in which no data blocks or control sequences are sent, the control station signals the termination of the current operation, returning the communication link to the control state, thus protecting against system stoppage.

In switched network operation, the party that originates (dials) the connection, by convention, sends first, as noted earlier. The means of establishing a connection are beyond the scope of BSC conventions (which define operation only while a connection is established). After connection, operation is basically the same as that on dedicated, two-point circuits, until disconnection. Either contention or supervised mode may be used in control state. In contention mode, the originating party operates as the primary and the answering party as the secondary station. In supervised mode, either the answering or the originating party may be the control station, but the only connections permitted are between a control station and a tributary. The control state is re-established when the originating party sends the end-of-transmission signal, turning the link over to the control station.

switched
network
operation

Circuit assurance mode is available for identification of either or both parties immediately after a switched network connection has been established, to ensure that the correct party has been reached and that an authorized party has been called. The originating party sends its identification sequence followed by a "Who are you?" signal (the ENQ character). The answering party, in turn, replies with its identification sequence.

circuit
assurance

In contention mode, the answering station's identification sequence indicates whether it is ready to receive. If it is, the originating party may send a message block; if it is not, the calling party may send an end-of-transmission signal to yield the link to the answering party, so that it, in turn, can initiate a transmission through the usual bidding procedures. The circuit assurance mode is terminated when an EOT signal is sent or when the transmission of text, transparent text, or heading takes place.

When in the supervised mode, circuit assurance mode is terminated following the identification exchange by the originating party sending the EOT signal. This places the communication link in supervised mode, and the control station can then poll or select the other (tributary) station.

In any case, if either the originating or answering party is not satisfied with the other's identification, it may initiate disconnection (sending the disconnect signal, DLE EOT, is optional).

Information formats

The various control signal transmission and message block formats are shown in Tables 2 and 3. Control state formats are given in Table 2 and message transfer state formats in Table 3.

All transmissions have three elements in common. First, each has a synchronizing pattern to establish character phase and, if necessary, bit synchronization; this pattern is represented by the Greek letter phi (ϕ). Second, each has an ending character or sequence that signals a line control function and also terminates character phase. The normal ending sequence for a block of text, transparent text, or heading also includes a block check character,

Table 2 Control state signal formats

<i>Type</i>	<i>Format</i>	<i>Remarks</i>
Contention mode selection	ϕ ENQ *	Request for permission to transmit
Supervised mode selection	ϕ A (up to 6 noncontrol characters) ENQ *	Basic format for selection address sequence, where graphic A is unique address of station
	ϕ A (up to 6 noncontrol characters) STX text . . .	Fast selection address for text transmission
	ϕ A (up to 6 noncontrol characters) DLE STX trans text . . .	Fast selection address for transparent text transmission
	ϕ A (up to 6 noncontrol characters) SOH heading	Fast selection address for heading transmission
Selection replies	ϕ ACK0 *	Basic affirmative acknowledge
	ϕ NAK *	Basic negative acknowledge
	ϕ (up to 7 noncontrol characters) ACK0 *	Affirmative acknowledge with up to 7 end-to-end control characters
	ϕ (up to 7 noncontrol characters) NAK *	Negative acknowledge with up to 7 end-to-end control characters
	ϕ WABT *	Wait before transmit
	ϕ (up to 7 noncontrol characters) WABT *	Wait before transmit with up to 7 end-to-end control characters
Supervised mode polling	ϕ A (up to 7 noncontrol characters) ENQ *	Polling address sequence, where graphic A is station address
Polling replies	ϕ EOT **	Negative reply ending transmission
	ϕ STX text . . .	Affirmative reply followed by text block
	ϕ DLE STX trans text . . .	Affirmative reply followed by transparent text block
	ϕ SOH heading . . .	Affirmative reply followed by heading block
Disconnect	ϕ DLE EOT **	Disconnection is initiated (switched network only)
Circuit assurance mode	ϕ (up to 15 noncontrol characters) ENQ *	"I am/who are you?" sequence with up to 15 characters for identification and end-to-end control (switched network only)
Identification replies	ϕ (up to 15 noncontrol characters) ACK0 *	"I am" response with up to 15 characters for identification and end-to-end control
	ϕ DLE EOT **	Originator's response unsatisfactory and disconnection being initiated
	ϕ (up to 15 noncontrol characters) NAK *	Not ready to receive with up to 15 characters for identification and end-to-end control
	ϕ (up to 15 noncontrol characters) WABT *	Temporarily not ready to receive with up to 15 characters for identification and end-to-end control

ϕ synchronizing pattern
trans text transparent text

* change of direction in transmission
** no reply expected

used to detect transmission errors. Third, a pad character is sent following the ending sequence to ensure that the data set will send the entire sequence before its modulator is turned off.

Ending characters or sequences generally call for a response by the other station. A selection sequence, a polling sequence, and a message block each call for a reply by the receiver, relating to its status and/or the outcome of the transmission. The receiver's reply, in turn, generally calls for a continuation of the transmission in progress. The only signals that do not require a response from the other station are the negative replies to initial selection and polling (WABT, NAK, and EOT), the EOT signal, and the disconnect signal (DLE EOT). All signals that call for a reply are referred to as change-of-direction (COD) signals; COD is denoted by a single asterisk (*) following the sequence in Tables 2 and 3. Ending signals that do not call for a reply are denoted by a double asterisk (**) following the sequence.

When operating with half-duplex communication facilities or as a tributary station on a multipoint link, there is a danger that when the transmitting station signals the data set to turn off its modulator, some of the immediately preceding bits will be garbled. Transmission of the pad character before stopping transmission helps to prevent meaningful characters from being garbled. The pad character is not recognized and therefore does not affect stations receiving the transmission preceding it.

Means are provided to prevent the start of a transmission by one transmitting station before the last station has completed sending its ending pad character, since the last station would not be ready to receive. All BSC stations delay sending a synchronizing pattern for at least the time required to send one full character following receipt of an ending sequence (this time can also be regarded as a pad character or be implemented by actually sending a beginning pad character). Beginning and ending pad characters can overlap each other in time when operating on a full-duplex communication facility. However, on half-duplex facilities, the modems cause the pad characters to be sent serially, because of the delay they cause before the transmitting station is permitted to begin sending.

Text, transparent text, and heading block formats have, in addition to an ending character, a starting character or sequence that identifies the type of block—STX for text, DLE STX for transparent text, and SOH for heading. Each starting sequence also switches the link from control to message transfer state.

Identical transmission formats with the same control characters or sequences can have different significances. Their explicit meaning at any time is determined by the state of and the roles being played by the stations sending and receiving them.

Control state is entered, re-affirmed, or continued by the EOT signal (which does not call for a reply). All other dynamic states and modes are reset, permitting the use of EOT as a general reset signal should the stations in the link somehow become functionally out of step.

control
state
formats

Table 3 Message transfer state information formats

<i>Type</i>	<i>Format</i>	<i>Remarks</i>
Normal text	ϕ STX text ETX bcc *	Basic text block format, last block in text message
	ϕ STX text ENQ *	Disregard this block
	ϕ STX text ETB bcc *	Text block other than last
	ϕ STX text ITB bcc text . . .	Intermediate text block
	ϕ STX text ITB bcc STX text . . .	Intermediate text block
Trans-parent text	ϕ STX text ITB bcc SYN SYN DLE STX trans text . . .	Intermediate text block followed by transparent text block
	ϕ DLE STX trans text DLE ETX bcc *	Last block in transparent text message
	ϕ DLE STX trans text ENQ *	Disregard this block
	ϕ DLE STX trans text DLE ETB bcc *	Transparent text block other than last
	ϕ DLE STX trans text DLE ITB bcc SYN	Intermediate transparent text block followed by another intermediate transparent text block
	ϕ DLE STX trans text DLE ITB bcc text . . .	Intermediate transparent text block followed by an intermediate block of normal text
	ϕ DLE STX trans text DLE ITB bcc STX text . . .	
Heading	ϕ SOH heading STX text . . .	Heading block followed by text block
	ϕ SOH heading ETB bcc *	Individual heading block
	ϕ SOH heading ENQ *	Disregard this block
	ϕ SOH heading DLE STX trans text . . .	Heading block followed by transparent text block
	ϕ SOH heading ITB bcc heading	Intermediate heading block followed by another intermediate heading block
	ϕ SOH heading ITB bcc SOH heading	
	ϕ SOH heading ITB bcc STX text . . .	Intermediate heading block followed by text block
	ϕ SOH heading ITB bcc SYN SYN DLE STX trans text . . .	Intermediate heading block followed by transparent text block

The irrevocable nature of the EOT signal can preclude recovery from an erroneous EOT signal. To limit the probability of erroneous recognition, the format has been restricted to the concise sequence ϕ EOT*. The EOT character must be the *first* character other than SYN; if any other characters precede EOT, a station would not interpret EOT as the end-of-transmission signal, thus minimizing the chance of stations being erroneously reset.

Control state operation depends on whether contention or supervised mode is being used. A different procedure is used in each mode for determining which station is to transmit and which is to receive in the forthcoming transmission. In contention mode, the simple enquiry signal is sufficient for performing the bidding

Table 3 Message transfer state information formats (cont'd.)

<i>Type</i>	<i>Format</i>	<i>Remarks</i>
Enquiry	ϕ ENQ *	Receiver requested to send or repeat current reply
Basic replies	ϕ ACK1 *	Odd affirmative acknowledge reply to first and all odd-numbered blocks
	ϕ ACK0 *	Even affirmative acknowledge reply to second and all even-numbered blocks
	ϕ NAK *	Negative acknowledge reply
Special replies	ϕ (up to 7 noncontrol characters) ACK1	Odd affirmative acknowledge reply with up to 7 end-to-end control characters
	ϕ (up to 7 noncontrol characters) ACK0	Even affirmative acknowledge reply with up to 7 end-to-end control characters
	ϕ (up to 7 noncontrol characters) NAK *	Negative acknowledge reply with up to 7 end-to-end control characters
	ϕ WABT *	Wait before transmit reply
	ϕ (up to 7 noncontrol characters) WABT *	Wait before transmit reply with up to 7 end-to-end control characters
Special conversational replies	ϕ STX text...	Conversational reply of text block
	ϕ DLE STX trans text...	Conversational reply of transparent text block
	ϕ SOH heading ...	Conversational reply of heading block
ϕ	synchronizing pattern	
trans text	transparent text	
*	change of direction in transmission	

function. Supervised mode is used on multipoint links where stations must be explicitly identified as they are selected to receive or are polled; both the selection and polling functions are performed by addressing.

The poll and select address formats are identical. The first character other than SYN is the station address, and it must be unique for a single station unless it is a group selection address. The station address character may be any valid character (such as an alphabetic) that is not a control character, and it can be followed by up to six other noncontrol characters for the purpose of end-to-end control, such as selection of input/output components. One station may have either:

polling and
selection
addresses

- Two different station address characters, one for polling and the other for selection, that can be used with additional characters, or
- A single station address character that can be used when additional characters accompanying the address identify input or output components.

The first case indicates polling and the second selection. The basic ending character for an address is ENQ, which causes a COD so that the other station can reply. If selected, the station's reply indicates whether it is or is not ready to receive. If polled but not ready to transmit, the reply is the EOT signal; if ready to transmit, the reply depends on whether centralized or noncentralized operation is being used. The centralized reply is the first text, transparent text, or heading block in the transmission. The noncentralized affirmative reply to polling is the selection address of the station to which the transmission is directed; that station then replies, and, if the reply is affirmative, message transmission takes place.

The replies to initial selection signals are identical in format for both contention and supervised modes. The even affirmative acknowledge (ACK0) sequence indicates that the station has been selected and is ready to receive. The negative acknowledge (NAK) and wait before transmit (WABT) sequences indicate not selected and not ready to receive. WABT implies that the not-ready condition is temporary and selection should be re-attempted soon. All of the reply signals may, optionally, be accompanied by up to seven noncontrol characters for end-to-end control purposes. The ACK0, NAK, and WABT signals each act as an ending sequence.

In centralized, supervised mode, the reply to initial selection can be eliminated through a special-purpose operation termed fast selection. (Fast selection is not available in noncentralized operation.) If operational when addressed, a station that uses fast selection must be prepared to accept a transmission, since there is no way to reply negatively to initial selection. The selection address is ended with the beginning of the first block of text, transparent text, or heading, instead of the ENQ character; the two are transmitted together. The selected station's reply following the first block is the response to the outcome of the block's transmission, rather than to initial selection. The total time required for a transmission is reduced by the amount of time required for a reply and two changes in the direction of transmission, including the time for two data set turnarounds and a round-trip propagation delay (up to a 0.6 second on a long, half-duplex communication line).

Fast selection is especially effective for improving throughput where there are only one or two blocks per transmission and the reply time is a significant fraction of, or longer than, the time required to transmit a block.

Group addressing is a special-purpose extension that is achieved by assigning the same station address character to a number of

stations, permitting the group of stations to receive a single transmission (eliminating separate transmissions of the same message to each of the stations in the group). Only one station is conditioned to reply both to initial selection of the group and during message transmission. All other stations in the group copy the transmission without replying.

To protect the system from errors resulting from stations being either selected and/or polled erroneously, bsc stations react only to their predefined addressing or bidding sequences. Any variations will result in the address sequence being disregarded, even though portions of the sequence are correct.

In circuit assurance mode the "I am/who are you?" sequence sent by the originating station can consist of up to 15 noncontrol characters used for identification and possibly end-to-end control; the ending character is ENQ (which asks "Who are you?"). If the answering party is satisfied with the received "I am" sequence, it replies with its identification sequence, comprising up to 15 non-control characters and normally ending with ACK0 (in certain cases, NAK or WABT may end the sequence). This exchange may be repeated while both stations remain in circuit assurance mode.

On links using contention mode, the "I am/who are you?" sequence also acts as the initial selection sequence, in place of the bidding signal. The originating station thus always has the first opportunity to transmit. The ending sequence of the answering party's identification reply signal is used to indicate its status: ACK0 if ready to receive, NAK if not ready to receive, and WABT if temporarily not ready to receive. In the supervised mode, only ACK0 is used for ending the identification sequence.

The originating station terminates circuit assurance mode by sending the EOT signal. The link then reverts to supervised mode, and the control station (whether it is the originating or answering party) is free to poll or select the tributary.

Message transfer state is entered when an STX, DLE STX, or SOH character or sequence is transmitted or received at the beginning of the first block of text, transparent text, or heading in the transmission. This state is then maintained until the end-of-transmission signal is sent, which returns the link to the control state. The three types of information blocks have similar, though not identical, formats. Each has a starting and an ending character. The starting character terminates the control and establishes the message transfer state, identifies the type of block, and initiates block checking. The ending character signals the end of the block; in most instances it signals a change of direction of transmission and precedes immediately a block check character (bcc) used for error detection.

An ending character terminates transmission blocks in order to accommodate any desired block length. A particular system can use either fixed- or variable-length blocks, according to requirements.

The fundamental unit of bsc message exchange is the text message, which may not correspond with what the system regards as a message. Text begins with STX and ultimately ends with ETX

message
transfer
state
formats

text

(followed by the bcc). The BSC conventions treat each message as an entity that is independent of all other messages transmitted in the same or other transmissions. A message is not considered successfully transmitted unless and until all blocks comprising that message have been accepted by the receiving station, as signaled to the transmitter through affirmative replies. In BSC, the outcome of the transmission of any message has no bearing on the messages that have already been transmitted and accepted, whether those messages were sent in the same or in earlier transmissions. BSC conventions apply only to the message or block currently being handled. A system conforming to BSC conventions may consider separate messages as being related in a number of ways beyond the BSC conventions, and failure to receive a particular group or sequence of messages may thus be deemed an error condition. This level of control has been left to whatever end-to-end procedures are appropriate for a particular system or application.

Blocking within a message is possible through use of end-of-transmission block (ETB) and intermediate block (ITB) control characters; the bcc is transmitted immediately following these characters. ETB, like ETX, results in a COD following the bcc, to permit the receiving station to send its reply for the block. The reply, in turn, results in a COD, and another message block may then be sent following an affirmative acknowledge reply; a retransmission of the last block follows the negative acknowledge reply. The ITB character does not result in COD, since the receiver does not reply for each intermediate block. Instead, text message transmission resumes immediately after the bcc has been sent. A transmission block that contains intermediate blocks ends with ETB bcc or ETX bcc, at which point a COD does occur, to permit the receiver to reply in the usual manner. The reply applies to the entire block of intermediate blocks. ETX is used only to end the last block in a text message. When a message is subdivided into two or more blocks, each block except the last is ended with ETB bcc.

The receiver's accumulation of the bcc is synchronized with the transmitter's through the STX, ETX, ETB, and ITB characters. The bcc accumulation is initiated with the first STX in a transmission block, which causes the accumulation to be reset, so that this STX is not included. Thereafter, all characters except SYN are accumulated until the block ends. The end-of-block character (also accumulated) signals that the block check accumulation follows immediately. Since it is possible for the accumulation to assume any bit pattern, all control character recognition (including SYN) is suppressed while the bcc is being sent or received; SYN characters cannot be inserted at this point, since they would be interpreted as the bcc by the receiver.

The bcc character is reset at the beginning of each text block, to permit isolation of blocks containing errors, by beginning each block following a COD with STX. Intermediate blocks that do not immediately follow a COD need not start with STX, although it is permitted. Isolation of intermediate block errors is achieved by

resetting the bcc accumulation immediately after each ITB bcc; an STX following an ITB bcc does not reset but is included in the accumulation.

The bcc accumulation is never considered valid unless initiated by STX or SOH at the beginning of the transmission block. Receiving and recognizing ETX, ETB, or ITB while in character phase and not in text, transparent text, or heading mode and with bcc accumulation not initiated is considered to be an error; checking of the bcc is initiated, no reply is made (at that time), and the receiver's current reply is not modified.

The method of bcc accumulation provides protection from failure to synchronize at the beginning of a block consisting of intermediate blocks. A receiver that is out of phase and hunting during such a transmission can become correctly synchronized (by recognizing the inserted SYN characters) and receive a later intermediate block that begins with STX and so appears to have the proper format. Although the receiver is not aware that preceding intermediate blocks were lost, a bcc check will occur and prevent acceptance of the first intermediate block it received (even if that block were received without error). The bcc check occurs because the transmitter would accumulate the STX character in that intermediate block, while the receiver would reset its accumulation and not include the STX.

Subdividing messages into a number of shorter transmission blocks has two advantages:

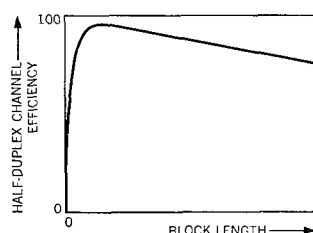
- It improves performance by helping to overcome the loss of time due to transmission errors.
- Block length can be matched to input and output elements, such as buffer size and media limitation (e.g., characters per punched card or printed line).

Performance is affected because the longer a block, the greater the probability of an error during its transmission. Transmitting blocks containing errors contribute nothing to throughput; the transmission time for a block received with errors is effectively lengthened by the time required to recover and retransmit the block. Effective data transmission rate is reduced by the average amount of time spent in performing retransmission, which is directly related to the probability of an error in a block.

Shorter messages, longer turnaround delays, and lower error rates each act to reduce the effect of blocking on total throughput. Turnaround delay is the total time required to receive the reply for a block before the next block is sent. It comprises the sum of propagation and modem delays, the reaction time of the receiver and transmitter following a received COD signal, and the time required to end the reply signal.

The control character and turnaround delays increase with the number of blocks per message. There is actually an optimum block length with any combination of message length, turnaround delay,

Figure 4 Half-duplex channel efficiency vs block length



transparent
text

and transmission error rate, for achieving maximum throughput. An increase in block length from the optimum tends to reduce throughput, because of the increased probability of an error in a block. However, with a shorter block length, the fixed overhead of control character and turnaround delays becomes increasingly significant in reducing throughput.

An example of how half-duplex channel efficiency varies with block length in bsc is shown in Figure 4. Half-duplex efficiency is the ratio of transmission time for a block of data characters only to average total transmission time for the same size block including all turnaround delays, times for transmitting control characters, check characters, and replies, and time spent in retransmissions.

Intermediate blocking is an effective means for overcoming extensive turnaround delays, particularly when the receiver must process each intermediate block individually.

Conditions can arise within a transmitting station that prevent the complete transmission of a block whose transmission is already in progress. This condition might result from an equipment malfunction, such as a card jam or a parity check occurring while obtaining characters from a buffer or reading mechanism. In such situations, the transmitter can signal the receiver to disregard the block by terminating it with the ENQ character. ENQ causes a COD and calls for the receiver to reply; if the receiver can accept a retransmission, the proper reply is the negative acknowledgment (NAK).

Transparent text renders the communication link insensitive to all communication control characters and sequences within the data block. All bit combinations, including those assigned as control characters, can therefore be used as data characters within transparent text (the channel becomes "transparent" to the data code). Transparent text block format is essentially the same as that for normal text blocks. The principal differences between the two are in the sequences that begin and end the blocks; there are, in addition, some special format considerations.

All communication control signals for transparent text are two-character sequences that begin with the data link escape (DLE) character, as shown in Table 4. The second character identifies the sequence. These two-character sequences and their normal text counterparts are used in an identical fashion (see Table 2).

Table 4 Transparent text control sequences

DLE STX	Start of transparent text
DLE ETX	End of transparent text
DLE ETB	End of transparent text block
DLE ITB	End of intermediate transparent text block
DLE ENQ	Disregard this transparent text block
DLE SYN	Transparent synchronous idle

A special procedure is followed during the transmission of transparent text to ensure that the above communication control sequences are unique in the transmitted data stream, so that they can be separated from data. This is done in such a way that these same communication control sequences can be transmitted as data within the message, without initiating their communication control function. This is accomplished by breaking up all potential communication control sequences within transparent text before their transmission. When a DLE character occurs within the data, it is recognized by the transmitter, which then causes two consecutive DLE characters to be transmitted in the place of each original one.

The receiver enters transparent text mode upon recognizing the DLE STX sequence. Thereafter, it ignores all communication control characters occurring singly except DLE. However, upon recognizing a first DLE, a receiver determines whether the following character is for communication control. If the following character is ETX, ETB, ITB, ENQ, or SYN, its corresponding function takes place, as it would if the sequence had occurred within a normal text block. However, if the following character is DLE, one of the pair of DLE characters is discarded and the other is treated as data that happens to have the same bit pattern as DLE. The second or data DLE is not treated as a control character; if an ETX, ETB, ITB, ENQ, or SYN character follows the second DLE, no communication control action is taken. If the character following the first DLE is not a defined transparent text communication control character, the sequence is treated as a transmission error in the data.

Operation in transparent text mode can be seen by assuming that the following sequence of characters is a data message before being formatted for transmission:

A 2 ENQ DLE ETX B C DLE DLE SYN

The transparent text message block actually transmitted would be:

ϕ DLE STX A 2 ENQ DLE DLE ETX B C DLE DLE DLE DLE SYN
DLE ETX bcc

All first DLE characters are underlined. Note that only the final DLE ETX is recognized as the end-of-text sequence, because it is the only DLE sequence following the DLE STX in which a communication control character follows a first DLE.

The synchronous idle sequence that is used within transparent text blocks is DLE SYN. Should time fill be required within a transparent text transmission, an integral number of complete two-character DLE SYN sequences must be inserted until a data character is again available. A transmitter cannot insert a synchronous idle between a first DLE and the following character within any two-character transparent text control sequence. The receiver removes all synchronous idle sequences from the received data. The DLE SYN sequence is inserted at approximately 1-second intervals, just as in normal text. Also, in order to maintain character phase, a receiver must recognize this sequence at least once within

each 3-second interval during a prolonged transparent text transmission.

The bcc accumulation is done as in normal text. The STX character in the start of a transparent text sequence that occurs in a transmission block, but does not follow an STX or SOH in the same transmission block, resets the bcc accumulation but is not included in the new accumulation. Thereafter, all synchronous idle sequences are excluded from this accumulation; both the first DLE and the SYN characters are excluded. For simplification, all first DLE characters within transparent text blocks and intermediate blocks are also excluded from the accumulation, so that a receiver need not examine the following character before deciding to include or exclude it from the accumulation.

When sending intermediate transparent text blocks, each intermediate block must begin with DLE STX, to re-establish transparent text mode. Transparent text mode does not automatically propagate from one intermediate block to the next within a transmission block so that, without a DLE STX, the communication link would revert to normal text mode. In each intermediate block except the first, both the DLE and STX characters in the sequence that re-establishes transparent text mode are accumulated in the bcc. The DLE is included in this case, because the stations have not yet returned to transparent text mode, following the DLE ITB bcc.

heading A heading provides supplementary control information relating to one or more text and/or transparent text messages immediately following it. A heading may remain in effect until canceled by the transmission of an EOT signal or another heading.

The format for heading blocks is identical to that of text except that heading blocks begin with SOH instead of STX and are not permitted to end with ETX. A heading may comprise one or more consecutive heading blocks, each initiated by SOH.

A heading block may end with an STX character or a DLE STX sequence without an intervening ETB bcc or ITB bcc. In this format, the transmission block simply continues directly into the text or transparent text block, beginning with the start-of-text character or start-of-transparent-text sequence. The bcc accumulation is initiated by the SOH character; an STX or DLE STX sequence sent in the same transmission block is included and does not reset the accumulation (similar to intermediate block check operation except that the accumulation is not reset at the end of the heading block). A transmission cannot end normally with a heading block that is not followed by a complete text or transparent text message.

message transfer state formats The three basic replies of receiving stations in response to COD signals are the odd and even alternating affirmative acknowledgments and the negative acknowledgment. Reply sequences cause a COD, so that the transmitter can resume sending. The affirmative acknowledgment indicates that the receiver accepted the last transmission block and that the transmitter can proceed immediately with the next block (if any). The negative acknowledgment reply signals that the receiver did not accept the last transmission block

and requests its retransmission, which can proceed immediately.

The two alternating affirmative replies, odd and even, are used as a means to detect the loss or duplication of a transmission block. The odd affirmative acknowledge (ACK1) reply is used for the first block in a transmission and every alternate block thereafter. The even affirmative acknowledge (ACK0) reply is used for initial selection (in control state) and for the second block in a transmission, as well as every alternate block thereafter. The odd or even property of a particular block does not change, even if that block is retransmitted. Thus, the transmitting station can verify that the received affirmative replies alternate between odd and even as the transmission progresses. The odd-even count is reset to the initial state by the EOT signal (sent in either direction). Separate odd-even counts exist for both directions of transmission whenever conversational mode is being used. To illustrate how alternating replies protect against lost transmission blocks, consider the following situation: The first block of data is received correctly and the receiver replies with ACK1. The transmitting station then sends the next block, but the receiver fails to synchronize because of a bit reversal in the synchronizing pattern and misses the entire transmission. The receiver does not send a reply following the COD signal of the transmitted block, so that the transmitter's timeout eventually elapses and the transmitter sends an enquiry signal to obtain the receiver's current reply. The receiver repeats the ACK1 reply, since it had failed to synchronize and does not know that a second block was sent. However, the transmitter expects ACK0 and thus recognizes that the second block was not received; it can then retransmit the second block. When ACK0 is received in reply to the retransmission of the second block, the transmitter can continue with its transmission. Note that without alternating affirmative replies, the second block would have been lost if the ACK reply to the ENQ was interpreted as the reply to the second block.

The basic affirmative and negative acknowledgments are transmitted alone, following their synchronizing pattern. A special-purpose format is also provided for transmitting auxiliary end-to-end control information where required, along with the replies. Up to seven noncommunication control characters may accompany each reply. The characters are inserted between the synchronizing pattern and the reply character sequence.

The special-purpose reply signal Wait Before Transmit (WABT) indicates that the receiver is temporarily not ready to continue receiving the transmission. It may be sent in place of an affirmative or a negative acknowledge reply; hence, it does not indicate whether the block was or was not accepted. WABT causes a COD, so the transmitter may, by sending enquiry, request the receiver to send its current reply. The receiver continues to send WABT in reply to ENQ until it is again ready to receive, at which time its reply changes to its current affirmative or negative acknowledge reply. WABT may also be preceded by up to seven noncommunication control characters.

If not ready to continue receiving, a receiver may simply not send its affirmative or negative acknowledge reply until it becomes ready. However, in this case, the transmitter can misinterpret the not-ready condition as a transmission line failure. WABT provides a positive indication that the communication facility is operational.

A receiver cannot ordinarily use the EOT signal as a reply while in message transfer state. The EOT signal is sent by a receiver only under certain unusual timeout conditions, in which the signal permits recovery from error conditions.

A special-purpose extension called conversational mode permits a station to send an inquiry type of message (a text or transparent text message requiring a reply—not the ENQ character) to another station, which then sends back an answer message. Instead of being handled with two separate transmissions in opposite directions, conversational mode permits the direction of transmission to reverse following a message, within a single transmission; however, only one such reversal is permitted per transmission.

The original transmitting and receiving stations are determined through the basic or special control state selection and/or polling procedures, in either contention or supervised mode. One or more text or transparent text messages (preceded by a heading, if desired) is then transmitted in the usual fashion. A conversational reply message is called for at a point determined by the system's particular operating (end-to-end) procedures. The last block must have ended with ETX bcc or DLE ETX bcc, signaling that the last message is complete. If the receiver accepts that block, it may then send a message in place of the normal affirmative acknowledge reply, causing the roles of the two stations to switch.

The conversational reply may comprise one or more text and transparent text messages, including headings. When the reply transmission has been completed, the new transmitter (only) sends the EOT signal to terminate message transfer state. Conversational mode reduces transmission time, as well as simplifying operating procedures.

transmitter
control
signals

Two control signals are provided for the BSC transmitting station in the message transfer state. The enquiry signal (ENQ) enables the transmitter to maintain control of the link and the EOT signal to relinquish control.

The ENQ signal is used by the transmitter to request the receiver to repeat its current reply signal—normally, a reply for the last block it received. The ENQ signal enables the transmitter to recover from lost or garbled reply signals and also to deal with the receiver's WABT signal. It is particularly useful when a number of blocks are sent per transmission, since the recovery following a garbled reply to a block might otherwise require retransmission of the entire message.

If the receiver is not ready to receive another block or a retransmission when ENQ is received, it can reply with WABT or it may send nothing, causing the transmitter's timeout to expire. In either case, the transmitter then repeats ENQ until an affirmative or

negative acknowledge reply is received, at which point it continues or terminates its transmission. Should no reply be received to a number of consecutive ENQ signals, a permanent error condition is presumed, which calls for outside intervention. A BSC device normally attempts at least three retries of an event before calling for intervention. Such a prolonged failure may be due to the receiver becoming reset or a failure of the communication facility.

The EOT signal is normally sent by the transmitter at the successful completion of transmission of a message (the last block ends with ETX bcc or DLE ETX bcc). A transmission is terminated early if errors or other conditions prevent its completion; end of transmission is signaled following a block ending with ETB bcc or DLE ETB bcc only in the event of such unusual conditions.

Timeouts

Timeouts supplement the transmission and recognition of control character sequences. They prevent the stoppage of operation on false or garbled communication control sequences and cause initiation of retry and recovery procedures; hence, timeouts act as a means of error detection. Timeouts establish a time for each operation, within which functions are required or expected to occur. Due to widely varying requirements in different situations, four timeout functions have been established: transmit, receive, text, and long timeouts.

The transmit and receive timeouts are related to the character synchronizing scheme, and their operation in this respect has already been discussed. The 3-second receive timeout is also used by the transmitter in message transfer state, to limit the time spent waiting for a reply after sending a COD sequence. If no reply is received within this period, the transmitter sends the ENQ signal, requesting the receiver to repeat its reply.

A reply following a COD must be made within a period that will, allowing for all transmission delays, be received within the minimum allotted time (2.6 seconds). In message transfer state, a receiving station must reply within a maximum 2 seconds following a COD. A greater delay could combine with propagation and data set delays to exceed 2.6 seconds, which could result in the reply being received after the transmitter's timeout had expired.

In control state, the receive timeout limits the time that a station waits for a reply to the initial selection address or to the "I am/who are you?" sequence in circuit assurance mode. In supervised mode, it limits the time that a station continues to actively monitor the line for its polling or selection address in the control state, without becoming synchronized and recognizing a COD character. Hence, should the link be idle for 3 seconds, all stations revert to a passive monitoring state, in which they cannot be selected or polled; an EOT signal is required to return the stations to control state. This timeout function in control state provides protection against the possibility of a station becoming selected or polled if it

is falsely synchronized by limiting the time in which a station that has lost true character synchronism can recognize its address.

In contention mode, a transmitter, after sending the EOT signal, normally relinquishes its use of the line for at least the period of the receive timeout, to give the other station an exclusive opportunity to become the transmitter through the bidding procedure. Within this interval, the last receiver can bid for the link without contention, helping to prevent the primary station from continually taking over the link because it always "wins" contention bidding exchanges.

The text timeout has been defined in principle, but its period has not been specified so that it can be chosen in accordance with requirements of each device or system. The text timeout acts as a "reasonableness" test, by imposing an upper limit on the length of a received intermediate block of text, transparent text, or heading. If the timeout period is exceeded, character phase is terminated, the system begins to hunt for a synchronizing pattern, and the block is discarded. The station does not send a reply until an enquiry is received; it may then send the NAK reply to obtain a retransmission of the block. The text timeout may be implemented in the form of a character count; e.g., the maximum number of characters in a printed line, a data buffer, a punched card, etc.

The long timeout is also defined in principle, and its period has been left to be specified for individual devices and systems. Its period might be about 30 seconds. The long timeout is used by stations operating on a switched network, operating in contention mode, and by the control station in supervised mode. It prevents extended periods of inactivity due to noise or garbled transmissions or to equipment malfunctions. The situations that usually lead to expiration of a long timeout are garbled EOT or switched network disconnect signals. Its expiration may initiate recovery procedures, such as sending an EOT signal and bidding or resuming polling, initiating disconnection in switched network operation, or signaling for local intervention.

Error control

Error control is the term applied to those BSC conventions related to detecting and correcting the errors that can occur during transmissions of data and control information between stations. Digital data communication facilities are generally subject to fairly frequent, intermittent transmission errors, which are caused by the presence of noise and by signal distortion. During certain periods of the day (normally midmorning and midafternoon), the error rate can increase to several times the average; this is balanced by lower than average error rates during other periods.

Error rates depend to a degree on the network configuration and the grade or quality of the communication facility. Switched circuits are generally subject to more errors than are dedicated circuits; multipoint lines can be expected to have a greater average

error rate than two-point lines of the same grade. The error rate can sometimes be improved by investing in better equalizing and signal conditioning equipment, but errors can never be entirely eliminated and practicality generally dictates the use of facilities with a non-negligible error rate.

These facts have involved error control in almost every functional element of BSC. This is the reason that a great deal has already been said about the detection of and the recovery from error situations that can result from false or garbled synchronizing patterns and control characters.

Reliable BSC is sought through error detection and correction. Errors are detected through use of timeouts and by checking control sequences, information formats, block check characters, and character parity (used with USASCII). Error detection initiates the appropriate recovery action to correct the situation.

error
detection

The principal means of checking data in text, transparent text, and heading blocks is through systematically generated redundancy characters and bits sent accompanying the data. The block check character (bcc), which is either one or two characters long, is sent at the end of each block. It is generated from the data in an identical fashion at both the transmitter and receiver, and the receiver compares the received bcc with the one that it generated from the received data. If not identical, an error has occurred; if identical, the block is assumed to be error free.

When the transmission code is USASCII, all data and control characters are transmitted with odd parity except for data characters within transparent text, which may have either odd or even parity. USASCII transmission characters comprise eight bits, including seven data bits and one parity bit. A receiver checks for odd character parity except when receiving transparent text data characters. However, the communication control characters in transparent text blocks must have odd parity to be recognized as such.

The error checking arrangement that is used in BSC depends on the transmission code and, in the case of USASCII, on whether the transparent text mode is used. A combination of vertical and longitudinal redundancy checking (VRC and LRC) is used for standard USASCII operation. If transparent text mode is used in conjunction with USASCII, all blocks of text, transparent text, and heading are checked with a sixteen-bit cyclic redundancy check (CRC). The VRC parity check of data characters is suppressed, to make all eight bits available for transmission of data.

The error detection capability of CRC depends partly on block length.³ But, regardless of block length, the CRC used with BSC can detect all errors comprising an odd number of error bits, all possible single error bursts not exceeding 16 bits long, 99.9969 percent of all possible single bursts 17 bits long, and 99.9984 percent of all possible longer bursts. Note that these percentages are not equivalent to the probability of detecting an error unless all errors are equally likely. Also, the length of an error burst is counted begin-

ning with the first bit and continuing through the last bit in the error burst; all bits within the burst, whether good or in error, are counted. It is assumed that true character phase is maintained. If the number of eight-bit data characters in a block does not exceed 4091 (not including communication control characters), this CRC will also detect any two bursts in a block each not exceeding two bits in length.

A combination of VRC and LRC is prescribed for standard USASCII operation. The odd parity VRC alone can detect any odd number of bits in error but no errors involving an even number of bits in a character. The effectiveness of VRC increases with block length; the fraction of all possible erroneous blocks that will not be detected approaches $1/2^N$ for large values of N (where N is the number of characters in the block). The LRC includes the seven data bits of the transmitted characters; the eighth bit of the LRC character is used for creating odd parity. Alone, LRC can detect all errors comprising an odd number of bits in a seven-bit data field and at least 99.2156 percent of all other errors in the data field. In combination, VRC/LRC detects all bursts not exceeding eight bits in length. To detect other possible errors, the two act together in such a way that an undetected error can occur only when every erroneous character and every erroneous bit position contain an even number of error bits. The total number of error bits must be an even number, four or greater, to cause a combined VRC/LRC detection failure.

While many control sequences are not subjected to the same type of checking as data in text, transparent text, and heading blocks, the permissible BSC formats and sequences of operation in effect impose a check at every point in a transmission. Only with USASCII is redundancy checking (character parity) performed on all control sequences. However, failure to recognize an acceptable control character at any given point is detected and treated as an error. Undetected transmission errors are possible only if an error results in one of the acceptable control sequences being created. Even in this event, the error can be detected later in the operation.

The probability of such control character conversion errors has been minimized through a judicious choice of control character codes, so that two or more bit errors are required to transform one control character into a similar type of control character. This provides protection from single bit errors, which are two or more times as likely as a multiple bit error in a single character. The frequency of this type of error is kept small because these errors can only result from the coincidental occurrence of a number of unlikely events whose combined probability is extremely small.

Format and sequence checks are also imposed on all text, transparent text, and heading blocks. Deviations from the prescribed sequencing and formatting of transmission blocks are treated as errors, regardless of the outcome of any bcc and VRC checks.

Timeouts too play an important role in error detection, providing protection against garbled control characters and loss of true character phase, as has been discussed.

Error recovery procedures permit bsc to continue without outside assistance through most periods of intermittent transmission errors and to correct those errors. Transmissions can be completed after the condition causing the error has cleared. In bsc, retries and retransmissions are used for error correction. Outside intervention is necessary only for outright failures, prolonged periods of transmission errors, and error events that are relatively unlikely and infrequent. Error recovery procedures are necessary to sustain automatic operation and to achieve good system performance in typical medium- and high-speed data transmission systems. For example, in a transmission link operating at 150 characters per second and handling a large volume of traffic consisting of 1,000-character transmission blocks with an average block error rate of 4 percent, an error could occur and a retransmission become necessary on the average of once every 1 to 4 minutes. If operator intervention were necessary to recover from each of these errors, virtually continuous assistance would be required, probably reducing the average block transmission rate.

The primary responsibility for carrying on a transmission rests with the transmitter. A receiver is responsible for checking the validity of the data it receives, and for signalling its status from time to time, but primary responsibility for recovery in the event of a detected error rests with the transmitter. A control station on a link operating in supervised mode has a special responsibility to guard against errors or failures that result in the link becoming idle. However, while a transmission is in progress, the transmitter controls the link.

A transmitter checks the progress of the transmission by monitoring the replies to transmitted blocks and through timeouts that limit the time spent waiting for a reply. Only the correctly numbered alternating affirmative acknowledge reply (or a conversational reply of a text, transparent text, or heading block, if allowed and expected) will be accepted. Either failure to receive a reply within 3 seconds or receipt of other than the affirmative reply is treated as a situation requiring recovery and, in most cases, as an error. A response of WABT is a special case, not a true error, but the transmitter uses recovery procedures to determine when the receiver is ready to continue.

A NAK reply and, in certain cases, the wrong alternating affirmative acknowledge result in retransmission of the last block. All other cases lead to the transmission of the enquiry signal, requesting the receiver to send its outstanding reply. That reply determines whether the transmitter sends the next block (if the correct affirmative reply is received), retransmits the last block, or sends another enquiry. Normally, a transmitter makes from three to seven attempts to recover after an initial action failed.

An error condition that arises in the course of operation, whether or not it is detected as such, may result from a single isolated error or error event or from a sequence of error events spanning several transmissions of either control sequences or data

blocks, sent in one or both directions. The number of possible isolated error events and sequences of error events is practically unlimited. But over the long term, it must be assumed that any error situation that is possible can, and in all likelihood, will occur. Of course, all error situations are not equally likely; their respective probabilities can span an extremely wide range. It is the aim of BSC procedures to recover from and correct those error situations that are more likely to occur. It is not practical to attempt to correct many of the possible error conditions whose probability of occurrence is relatively small, since the additional expense and burden is not justified. Calling upon outside intervention in these situations should not significantly affect overall performance.

From the standpoint of recovery and correction, the most important class of error occurrences is isolated error events, because they are the most likely. Isolated errors include individual transmissions that are received with one or more characters containing errors, while preceding and following transmissions contain no errors. The error condition may be detected immediately through the bcc if it occurs in a data block, through format and sequence check when true communication control characters are garbled or false sequences are generated, through character parity checks when using USASCII, and through timeouts when a synchronizing pattern or COD sequence is garbled during transmission.

Generally, the BSC conventions enable recovery from isolated error events without outside intervention, but there are some exceptions. Among the exceptions are errors that result in a station falsely entering or being reset and leaving the message transfer state. The most important case is that of a false EOT signal occurring, as a result of noise or transmission errors, in the midst of a message, terminating message transfer state and resetting the receiver prematurely. Also, in controlled mode, recovery from detected false polling or selection sequences cannot generally be done without outside intervention of some sort. However, the probability of occurrence of these errors is held to a minimum by checking formats and states strictly according to their definitions. The effect of these particular errors on performance should be small, because the exposure is very limited.

From the standpoint of recovery, error situations that result from multiple error events are often much harder to deal with than isolated errors. Because they result from a combination of error events, their probability of occurrence is much smaller than that of an isolated error. Detection and automatic recovery from a sequence of error events is very often possible through standard BSC procedures. However, there are also instances in which the communication link is left in an indeterminant or ambiguous condition that requires some type of outside intervention to recover. In other cases, one error may complement or compensate another, with the result that the error condition is not detected.

While the chance of multiple error events is somewhat limited, the probability of undetectable and unrecoverable error conditions

is further reduced, because they can result only from specific and limited combinations of errors. An example of such an undetectable error is the condition in which an odd-numbered block is received without error but the receiver's ACK1 reply is converted by noise to NAK. The transmitter would continue by retransmitting the block, which would be duplicated at the receiver. The receiver would reply ACK0 at this point. Ordinarily this would be detected as being out of sequence by the transmitter (since it expects ACK1 as a response to the retransmission), and the error condition would be detected. However, if through a second error, an ACK0 reply was transformed by noise into either ACK1 or NAK, a duplicated block error would result. Unless some form of block numbering or other end-to-end checking were performed in conjunction with the BSC procedures, the error would not be detected. However, the coincidence of the two specific errors in this particular sequence is a great deal less probable than that of an individual occurrence of a reply being transformed into a different reply; also, the chance of a reply being transformed into another reply is somewhat less than the probability of just any other error in the reply.

The recovery action taken by a transmitter when the wrong alternating affirmative reply is received for a block is oriented toward correction of single event errors. A wrong alternating reply at that point indicates that either the received reply is a "line hit" (result of a transmission error) or the receiver is out of step with the transmitter and has accepted the last block. Recovery from the second situation is not possible using ordinary means in BSC and generally requires outside intervention; the receiver has either accepted a duplicate block because one of its NAK replies was received as the correct affirmative reply (as described above) or it has somehow received two blocks when only one was transmitted. Therefore, the BSC recovery procedures are directed toward automatic recovery from an error in the received reply.

Should the wrong alternating reply be received immediately following an ETB or ETX, the transmitter responds with an enquiry, causing the receiver to repeat its reply. If the same reply is received again or if a timeout is completed, the transmitter tries the enquiry signal at least two more times. If the retries fail, operator or other outside intervention should be called upon to diagnose whether a block was duplicated or lost, so that proper corrective action can be taken.

Note that this procedure only applies if the wrong alternating affirmative reply is received immediately following an ETB or ETX. If the correct affirmative reply is then received to an enquiry, the last block is presumed to have been accepted in correct sequential order and the transmitter continues by sending the next block (if any). Similarly, if NAK is received in reply to an enquiry, the previous block is retransmitted.

The above procedure does not apply if, after the transmitter timeout expires following an ETB or ETX, an enquiry is sent and then the wrong alternating affirmative reply is received. In this

case, it is presumed that the receiver missed the entire preceding block, and its reply to an enquiry is a repeat of its reply to the block before that. Therefore, the transmitter will retransmit the last block.

A special procedure is followed if an STX or SOH is altered by a "line hit." If the receiver receives an ETB or ETX when it is not in the text, transparent text, or heading mode, it does not alter nor transmit its outstanding reply. The affirmative reply for the preceding block is sent in response to an enquiry. The transmitter then retransmits the block in which the STX or SOH was altered, thus correcting the error.

Summary comment

The BSC conventions prescribe the transmission formats and operational control procedures to be used in half-duplex, digital data communications links. They are intended for systems that operate automatically, without operator intervention.

The conventions have been defined in terms of interrelated functional elements that fall within one of three categories: basic, selective, and special purpose or optional. The basic elements are required for BSC and include synchronization procedure, text message block formats, negative and alternating affirmative acknowledge replies, error detection and correction procedures, the enquiry function, timeouts, and the end-of-transmission signal. Selective elements are those chosen for a particular type of link and include transmission code and the mode of transmission initialization (contention or centralized, supervised mode). The function provided by selective elements is required for BSC, but different means are available for accomplishing these functions. Special-purpose elements may be used to extend the basic capabilities of a link and its level of control or to assist in improving performance. The use of special-purpose elements is optional, depending on the requirements of the application and on the capabilities of the particular device. Special-purpose elements that extend capabilities and the level of control include transparent text and heading capabilities, circuit assurance mode operation, the disconnect signal, and the wait-before-transmit reply. The elements that can improve performance include the blocking and intermediate blocking capability, conversational mode operation, fast selection, and noncentralized mode.

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