

MODEMS FOR THE PSTN AND INTERFACE STANDARDS

Some Terminology:

DTE: Data Terminal Equipment

- Ultimate source or destination of data over a path through a network, e.g. PC connected through modem to a network.

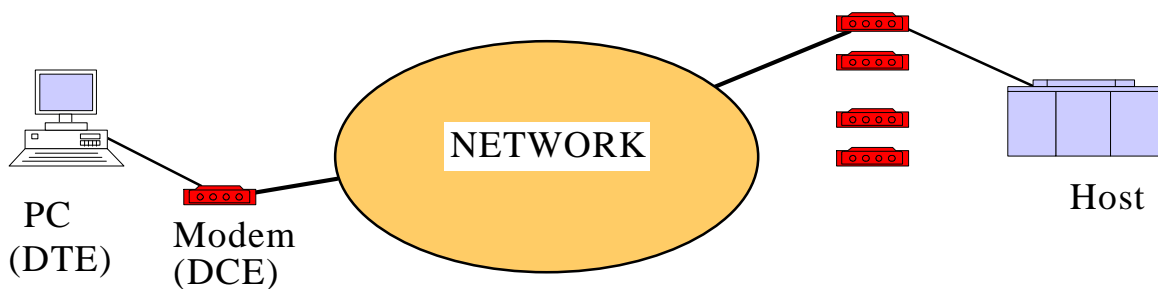
DTE's typically do not have the means to transmit electrical waveforms of the appropriate form *directly* onto the transmission links into the network.

For data transmitted over the PSTN, the telephone line from the telephone network terminates at a *DCE (modem)* which in turn connects to the DTE.

DCE: Data Circuit-Terminating Equipment

A DCE provides the interface for the DTE to the network ("data circuit") at both ends. (Sometimes the distinction is not obvious, because the DCE may sit within the physical DTE box.)

[For the Integrated Services Digital Network (ISDN) which is also accessed by special telephone lines, the DCE is called the Network Terminating Equipment (NTE)].



DCE transmits and receives data on its network side in the form of appropriate electrical signaling waveforms accepted by the network link. On the other side, it exchanges data as well as control information with the DTE to which it is connected. *Standards* are in place for such communications between DTE and DCE, and between DCE's across a network.

Modem Standards

Modem operation for telephone line interfacing is standardized by the *International Telecommunications Union - Telecommun. Sector*, which is part of the *ITU*, a UN specialized agency whose members are governments. Modem standards are set as ITU-T "V series" specifications.

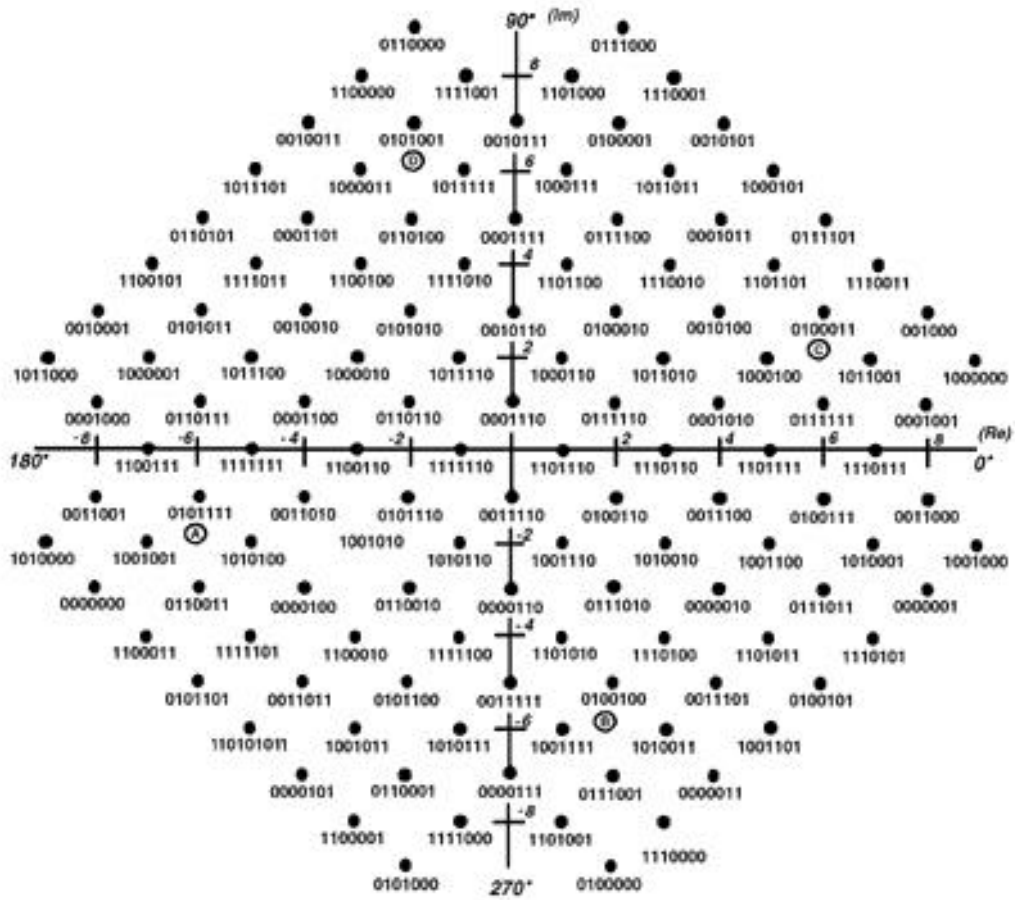
V.32bis Standard:

For example, the V.32bis standard is for modems operating at a maximum rate of **14.4 Kbps** using a **2400 symbols per sec.** signaling rate (baud rate). This standard is based on a **QAM constellation of size 128**, with **6 data bits** transmitted with each symbol ($6 \times 2400 = 14400$). The 128-point QAM constellation is essentially a square 12×12 constellation with 4 points removed at each corner and the whole rotated by 45 deg. The extra bit redundancy available in the constellation ($128 = 2^7$) is exploited to build-in error correction, as we will discuss later.

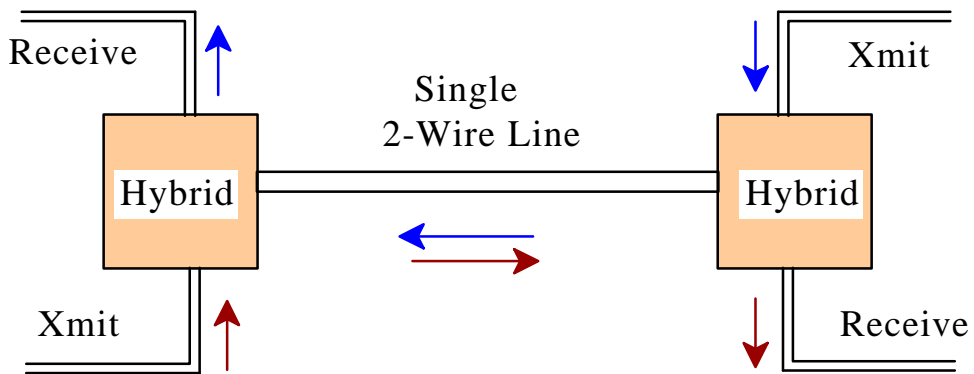
- The bandwidth efficiency of this modem is $14400/3000 = 4.8$ bits/Hz

Notice that with approximately 3.1 KHz of transmission bandwidth (300 to 3400 Hz), the baud rate of 2400 implies that each pulse (of duration roughly $1/2400$ sec) has a bandwidth of roughly 1500 Hz, a little above that implied by the Nyquist limit (1200 Hz). Thus the pulses have a fairly carefully chosen shape.

These modems operate in **full duplex** mode (data can be received and transmitted simultaneously); this is achieved over the **two-wire** (single wire-pair) telephone line by employing **hybrid transformers** and **echo cancelers**.



128-Point QAM Constellation Used in a V.32bis Modem



Full-Duplex Operation Over Two-Wire Line

A "**hybrid**" in this context is a circuit (transformer) or electronic component that acts like a "**traffic circle**". When hybrids are used to separate the two directions of transmission on a single wire pair link, their electrical imperfections cause a portion of the transmission in the forward direction to be *reflected* in the reverse direction. Thus *echoes* (near-end echo and far-end echo) of the transmitted data from a modem may return to it, in the presence of actual data from the far-end modem. The echoes may be strong and swamp the data from the far-end. **Echo cancelers** are devices that operate automatically to reduce to insignificance the strength of any echo signal. They are generally necessary for full-duplex operation where the full bandwidth of the medium is used simultaneously for both directions of data flow. Otherwise, half the bandwidth available may be used for each direction of transmission, in which case echo cancelers are not needed.

There are several other features that such modems incorporate to allow fairly reliable data exchange at the specified rates. These include **automatic equalizers** to compensate for any amplitude and delay distortion on the required band over the transmission line, as well as *synchronization* circuits, *data scramblers* (to make the data random-looking), *data compression*, and *error control*.

V.34 and V.34bis Standard

A more recent modem standard (V.34) specifies a full-duplex data rate of 28.8 Kbps, and V.34bis includes specifications for a top data rate of 33.6 Kbps. These standards allow for various symbol and data rates, depending on channel conditions. For example, a constellation size of 768 with a symbol rate of 3200 baud and 9 data bits per symbol (with redundancy in the constellation for coding) gives a 28.8 Kbps data rate.

Note that here the minimum theoretical bandwidth required is 3200 Hz (Nyquist limit) for the amplitude/phase *modulated* pulse stream at 3200 baud. Thus very good equalization and pulse shaping has to be incorporated.

These modems use rather sophisticated error control coding to provide reliable data transmission. We shall discuss simple error control coding schemes later on.

[The most recent modems for data transmission over the PSTN are the 56 Kbps modems. It would appear that this rate is in violation of the Shannon limit, given the bandwidth and the SNR for the line! However, these modems exploit the fact that the PSTN for the most part uses *digital* techniques, whereas the other modems view the PSTN as the analog system that it was originally designed as. The only part that must be viewed as an analog waveform channel is the local loop. The noise in the system is in large part that due to *quantization*; but in the digital view of the system this is not an impairment.) By very careful equalization, it is possible to *receive* data at 56 Kbps over a 3500 Hz bandwidth. Think of this as 8 bits per pulse at 7000 specially designed (not modulated versions of baseband) pulses per sec.]

DTE to Modem (DCE) Interface - (EIA-232-E)

The interface between a modem and the DTE, more generally between a DCE and a DTE, is standardized to allow inter-operability of equipment from different vendors.

A very common interface standard is the ITU-T V.24/V.28 specifications. It was previously known as the RS-232 and is also known as the EIA-232 standard for serial data transfer; the current version is EIA-232-E. It is commonly used to connect a PC and an external modem.

The EIA-232-E standard specifies the mechanical aspects [connector size, shape, number of pins in the connector (the 25-pin DB25 connector)] as well as the electrical signal levels (this aspect is covered by the V.28 specifications). The V.24 specs. are for the *functional* and *procedural* characteristics of the serial data transfer across this interface. That is, the functions of each of the circuits ending on the pins is specified (e.g. data out from DTE, data in from DCE, request-to-send from DTE, etc.), as well as the procedure of setting-up, using, and terminating a connection between DTE and DCE (e.g. DTE sets request-to-send and gets clear-to-send before transmitting data, etc.).

(*Serial data transfer* means bits are sent one at a time across a single physical electrical connection. Parallel transfer takes place when a group of bits (say each 8-bit byte) is transferred simultaneously across a group of electrical connections operating in parallel. Thus in the serial EIA-232 standard there is one pin for the transmit data line and one pin for the receive data line in each connector. The voltages on these pins are referenced to the "signal ground" pin. Another serial connection standard is the V.11, which uses a different electrical specification for twisted-pair cables providing a balanced 2-wire signal path in each direction.)

Coaxial Cable

This is used for high data rate applications; for example, in the ethernet LAN. It provides a *high-bandwidth medium*, of up to a few hundred MHz. To allow multiple DTE's to share a coaxial cable as a common transmission medium, we may employ frequency division multiplexing (FDM) through the use of modems operating in the MHz range to shift different DTE transmissions to distinct frequency bands. This is the *broadband* mode.

An alternative is to use time division multiplexing (TDM), in which the lower data rate transmissions of all the DTE's are carried simultaneously in the form of a single high data rate composite signal (narrow *baseband* pulses without modulation) on the cable. This is achieved by assigning to each data stream specific time slots on the cable. The slot assignments can be pre-determined and fixed, or the DTE's may "grab" the medium when it is free, transmit at a high rate for a short period, and then release the medium, on an as-needed basis. In this case there has to be a provision to allow each DTE an equal chance to transmit. An example is the ethernet LAN using a coaxial cable. (We will consider ethernet LAN's in more detail later).