Theory and Application of G.SHDSL.bis

1. Introduction

Since the earliest use of copper wire pairs for voice services over a century ago, business, government, and military used those same wires for digital services. The mechanical Teletype was most familiar, using a data rate of 50 bps (bits per second).

The advent of electronic computers stimulated the use of higher data rates, and extended use to residential customers. As modems improved, the data rate on a voice circuit grew from 50 to 9600 bps (9.6 Kbps). Further breakthroughs in signal processing technology resulted in today's maximum of 56 Kbps over a dial-up voice circuit.

1.1 Overview of DSL Technology

Electronic transport of high resolution still and motion pictures resulted in ever increasing need to increase the data rate delivered to end users. Several approaches are available. One is to run optical fiber to the office or home, which is costly and slow to install. Another is to share bandwidth on existing cable television (CATV) service. The issues of using CATV is that (a) the finite bandwidth must be shared by all customers resulting in frequent congestion, and (b) the coverage is not yet ubiquitous as telephone lines. Converting the existing copper wire pair used for telephone service into digital subscriber line (DSL) is attractive because the copper wires are already in place, only electronics need to be installed. With this technology, delivery of data to end users at megabit rates (Mbps) becomes possible.

Over decades, DSL technology evolved. The limitations of the copper wire pair is such that when the transmitted signal is of higher frequency, the distance the signal can travel becomes shorter, called the *reach*. Using various techniques to be described, for a given reach, the data rate of DSL systems have been increasing over the years. These techniques were used on systems like IDSL, ADSL, HDSL, SHDSL, VDSL, G.SHDSL, and finally G.SHDSL.bis, collectively termed xDSL. Because the very same copper wire already installed for voice is now reused to carry high-speed data, overspreading xDSL is akin to *mining that underground copper*.

1.2 Overview of H3300-3s & H3308

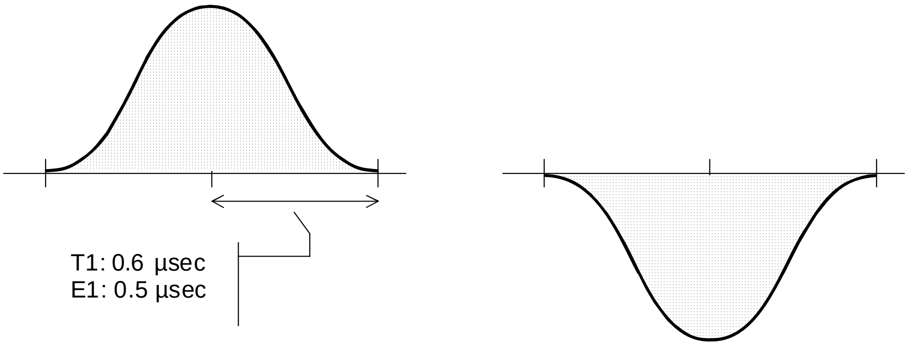
The copper wire pair, also known as UTP (unshielded twisted pair), provides a physical path already in place. Over this path, G.SHDSL technology provides the transport of high-speed data. What remains are interfaces to match the needs of customers. Two products, Loop-H3300-3s and Loop-H3308, will be described. One uses two UTPs to provide E1/T1 interface plus Ethernet and V.35. The other uses 4 or 8 UTPs to provide 10/100BaseT Ethernet plus V.35 or RS232.

2. Evolution of DSL Technology

The unshielded twisted copper wire pair was designed to serve voice frequency signals. The technology to use this medium to send digital signals evolved over decades, ever increasing in data rate for a given reach. Some of these technologies are described below.

2.1 T1/E1 basics

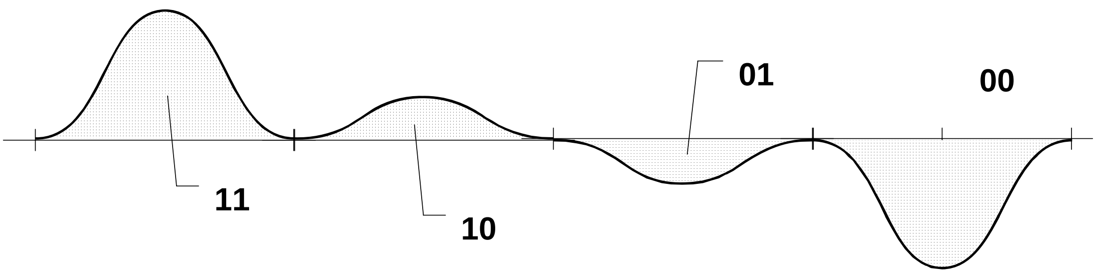
Although not a DSL system, the T1 system, beginning in 1960 in the US, was the first commercial instance of sending high-speed digital pulses over UTP. Later, the E1 system in Europe used the same scheme. Compared to xDSL, these systems are simple in concept. A binary 1 is sent as an electrical pulse. The pulses are either positive or negative to balance out the net DC.

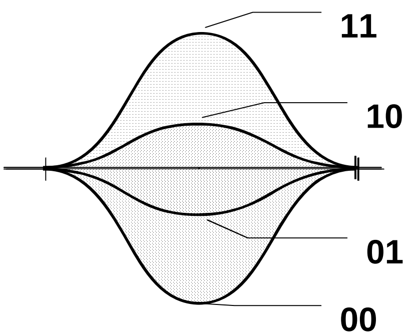


A binary 0 is no pulse. Each pulse, or no pulse, is sent every time interval, which is the inverse of the data rate. For T1 at 1.544 Mbps, the interval is 0.6 µsec. For E1 at 2.048 Mbps, 0.5 µsec. For both systems, two pairs of wire are used, one for each direction of transmission.

2.2 QAM and Other Multilevel Modulation

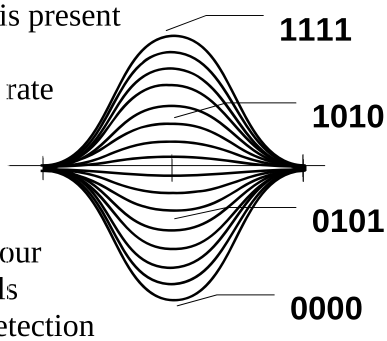
In the above method, each pulse carry one binary unit (bit) of information. To increase the data rate sent per pulse, the height of the pulse can be assigned to more than two levels. For quadrature amplitude modulation (QAM), four different pulse amplitudes can be sent, each level now representing two bits.





The representation of the four levels are usually combined in an *eye diagram*.

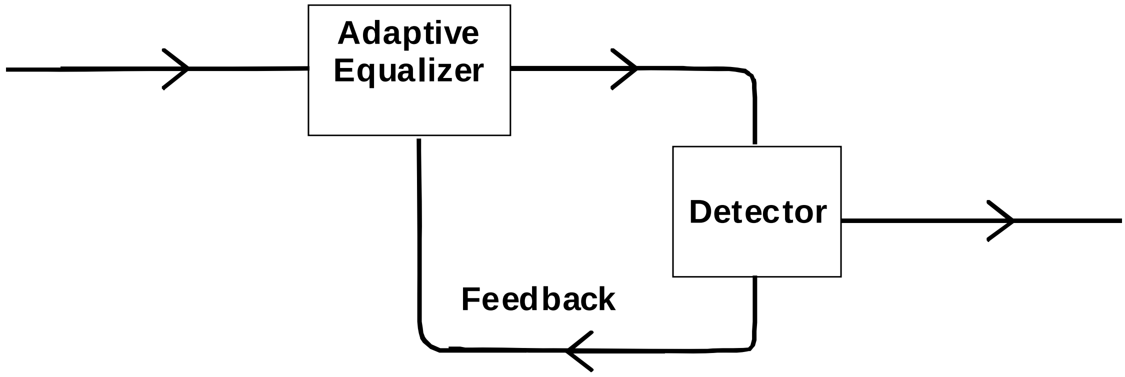
Detecting whether the signal is one of the four levels is of course more complex than detecting whether a pulse is present or absent. QAM doubles the data rate per pulse sent.



The QAM concept can be carried further to many more levels. For 16 levels, four bits are sent with each pulse. As the number of levels increase, each pulse will carry more data bits, but detection will become more vulnerable to noise and interference.

2.3 Adaptive Equalization

With many levels of transmitted pulse, the receiver must know exactly each of the levels as received in order to decide which of the signal level was sent. When a signal has traversed some distance on a wire pair, it becomes smaller due to loss, and changes shape due to frequency distortion. Such loss and distortion can be equalized to allow correct interpretation by the receiver. However, if the loss and distortion are subject to change due to variations of line length and temperature, then more sophisticated adaptive equalizer is necessary for proper operation. The required sophistication of the equalizer increases with increased levels transmitted.

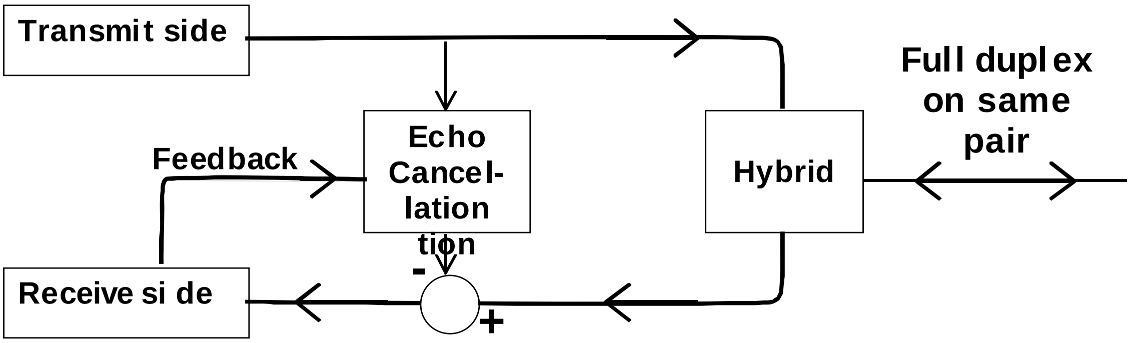


In the adaptive equalizer, upon startup, a training sequence is started to allow the equalizer to adapt to the condition of the UTP. Once trained, customer data can start flowing. While in use, the detector measures the expected signal levels to that actually received. The difference is fed back to fine tune the equalizer so that continued good performance can be assured despite gradual changes in the environment.

2.4 Echo cancellation

For T1 and E1, two pairs of wire are used for each system, one for each direction of transmission. This is to avoid crosstalk between the transmitted signal and the received signal. For voice signals, the two directions share the same wire pair. A hybrid coil is used to separate the transmitted and received signals. What crosstalk left over due to hybrid imperfection results in acceptable faint echoes. Such echoes, however, cause digital errors, especially for the multi-level signals used.

One method to allow two directions of transmission on the same pair is to place the two directions into two different frequency bands. But this results in half of the data capacity in each band compared to using the entire available band of a wire pair.



Using echo cancellation technology, two directions of the signal can share the same wire pair, and using the same frequency band, effectively doubling the utilization for each wire pair. To achieve this goal, sophisticated signal processing is used. First, with only one side transmitting, the echo on the receive side is measured and analyzed. From this analysis, a prediction of what the echo will be is made, the inverse of this predicted echo is then used to cancel out the actual echo.

As in the case of the adaptive equalizer, feedback from the receiver detector will refine the estimated echo as the situation warrants.

2.5 HDSL

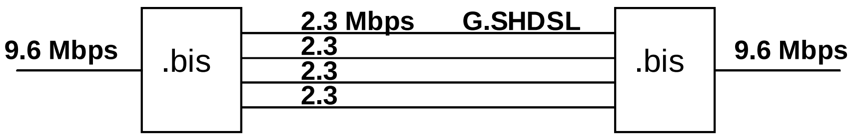
Combining the above technologies, a high rate DSL (HDSL)was designed. On a single UTP, and with a reach of 3.6 Km, which is compatible to most telephone lines, a data service 1.5 to 2 Mbps can be delivered. The advantage of HDSL is obvious when compared to T1 or E1, where two UTPs will be needed, with a reach of only 1.4 Km.

2.6 G.SHDSL

As technology marches on with increasing data rate on UTP, an ITU standard, G.991, was established to allow interoperability between different manufacturers. This G *S*tandard also established a *S*uperior method to adapt the rate to the condition of the line for *S*ymmetrical operation over a *S*ingle UTP, hence the name G.*S*HDSL. Use of this standard results in data rate of 2.3 Mbps to 192 Kbps with a reach 3 to 7.5 Km respectively.

2.7 Bonding in G.SHDSL.bis

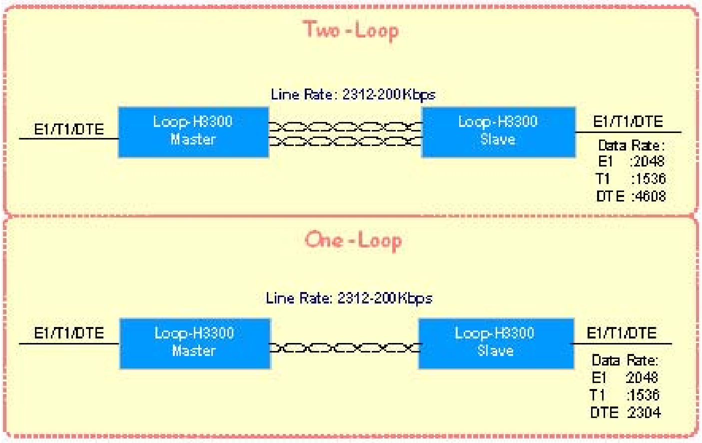
When the customer data rate is higher than achievable by any single G.SHDSL system, the data can be split into several lower rates and transported in separate lines. At the receiving end, the data from these several lines are recombined back into the original data stream. Naturally, numbered header bits must be inserted into the split data such that the separate stream can be correctly recombined. This technique is called inverse multiplexing, or bonding. Both IEEE and ITU have established standards for such header bits so that the bonding interface standard (bis) can be compatible among different manufacturers.



One significant feature of this standard is the automatic adaptation to degradation or failure of any component lines used in the bonding. If four lines of 2.3 Mbps G.SHDSL lines are used to achieve a combined data rate of 9.2 Mbps, then should one of the lines fail, operation would continue with a data rate of 6.9 Mbps. The rate would return to original rate when the failed line is restored.

3. H3300-3S

The Loop-H3300-3S uses one or two UTP lines to provide end users with a combination of data interfaces, which includes E1/T1, DTE, and Ethernet. The technology used is G.SHDSL.bis. Whereas the data rate of T1 or E1 is fixed, the rate for DTE and Ethernet can be user configured to match available bit rate on the combined rate of the lines.



4. H3308

The Loop-H3308 uses 4 or 8 UTP lines to provide end users with a combination of data interfaces, which includes Ethernet, V.35, and RS232. The technology used on the lines is G.SHDSL.bis. The total data rate available to the end user is the sum of the data rates of all the lines.

The bonding method ensures line cut resilience by removing a failed pair from an aggregation group within 50ms. This removal maintains connectivity albeit with decreased total user bandwidth. When the failed pair has recovered, the aggregation bandwidth will become normal without disrupting the service. The same is true for intentional addition or removal of pairs.

In addition, the data rate on each of the G.SHDSL lines can be different, up to a maximum ratio of 4:1.