Project: **HDSL Standard Project**

Title: **Proposal For Single-Loop HDSL Using Simple Coded PAM**

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ABSTRACT

This contribution describes Simple Coded Pulse Amplitude Modulation (SC-PAM), which is proposed as the line code for the single-loop HDSL (SHDSL) project. The SC-PAM line code consists of: 1) 3 information bits per symbol, 2) 1 bit per symbol added for trellis coded modulation, and 3) Tomlinson precoding in the transmitter path. Performance estimates with reduced number of disturbers are included that provide 6 dB margin for CSA range compliance. Loop reach estimates using 49 self-NEXT disturbers are also presented. SC-PAM has been shown to be spectrally compatible with other services, i.e., it produces minimal interference into the other services and suffers less interference from these other services than do other suggested line codes. SC-PAM provides a good tradeoff between performance and spectral compatibility with other services.

1. INTRODUCTION

This contribution describes a relatively low complexity line code, identified as Simple Coded Pulse Amplitude Modulation (SC-PAM), which is proposed for adoption as the line code for the single-loop HDSL (SHDSL) project. Performance of SC-PAM is enhanced by using trellis coded modulation and Tomlinson precoding. Complexity is limited and spectral compatibility is enhanced by using by using PAM signaling with multiple bits per symbol. As determined in [1] and [2], coded 16-PAM or SC-PAM yields the best tradeoff between performance and spectral compatibility with existing services, especially when considering ADSL[8]. It produces minimal interference into the other services and suffers less interference from these other services than do other suggested line codes. As a result, SC-PAM provides a good tradeoff between performance (range) and spectral compatibility.

The tradeoff between range and self-NEXT margin is considered for two cases. First, performance estimates are presented for the self-NEXT models with a reduced number of disturbers which permit the system to achieve CSA range with 6 dB of margin. Second, loop reach estimates are provided for SC-PAM in the presence of 49 self-NEXT disturbers.

A coded PAM format is used which maps 3 information bits per transmit symbol. The data rate is 1.552 Mbps, which is the standard T1 1.544 Mbps plus 8 kbps overhead. Since there are 3 information bits per symbol, the symbol rate is 1.552e6/3 = 517,333.33 symbols per second. The addition of a single bit for trellis coded modulation increases the total number of bits per symbol to 4, which are then mapped to a 16-point one-dimensional constellation. This modulation format is known as coded 16-PAM, or in this contribution as SC-PAM (Simple Coded PAM).

This contribution is divided into two main parts : Section 2 presents the data mode and Section 3 gives details on the startup mode. The transmitter is specified for each mode. The generic receiver description is given for information only. Section 4 discusses the NEXT models. Section 5 is a presentation of the conclusions.

2. DATA MODE OVERVIEW

The top level block diagram for the SHDSL transmitter and a generic data mode receiver is shown in Figure 1. In the transmitter, the SHDSL framer converts from the 1.544 Mbps T1 format to the 1.552 Mbps SHDSL serial data format. The scrambler randomizes the incoming data stream. The serial to parallel converter produces 3 information bits per symbol time. The trellis encoder adds redundancy in the form of a trellis bit, resulting in a total of 4 coded bits per symbol. The bit-to-level mapper maps the 4 bits output from the trellis encoder to one of 16 levels in a one-dimensional PAM constellation. The constellation symbols are passed through a Tomlinson precoder to counter the effect of the loop transfer function. These functions are described in more detail in the following sections.

In the receiver, the adaptive linear equalizer suppresses channel precursors and whitens the noise. The trellis decoder picks the most likely received constellation sequence. The Tomlinson modulo operator removes the modulo sequence added by the transmitter's Tomlinson precoder (see section 2.4). The level-to-bit mapper maps each of the 16 possible constellation points to a unique 4-bit number, then discards the trellis bit leaving the original 3-tuple information sequence. The parallel to serial converter serializes the 3-tuple sequence. The descrambler removes the randomizing sequence, leaving the original 1.552 Mbps sequence. The SHDSL framer converts from the 1.552 Mbps SHDSL format to the 1.544 Mbps T1 format.

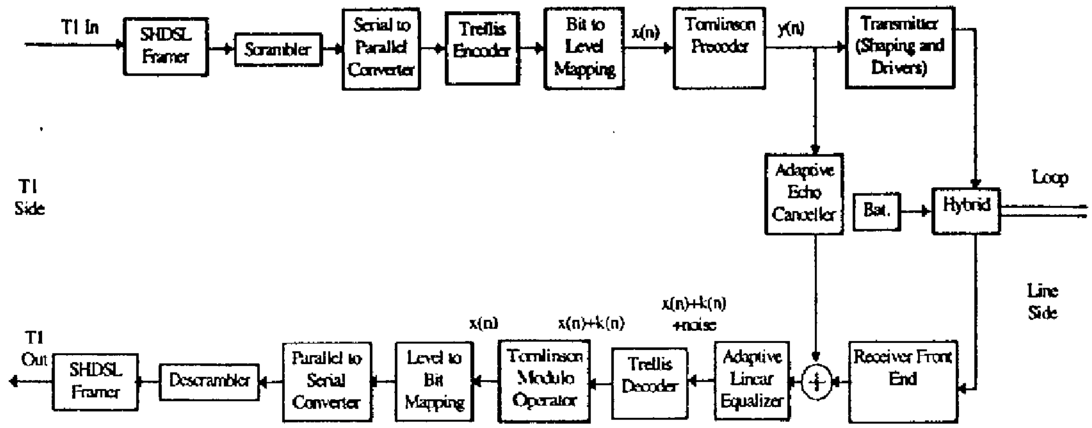

Figure 1. Data Mode Top Level Block Diagram

2.1 Data Mode Scrambler

The data mode scrambler/descrambler is the same as the scrambler/descrambler used in the HDSL Technical Bulletin [3]. Use of scramblers which do not multiply errors is for further study.

2.2 Trellis Encoder

The trellis encoder is shown in Figure 3. It is shown in systematic feedback form. This code is described by Ungerboeck in [4]. The asymptotic coding gain of this code is approximately 4 dB, with an effective coding gain (accounting for the 4 nearest neighbors of the same probability and the average number of bit errors per trellis error) of approximately 3.2 dB. The three inputs bits are passed directly to the output, and the trellis bit becomes the least significant bit of the four output bits.

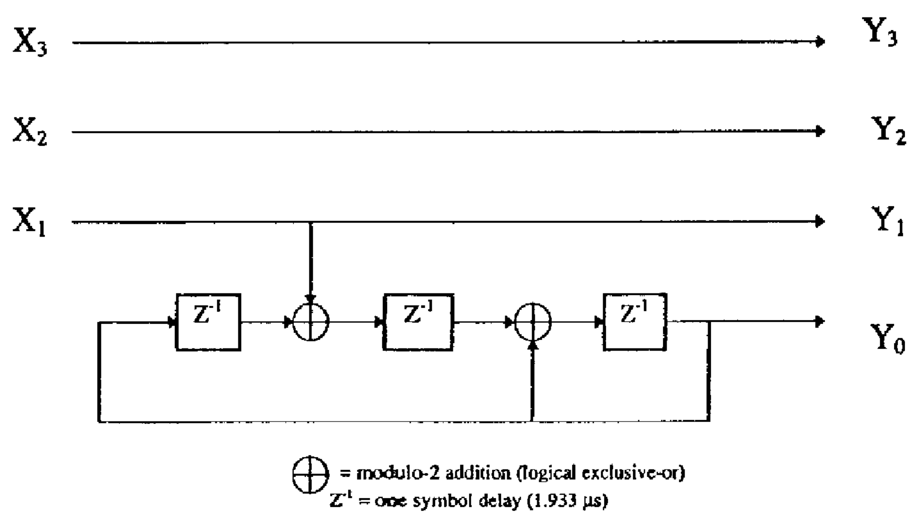

Figure 3. Trellis Encoder

2.3 Bit-to-Level Mapper

The mapping from the four bits from the trellis encoder to a constellation point satisfies a 4-way one-dimensional lattice partition. This mapping is shown in Table I.

Table I. Bit-to-Level Mapping

Trellis Encoder Output (Y3 Y2 Y1 Y0)	Constellation Point
0000	+15
0001	+13
0010	+11
0011	+9
0100	+7
0101	+5
0110	+3
0111	+1
1000	-1
1001	-3
1010	-5
1011	-7
1100	-9
1101	-11
1110	-13
1111	-15

2.4 Tomlinson Precoder

The block diagram for the Tomlinson precoder is shown in Figure 4. It consists of a stable feedback filter H(z) modified with a Tomlinson modulo function. The input to the Tomlinson precoder, x(n), is a random sequence of points taken from Table I. The input to the Tomlinson modulo function is s(n), the sum of the precoder input x(n) and the feedback filter output f(n). The output of the Tomlinson modulo function is $y(n) = s(n) + k(n) = x(n) - f(n) + k(n)$, where the integer sequence k(n) is selected from the set {...,-64,-32,0,32,64,...} such that

$$-16 \leq x(n) - f(n) + k(n) < 16$$

Thus, the output of the Tomlinson precoder is bounded between -16 and +16, and since H(z) is stable, the precoder is stable. All functions operate at the symbol rate.

The combined use of coding and precoding is described in [5].

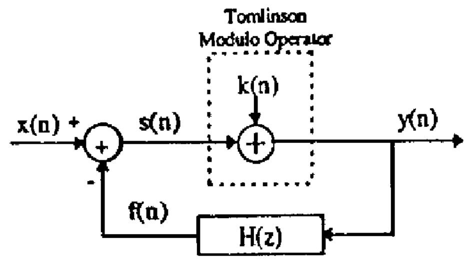

Figure 4. Tomlinson Precoder

3. STARTUP MODE OVERVIEW

The top level block diagram for the startup mode transmitter is shown in Figure 5. The adaptive linear equalizer and the decision feedback filter, H(z), are trained using a random uncoded PAM sequence. The decision feedback filter H(z) is sent to the transmitter prior to the start of data mode to be used in the Tomlinson precoder. The details of the startup procedure are to be determined by the T1E1.4 committee.

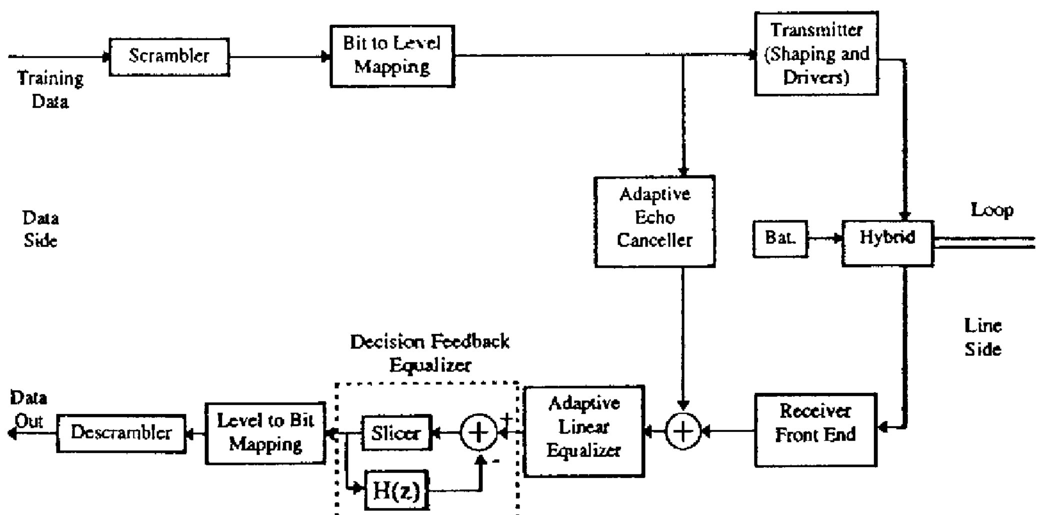

Figure 5. Startup Mode Top Level Block Diagram

4. PERFORMANCE

The performance estimates provided in this section use the two-piece Unger NEXT coupling model and transformer coupling of the disturber spectra as described in [6]. By assuming a 3 dB real coding gain and ideal DFE performance, SC-PAM achieves a range of 9000 feet on a 26 AWG loop in the presence of 9 self-NEXT disturbers in the same binder group. With 49 disturbers in the same binder, the range is 7700 feet. On 24 AWG loops, SC-PAM has a range of 12000 feet with 15 self-NEXT disturbers in the same binder. With 49 disturbers in the same binder, the range is 10700 feet. (These numbers are slightly different from those presented in a previous contribution [7] due to differences in the assumed coding gain, data rate, and crosstalk models.)

5. SPECTRAL COMPATIBILITY

SC-PAM is spectrally compatible and can share a binder group with existing services. Interference from DSL, HDSL, and ADSL and T1 NEXT into SC-PAM is approximately the same or less than that of the same number of self-NEXT disturbers.

Crosstalk from SC-PAM into existing services is minimal. It disturbs DSL and HDSL less than self-NEXT. It reduces the margin of ADSL by less than 0.5 dB compared to the same number of HDSL disturbers. Interference into T1 is minimal.

6. CONCLUSION

This contribution proposes a low-complexity method for achieving single loop HDSL rates with 6 dB margin at CSA range with reduced number of disturbers. With 49 disturbers, 6 dB of margin can be achieved with a 10-15% reduction in range. A detailed description of each of the data mode components has been given. The SC-PAM line code provides a good tradeoff between performance and spectral compatibility with other services.

References

[1] R. Goodson, K. Schneider, M. Turner, "Effect of Single-Loop HDSL on T1, ADSL, HDSL, and ISDN," ADTRAN Contribution, T1E1.4/95-137, 13 November 1995, Orlando, FL.

[2] R. Goodson, K. Schneider, M. Turner, "Performance of Single-Loop HDSL Including DMT," ADTRAN Contribution, T1E1.4/95-138, 13 November 1995, Orlando, FL.

[3] "A Technical Report on High-Bit-Rate Digital Subscriber Lines," Committee T1-Telecommunications, Report No. 28, February 1994.

[4] G. Ungerboeck, "Channel Coding with Multilevel/Phase Signals," IEEE Transactions on Information Theory, vol. IT-28, No. 1, Jan. 1982, pp. 55-67.

[5] G. Pottie and M.V. Eyuboglu, "Combined Coding and Precoding for PAM and QAM HDSL Systems," IEEE JSAC, August 1991, pp. 861-870.

[6] R. Goodson, J. Moore, K. Schneider, "Effect of NEXT Models on SHDSL," ADTRAN Contribution, T1E1.4/96-036, 22 January 1995, Orlando, FL.

[7] R. Goodson, K. Schneider, M. Turner, "Single-Loop HDSL CAP/PAM Comparison," ADTRAN Contribution, T1E1.4/95-107, 21-23 August 1995, SilverCreek, CO.

[8] ADSL Draft Standard, T1E1.4/95-007R2.