Conclusion: A method based on dual frequency pumping of a fibre loop was proposed for the generation of high repetition rate trains of independent soliton pulses. The advantage with respect to the CW pumped MI laser is the possibility of cancelling the background and controlling the distance between the pulses. The method also compares favourably with dual frequency pumping of a variable dispersion fibre in that a standard fibre of much shorter length may be used. However, a practical drawback of the present method is the necessity for an interferometric control of the fibre loop length.

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IMPULSE NOISE PROTECTION WITH 4-D TCM

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Indexing terms: Trellis coded modulation, Pulse-code modulation, Quadrature amplitude modulation

A four dimensional trellis code that protects QAM data transmission against impulse noise occurring on single symbols (as found from PCM codecs) is presented. The code is based on an eight-way 2-D partition. The 4-D subsets are built from this partition in an apparently suboptimal way. This leads to a code with high immunity to impulse noise and moderate complexity.

Introduction: Multidimensional trellis codes [1] gain an advantage over 2-D trellis codes because they spread their redundancy over several transmitted symbols. In bandwidth limited applications such as QAM data transmission on the PSTN, this leads to less expansion of the QAM signal constellation. However, because the complexity of decoding a code is dependent on the size of the code's trellis which is in turn dependent on the number of subsets the code uses, it is necessary to keep the number of such subsets low. When combining 2-D subsets to form multidimensional subsets the number of multidimensional subsets formed is a function of the number of 2-D subsets used. Therefore, to keep the complexity of a multidimensional trellis code low, it is normal to start from a small partitioning in 2-D. For most practical codes a four-way partitioning is used in 2-D.

The minimum distance between points in the same 2-D subset of this four-way partitioning is usually the limiting factor in the performance of the code. When decoding, intra-subset errors (possible due to the use of parallel transitions in the trellis) become more likely than trellis path errors. This is not a problem on a channel affected by signal independent noise but it can become a problem on channels affected by signal dependent noise. Channels affected by signal dependent noise include those that incorporate PCM codecs. These channels account for the majority of telephone channels in modern networks.

Work carried out at BT Laboratories [2] suggests that the signal dependent noise from PCM codecs is in the form of impulses that affect single transmitted QAM symbols. In such conditions a four-way 2-D partitioning is no longer adequate. If this partition were increased to an eight-way partition, suitable protection against this impulse noise would be afforded. However, the number of multidimensional subsets needed to keep this distance between the points in each multidimensional subset becomes large. A trellis code formed from this number of multidimensional subsets becomes complex. Luckily the trials at BT Laboratories suggested that PCM codecs do not generate much impulse noise beyond that affecting QAM symbols and so it is not necessary to ensure that the multidimensional subsets keep the eight-way partition distance beyond two dimensions.

Forming 4-D subsets: A 2-D QAM signal constellation (with points spaced a distance d apart) is partitioned into eight 2-D subsets as shown in Fig. 1. The minimum squared distance

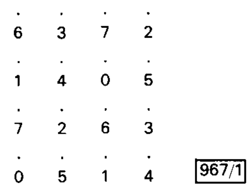

Fig. 1 *Eight-way partition of 2-D QAM signal constellation*

between points in the same 2-D subset is $8d^2$. To form 4-D subsets the 2-D subsets are paired. There are 64 possible pairs which could be split into 32 4-D subsets each with a minimum squared distance of $8d^2$. Use of these 4-D subsets could lead to a code with high immunity to noise impulses that affect both single and double QAM symbols. Unfortunately the code would be complex. It is also possible to split the pairs into 16 4-D subsets with a minimum squared distance of $4d^2$ between points in the same 4-D subset. This minimum squared distance only arises between pairs of QAM symbols, whereas between single QAM symbols the minimum squared distance in each 4-D subset is still $8d^2$. Because there are only 16 subsets, a simpler code can be constructed. The code will have good immunity against noise impulses causing single QAM symbol errors but not against those causing double QAM symbol errors. This is satisfactory for the type of noise seen from PCM codecs [2]. The 16 4-D subsets are shown in terms of their constituent 2-D subsets in Fig. 2.

4-D subset		4-D subset	
0	00, 11, 22, 33	1	01, 10, 23, 32
2	44, 55, 66, 77	3	45, 54, 67, 76
4	02, 13, 20, 31	5	03, 12, 21, 30
6	46, 57, 64, 75	7	47, 56, 65, 74
8	04, 15, 26, 37	9	05, 14, 27, 36
10	42, 53, 60, 71	11	43, 52, 61, 70
12	06, 17, 24, 35	13	07, 16, 25, 34
14	40, 51, 62, 73	15	41, 50, 63 72

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Fig. 2 *16 4-D subsets in terms of their component 2-D subsets*

Building a code: The minimum squared distance between points in the same 4-D subset is $4d^2$. This is also the minimum squared distance between points in the two 4-D subsets on each row of Fig. 2. The minimum squared distance between points in 4-D subsets from the same half (top or bottom) of Fig. 2 is $2d^2$. The minimum squared distance between points in 4-D subsets from opposite halves (top and bottom) of Fig. 2 is d^2. These distances can be used to build a trellis code.

The smallest practical trellis code that can be built using these 4-D subsets has 16 states. There are eight transitions from (and to) each state. The transitions from (or to) any particular state are either all from the top half of Fig. 2 or all from the bottom half of Fig. 2. This ensures that all trellis paths have a squared distance of at least $4d^2$ between them ($2d^2$ out of a state $+2d^2$ into a state). This is the same as the minimum squared distance between points in the same 4-D subset and is therefore sufficient. Minimum distance errors will occur both from trellis path errors and from intrasubset errors. The number of minimum distance errors could severely degrade the performance of the code.

By increasing the number of states to 32 it is possible to ensure all trellis path errors that are two code symbols long have either a divergence or a convergence that chooses between the two 4-D subsets from one row of Fig. 2. This gives such error events a squared distance of $6d^2$ ($2d^2 + 4d^2$). Furthermore, it can also be ensured that any error event longer than this builds up a squared distance of at least $5d^2$. The minimum distance of such a trellis code is therefore limited by the $4d^2$ minimum squared distance between points from the same 4-D subset. Minimum distance errors will always be intrasubset errors. These errors only occur when there is an error in both 2-D symbols. For any particular point in a 4-D subset there are at most only four such possibilities. Hence the number of nearest neighbours of this code is four which is the same as the number of nearest neighbours in the uncoded case. This means that there is no degradation in coding gain due to the number of nearest neighbours. The effective coding gain of this scheme is the same as its asymptotic gain of 4·52 dB (6·02 dB for the $4d^2$ minimum squared distance less 1·5 dB for the constellation expansion necessary to account for the 1/2 bit redundancy per transmitted QAM symbol).

The generator circuit for such a code is shown in Fig. 3. Six bits choose which of the 64 pairs of 2-D subsets is to be transmitted. Of course only four bits are required to determine

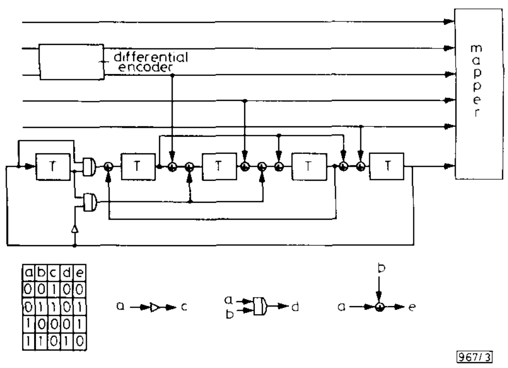

Fig. 3 *Code generator circuit*

which 4-D subset is to be transmitted so the code is basically a 3/4 rate, 32 state, 4-D code. Two of the six bits are differentially encoded with a standard mod 4 differential encoder. This ensures transparency of the coding scheme to 90° phase shifts that may occur (undetected) in the QAM signal constellation. The code is also suitable for use with four point signal constellations even though it is based on eight subsets in 2-D. The number of allowable 4-D subsets halves (only the even 4-D subsets remain) and so the number of transitions from and to each state falls to four. The code is now a 2/3 rate, 32 state, 4-D code. This allows a coded four point constellation to be used which gives very robust transmission at 4800 bit/s with a symbol rate of 3200 symbol/s.

Conclusion: A coding scheme has been presented for QAM data transmission that has, in general, an effective coding gain of 4·52 dB. The code has an immunity against single QAM symbol errors of 7·52 dB. This code is therefore effective both in a signal independent noise environment and over channels containing PCM codecs. As the vast majority of telephone connections now involve PCM codecs, this code should be considered for data transmission applications on the PSTN. The code presented here is currently a candidate for inclusion in the emerging CCITT V. fast modem recommendation.

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ANALYTICAL MODELLING OF THE PROGRAMMED WINDOW IN FLOTOX EEPROM CELLS

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Indexing terms: Modelling, Memories

A new simple analytical model for evaluating the programmed window of FLOTOX EEPROM cells at design level, for given programming waveforms and memory cell geometry, is proposed. The model enables optimisation of the memory cell geometry with respect to programmed window amplitude to be easily conducted, as well as correct selection of the programming conditions.

Introduction: To date, the designer of FLOTOX EEPROM cells has had to employ electrical simulators [1] to evaluate the programmed window amplitude W_p of a memory cell at design level, given the programming conditions and memory cell geometry. Besides, the optimisation of cell geometry as regards W_p required a complicated numerical treatment.

We propose a simple analytical model which enables the designer to easily evaluate W_p at design level, for given programming conditions (hold time t_h and amplitude V_{pp}) and memory cell geometry (control gate coupling ratio A_{cg}, drain coupling ratio A_d, control gate coupling capacitance C_{pp}, tunnel oxide thickness t_{fd}, injection tunnel area surface α, geometry of the sensing transistor, etc). Furthermore, after using the proposed model, optimisation of the cell geometry as regards W_p can be easily conducted, as well as correct selection of the nominal programming voltage.

Experimental details: The devices used throughout this project are single-poly FLOTOX EEPROM cells, fabricated by SGS-Thomson Microelectronics in the context of the 'Advanced PROM building blocks' ESPRIT project. Four different cells with A_{cg} values ranging between 0·8 and 0·64, have been investigated. In all cases, t_{fd} is ~8·5 nm, α lies around 1·5 μm^2, and C_{pp} varies from 50 fF to 20 fF, such that the corresponding A_d lies around 0·1. All these parameters have been extracted from the layout of the cells.

Fig. 1 (solid lines) shows W_p against V_{pp}, as obtained experimentally on all the cells ($t_r = 1$ ms and $t_h = 4$ ms). The mode used for writing/erasing the cells, as well as the adopted definition of the device threshold voltage, were the same as in Reference 2.

Theoretical analysis: We now consider the case of a virgin FLOTOX EEPROM cell. From Reference 2, for program-