TCM - TRELLIS CODING

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ACHIEVEMENTS: *introduction to trellis code modulation (TCM) implemented as one-dimensional ASK, with soft-decision Viterbi decoding. Measurement of BER over a noisy baseband channel. Comparison with a reference signal to estimate coding gain.*

PREREQUISITES: *completion of the experiments entitled **Convolutional coding** (in this Volume) and familiarity with bit error rate (BER) measurement.*

EXTRA MODULES: *CONVOLUT'L ENCODER, DECISION MAKER, DIGITAL UTILITIES, ERROR COUNTING UTILITIES, INTEGRATE & DUMP, LINE-CODE DECODER, LINE-CODE ENCODER, NOISE GENERATOR, TMS320 DSP-HS, WIDEBAND TRUE RMS METER, a second SEQUENCE GENERATOR.*

PREPARATION

Trellis coding offers a means of increasing data rate without increasing transmitted bandwidth. This is ideally suited to experimental verification.

The gain is achieved with multi-level, multi-phase signalling. In this experiment it will be implemented with 4-level ASK, which is indeed multi-level, although only one phase dimension. Thus the coding gain is relatively small.

In this experiment the performance advantages of TCM with Viterbi decoding are investigated. Details of the operation of the encoding and decoding processes are not included here. The TCM bit error rate (BER) will be measured under a defined set of conditions. This is then compared with performance when transmitting the same pseudo-random binary sequence (PRBS), of the same bandwidth, operating under similar conditions, but without TCM.

Information regarding the coding (in the CONVOLUT'L ENCODER), and the decoding algorithm (EPROM in the TIMS320 DSP-HS), may be obtained from the *Advanced Modules User Guide*.

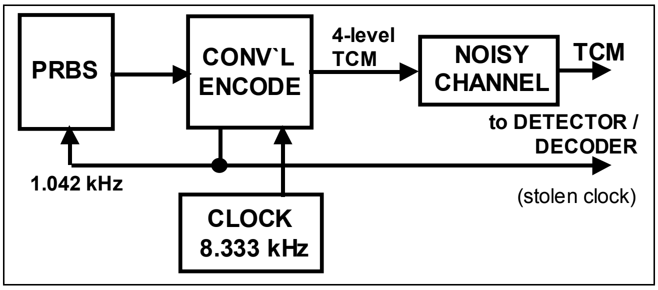

Figure 1: TCM generator & channel

The TCM generator and channel is illustrated in block diagram form in Figure 1 above. Note that this is a baseband system, although it could easily be modified to include modulation to a carrier frequency – typically 100 kHz in a TIMS system. This would be transparent to the TCM and would not materially affect the understanding of the experiment, or its results.

Viterbi decoding

The Viterbi soft-decision decoding algorithm is implemented using the TIMS320 DSP-HS module, in which your Laboratory Manager will have installed the appropriate EPROM. This will be referred to, below, as the *Viterbi decoder*.

The received TCM signal will be reconstituted by a decision maker implemented by an INTEGRATE-&-HOLD subsystem in the INTEGRATE & DUMP module. This will provide performance equivalent to matched filtering (since we are using flat top NRZ pulses).

The output of the INTEGRATE-&-HOLD, a 4-level ASK, is the input to the Viterbi-decoder. In turn, the decoder output (under no-noise conditions) is the original serial PRBS message.

A stolen bit clock will be used.

A block diagram of the detector/decoder is shown in Figure 2 below.

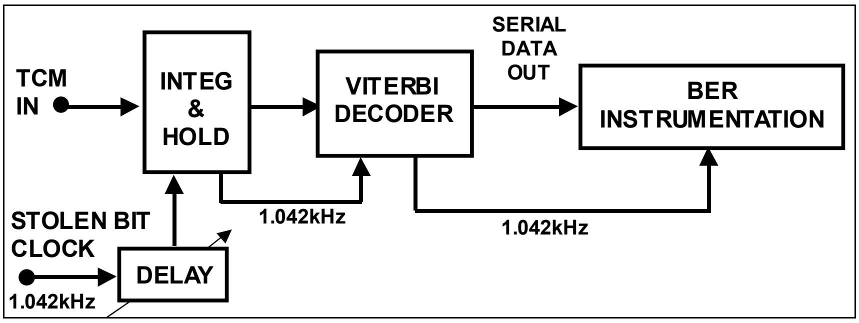

Figure 2: TCM detector/Viterbi decoder & BER instrumentation

overall system

Transmitter and receiver will be connected via a noisy baseband channel. At the receiver output will be instrumentation to measure the BER under defined signal-to-noise-ratio (SNR) conditions.

The SNR will be measured at the *output of the integrate-and-hold sub-system*.

The message data rate will be fixed at 1.042 kbit/s.

reference system

The reference system will be a pseudo-random binary sequence, the same sequence as was used to generate the four-level TCM signal. It will:

1. have the same transmitted signal bandwidth
2. have the same message data rate
3. be transmitted via the same channel (bi-polar format)

The SNR of the reference system is then compared with that of the TCM system for the same BER. The difference in SNR is then the coding gain achieved by the TCM.

note that: the reference system uses a 2-level signal, with no error correction, and so the message bit rate and the raw (symbol) data rate are the same.

The TCM system *adds* bits to the raw data, and so for a 2-level transmitted format the message rate would need to be slower than the raw data rate, for the same transmitted bandwidth. But since in this case the TCM is to be a 4-level signal, and there is one extra bit added per message bit, the message rate will be the same as that of the reference system.

A block diagram of the reference system is shown in Figure 3 below.

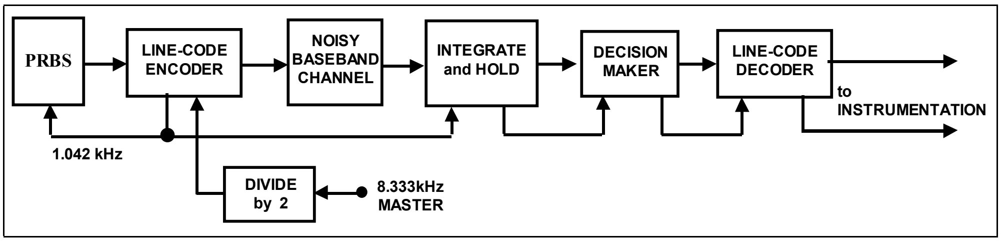

Figure 3: reference system

The line-code modules are present for practical reasons: the decoder provides a convenient conversion from analog-to-TTL between the decision maker and the error counting module. The encoder is included for compatibility.

EXPERIMENT

You are about to model, separately, two relatively large systems (with some common sub-systems). As usual, it is suggested that these be built and tested in stages, as outlined below.

the TCM system

transmitter

T1 *before plugging in the SEQUENCE GENERATOR MODULE select a short sequence (both toggles of the on-board switch SW2 UP). Then patch up the transmitter as shown in Figure 4 below.*

T2 *confirm the SEQUENCE GENERATOR is clocked at 1.042 kHz (one eighth of the 8.333 kHz MASTER CLOCK).*

T3 *on the CONVOLUT`L ENCODER select NORMAL and CODE 2 with the two toggle switches. Confirm a 4-level output from* OUT_4.

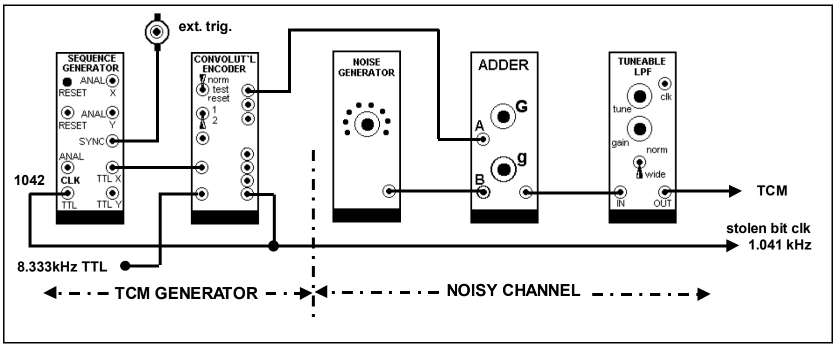

Figure 4: TCM generator and channel model of Figure 1.

the channel

The channel will be modelled with a TUNEABLE LPF module, set to its widest bandwidth. This will have negligible effect upon the signal waveform. It is present as a formality, but also convenient in that it provides some gain adjustment. At its input is an ADDER, to combine the TCM signal with NOISE.

T4 *patch up the channel as just described. Initially add no noise. Set the front panel* GAIN *control of the TUNEABLE LPF to a mid-way position.*

T5 *adjust the 4-level signal from the ADDER to about 0.2 volt peak-to-peak (this will be reset later) to the TUNEABLE LPF.*

TCM detector

T6 *before inserting the INTEGRATE & DUMP module read about it in the* ***Advanced Modules User Guide****. Then:*

a) set the on-board switch SW1 to I&H1. This makes the I&D1 sub-system perform an integrate and hold operation

b) *set the on-board switch SW2 to I&D2. This makes the I&D2 sub-system perform an integrate and dump operation.*

c) set the toggles of the on-board switch SW3; upper to the LEFT, and lower to the RIGHT. These govern the range of delay introduced by the DELAY front panel control.

T7 *patch the detector/decoder and instrumentation according to the details of Figure 5 below.*

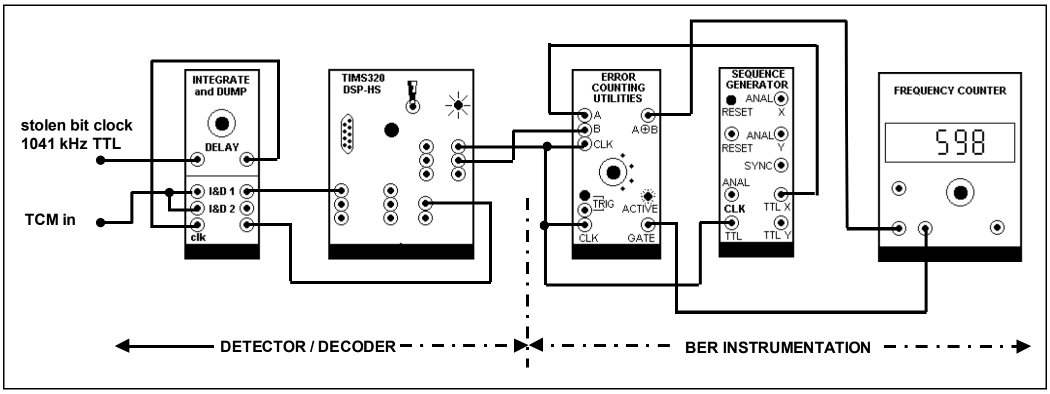

Figure 5: TCM detector/decoder model of Figure 2

The bit clock phase (delay) is adjusted so that the integration of the INTEGRATE & HOLD operation is timed correctly. There are two methods of adjusting the timing, namely:

a) observe the INTEGRATE & HOLD operation (I&D 1), and adjust for a 4-level waveform (otherwise it will be an 8-level waveform).
b) watch the output of the INTEGRATE & DUMP operation (I&D 2) and adjust for single slope ramps within the bit clock period.

T8 *connect the TCM to both the I&D 1 and the I&D 2 inputs of the INTEGRATE & DUMP module. Observe the INTEGRATE & HOLD operation from the I&D 1 output, and the INTEGRATE & DUMP operation from the I&D 2 output. Adjust the delay (start from the fully anti-clockwise, or minimum, delay condition) for a 4-level signal from the INTEGRATE & HOLD output (otherwise will be an 8-level signal); alternatively adjust for a constant slope ramp from the INTEGRATE & DUMP output. With no noise these are simple operations, and both results should occur simultaneously.*

T9 *re-set the GAIN of the TUNEABLE LPF so that the input to ADC 1 of the TIMS320 DSP-HS module is 3 volt peak-to-peak (the 4 levels should be ±1.5 and ±0.5 volts). Correct operation of the Viterbi decoder is dependent on this adjustment.*

Viterbi decoder

T10 *confirm the stolen clock to the BIO input of the Viterbi decoder is at 1.042 kHz.*

T11 *confirm that there is a TTL output sequence from the Viterbi decoder (DSP-HS TTL output #2), and a clock of 1.042 kHz from TTL output #1.*

The TTL output sequence should be the same as that sent from the transmitter. Confirm this by inspection (it is a short sequence) of the two waveforms. Remember that there is a considerable off-set (processing and other delay) between the two waveforms.

If there is a polarity inversion this can be reversed by flipping the USER I/O toggle on the front panel of the Viterbi decoder module (UP is one polarity, CENTRE and DOWN the other).

Checking for no errors is easier, and certainly more positive, by using the error counting instrumentation.

BER instrumentation

This sub-system is common to both the TCM and the reference system, although with different input signals.

Refer to the experiment entitled *BER instrumentation macro model* (in this Volume) for patching, alignment, and measurement procedures.

T12 *error measurements are best made with a long sequence, but during set-up a short sequence is more convenient. So before plugging in, set the reference SEQUENCE GENERATOR to a short sequence to match that at the transmitter.*

T13 *patch up the instrumentation.*

T14 *using the X-OR gate of the ERROR COUNTING UTILITIES align the received and locally generated sequences (momentarily connect the output of the X-OR gate to the RESET input of the reference SEQUENCE GENERATOR - the procedure is described in the experiment entitled* **PRBS generation** *- Volume D1).*

T15 *demonstrate the absence of errors when the two sequences are aligned (but confirm their presence when mis-aligned).*

T16 *add noise into the channel and confirm that errors start accumulating for low SNR - say below about 10 dB.*

When satisfied all is operating satisfactorily, increase the sequence length (transmitter and reference), re-align, and then make some BER measurements.

T17 *change the SEQUENCE GENERATOR modules to long sequences (both toggles of the on-board switch SW2 DOWN).*

T18 *re-align received and reference sequences at the X-OR gate.*

T19 *adjust SNR to give about 1 error per few seconds. Record the error rate as BER_1. Record this as SNR_1 in dB. Confirm this result is repeatable.*

the reference system

The TCM system has been evaluated. The reference system will now be set up.

T20 *before plugging in the DECISION MAKER, set the on-board switch SW1 to NRZ-L, and SW2 to INT. It is assumed the z-modulation jumper J1 will have been set by your Laboratory Manager to suit the oscilloscope in use*

T21 *patch up the reference system. The model is shown in Figure 6 below. There are sub-systems common with the TCM system. Clock signals need to be re-arranged. Leave the bandwidth of the channel (the TUNEABLE LPF) as set for TCM, and set the gain to maximum (control fully clockwise). Leave the INTEGRATE & DUMP module on-board switches as set for the TCM system.*

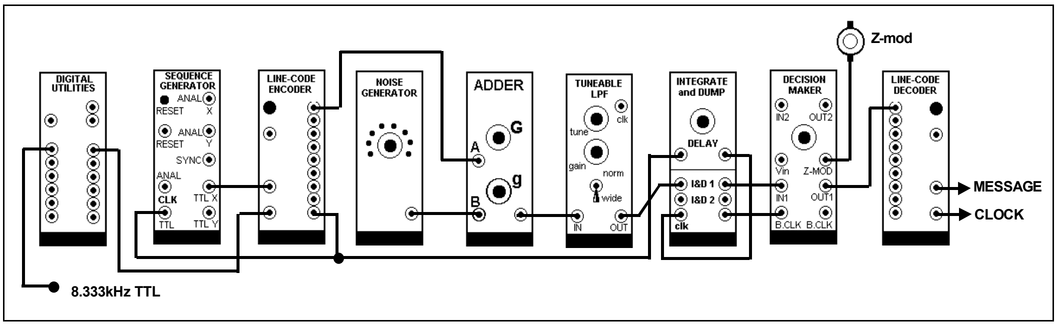

Figure 6: model of reference system

T22 *for simplicity start with a short sequence, and no noise. Adjust the gain of the ADDER so that the signal from the* I&D 1 *output of the INTEGRATE & DUMP module is about 2 volt peak. Adjust the INTEGRATE & DUMP clock signal delay so this is a two-level waveform.*

T23 *confirm the same signal as observed in the previous* TASK *appears at the output of the DECISION MAKER. This will be a TTL waveform. With a wide band channel the decision point setting is unlikely to require precise setting. Explain.*

T24 *confirm that alignment of the two sequences into the ERROR COUNTING UTILITIES module is possible.*

T25 *change to long sequences in both SEQUENCE GENERATOR modules, reset them and the LINE-CODE DECODER, and re-align the system.*

T26 *adjust SNR to match the error rate BER_1 (of the TCM arrangement). See the comment on this matching in the Appendix to this experiment. Record the SNR as SNR_2 in dB.*

T27 *the difference between SNR_1 and SNR_2 is the coding gain obtained using TCM. What might it be expected to be ?*

TUTORIAL QUESTIONS

Q1 *what was the message bit rate of the TCM system ?*

Q2 *discuss the terms <u>message data rate</u>, <u>symbol rate</u>, and <u>raw data rate</u> (you may have different names again for them), and the relationships between them, in this experiment.*

Q3 *what was the symbol rate of the TCM system ?*

Q4 *the noise was combined with the signal at the <u>input</u> to the channel. Could it have been added at the <u>output</u> of the channel? Explain.*

Q5 *in this experiment for how long will the gate of the COUNTER stay open if the front panel switch of the ERROR COUNTING UTILITIES is set to count 10^5 pulses ?*

Q6 *the TCM system added symbols to the message serial data stream, and transmitted the message at the same rate, yet had the same transmitted bandwidth as the reference system. How was this achieved ?*

Q7 *in aligning the received and reference sequences you were instructed to 'momentarily connect the output of the X-OR gate to the RESET input of the reference SEQUENCE GENERATOR'. In fact, this connection should be for more than a fraction of a second – explain.*

Q8 *in this experiment you will have found that with trellis coding there is a net advantage compared with the uncoded case. This advantage is called the coding gain and is expressed as the SNR degradation that can be tolerated to maintain a specified error probability when coding is introduced. In this instance it will be found to be approximately 2.5dB. You will have noted that with trellis coding four levels are used compared with only two in the absence of coding (i.e., with peak power remaining unchanged). This means that the raw noise margin is significantly less in the coded case.*

a. state the noise margin disadvantage of the coded case.

b. hence determine the gross difference in noise margin in the experimental results.

APPENDIX 1

matching bit error rates

An examination of a typical curve of BER versus SNR will show that the rate of change of BER for small change of SNR is rapid when the SNR is above 0 dB. Thus, if the matching of the BER of the reference system (BER_2) to that obtained previously for TCM (BER_1) is within, say, ±50%, then the error in the measured SNR will be small.

Thus the matching need only be approximate.