J. Indian Inst. Sci., Nov.–Dec. 1987, 67, pp. 447–452.

An analysis of HCFIDM and MCVSDM coders*

V. D. MYTRI AND A. P. SHIVAPRASAD
Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore 560 012, India.

Abstract

This paper presents an analysis and the simulation study of the performance of Hybrid Constant Factor Incremental Delta Modulator (HCFIDM) and Modified Continuously Variable Slope Delta Modulator (MCVSDM) under a number of constraints which can exist in real digital communication systems. The performance factors used *in these simulations are the conventional Signal-to-Noise Ratio (SNR) and Segmented Signal-to-Noise Ratio* (SNRSEG). Results indicate that these coders perform better than the existing coders.

Key words: Speech coding, hybrid constant factor, *incremental delta modulator, modified continuously variable* slope delta modulator, incremental adaptation, syllabic adaptation, hybrid adaptation.

1. Introduction

Hybrid Constant Factor Incremental Delta Modulator (HCFIDM)[1] and Modified Continuously Variable Slope Delta Modulator (MCVSDM)[2] coders have been proposed as a technique of digitizing speech at medium bit rates. In practical digital communication systems, the quality of A/D converted speech can be affected and degraded by a number of factors, particularly the dynamic range, channel errors and tandem encoding. The dynamic range of a system gives an indication of how accurately the system would reproduce both low- and high-level signals. Since speech is a nonstationary signal and may vary over a relatively broad range, the coders may not necessarily be operating at their optimum input levels. This effect has been evaluated by varying the input signal over a range of 80 dB. The effect of transmission errors, which may degrade the quality of the signal, has been evaluated for bit-error probabilities of up to 10 per cent. Finally, the effects of tandem connections up to four coders in tandem are examined.

We describe in section 2, the principles of HCFIDM and MCVSDM coders and in section 3, the results obtained by computer simulation. In section 4, we draw conclusion.

2. Principles and analyses of HCFIDM and MCVSDM coders

2.1 *HCFIDM*

The block diagram of the HCFIDM system is shown in fig. 1. $x(n)$ represents a sample from the input signal and $b(n)$ is the binary-output signal at the nth instant. The $b(n)$

* First presented at the Platinum Jubilee Conference on Systems and *Signal Processing* held at the Indian Institute of Science, Bangalore, India, during December 11–16, 1986.

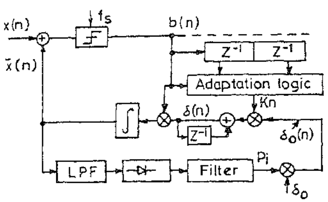

FIG. 1. Block diagram of HCFIDM.

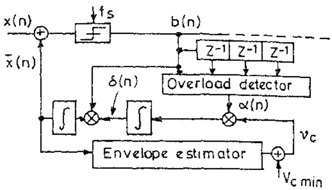

FIG. 2. Block diagram of MCVSDM.

signal is transmitted over a binary channel to the receiver, and these bits are used to construct the original signal at the receiver. The instantaneous adaptation is of incremental type[3] and can use either 2-recent output bits (SVADM)[3] or 3-recent output bits (CFIDM-2)[4] or 4-recent output bits (CFIDM-3)[4]. The logic rule for CFIDM-2 is presented in Table I. The significant feature of HCFIDM is the simultaneous use of the syllabic adaptation and the instantaneous adaptation. This is achieved by multiplying the minimum step size δ_0 by the envelope of the estimated signal. The step size at the nth sampling instant for the HCFIDM system is, therefore, as follows:

$$\delta_n = \delta_{n-1} + K_n \delta_0(n) \tag{1}$$

where K_n is determined from the logic rule, and

$$\begin{aligned} \delta_0(n) &= p_i \delta_0 \quad \text{if } \delta_0(n) \geqslant \delta_0 \\ &= \delta_0 \quad \text{if } \delta_0(n) < \delta_0 \end{aligned} \tag{2}$$

in which P_i is the envelope of the input signal at the $(n-1)$th instant.

Consider the incremental adaptation system having the maximum to minimum step-size ratio R and the minimum step size δ_0. Let the maximum and the minimum input-envelope values be $p_{\max}$ and $p_{\min}$, respectively. The minimum step size $\delta_0(n)$ of the HCFIDM system, therefore, varies in the limits of $\delta_0 p_{\min}$ to $\delta_0 p_{\max}$, and the corresponding maximum step sizes are $R\delta_0 p_{\min}$ and $R\delta_0 p_{\max}$. Therefore, the absolute

Table I

b(n − 2)	b(n − 1)	b(n)	k_n
+	+	+	2
−	−	−	2
−	+	+	1
+	−	−	1
−	+	−	−1
+	−	+	−1
−	−	+	−2
+	+	−	−2

maximum step size δ_{max} and the minimum step size δ_{min} for the HCFIDM system are given by

$$\delta_{max} = R\delta_0 p_{max}; \qquad \delta_{min} = \delta_0 p_{min}. \tag{3}$$

Hence, the step size ratio R' for the HCFIDM system is

$$R' = (\delta_{max}/\delta_{min}) = R(p_{max}/p_{min}). \tag{4}$$

From eqn (4) it is clear that the proposed technique leads to an improved dynamic range and hence to improved coding. Theoretically, it should be possible to make R' as large as possible. However, in practice the value of R' is limited by the maximum signal-handling capability and the resolution of the circuit.

If R' is made the step-size ratio for CFIDM coder is an attempt to handle larger dynamic range of the input signal, then an excessive slope overload results at the higher input levels. This is because under this condition, the minimum step size becomes too small and the step-size increase is too slow with respect to the input-signal level. In other words, the input signal overtakes the step-size increase and SNR degrades. This has been verified by computer simulation and discussed in section 3.

2.2 MCVSDM

The block diagram of the MCVSDM coder employing first order predictor is shown in fig. 2. The 4-recent output bits are used to control the quantizer step size by syllabic compander which consists of a 3-bit memory, adaptation logic and a syllabic filter. The significant feature of the MCVSDM coder is the use of input-power level for changing the minimum step size δ_0 of the CVSDM coder. The step size at the nth sampling instant for the MCVSDM is, therefore, as follows:

$$\delta(n) = \beta\delta(n-1) + \alpha(n)\,\delta_0(n) \tag{5}$$

with

$$\begin{aligned} \alpha(n) &= 1 \text{ if } b(n) = b(n-1) = b(n-2) = b(n-3) \\ &= 0 \text{ otherwise, and} \\ \delta_0(n) &= (1-\beta)\,v_c \qquad \text{if } \delta_0(n) \geqslant \delta_0 \\ &= \delta_0 \qquad \text{if } \delta_0(n) < \delta_0 \\ \delta_0 &= (1-\beta)\,V_{cmin} \end{aligned} \tag{6}$$

where the parameter β is in the range of 0.9 to 0.995 corresponding to the syllabic filter time constant of 0.5 to 12 msec and v_c is a control signal which is a function of the input signal and can vary between two limits, *viz.*, V_{cmin} and V_{cmax}. V_{cmax} is the maximum value of v_c and is limited by the onset of the saturation in the circuit while V_{cmin} is the minimum value of v_c and is determined by the resolution of the circuit.

Therefore, the minimum step size $\delta_0(n)$ varies from the smallest value δ_0 to the largest value δ_{0max} and these are expressed as follows:

$$\delta_0 = (1-\beta)\,V_{cmin}; \qquad \delta_{0max} = (1-\beta)\,V_{cmax}. \tag{7}$$

From eqn (5), the absolute maximum step size δ_{maxM}, for the MCVSDM coder can be shown to be

$$\delta_{maxM} = \delta_{0max}/(1-\beta). \tag{8}$$

If the minimum step size for the CVSDM coder is kept at δ_0, then the maximum step size δ_{max} for the CVSDM coder can be shown to be

$$\delta_{max} = \delta_0/(1-\beta). \tag{9}$$

The ratio of the maximum step size of the MCVSDM coder to the maximum step size of the CVSDM coder is give by

$$(\delta_{maxM}/\delta_{max}) = (\delta_{0max}/\delta_0). \tag{10}$$

Substituting eqn (7) in eqn (10),

$$(\delta_{maxM}/\delta_{max}) = (V_{cmax}/V_{cmin}). \tag{11}$$

Rewriting eqn (11) as,

$$(\delta_{maxM}/\delta_0) = (\delta_{max}/\delta_0)(V_{cmax}/V_{cmin}). \tag{12}$$

It is reasonable to assume that the dynamic range of the system can be expressed as the ratio of the maximum to minimum step size, and from eqn (12)

$$DR_M(dB) = DR(dB) + 20\log_{10}(V_{cmax}/V_{cmin}) \tag{13}$$

where DR_M is the dynamic range for the MCVSDM coder and DR is the dynamic range for the CVSDM coder.

It is seen from eqn (13), that the ratio (V_{cmax}/V_{cmin}) is an important factor in determining the amount of dynamic range improvement. Therefore, larger is this ratio, wider is the dynamic range obtained. However, in practice, the ratio is limited by the circuit parameters as pointed out earlier.

3. Computer simulation results and discussion

This section presents the results obtained by computer simulation under various constraints. The coders were simulated on a DEC-10 with digitized speech as the coder input. The input filter used at the decoder was a fourth-order Butterworth low-pass filter. To make a fair comparison we have kept the maximum to the minimum step-size ratio at 60 dB for all the coders.

3.1 Dynamic range

An important characteristic of a speech coder is its dynamic range, which is the range of input-signal level over which the system has a relatively flat performance. The SNR and SNRSEG performance of these coders are shown in fig. 3. Figure 3(a) presents the results for the CFIDM-2 and the HCFIDM-2 coders. We notice that the SNR/SNRSEG degrade in the case of CFIDM coder at higher input levels in spite of keeping the same

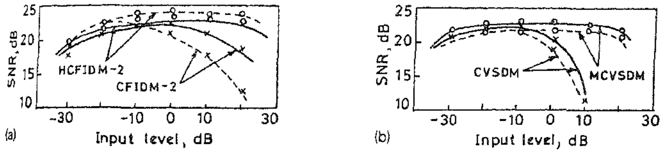

FIG. 3. SNR *vs* speech input, $f_s = 40\,\text{kHz}$; —— SNR; ---- SEG.

step-size ratio for both the systems. As pointed out in section 2.1, the large step-size ratio makes the increment δ_0 very small and the step size may not vary quickly enough to keep pace with the input resulting in excessive quantizing noise. Thus, we see that the computer-simulation results are in agreement with the analysis presented in section 2.1.

Figure 3(b) presents the results for the CVSDM and the MCVSDM coders. In these simulations, the parameter, β, was chosen to be 0.994 which gives the step-size ratio of about 44 dB (eqn 9) in the case of the CVDSM coder. However, we have kept the step-size ratio at 60 dB. Therefore, the improvement expected in the dynamic range is 16 dB and this improvement is clearly noticeable from fig. 3(b). Hence, the simulation results confirm the analysis presented in section 2.2.

3.2 Channel errors

To study the performance of the same coders under noisy channel, we generated a controlled number of random errors in the encoder-output bit stream. Figure 4 shows the results for the SNRSEG as a function of bit-error probability (BEP). It is seen that HCFIDM coder gives an improvement of about 1 to 2 dB as compared with CFIDM coder. However, the MCVSDM coder works as well as the CVSDM coder.

3.3 Tandem connections

In the tandem simulation, each system was cascaded with itself with the output of one stage becoming the input to the next stage. The method of computing SNR in the simulation is similar to the approahes of Jayant and Shipley[5]. The results are presented in fig. 5. It is seen that the SNR drops by about 2 dB per doubling of the number of tandem coders in all the cases.

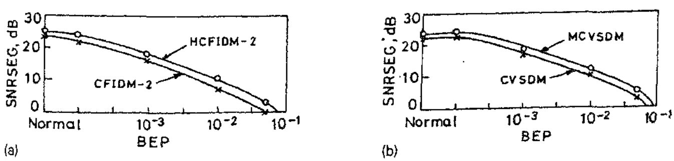

FIG. 4. SNRSEG *vs* bit-error probability for speech input.

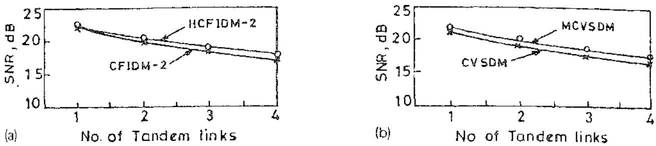

FIG. 5. SNR *vs* tandem links for speech input.

4. Conclusion

In this paper, we have studied the performance of HCFIDM and MCVSDM coders under various practical constraints. Analysis of these systems in terms of dynamic range has been presented and verified by computer simulation. The results of computer simulation indicate that the dynamic range improvement for HCFICM is of the order of 8 dB as compared with CFIDM coder, whereas there is 15–20 dB improvement in the case of MCVSDM as compared with CVSDM. The HCFIDM and MCVSDM coders work as well as CFIDM and CVSDM coders in the presence of noisy channel and tandem encoding.

References

1. MYTRI, V. D. AND SHIVAPRASAD, A. P. — Hybrid constant factor incremental delta modulators, *IEE Proc. F*, 1986, **133**, 522–525.

2. MYTRI, V. D. AND SHIVAPRASAD, A. P. — Improving the dynamic range of CVSD coder, *Electronics Lett.*, 1986, **22**, 429–430.

3. SONG, C. L., GARODNICK, J. AND SCHILLING, D. L. — A variable step size robust delta modulator, *IEEE Trans.*, 1971, **COM-19**, 1033–1044.

4. MYTRI, V. D. AND SHIVAPRASAD, A. P. — Constant factor incremental delta modulator, *Int. J. Electronics*, 1986, **61**, 129–135.

5. JAYANT, N. S. AND SHIPLEY, K. — Multiple delta modulator of a speech signal, *Proc. IEEE*, 1971, **59**, 1382.