CCITT SGXV
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Specialists Group on Coding for Visual Telephony

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TITLE : MISMATCH ERRORS OF MATRIX MULTIPLICATION IDCT

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1. Introduction

This document is an extension of the document presented at the "DCT chip manufacturers meeting" held in May 1988.

In addition to the mismatch error against the reference ideal IDCT, mismatch errors between non-ideal IDCTs are calculated. Effects of rounding to 9 bits at the IDCT output as well as quantization at the DCT output are also discussed by observing the error distribution.

2. Simulation method

Mismatch errors of a matrix approach IDCT have been simulated according to the method defined in Annex 3 to Document #346R. (Note: The changing signs of random integer pixels described in Step 9 has not been carried out.)

Configuration of the simulation experiment is shown in Fig. 1, where the IDCT is structured as in Fig. 2. The significant number of bits for the transform coefficients and the first one-dimensional IDCT output, M and N, are varied. The transform coefficients are rounded to M bits, whereas both of rounding and truncation are applied to the first 1-dimensional IDCT output.

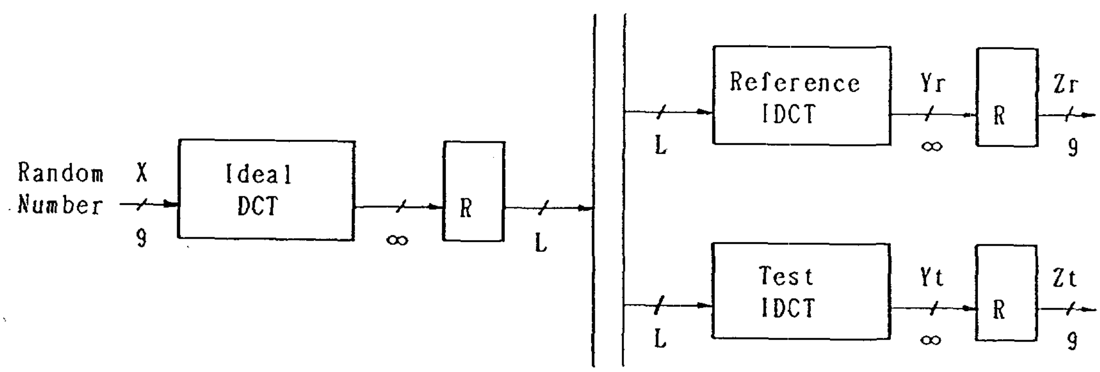

Fig. 1 Configuration of IDCT mismatch simulation

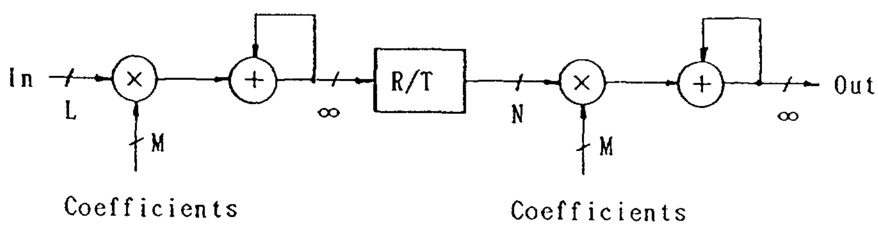

Fig. 2 Configuration of IDCT

The following items have been measured for 1024 test blocks which were generated by "C rand()";

- Peak error,
- Overall mean square error,
- Overall mean error,
- Maximum pel mean square error, and
- Maximum pel mean error.

Peak errors are always 1 for the range of parameters experimented; $11 \leq M \leq 16$, $12 \leq N \leq 19$ except for the case of truncation N=12 in the test IDCT (peak error = 2 for all values of M).

3. Simulation results

The remaining four items are plotted in the following figures.

Fig. 3: (Zt - Zr) when the reference is ideal (M, N >> 20) and L=12.
Fig. 4: (Zt - Zr) when the reference is a matrix multiplication IDCT with M=14, N=16(rounded) and L=12.
Fig. 5: (Zt - Zr) when the reference is a matrix multiplication IDCT with M=14, N=16(truncated) and L=12.

In order to further investigate the behavior of the mismatch error, the following two measurements have been carried out.

Fig. 6: (Yt - Yr) when the reference is ideal (M, N >> 20) and L=12.
Fig. 7: (Zt - Zr) when the reference is a matrix multiplication IDCT with M=14, N=16(rounded) and L=8.

These two figures give the effect of rounding to 9 bits at the output of IDCT (Fig. 6), and the effect of quantization at the DCT output (Fig. 7).

4. Observation

We can observe as follows from these results;

1) Since the peak error value is 1, square error sum increases by 1 for each errored pel. The overall mean square error is equal to the average number of errored pels.

2) For a 1 bit increase in M or N, overall mean square error is halved. Truncation of the first 1-D IDCT output gives an overall m.s.e. corresponding to rounding with 1 bit less precision (Fig. 3).

3) If the specification in Annex 3 to Doc. #346R is applied, required number of bits are as follows (Fig. 3);

   - For rounding, (M>12 and N>14) or (M>13 and N>13). The decisive factor is "overall m.s.e".

   - For truncation, M>12 and N>17. The decisive factor is "maximum pel mean error".

   It is noted that the specification may need further clarification based on the experimental results on the relation between mismatch error and picture quality.

4) Initial compatibility check parameters of the transform part in the flexible hardware specification (Doc. #249) correspond to M = 14 (rounding) and N = 16 (truncation). This set of parameters gives an overall m.s.e. of 0.01. On the other hand, "Baseline IDCT" defined in Doc. #281 corresponds to M=16 (rounding) and N = 16 (rounding), thus its overall m.s.e. is 0.005. Flexible Hardware specification does not clear the provisional maximum mean error requirement 0.015.

5) If rounding is used for the first 1-D IDCT output, overall mean error is well below the specified value 0.01 (Fig. 3).

6) For truncation, error occurrence is much higher in the pels of the first line (or row) of 8x8 matrix than other pels. It is uniformly distributed, however, for rounding.

7) If the coder uses a combination of M=14 and N=16 (rounded), all the combinations listed in 3) above also meet the provisional specification (Fig. 4).

8) If the coder uses a combination of M=14 and N=16 (truncated), however, all the combinations listed in 3) above fail to meet the provisional specification in the maximum mean error (Fig. 5).

9) Comparison of IDCT outputs before 9 bit rounding reveals that the mismatch error is much smaller than that for the error after the 9 bit rounding, except in mean error and maximum mean error for truncation cases (Fig. 6).

10) If the DCT output is quantized to 8 bits instead of 12 bits, square errors increase by 50 % (Fig. 7).

To understand the mechanism of mismatch errors, distribution of errors has been measured. Figure 8 shows the difference between the non-rounded IDCT output and the 9-bit DCT input. Even for an ideal IDCT and L=12, there is possibility of deviating by +/-1 through DCT-IDCT conversion. If the DCT output is quantized to L=8, standard deviation becomes 16 times larger.

Figure 9 shows the mismatch error at the IDCT outputs before the 9-bit rounding. Distribution of error is much narrower than that of Fig. 8, its standard deviation being less than 1/10 of that for DCT-IDCT conversion with L=12.

Though the IDCT mismatch error is fractional and rather small, it generates occasional errors of +/-1 after rounding to 9 bit at the final output because the DCT-IDCT conversion does not make the IDCT output integer values. If the DCT output is quantized, DCT-IDCT conversion makes the IDCT output widely distributed, thus there is more chance of +/-1 error where the IDCTed fractional values are around 0.5.

5. Conclusion

IDCT mismatch errors have been analyzed through computer simulation for random numbers. It is expected that the data given here will lead to finalization of the IDCT part specification of Rec. H.261.

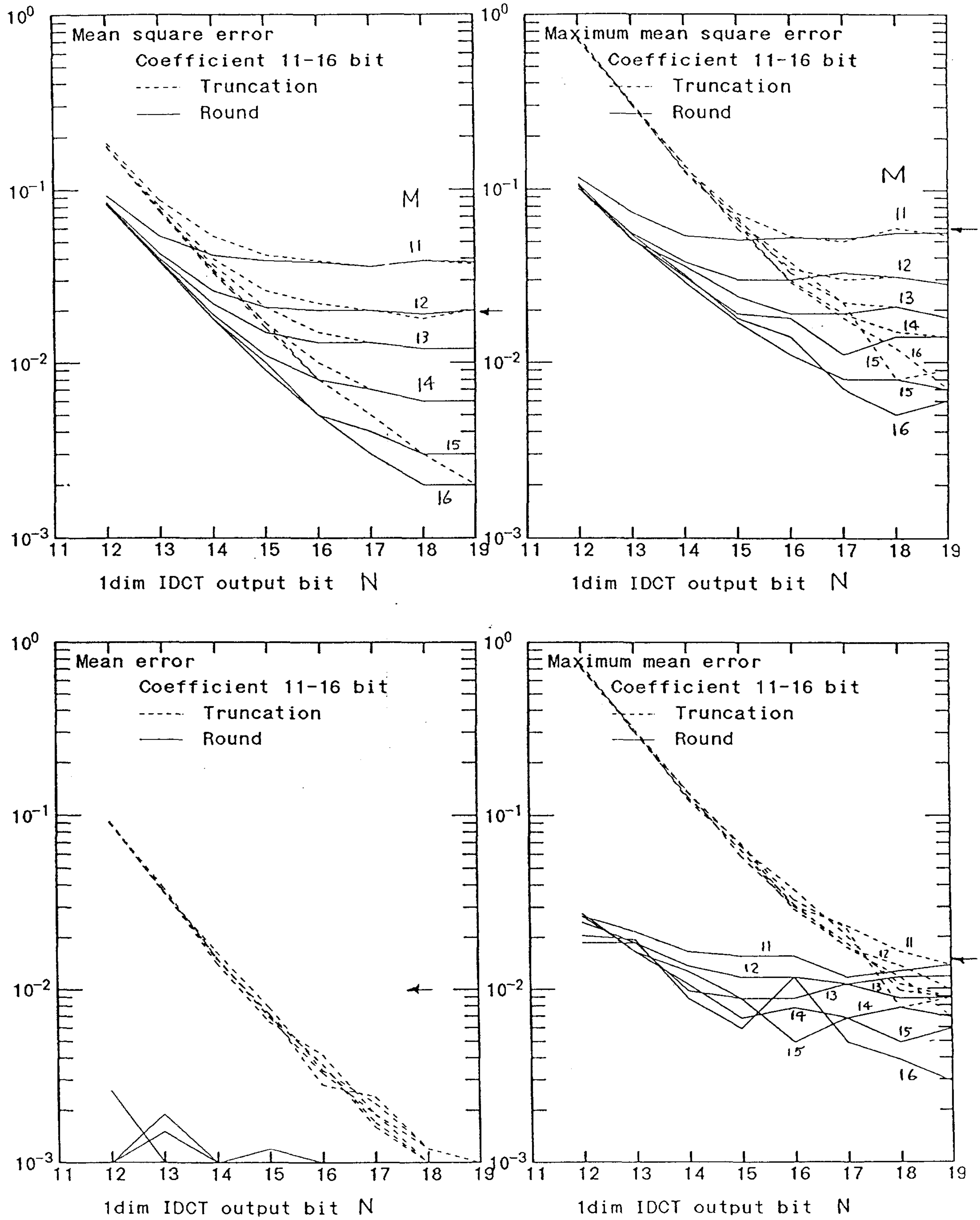

Figure 3 Error between IDCT outputs after 9-bit rounding (Zt - Zr) for ideal IDCT (M,N >> 20) as reference, L=12

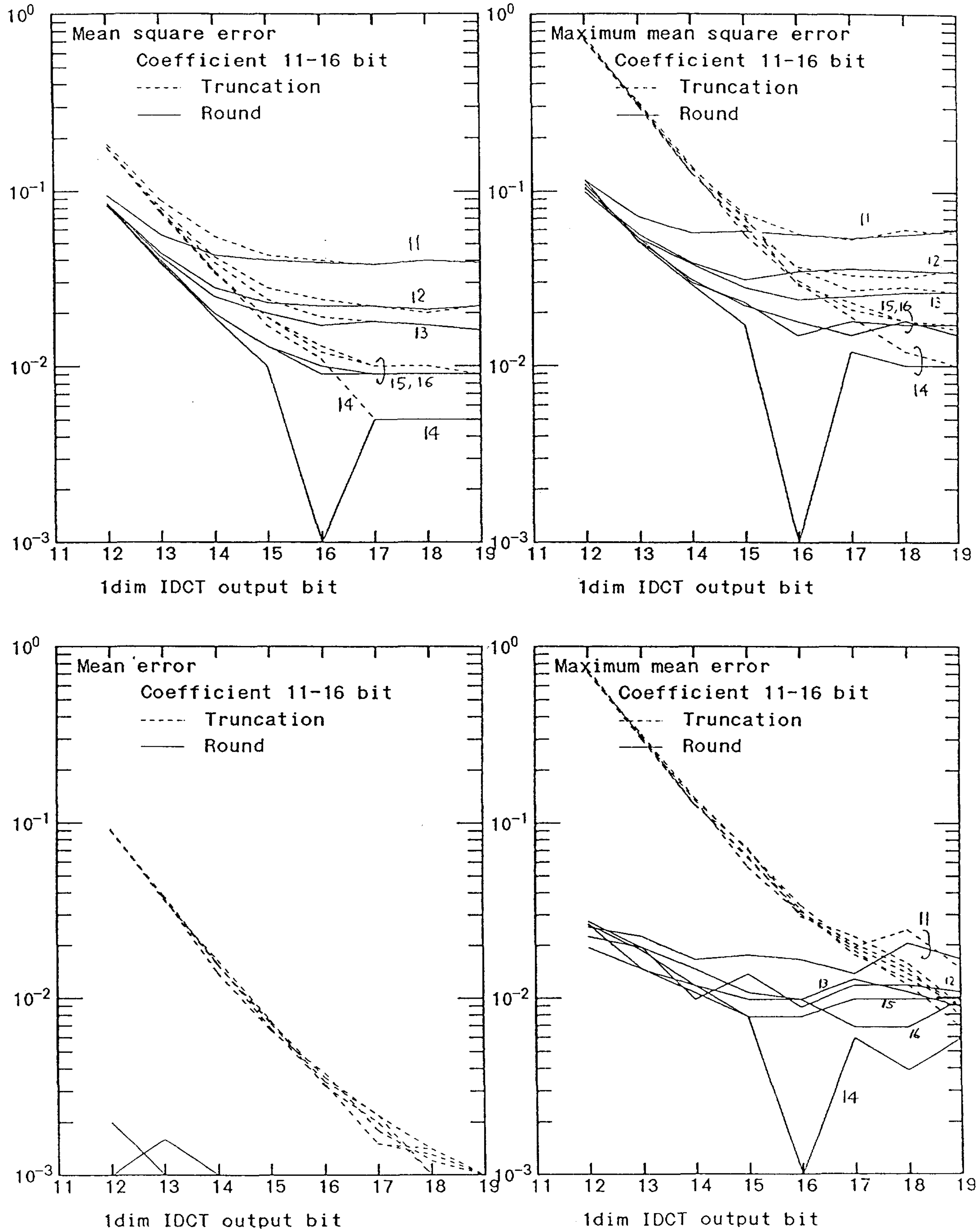

Figure 4 Error between IDCT outputs after 9-bit rounding (Zt - Zr) for matrix multiplication IDCT (M=14, N=16 rounded) as reference, L=12

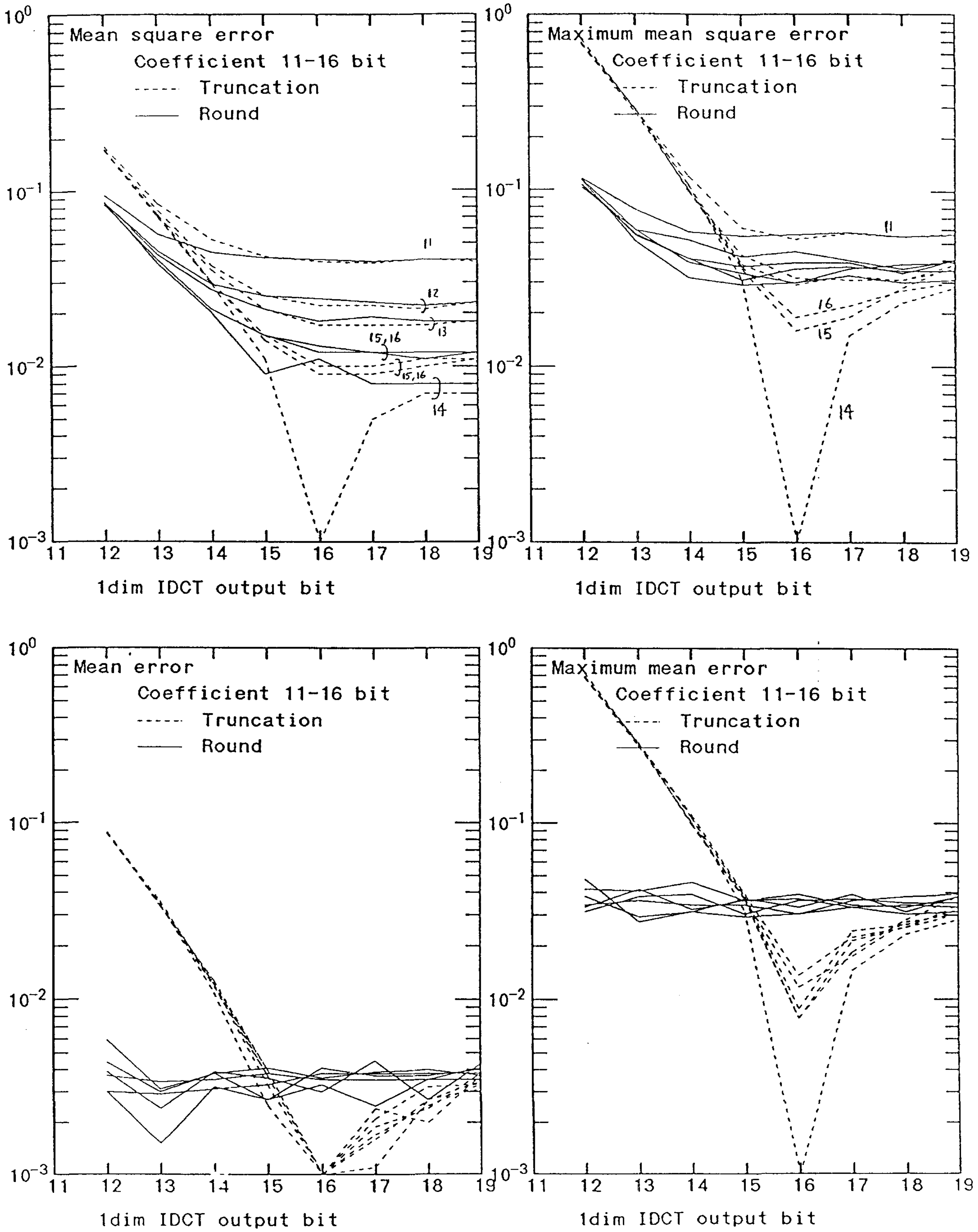

Figure 5 Error between IDCT outputs after 9-bit rounding (Zt - Zr) for matrix multiplication IDCT (M=14, N=16 truncated) as reference, L=12

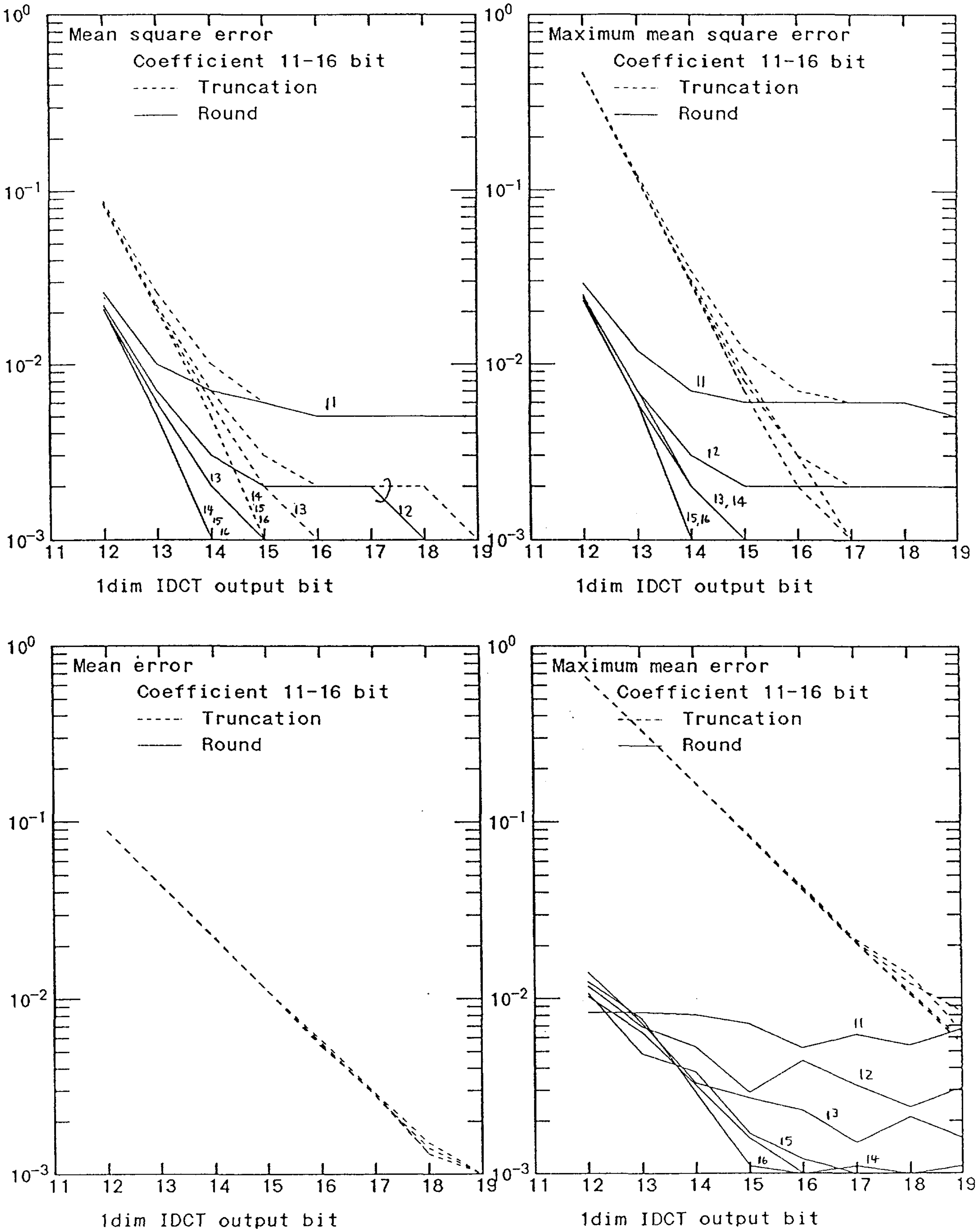

Figure 6 Error between IDCT outputs before 9-bit rounding (Yt - Yr) for ideal IDCT (M.N >> 20) as reference. L=12

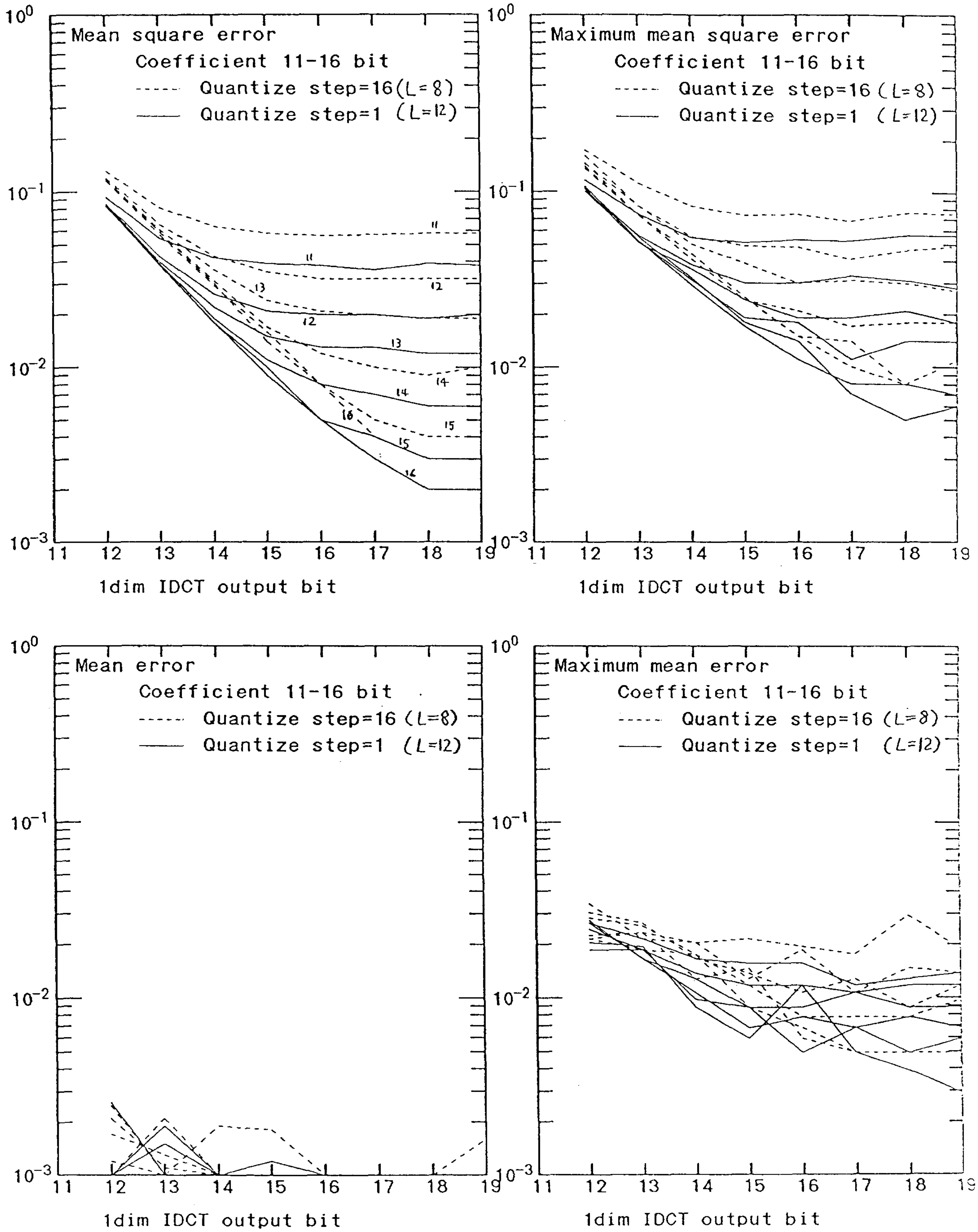

Figure 7 Error between IDCT outputs after 9-bit rounding (Zt - Zr) for ideal IDCT (M, N >> 20) as reference. L=8

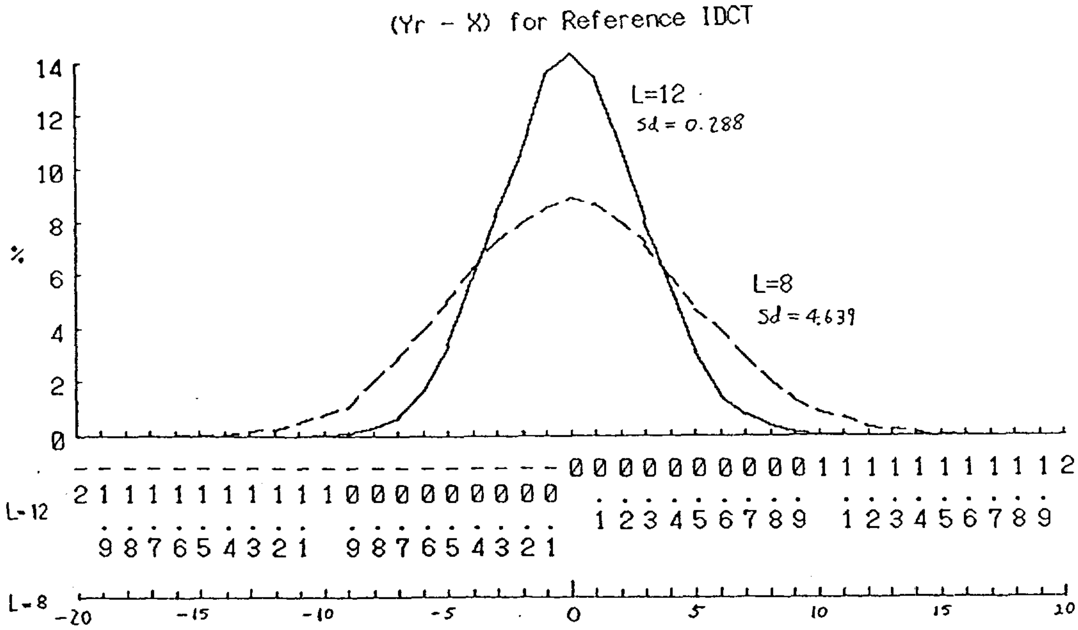

Figure 8 Distribution of DCT-IDCT conversion error (Yr - X)

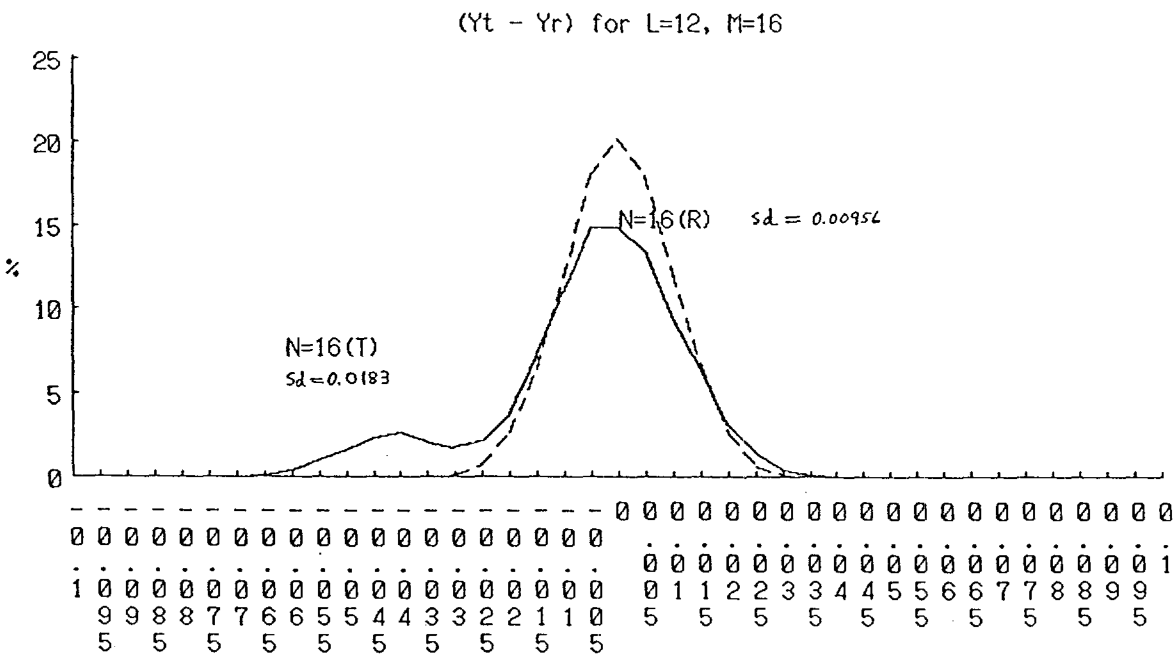

Figure 9 Distribution of mismatch error (Yt - Yr)