CCITT Study Group XV
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Title : CODING OF COEFFICIENTS QUANTIZATION INDEX WITH A TWO-DIMENSIONAL TABLE

1. Introduction

At the last meeting in Germany, a new coefficients coding method with wonderful efficiency was reported by FRG (Doc. # 170). This contribution describes a coefficients quantization index coding method following the concept of the Doc. # 170 and shows the experimental results with respect to bit saving based on the RM3 simulation. In addition, a considerable improvement (3 to 10 % of bit saving in equivalent SNR) is presented by the comparison with the bit rate versus SNR characteristics of the RM3.

2. Coefficients coding with a two-dimensional table

The general algorithm of the method is as follows.

(i) "Event" is defined as a combination of a LEVEL (non-zero quantization index) and a RUN (number of zero indexes preceding the current non-zero index).

(ii) A limited number of events with higher statistical probability are coded with Huffman's algorithm, hence variable length coded. The number of Huffman-coded events is 126.

(iii) The other events are coded using fixed length codes. These codes consist of the following three parts.

(a) Escape code (6 or 7 bits) for indicating the use of fixed length codes. This code is one of the above Huffman's codes.
(b) LEVEL (7 bits. Here, it is assumed that the number of quantization indexes is less than 128).
(c) RUN (6 bits).

Two kinds of the EOB coding method are combined with the two-dimensional coding.

Method 1: The EOB word is included in the two-dimensional table as one of the Huffman's codes. The word lengths of Huffman-coded events are shown in Table 1.

Method 2: The two-dimensional table does not include the EOB word. The number of significant (non-zero) coefficients is coded by Huffman's code as in Reference Model 1. The code set for the number of significant coefficients is shown in Table 2. The word lengths of Huffman-coded events are shown in Table 3.

3. Experimental results (evaluation in number of saved bits)

The two-dimensional tables were designed based on the two-dimensional histogram of the RM3 simulation result. The saved bits compared with RM3 are as follows:

	saved bits / coded picture	saved bits / coded block
Method 1:	950	1.5
Method 2:	1300	2.0

(average data of MA, CJ and ST sequences)

This result shows that the two-dimensional coding has a remarkable efficiency compared with the RM3. In addition, we can see that the Method 2 has an advantage of giving more bit saving than the Method 1.

4. Coding simulations and the bit-rate versus SNR characteristics of RM3

Coding simulations of the two-dimensional coding were carried out. In addition, RM3 simulations were performed at several bit rates. The results are shown in Tables 4-6 and Figure 1, where the abbreviation represent:

Item	Coding scheme	Information rate
RM3:	Reference Model 3,	300Kbit/sec
MOD:	Two-dimensional coding (Method 2),	300Kbit/sec
RM3-1:	Reference Model 3,	210Kbit/sec (-30%)
RM3-2:	Reference Model 3,	270Kbit/sec (-10%)
RM3-3:	Reference Model 3,	330Kbit/sec (+10%)
RM3-4:	Reference Model 3,	390Kbit/sec (+30%).

From Figure 1, the efficiency improvement of the two-dimensional coding (Method 2) is equivalent in SNR to the following increase of channel rate in the RM3.

Miss America :	8.0 %	=	1600 saved bits/coded picture
Checked Jacket:	10.5 %	=	2100 saved bits/coded picture
Split-Trevor:	3.5 %	=	1050 saved bits/coded picture

5. Conclusion

The considerable improvement is obtained by the two-dimensional coding of coefficients quantization index. This is supported by the results of 3 to 10 % efficiency improvement from the RM3, which had already been improved from the RM2 by introducing the selective scanning and the last non-zero trick. As a conclusion, introduction of the two-dimensional coding deserves serious consideration as far as coding efficiency is concerned. Hardware implementation aspects need further study. It is noted that no change is required in the coding loop when the two-dimensional coding is introduced, thus modification of the current Flexible Hardware may be comparatively easy.

Table 1. Word Length of VLC for 2-dimensional Coding. (Method 1, length of EOB word = 2)

RUN	LEVEL <---- (scalar quantization index) ---->																															
	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	20	13	13	12	12	12	11	11	11	10	10	9	8	7	6	5	3	20	3	5	6	7	8	9	10	10	11	11	12	12	13	20	20
1	20	20	20	20	20	20	20	20	20	20	12	11	10	9	8	7	5	20	4	7	8	10	11	11	12	20	20	20	20	20	20	20	20
2	20	20	20	20	20	20	20	20	20	20	20	20	12	11	10	8	5	20	5	8	10	11	12	20	20	20	20	20	20	20	20	20	20
3	20	20	20	20	20	20	20	20	20	20	20	20	13	12	10	8	6	20	6	8	10	12	20	20	20	20	20	20	20	20	20	20	20
4	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	9	6	20	6	9	11	13	20	20	20	20	20	20	20	20	20	20	20
5	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	10	7	20	7	10	12	20	20	20	20	20	20	20	20	20	20	20	20
6	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	10	7	20	7	10	13	20	20	20	20	20	20	20	20	20	20	20	20
7	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	7	20	8	11	20	20	20	20	20	20	20	20	20	20	20	20	20
8	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	8	20	8	11	20	20	20	20	20	20	20	20	20	20	20	20	20
9	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	8	20	8	12	20	20	20	20	20	20	20	20	20	20	20	20	20
10	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	9	20	9	12	20	20	20	20	20	20	20	20	20	20	20	20	20
11	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	9	20	9	20	20	20	20	20	20	20	20	20	20	20	20	20	20
12	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	10	20	10	20	20	20	20	20	20	20	20	20	20	20	20	20	20
13	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	10	20	10	20	20	20	20	20	20	20	20	20	20	20	20	20	20
14	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	10	20	10	20	20	20	20	20	20	20	20	20	20	20	20	20	20
15	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	10	20	10	20	20	20	20	20	20	20	20	20	20	20	20	20	20
16	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	20	11	20	20	20	20	20	20	20	20	20	20	20	20	20	20
17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	20	11	20	20	20	20	20	20	20	20	20	20	20	20	20	20
18	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	20	11	20	20	20	20	20	20	20	20	20	20	20	20	20	20
19	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	11	20	12	20	20	20	20	20	20	20	20	20	20	20	20	20	20
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	20	11	20	20	20	20	20	20	20	20	20	20	20	20	20	20
21	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	20	12	20	20	20	20	20	20	20	20	20	20	20	20	20	20
22	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	20	20	20	20	20	20	20	20	20	20	20	20	20	20
23	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	12	20	12	20	20	20	20	20	20	20	20	20	20	20	20	20	20
24	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
25	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
26	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	13	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
27	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

(Codes with length 20 consist of three parts, escape code (7 bits), LEVEL (7 bits, fixed length) and RUN (7 bits, fixed length)

Table 3. Word Length of VLC for two-dimensional Coding, (Method 2)

RUN ^ number of	LEVEL <---- (scalar quantization index) ---->																																	
	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	19	12	12	12	11	11	11	10	10	9	9	8	8	7	6	4	3	19	3	4	6	7	7	8	9	9	10	11	11	11	12	19	19
1	19	12	12	12	11	11	11	10	10	9	9	8	8	7	6	4	3	19	3	4	6	7	7	8	9	9	10	11	11	11	12	19	19
2	19	19	19	19	19	19	19	19	19	19	12	11	10	9	7	6	4	19	4	6	8	9	10	11	12	19	19	19	19	19	19	19	19
3	19	19	19	19	19	19	19	19	19	19	19	19	11	10	9	7	5	19	5	7	9	10	11	19	19	19	19	19	19	19	19	19	19
4	19	19	19	19	19	19	19	19	19	19	19	19	12	11	10	8	5	19	5	8	10	11	19	19	19	19	19	19	19	19	19	19	19
5	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	8	6	19	6	8	10	12	19	19	19	19	19	19	19	19	19	19	19
6	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	9	6	19	6	9	11	19	19	19	19	19	19	19	19	19	19	19	19
7	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	10	6	19	7	9	12	19	19	19	19	19	19	19	19	19	19	19	19
8	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	7	19	7	10	19	19	19	19	19	19	19	19	19	19	19	19	19
9	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	7	19	7	10	19	19	19	19	19	19	19	19	19	19	19	19	19
10	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	7	19	7	11	19	19	19	19	19	19	19	19	19	19	19	19	19
11	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	8	19	8	12	19	19	19	19	19	19	19	19	19	19	19	19	19
12	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	8	19	8	19	19	19	19	19	19	19	19	19	19	19	19	19	19
13	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	9	19	9	19	19	19	19	19	19	19	19	19	19	19	19	19	19
14	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	9	19	9	19	19	19	19	19	19	19	19	19	19	19	19	19	19
15	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	19	10	19	19	19	19	19	19	19	19	19	19	19	19	19	19
16	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	19	9	19	19	19	19	19	19	19	19	19	19	19	19	19	19
17	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	19	10	19	19	19	19	19	19	19	19	19	19	19	19	19	19
18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	19	10	19	19	19	19	19	19	19	19	19	19	19	19	19	19
19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	19	11	19	19	19	19	19	19	19	19	19	19	19	19	19	19
20	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	19	11	19	19	19	19	19	19	19	19	19	19	19	19	19	19
21	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	19	11	19	19	19	19	19	19	19	19	19	19	19	19	19	19
22	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	11	19	11	19	19	19	19	19	19	19	19	19	19	19	19	19	19
23	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	12	19	19	19	19	19	19	19	19	19	19	19	19	19	19
24	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	12	19	12	19	19	19	19	19	19	19	19	19	19	19	19	19	19
25	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
26	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	12	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
27	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19

(Codes with length 19 consist of three parts, escape code (6 bits), LEVEL (7 bits, fixed length) and RUN (6 bits, fixed length)

Table 2. Word Length of VLC for Coding Non-zero Coefficient Number (used in the Method 2)

number of non-zero	word length	number of non-zero	word length
1	1	28	12
2	3	29	13
3	3	30	13
4	4	31	14
5	5	32	16
6	5	33	15
7	5	34	15
8	6	35	15
9	6	36	15
10	6	37	16
11	7	38	16
12	7	39	16
13	7	40	16
14	8	41	16
15	8	42	16
16	8	43	16
17	9	44	16
18	9	45	16
19	9	46	16
20	10	47	16
21	10	48	16
22	10	49	16
23	11	50	16
24	11	.	.
25	11	.	.
26	13	.	.
27	12	.	.

Table 4. Simulation Results 1, Sequence: Miss America (Average)

Item			RM3	MOD	RM3-1	RM3-2	RM3-3	RM3-4
1)R.M.S. for luminance			2.54	2.49	2.82	2.61	2.48	2.38
2)SNR for luminance			40.03	40.21	39.12	39.78	40.24	40.58
3)Mean value of the step size			8.23	7.74	11.39	8.97	7.65	6.82
4)Mean value of the number of non-zero coefficients			2.47	2.56	2.14	2.39	2.57	2.77
5)Mean value of the number of zeroes before the last non-zero coefficient			6.38	6.67	4.99	5.95	6.67	7.49
6) Block type of Y	Intra		0	0	1	0	1	0
	Fixed (Inter/No MC/No coded)		1124	1101	1199	1149	1097	1046
	Inter (Inter/No MC/Coded)		169	194	81	139	200	255
	Fixed MC (Inter/MC/No coded)		133	124	194	150	120	98
	Inter MC (Inter/MC/Coded)		155	162	107	142	165	183
	Filtered		273	277	260	269	281	296
7) Block type of C	Intra		0	0	1	0	0	0
	Fixed (Inter/No Coded)		474	443	599	513	437	382
	Inter (Inter/Coded)		316	347	191	277	353	408
	Filtered		248	271	163	219	276	318
8) Number of bits	Attributes	Y	3693	3753	3559	3643	3752	3868
		Cr	905	925	823	881	926	960
		Cb	1116	1140	992	1086	1144	1175
		Total	5715	5819	5376	5610	5824	6004
	Classification indexes		651	716	379	567	733	878
	EOBs		1928	1740	1147	1686	2163	2547
	Motion Vectors		2313	2294	2416	2348	2284	2253
	Coefficients	Y	5793	5680	2823	4812	6775	8798
		Cr	1289	1321	736	1095	1448	1774
		Cb	2190	2330	923	1740	2681	3660
		Total	9273	9332	4483	7647	10905	14233
	Total		19882	19903	13803	17860	21910	25917
Number of significant blocks			643	707	382	562	721	849
Number of quantized coefficients			5720	6568	2786	4722	6680	8719

Table 5. Simulation Results 2, Sequence: Checked Jacket (Average)

Item			RM3	MOD	RM3-1	RM3-2	RM3-3	RM3-4
1)R.M.S. for luminance			3.35	3.22	3.86	3.47	3.24	3.05
2)SNR for luminance			37.64	37.96	36.39	37.32	37.93	38.45
3)Mean value of the step size			8.89	8.24	12.26	9.70	8.18	7.12
4)Mean value of the number of non-zero coefficients			3.14	3.13	2.60	3.02	3.09	3.18
5)Mean value of the number of zeroes before the last non-zero coefficient			8.60	8.37	8.67	8.83	8.09	7.74
6) Block type of Y	Intra		2	1	2	1	1	1
	Fixed (Inter/No MC/No coded)		1102	1051	1217	1146	1043	950
	Inter (Inter/No MC/Coded)		329	383	208	286	393	488
	Fixed MC (Inter/MC/No coded)		42	39	72	48	37	30
	Inter MC (Inter/MC/Coded)		107	107	84	101	107	112
	Filtered		185	192	181	185	193	194
7) Block type of C	Intra		0	0	0	0	0	0
	Fixed (Inter/No Coded)		656	633	727	683	626	573
	Inter (Inter/Coded)		135	158	64	108	165	218
	Filtered		53	56	31	49	56	68
8) Number of bits	Attributes	Y	3669	3858	3301	3526	3883	4173
		Cr	718	745	614	685	753	805
		Cb	852	877	788	829	875	923
		Total	5240	5481	4704	5040	5512	5902
	Classification indexes		878	985	588	778	1005	1205
	EOBs		1723	1660	1076	1494	2005	2462
	Motion Vectors		1203	1173	1251	1199	1162	1148
	Coefficients	Y	9812	9424	5596	8490	11015	13622
		Cr	429	500	164	330	536	774
		Cb	272	345	88	198	346	525
		Total	10514	10270	5849	9018	11897	14922
	Total		19559	19570	13470	17531	21582	25639
Number of significant blocks			575	652	359	498	668	821
Number of quantized coefficients			6645	7371	4060	5870	7369	8861

Table 6. Simulation Results 3, Sequence: Split-Trevor (Average)

Item			RM3	MOD	RM3-1	RM3-2	RM3-3	RM3-4
1)R.M.S. for luminance			3.53	3.46	4.49	3.79	3.33	2.99
2)SNR for luminance			37.17	37.35	35.09	36.57	37.69	38.63
3)Mean value of the step size			10.34	10.01	15.33	11.53	9.38	7.95
4)Mean value of the number of non-zero coefficients			3.86	3.96	2.90	3.56	4.11	4.62
5)Mean value of the number of zeroes before the last non-zero coefficient			6.32	6.46	4.60	5.79	6.76	7.57
6) Block type of Y	Intra		43	43	43	43	43	43
	Fixed (Inter/No MC/No coded)		859	852	920	882	838	799
	Inter (Inter/No MC/Coded)		168	175	95	142	192	234
	Fixed MC (Inter/MC/No coded)		116	110	219	140	99	70
	Inter MC (Inter/MC/Coded)		396	402	305	374	410	436
	Filtered		413	409	426	418	403	396
7) Block type of C	Intra		10	10	11	10	10	10
	Fixed (Inter/No Coded)		645	640	697	659	629	600
	Inter (Inter/Coded)		136	141	83	121	152	180
	Filtered		116	121	68	100	126	143
8) Number of bits	Attributes	Y	4056	4062	4096	4043	4086	4154
		Cr	757	763	667	737	777	808
		Cb	916	923	867	907	932	952
		Total	5729	5748	5631	5688	5796	5914
	Classification indexes		1216	1242	888	1121	1293	1427
	EOBs		2264	2559	1616	2079	2429	2714
	Motion Vectors		4105	4100	4199	4125	4078	4059
	Coefficients	Y	14994	14593	7653	12559	17380	22266
		Cr	693	733	325	562	851	1146
		Cb	737	775	316	577	922	1272
		Total	16425	16102	8295	13699	19154	24685
	Total		29741	29753	20632	26715	32751	38801
Number of significant blocks			755	773	539	693	810	905
Number of quantized coefficients			7593	7972	3987	6407	8727	10950

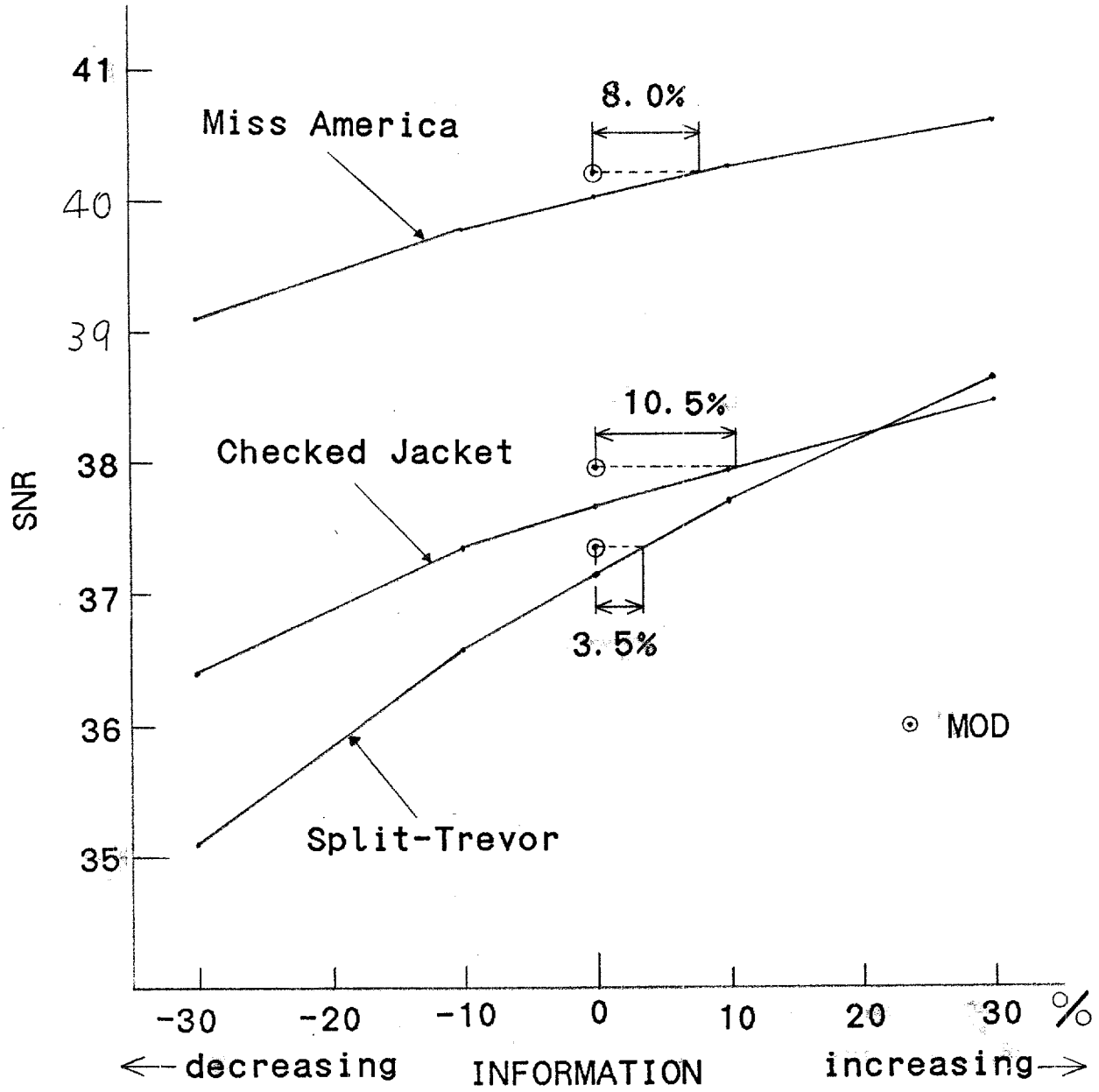

Figure 1. Bit rate versus SNR