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TERMINAL EQUIPMENTS

PULSE CODE MODULATION (PCM) OF VOICE FREQUENCIES

ITU-T Recommendation G.711

(Extract from the *Blue Book*)

NOTES

1 ITU-T Recommendation G.711 was published in Fascicle III.4 of the *Blue Book*. This file is an extract from the *Blue Book.* While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Recommendation G.711

PULSE CODE MODULATION (PCM) OF VOICE FREQUENCIES

(Geneva, 1972; further amended)

1 General

The characteristics given below are recommended for encoding voice-frequency signals.

2 Sampling rate

The nominal value recommended for the sampling rate is 8000 samples per second. The tolerance on that rate should be ± 50 parts per million (ppm).

3 Encoding law

3.1 Eight binary digits per sample should be used for international circuits.

3.2 Two encoding laws are recommended and these are commonly referred to as the A-law and the μ-law. The definition of these laws is given in Tables 1a/G.711 and 1b/G.711 and Tables 2a/G.711 and 2b/G.711 respectively.

When using the μ-law in networks where suppression of the all 0 character signal is required, the character signal corresponding to negative input values between decision values numbers 127 and 128 should be 00000010 and the value at the decoder output is -7519. The corresponding decoder output value number is 125.

3.3 The number of quantized values results from the encoding law.

3.4 Digital paths between countries which have adopted different encoding laws should carry signals encoded in accordance with the A-law. Where both countries have adopted the same law, that law should be used on digital paths between them. Any necessary conversion will be done by the countries using the μ-law.

3.5 The rules for conversion are given in Tables 3/G.711 and 4/G.711.

3.6 *Conversion to and from uniform PCM*

Every "decision value" and " quantized value" of the A (resp. μ) law should be associated with a "uniform PCM value". (For a definition of "decision value" and "quantized value", see Recommendation G.701 and in particular Figure 2/G.701). This requires the application of a 13 (14) bit uniform PCM code. The mapping from A-law PCM, and μ-law PCM, respectively, to the uniform code is given in Tables 1/G.711 and 2/G.711. The conversion to A-law or μ-law values from uniform PCM values corresponding to the decision values, is left to the individual equipment specification. One option is described in Recommendation G.721, § 4.2.8 subblock COMPRESS.

4 Transmission of character signals

When character signals are transmitted serially, i.e. consecutively on one physical medium, bit No. 1 (polarity bit) is transmitted first and No. 8 (the least significant bit) last.

5 Relationship between the encoding laws and the audio level

The relationship between the encoding laws of Tables 1/G.711 and 2/G.711 and the audio signal level is defined as follows:

A sine-wave signal of 1 kHz at a nominal level of 0 dBm0 should be present at any voice frequency output of the PCM multiplex when the periodic sequence of character signals of Table 5/G.711 for the A-law and of Table 6/G.711 for the μ-law is applied to the decoder input.

The resulting theoretical load capacity (T_{max}) is +3.14 dBm0 for the A-law, and +3.17 dBm0 for the μ-law.

Note - The use of another digital periodic sequence representing a nominal reference frequency of 1020 Hz at a nominal level of -10 dBm0 (preferred value, see Recommendation O.6) or 0 dBm0 is acceptable, provided that the theoretical accuracy of that sequence does not differ by more than ± 0.03 dB from a level of -10 dBm0 or 0 dBm0 respectively. In accordance with Recommendation O.6, the specified frequency tolerance should be 1020 Hz + 2 Hz, -7 Hz.

If a sequence representing -10 dBm0 is used, the nominal value at the voice frequency outputs should be -10 dBm0.

TABLE 1a/G.711

A-law, positive input values

1	2	3	4	5	6	7	8
Segment number	Number of intervals × interval size	Value at segment end points	Decision value number n	Decision value x_n (see Note 1)	Character signal before inversion of the even bits Bit number 1 2 3 4 5 6 7 8	Quantized value (value at decoder output) y_n	Decoder output value number
		4096	(128)	(4096)			
					1 1 1 1 1 1 1 1	4032	128
7	16 × 128		127	3968			
					(see Note 2)		
			113	2176			
					1 1 1 1 0 0 0 0	2112	113
		2048	112	2048			
6	16 × 64				(see Note 2)		
			97	1088			
					1 1 1 0 0 0 0 0	1056	97
		1024	96	1024			
5	16 × 32				(see Note 2)		
			81	544			
					1 1 0 1 0 0 0 0	528	81
		512	80	512			
4	16 × 16				(see Note 2)		
			65	272			
					1 1 0 0 0 0 0 0	264	65
		256	64	256			
3	16 × 8				(see Note 2)		
			49	136			
					1 0 1 1 0 0 0 0	132	49
		128	48	128			
2	16 × 4				(see Note 2)		
			33	68			
					1 0 1 0 0 0 0 0	66	33
		64	32	64			
1 ↓	32 × 2				(see Note 2)		
			1	2			
					1 0 0 0 0 0 0 0	1	1
			0	0			

Note 1 – 4096 normalized value units correspond to T_{max} = 3.14 dBm0.

Note 2 – The character signals are obtained by inverting the even bits of the signals of column 6. Before this inversion, the character signal corresponding to positive input values between two successive decision values numbered n and $n + 1$ (see column 4) is $(128 + n)$ expressed as a binary number

Note 3 – The value at the decoder output is $y_n = \frac{x_{n-1} + x_n}{2}$ for n = 1, ..., 127, 128.

Note 4 – x_{128} is a virtual decision value.

***Note 5* – In Tables 1/G.711 and 2/G.711 the values of the uniform code are given in columns 3, 5 and 7.**

TABLE 1b / G.711

A-law, negative input values

1	2	3	4	5	6	7	8
Segment Number	Number of intervals × interval size	Value at segment end points	Decision value number n	Decision value x_n (see Note 1)	Character signal before inversion of the even bits Bit number 1 2 3 4 5 6 7 8	**Quantized value (value at decoder output) y_n**	Decoder output value number
			0	0			
1	32 × 2		1	−2	0 0 0 0 0 0 0 0	−1	1
					(see Note 2)		
		−64	32	−64			
2	16 × 4		33	−68	0 0 1 0 0 0 0 0	−66	33
					(see Note 2)		
		−128	48	−128			
3	16 × 8		49	−136	0 0 1 1 0 0 0 0	−132	49
					(see Note 2)		
		−256	64	−256			
4	16 × 16		65	−272	0 1 0 0 0 0 0 0	−264	65
					(see Note 2)		
		−512	80	−512			
5	16 × 32		81	−544	0 1 0 1 0 0 0 0	−528	81
					(see Note 2)		
		−1024	96	−1024			
6	16 × 64		97	−1088	0 1 1 0 0 0 0 0	−1056	97
					(see Note 2)		
		−2048	112	−2048			
7	16 × 128		113	−2176	0 1 1 1 0 0 0 0	−2112	113
					(see Note 2)		
			127	−3968			
		−4096	(128)	(−4096)	0 1 1 1 1 1 1 1	−4032	128

Note 1 – 4096 normalized value units correspond to T_{max} = 3.14 dBm0.

Note 2 – The character signals are obtained by inverting the even bits of the signals of column 6. Before this inversion, the character signal corresponding to negative input values between two successive decision values numbered n and $n + 1$ (see column 4) is n expressed as a binary number.

Note 3 – The value at the decoder output is $y_n = \frac{x_{n-1} + x_n}{2}$ for n = 1, ..., 127, 128.

Note 4 – x_{128} is a virtual decision value.

Note 5 – **In Tables 1/G.711 and 2/G.711 the values of the uniform code are given in columns 3, 5 and 7.**

TABLEAU 2a / G.711

μ-law, positive input values

1	2	3	4	5	6	7	8
Segment number	Number of intervals × interval size	Value at segment end points	Decision value number n	Decision value x_n (see Note 1)	Character signal Bit number 1 2 3 4 5 6 7 8	Quantized value (value at decoder output) y_n	Decoder output value number
		8159	(128)	(8159)			
					1 0 0 0 0 0 0 0	8031	127
			127	7903			
8	16 × 256				(see Note 2)		
			113	4319			
					1 0 0 0 1 1 1 1	4191	112
		4063	112	4063			
7	16 × 128				(see Note 2)		
			97	2143			
					1 0 0 1 1 1 1 1	2079	96
		2015	96	2015			
6	16 × 64				(see Note 2)		
			81	1055			
					1 0 1 0 1 1 1 1	1023	80
		991	80	991			
5	16 × 32				(see Note 2)		
			65	511			
					1 0 1 1 1 1 1 1	495	64
		479	64	479			
4	16 × 16				(see Note 2)		
			49	239			
					1 1 0 0 1 1 1 1	231	48
		223	48	223			
3	16 × 8				(see Note 2)		
			33	103			
					1 1 0 1 1 1 1 1	99	32
		95	32	95			
2	16 × 4				(see Note 2)		
			17	35			
					1 1 1 0 1 1 1 1	33	16
		31	16	31			
	15 × 2				(see Note 2)		
			2	3			
1 ↓					1 1 1 1 1 1 1 0	2	1
			1	1			
	1 × 1				1 1 1 1 1 1 1 1	0	0
			0	0			

Note 1 – 8159 normalized value units correspond to T_{max} = 3.17 dBm0.

Note 2 – The character signal corresponding to positive input values between two successive decision values numbered n and $n + 1$ (see column 4) is $(255 - n)$ expressed as a binary number.

Note 3 – The value at the decoder output is $y_0 = x_0 = 0$ for $n = 0$, and $y_n = \frac{x_n + x_{n+1}}{2}$ for $n = 1, 2, \ldots, 127$.

Note 4 – x_{128} is a virtual decision value.

Note 5 – **In Tables 1/G.711 and 2/G.711 the values of the uniform code are given in columns 3, 5 and 7.**

TABLE 2b / G.711

μ-law, negative input values

1	2	3	4	5	6	7	8
Segment number	Number of intervals × interval size	Value at segment end points	Decision value number n	Decision value x_n (see Note 1)	Character signal Bit number 1 2 3 4 5 6 7 8	**Quantized value (value at decoder output) y_n**	Decoder output value number
1	1 × 1		0	0			
					0 1 1 1 1 1 1 1	0	0
			1	–1			
	15 × 2				0 1 1 1 1 1 1 0	–2	1
			2	–3			
					(see Note 2)		
		–31	16	–31			
2	16 × 4				0 1 1 0 1 1 1 1	–33	16
			17	–35			
					(see Note 2)		
		–95	32	–95			
3	16 × 8				0 1 0 1 1 1 1 1	–99	32
			33	–103			
					(see Note 2)		
		–223	48	–223			
4	16 × 16				0 1 0 0 1 1 1 1	–231	48
			49	–239			
					(see Note 2)		
		–479	64	–479			
5	16 × 32				0 0 1 1 1 1 1 1	–495	64
			65	–511			
					(see Note 2)		
		–991	80	–991			
6	16 × 64				0 0 1 0 1 1 1 1	–1023	80
			81	–1055			
					(see Note 2)		
		–2015	96	–2015			
7	16 × 128				0 0 0 1 1 1 1 1	–2079	96
			97	–2143			
					(see Note 2)		
		–4063	112	–4063			
8	16 × 256				0 0 0 0 1 1 1 1	–4191	112
			113	–4319			
					(see Note 2)		
			126	–7647			
					0 0 0 0 0 0 0 1	–7775	126
			127	–7903			
					0 0 0 0 0 0 0 0	–8031	127
		–8159	(128)	(–8159)			

Note 1 – 8159 normalized value units correspond to T_{max} = 3.17 dBm0.

Note 2 – The character signal corresponding to negative input values between two successive decision values numbered n and n + 1 (see column 4) is (127 – n) expressed as a binary number for n = 0, 1, ..., 127.

Note 3 – The value at the decoder output is $y_0 = x_0 = 0$ for $n = 0$, and $y_n = \frac{x_n + x_{n+1}}{2}$ for n = 1, 2, ..., 127.

Note 4 – x_{128} is a virtual decision value.

Note 5 – **In Tables 1/G.711 and 2/G.711 the values of the uniform code are given in columns 3, 5 and 7.**

TABLE 3/G.711

µ-A conversion

µ-law Decoder output value number	*A-law* Decoder output value number	*µ-law* Decoder output value number	*A-law* Decoder output value number
0	1	44	41
1	1	45	42
2	2	46	43
3	2	47	44
4	3	48	46
5	3	49	48
6	4	50	49
7	4	51	50
8	5	52	51
9	5	53	52
10	6	54	53
11	6	55	54
12	7	56	55
13	7	57	56
14	8	58	57
15	8	59	58
16	9	60	59
17	10	61	60
18	11	62	61
19	12	63	62
20	13	64	64
21	14	65	65
22	15	66	66
23	16	67	67
24	17	68	68
25	18	69	69
26	19	70	70
27	20	71	71
28	21	72	72
29	22	73	73
30	23	74	74
31	24	75	75
32	25	76	76
33	27	77	77
34	29	78	78
35	31	79	79
36	33	80	81
37	34	81	82
38	35	82	83
39	36	83	84
40	37	84	85
41	38	85	86
42	39	86	87
43	40	87	88
		.	.
		.	.
		.	.
		127	128

Notes relative to Table 3/G.711

Note 1 - The input signals to an A-law decoder will normally include even bit inversion as applied in accordance with Note 2 of Table 1a/G.711. Consequently the output signals from a µ-A converter should have even bit inversion embodied within the converter output.

Note 2 - If a μ-A conversion is followed by an A-μ conversion, most of the octets are restored to their original values. Only those octets which correspond to μ-law decoder output value numbers 0, 2, 4, 6, 8, 10, 12, 14 are changed (the numbers being increased by 1). Moreover, in these octets, only bit No. 8 (least significant bit in PCM) is changed. Accordingly, the double conversion μ-A-μ is transparent to bits Nos. 1-7.

Similarly, if an A-μ conversion is followed by a μ-A conversion, only the octets corresponding to A-law decoder output value numbers 26, 28, 30, 32, 45, 47, 63 and 80 are changed. Again, only bit No. 8 is changed, i.e. the double conversion A-μ-A, too, is transparent to bits No. 1-7.

A consequence of this property is that in most of the analogue voice frequency signal range the additional quantizing distortion caused by μ-A-μ or A-μ-A conversion is considerably lower than that caused by either μ-A or A-μ conversion (see Recommendation G.113).

The A-μ-A transparency for bits 1 to 7 was achieved by modifying the table slightly from the optimum conversion in that μ-80 is converted to A-81 instead of A-80, and A-80 is converted to μ-79 instead of μ-80. This has an insignificant effect on quantizing distortion.

TABLE 4/G.711

µ-A conversion

A-law Decoder output value number	*µ-law* Decoder output value number	*A-law* Decoder output value number	*µ-law* Decoder output value number
1	1	51	52
2	3	52	53
3	5	53	54
4	7	54	55
5	9	55	56
6	11	56	57
7	13	57	58
8	15	58	59
9	16	59	60
10	17	60	61
11	18	61	62
12	19	62	63
13	20	63	64
14	21	64	64
15	22	65	65
16	23	66	66
17	24	67	67
18	25	68	68
19	26	69	69
20	27	70	70
21	28	71	71
22	29	72	72
23	30	73	73
24	31	74	74
25	32	75	75
26	32	76	76
27	33	77	77
28	33	78	78
29	34	79	79
30	34	80	79
31	35	81	80
32	35	82	81
33	36	83	82
34	37	84	83
35	38	85	84
36	39	86	85
37	40	87	86
38	41	88	87
39	42	89	88
40	43	90	89
41	44	91	90
42	45	92	91
43	46	93	92
44	47	94	93
45	48	95	94
46	48	96	95
47	49	97	96
48	49	98	97
49	50	.	.
50	51	.	.
		.	.
		128	127

Notes relative to Table 4/G.711

Note 1 - The output signals of an A-law decoder will have even bit inversion as applied within the encoder in accordance with Note 2 of Table 1a/G.711. Consequently the input signals to an A-μ converter will already be in this state, so that removal of even bit inversion should be embodied within the converter.

Note 2 - If a μ-A conversion is followed by an A-μ conversion, most of the octets are restored to their original values. Only those octets which correspond to μ-law decoder output value numbers 0, 2, 4, 6, 8, 10, 12, 14 are changed (the numbers being increased by 1). Moreover, in these octets, only bit 8 (least significant bit in PCM) is changed. Accordingly, the double conversion μ-A-μ is transparent to bits 1 to 7.

Similarly, if an A-μ conversion is followed by a μ-A conversion, only the octets corresponding to A-law decoder output value numbers 26, 28, 30, 32, 45, 47, 63 and 80 are changed. Again, only bit 8 is changed, i.e. the double conversion A-μ-A, too, is transparent to bits 1 to 7.

A consequence of this property is that in most of the analogue voice frequency signal range the additional quantizing distortion caused by μ-A-μ or A-μ-A conversion is considerably lower than that caused by either μ-A or A-μ conversion (see Recommendation G.113).

The A-μ-A transparency for bits 1 to 7 was achieved by modifying the table slightly from the optimum conversion in that μ-80 is converted to A-81 instead of A-80, and A-80 is converted to μ-79 instead of μ-80. This has an insignificant effect on quantizing distortion.

TABLE 5/G.711

A-law							
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	1
0	0	1	0	0	0	0	1
0	0	1	1	0	1	0	0
1	0	1	1	0	1	0	0
1	0	1	0	0	0	0	1
1	0	1	0	0	0	0	1
1	0	1	1	0	1	0	0

TABLE 6/G.711

μ-law							
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0	0	0	1	1	1	1	0
0	0	0	0	1	0	1	1
0	0	0	0	1	0	1	1
0	0	0	1	1	1	1	0
1	0	0	1	1	1	1	0
1	0	0	0	1	0	1	1
1	0	0	0	1	0	1	1
1	0	0	1	1	1	1	0