International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.711

Amendment 2

(11/2009)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital terminal equipments – Coding of voice and audio signals

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Pulse code modulation (PCM) of voice frequencies

Amendment 2: New Appendix III – Audio quality enhancement toolbox

Recommendation ITU-T G.711 (1988) – Amendment 2

ITU-T

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Recommendation ITU-T G.711

Pulse code modulation (PCM) of voice frequencies

Amendment 2

New Appendix III – Audio quality enhancement toolbox

Summary

Appendix III to ITU-T Recommendation G.711 describes a toolbox to provide audio quality enhancements to ITU-T G.711. The toolbox comprises four tools that are algorithms initially developed in the context of ITU-T G.711.1 wideband speech and audio codec.

The four tools aim at enhancing the quality of ITU-T G.711 legacy for both encoder and decoder sides. At the encoder side is a noise shaping tool which is used in combination with a modified ITU-T G.711 encoder to perceptually shape the coding noise of the PCM encoder and produce a compatible bit stream. At the decoder, the three tools offer an improved audio quality and/or a better robustness against packet losses. The first tool is a noise gate which is used to increase the clearness of the audio signal during quasi-silent periods. The second tool is a postfilter which reduces the PCM quantization noise of legacy ITU-T G.711. The third is a frame erasure concealment algorithm which is used to extrapolate the signal in case of erased frames. The toolbox has been tested with a frame size of 5 ms. The overall complexity of the toolbox is about 4 WMOPS.

All of these tools can be used separately or in combination.

This appendix contains an electronic attachment containing the respective ANSI-C source code.

Source

Amendment 2 to Recommendation ITU-T G.711 (1988) was agreed on 6 November 2009 by ITU-T Study Group 16 (2009-2012).

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Electronic attachment: ANSI-C source code.

Recommendation ITU-T G.711

Pulse code modulation (PCM) of voice frequencies

Amendment 2

New Appendix III – Audio quality enhancement toolbox[1]

III.1 Scope

This appendix contains the description of a toolbox to provide audio quality enhancements to the legacy ITU-T G.711 codec.

This appendix is organized as follows. The references, definitions, abbreviations and acronyms, and conventions used throughout this appendix are defined in clauses III.2, III.3, III.4, and III.5, respectively. Clause III.6 gives a general outline of the four algorithms. The noise shaping (NS) is discussed in clause III.7.1. The frame erasure concealment (FERC) is presented in clause III.8.1. The noise gate (NG) and the postfilter (PF) are described in clauses III.8.2 and III.8.3, respectively. Clause III.9 describes the software that defines this toolbox in 16-32-bit fixed-point arithmetic.

III.2 References

– ITU-T Recommendation G.191 (2005), *Software tools for speech and audio coding standardization*.

– ITU-T Recommendation G.192 (1996), *A common digital parallel interface for speech standardization activities*.

– ITU-T Recommendation G.711.1 (2008), *Wideband embedded extension for G.711 pulse code modulation*.

III.3 Definitions

This clause is intentionally left blank.

III.4 Abbreviations and acronyms

This appendix uses the abbreviations and acronyms listed in Table III.1.

Table III.1 – Glossary of abbreviations and acronyms

Acronym	Description
FERC	Frame Erasure Concealment
NB	Narrow-Band
NG	Noise Gate
NS	Noise Shaping
PCM	Pulse Code Modulation
PF	PostFilter
WMOPS	Weighted Millions of Operations Per Second

[1] This appendix includes an electronic attachment containing the respective ANSI-C source code.

III.5 Conventions

Time-domain signals are denoted by their symbol and a sample index between parentheses, e.g., $s(n)$. The variable n is used as sample index.

Table III.2 lists the most relevant symbols used throughout this appendix.

Table III.2 – Glossary of most relevant symbols

Type	Name	Description
Filters	$F(z)$	Perceptual weighting filter
Signals	$s_{NB}(n)$	Input signal
	$s_{LB}(n)$	Pre-processed input signal
	$s'_{LB}(n)$	Perceptually weighted target signal
	$d_{L0}(n)$	Difference signal of $s_{LB}(n)$ and $s'_{LB}(n)$
	$s'_{L0}(n)$	Decoded signal of ITU-T G.711 bit stream, without offset c_{Loff}
	$\hat{s}_{L0}(n)$	Decoded signal of ITU-T G.711
	$\hat{s}_{LB1}(n)$	Signal after decoding and FERC
	$\hat{s}_{LB}(n)$	Signal after postfilter
	$\hat{s}_{NB}(n)$	Signal after noise gate
Parameters	c_{Loff}	Encoder offset value
	a_i	LP coefficient of the perceptual filter
	I_{L0}	ITU-T G.711 compatible bit stream

III.6 General description of the toolbox

This toolbox contains four algorithms for audio quality enhancement of the legacy ITU-T G.711. The noise shaping (NS) is applied only in the encoder, the frame erasure concealment (FERC), the noise gate (NG) and the postfilter (PF) are applied only in the decoder. These algorithms have been extracted from ITU-T G.711.1 scalable coder/decoder and can be used with ITU-T G.711 legacy coder/decoder. The tools may be used separately or in combination. This toolbox is implemented in fixed point using basic operators version 2.2 defined in the ITU-T G.191 software tool library. This appendix provides a detailed description of all four algorithms.

III.6.1 Tools for ITU-T G.711 encoder

Only one tool is applied in the encoder: the noise shaping (NS) tool. Figure III.1 shows the high-level block diagram of an ITU-T G.711 encoder with the NS tool. Figure III.1 is described in detail in clause III.7.

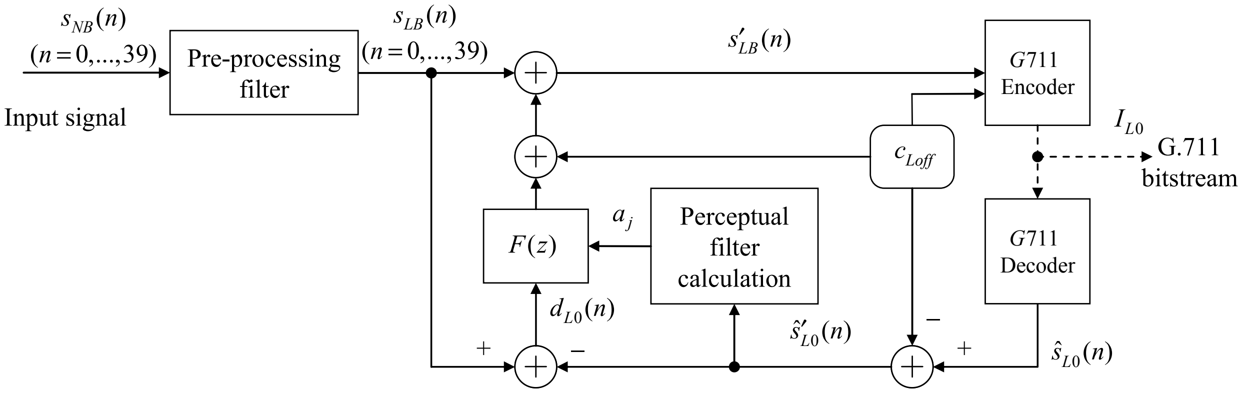

Figure III.1 – High-level block diagram of the noise shaping tool

III.6.2 Tools for ITU-T G.711 decoder

Figure III.2 shows a high-level block diagram of an ITU-T G.711 decoder combined with three tools: the frame erasure concealment (FERC), the noise gate (NG) and the postfilter (PF). This figure illustrates the recommended execution order of the tools when they are combined.

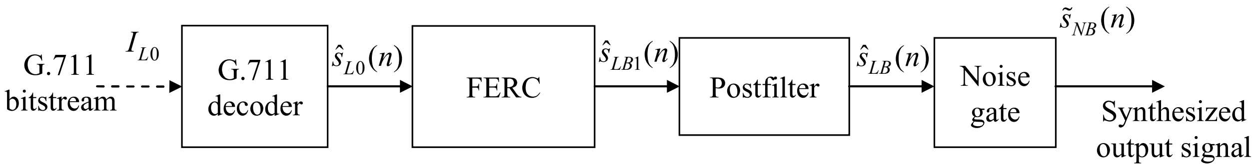

Figure III.2 – High-level block diagram of decoder toolbox

III.6.3 Algorithmic delay

Table III.3 gives the algorithmic delay of each tool and the algorithmic delay for the combination of the three tools at the decoder side. Note that these algorithmic delays are given for 5 ms frame size.

Table III.3 – Algorithmic delay of the toolbox (ms)

NS	NG	PF	FERC	FERC+PF+NG
0	0	2	5	5

III.6.4 Computational complexity and storage requirements

The observed worst-case complexity of the toolbox is based on the implementation with basic operators of the ITU-T software tool library STL2005 v2.2 in ITU-T G.191. The worst computational complexity is detailed in Table III.4, and all the figures show the observed worst complexity either in µ-law or A-law. The storage requirements in 16-bit words for the four tools are given in Tables III.5. Note that the RAM figures are based on the arrays which form the dominant part, but not on singular variables. It was found that the number of such variables was insignificant when compared with size required by arrays.

Table III.4 – Worst computational complexity of the toolbox [WMOPS]

NS	NG	PF	FERC	FERC+PF+NG
0.87	0.23	2.02	2.05	3.31

Table III.5 – Storage requirements of the toolbox

Memory type	NS	NG	PF	FERC
Static RAM (kWords)	0.093	0.003	0.353	0.984
Scratch RAM (kWords)	0.107	0.012	0.529	0.314
Data ROM (kWords)	0.088	0	0.191	0.121
Program ROM (number of basic ops)	191	37	593	728

III.6.5 Toolbox description

The description of the toolbox algorithms is made in terms of bit-exact fixed-point mathematical operations. The ANSI-C code indicated in clause III.9, which constitutes an integral part of this appendix, reflects this bit-exact, fixed-point descriptive approach. The mathematical descriptions of the encoder and decoder can be implemented in other fashions, possibly leading to a codec implementation not complying with this appendix. Therefore, the algorithm description of the ANSI-code of clause III.9 shall take precedence over the mathematical descriptions whenever discrepancies are found.

III.7 Functional description of the toolbox for the encoder

III.7.1 Noise shaping (NS) tool

The input signal $s_{NB}(n)$ is encoded using µ-law or A-law pulse code modulation (PCM) with noise feedback to perceptually shape the coding noise of the PCM encoder. The encoder with weighted noise feedback loop is shown in Figure III.1. First, the input signal $s_{NB}(n)$ is pre-processed by a high-pass filter with a cut-off frequency of 50 Hz. Then, the pre-processed signal $s_{LB}(n)$ is added to a noise feedback signal and the offset value c_{Loff}, and the resulting signal $s'_{LB}(n)$ is fed to the legacy ITU-T G.711 encoder. Based on the obtained bit stream I_{L0}(n) the legacy ITU-T G.711 decoder locally decodes the signal $\hat{s}_{L0}(n)$ and the offset value c_{Loff} is removed to obtain $\hat{s}'_{L0}(n)$. An LP analysis is then performed on $\hat{s}'_{L0}(n)$ to obtain the coefficients a_i, and the perceptual filter $F(z)$ is calculated. Then the quantization noise $d_{L0}(n)$, filtered by $F(z)$, is fed back to be added to the input signal $\mathrm{s}_{LB}(n)$. It should be noted that for very low energy signals, the legacy ITU-T G.711 encoding, based on log-PCM, is replaced by a different encoding scheme called "dead-zone quantizer". This is described later in clause III.7.1.4.

III.7.1.1 Pre-processing high-pass filter

Same as clause 7.1 of ITU-T G.711.1.

III.7.1.2 PCM encoder based on G.711

Same as clause 7.3.1 of ITU-T G.711.1.

III.7.1.3 Perceptual filtering

Same as clause 7.3.2 of ITU-T G.711.1.

III.7.1.4 Dead-zone quantizer

Same as clause 7.3.3 of ITU-T G.711.1.

III.8 Functional description of the toolbox for the decoder

The toolbox includes three tools at the decoder side. All these tools can be used either in combination or alone. Figure III.2 describes the tool position in the processing chain. The algorithmic descriptions of the tools are given in the following clauses.

III.8.1 Narrow-band frame erasure concealment (FERC)

Same as clause 8.4 of ITU-T G.711.1.

III.8.2 Noise gate (NG)

Same as clause 8.7 of ITU-T G.711.1.

III.8.3 Postfilter (PF)

Same as Appendix I of ITU-T G.711.1.

III.9 Bit-exact description of the audio quality enhancement toolbox for ITU-T G.711

The ANSI-C code simulating the audio quality enhancement toolbox in 16-bit fixed-point is available as an electronic attachment to this appendix. The following subclauses summarize the use of this simulation code, and how the software is organized.

III.9.1 Use of the simulation software

The C code consists of two main programs, `encoder.c` and `decoder.c` which simulate the toolbox for encoder and decoder, respectively.

The command line for the encoder is as follows:

encoder [-options] <law> <infile> <codefile>

where

law	is the desired ITU-T G.711 law (A or μ)
infile	is the name of the input file to be encoded
codefile	is the name of the output bit stream file
options:	
-ns	indicates that noise shaping tool is activated
-hardbit	output bit stream file is in multiplexed hardbit format
-quiet	quiet processing

The command line for the decoder is as follows:

decoder [-options] <law> <codefile> <outfile>

where

law	is the desired ITU-T G.711 law (A or μ)
codefile	is the name of the input bit stream file
outfile	is the name of the decoded output file
options:	
-ng	indicates that noise gate tool is activated
-pf	indicates that postfilter tool is activated
-ferc	indicates that frame erasure concealment tool is activated
-hardbit	input bit stream file is in multiplexed hardbit format
-quiet	quiet processing

The encoder input and the decoder output files are sampled data files containing 16-bit PCM signals. The encoder output and decoder input files follow the ITU-T G.192 bit stream format by default. The frame erasure can only be simulated with the ITU-T G.192 bit stream format.

III.9.2 Organization of the simulation software

Tables III.6 to III.9 describe the organization of the simulation software.

Table III.6 – Tables in C-code

Table name	Symbol	Size	Form at	Description
NS_window	$w_{LP1}(i)$	80	Q15	LPC analysis window for noise shaping
NS_lag_h	$w_{lag}(i)$	4	Q15	Lag windowing for noise shaping (MSB of double precision format)
NS_lag_l		4	Q16	Lag windowing for noise shaping (LSB of double precision format)
LBFEC_lag_h	$w_{lag}^{FERC}(i)$	16	Q15	Lag windowing for FERC (MSB and LSB of double precision format)
LBFEC_lag_l		16	Q16	Lag windowing for FERC (LSB of double precision format)
LBFEC_lpc_win_80	$w_{LP2}(i)$	80	Q15	LPC analysis window for FERC
LBFEC_fir_lp	$H_{dec}(z)$	9	Q16	FIR decimation filter coefficients in FERC
max_err_quant	$d'_{\max}(j)$	16	Q0	A-law quantization step size
Hann_sh16	$w_a(n)$	64	Q15	Asymmetric Hanning window (for 64-point FFT processing)
Hann_sh16_p6	$\gamma_w(n)$	7	Q15	Half of 16-point Hanning window for filter interpolation
Hann_sh16_p6m1	$1-\gamma_w(n)$	7	Q15	Complementary half of Hanning window for filter interpolation
WinFilt	$Wt_p(n)$	17	Q15	Truncating window for impulse response of noise reduction filter

Table III.7 – Summary of specific routines for encoder toolbox

Filename	Description
encoder.c	ITU-T G.711 toolbox encoder interface
G711Appenc.c	ITU-T G.711 toolbox main encoder
prehpf.c	High-pass pre-filter
lowband_enc.c	Encoder toolbox

Table III.8 – Summary of specific routines for decoder toolbox

Filename	Description
decoder.c	ITU-T G.711 toolbox decoder interface
g711Appdec.c	ITU-T G.711 toolbox main decoder
fec_lowband.c	Frame erasure concealment (FERC)
lowband_dec.c	Decoder toolbox
post.c	Main routine that calls all post-processing subroutines
post_anasyn.c	Analysis/synthesis subroutines for post-processing
post_gainfct.c	Subroutines for estimating of the post-processing filter
post_rfft.c	64-point real FFT and ifft
table_post.c	Tables for postfilter

Table III.9 – Summary of common routines

Filename	Description
softbit.c	Conversion between hardbit and softbit
autocorr_ns.c	Autocorrelation of signal for noise shaping
g711a.c	PCM coder and decoder (A-law)
g711mu.c	PCM coder and decoder (μ-law)
lpctools.c	Linear prediction tools
table_lowband.c	Tables for lower-band modules
dsputil.c	Fixed-point utility routines
errexit.c	Exit routine
mathtool.c	Square-root routines
oper_32b.c	Basic operators in double precision (32 bits)
table_mathtool.c	Tables for square-root routines

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