Log-Polar Quantizer with the Embedded ITU-T G.711 Codec

Milan R. DINCIC, Zoran H. PERIC

Faculty of Electronic Engineering, University of Nis, Aleksandra Medvedeva 14, 18000 Nis, Serbia

mdincha@hotmail.com, zoran.peric@elfak.ni.ac.rs

Abstract. *In this paper a new two-dimensional vector quantizer for memoryless Gaussian source, realized in polar coordinates, is proposed. The G.711 codec is embedded in our vector quantizer, and therefore our vector quantizer is compatible with the G.711 codec. It is simple for realization and it has much better performances, compared to the G.711 codec, such as much higher SQNR (signal-to-quantization noise ratio) for the same bit-rate, or bit-rate decrease for the same SQNR. The G.711 codec is widely used in many systems, especially in PSTN (public switched telephone network). Due to compatibility with the G.711 standard, our vector quantizer can be realized with simple software modification of the existing the G.711 codec, and therefore it can be very easily implemented in PSTN and other systems. So, small investments are needed for wide implementation of our model, but significant improvement of performances can be obtained.*

Keywords

The G.711 standard, two-dimensional quantizer, polar coordinates, compatibility.

1. Introduction

Quantization is the main step in the analog-to-digital conversion process and it is very important in all modern telecommunication systems. With good choice of quantizer signal quality improvement and bit-rate decrease can be achieved. One of the most popular quantizers is scalar logarithmic μ-law quantizer, with $\mu = 255$, defined with the G.711 standard [1], [2], [3]. It is widely used in many systems, especially in PSTN (public switched telephone network). Because of that, compatibility with the G.711 standard is very important, and it is required for many new models and standards. For example, new G.711.1 standard is compatible with the G.711 standard, [4] – [8]. Model proposed in [9] is also compatible with the G.711 standard.

Vector quantization gives better performances compared to scalar quantizers, since they have a higher degree of freedom for choosing the reconstruction values and the decision regions. But, the price for these increased performances is an increase in computational complexity. Two-dimensional vector quantizers are the simplest vector quantizers. One class of two-dimensional quantizers are polar quantizers [10], [11], [12], which are used very often, especially for circularly symmetric sources.

In this paper a new two-dimensional polar vector quantizer is proposed. It is developed for memoryless Gaussian source and realized in polar coordinates (r,Φ), where r denotes amplitude (radius) and Φ denotes phase. For quantization of amplitude r we use logarithmic μ -law companding quantizer with $\mu = 255$, which is defined with the G.711 standard. This means that the scalar G.711 quantizer is embedded in our vector quantizer and therefore our vector quantizer is compatible with the G.711 standard. So, our log-polar quantizer can be obtained by simple software modification of the existing scalar G.711 quantizers, and small investments are needed to achieve wide implementation of the log-polar quantizers in PSTN and other systems. For quantization of phase Φ uniform quantizer is used and number of phase levels is the same on each amplitude level (it is known as product (or strict) polar quantization). Because of that, our vector quantizer is very simple for realization. Since it is realized in polar coordinates and since logarithmic compression law is used for amplitude quantization, our vector quantizer will be called “the log-polar quantizer”.

It is shown in this paper that our log-polar quantizer gives much better performances compared to the scalar μ-law companding quantizer defined with the G.711 standard:

- it has constant *SQNR* in much wider range of the input variances;
- for the same bit-rate it gives for 2.51 dB higher maximal *SQNR* and for 3.72 dB higher the average *SQNR* (averaging is done in the wide range of input variances (-25 dB, 20 dB) in relation to the referent input variance);
- it can achieve the same average *SQNR* with bit-rate decrease of 0.5 bits/sample;
- it can satisfy the G.712 standard [13] with bit-rate decrease of 1 bits/sample.

So, we can summarize that our log-polar quantizer is simple for realization, compatible with the quantizer defined with the G.711 standard but it has much better performances. So, with small investments, a significant improvement of performances can be achieved.

The simulation of the log-polar quantizer is done using MATLAB. Also, an experiment is done using a real speech signal. The obtained simulation and experimental results are almost identical with theoretical results.

In the paper [14], the problem of the spherical logarithmic quantization (which for two-dimensional case becomes log-polar quantization) was considered. But, this solution is not compatible with the G.711 standard and it is more complex than our solution. In this paper we give an analysis of *SQNR* in the wide range of input variances, which is not given in [14].

In the paper [15], the design of the embedded polar quantizers was presented. It was shown in [15] that product (i.e. strict) polar quantizers are more suitable for construction of embedded polar quantizers, compared to the unrestricted polar quantizers (where the number of phase levels is not the same on different amplitude levels), since polar quantizers give smaller excess distortion. Since our polar quantizer is product, it can be used for construction of embedded polar quantizer.

This paper is organized in the following way. The new two-dimensional log-polar quantizer is described in Section 2. In Section 3 performances (distortion, *SQNR*, the bit-rate) of the log-polar quantizer are analyzed. In Section 4 we give numerical results obtained by theory and by simulation, for the log-polar quantizer. Also, the comparison with the scalar quantizer defined with the G.711 standard is done in Section 4. Section 5 concludes the paper.

2. Description of the Log-polar Quantizer

The design of the two-dimensional vector quantizer will be done in polar coordinates (r,Φ), where r denotes amplitude (radius) and Φ denotes phase of the point in the two-dimensional plane. Polar coordinates are connected with Cartesian coordinates (x_1, x_2) with expressions $x_1 = r\cos\Phi$ and $x_2 = r\sin\Phi$.

We assume that input signal has Gaussian distribution with zero mean value and with variance denoted with σ^2. Assuming that two consecutive input samples x_1 and x_2 are mutually independent, the joined pdf can be expressed as $f(x_1, x_2) = f(x_1) f(x_2) = 1/(2\pi\sigma^2)\exp[-(x_1^2 + x_2^2)/(2\sigma^2)]$. The joined pdf in the polar coordinates are given with $f(r, \Phi) = r/(2\pi\sigma^2)\exp[-r^2/(2\sigma^2)]$. Pdf for r coordinate is $f(r) = r/(\sigma^2)\exp[-r^2/(2\sigma^2)]$. ($r$ coordinate has Rayleigh distribution). Pdf for Φ coordinate is $f(\Phi) = 1/(2\pi)$, (phase Φ has uniform distribution, i.e., two-dimensional signal source is circularly-symmetric).

The two-dimensional quantizer will be done in the following way. r coordinate will be quantized using the logarithmic companding quantizer with μ compression law, $\mu = 255$, with L levels, whose compression function $g(r)$: $(0, r_{max}) \to (0, r_{max})$ is

$$g(r) = \frac{r_{\max}}{\ln(\mu+1)}\ln\left(1+\mu\frac{r}{r_{\max}}\right) \tag{1}$$

where r_{max} denotes the maximal amplitude of this quantizer. This quantizer is defined with the G.711 standard, and therefore our two-dimensional quantizer is compatible with the G.711 codec. Thresholds for this quantizer are denoted with $0 = r_0 < r_1 <\ldots< r_L = r_{max}$ and representational levels with $m_1 < m_2 <\ldots< m_L$, and it is valid that $m_i \in (r_{i-1}, r_i)$. Solving the equations $g(r_i) = ir_{max}/L$, $i = 0,\ldots, L$ and $g(m_i) = (i - ½)\, r_{max}/L$, $i = 1, \ldots, L$ we obtain the expressions for thresholds $r_i = r_{max}/\mu\, [(\mu + 1)^{i/L} - 1]$, $i = 0, \ldots, L$ and for representation levels $m_i = r_{max}/\mu\, [(\mu + 1)^{(i - ½)/L} - 1]$, $i = 1, \ldots, L$.

On each amplitude level we use the uniform quantizer with M levels for the quantization of the phase Φ. Using uniform quantization of the phase, it means that our two-dimensional quantizer is simple for realization. Phase thresholds on each amplitude level are given with $\Phi_j = j2\pi/M$, $j = 0, \ldots, M$ and phase representation levels are given with $\Psi_j = (j - ½)\, 2\pi/M$, $j = 1, \ldots, M$.

So, the two-dimensional log-polar quantizer has $N = LM$ cells. Some arbitrary cell (i, j), $i = 0,\ldots,L$; $j = 1,\ldots, M$ is placed between amplitude thresholds r_{i-1} and r_i and between phase thresholds Φ_{j-1} and Φ_j. Within this cell there is one representation point (m_i, Ψ_j). Since polar coordinates are used for the design of the two-dimensional quantizer and since logarithmic μ compression law is used for the r coordinate, our two-dimensional quantizer will be called *the log-polar quantizer.*

3. Performances of the Log-polar Quantizer

During the quantization process, an irreversible error is made. This error can be measured by distortion. The total distortion D is the sum of the granular distortion D_g (when $0 \le r \le r_{max}$) and the overload distortion D_{ov} (when $r > r_{max}$). D, D_g and D_{ov} depend on r_{max} and σ, so it can be written that

$$D(r_{\max},\sigma) = D_g(r_{\max},\sigma) + D_{ov}(r_{\max},\sigma)\,. \tag{2}$$

It should be mentioned that D, D_g and D_{ov} are distortions per dimension. It is common for vector quantization to use distortion per dimension, since in that way it is easy to compare distortions of vector quantizers with different dimensions.

It was proved in [10] that $D_g = D_{g1} + D_{g2}$ where

$$D_{g1} = \frac{1}{2}\sum_{i=1}^{L}\int_{r_{i-1}}^{r_i}(r-m_i)^2 f(r)dr\,, \tag{3}$$

$$D_{g2} = \frac{1}{2}\sum_{i=1}^{L}\int_{r_{i-1}}^{r_i} \frac{rm_i\pi^2}{3M^2} f(r)dr \cdot \qquad (4)$$

The article ½ on the beginning of the previous expressions means distortions per dimension. Since the logarithmic μ-law companding quantizer for the r coordinate has a large number of levels, the following approximations can be used:

$$f(r) = f(m_i) \text{ for } r_{i-1} \le r < r_i, \qquad (5)$$

$$r_{i-1} = m_i - \Delta r_i / 2 \,;\; r_i = m_i + \Delta r_i / 2, \qquad (6)$$

$$m_i = (r_i + r_{i-1})/2 \qquad (7)$$

where $\Delta r_i = r_i - r_{i-1}$. Using approximations (5) and (6), it is obtained:

$$D_{g1} = \frac{1}{2}\sum_{i=1}^{L} f(m_i)\int_{-\Delta r_i/2}^{\Delta r_i/2} t^2 dt = \frac{1}{2}\sum_{i=1}^{L}\frac{\Delta r_i^2}{12} f(m_i)\Delta r_i \,. \qquad (8)$$

Now, we should find Δr_i. For the companding quantizer with a large number of levels it is valid that $g'(m_i) = \Delta/\Delta r_i$, where $\Delta = r_{\max}/L$. It follows that $\Delta r_i = r_{\max}/(Lg'(m_i))$. For $g(r)$ given with (1), it is valid that $g'(r) = \mu/[\ln(\mu+1)(1+\mu r/r_{\max})]$. Therefore, we have that $\Delta r_i = [\ln(\mu+1)/L]\, m_i\,[1 + r_{\max}/(\mu m_i)]$. Changing this in (8), we obtain

$$D_{g1} = \frac{\ln^2(\mu+1)}{24L^2}\sum_{i=1}^{L} m_i^2\left(1+\frac{r_{\max}}{\mu m_i}\right)^2 f(m_i)\Delta r_i \cdot$$

For the large number of the amplitude levels L, summation can be changed with integration and it is valid that $\Delta r_i \approx dr$. Therefore, it is obtained that

$$D_{g1} = \frac{\ln^2(\mu+1)}{24L^2}\int_0^{r_{\max}} r^2\left(1+\frac{r_{\max}}{\mu r}\right)^2 f(r)dr \cdot$$

After integration, the following expression for D_{g1} is obtained:

$$D_{g1} = \sigma^2\frac{\ln^2(\mu+1)}{12L^2\mu^2}\left[\frac{r_{\max}^2}{2\sigma^2} + \mu\sqrt{\pi}\frac{r_{\max}}{\sqrt{2}\sigma}\operatorname{Erf}\left(\frac{r_{\max}}{\sqrt{2}\sigma}\right) + \mu^2 - e^{-\frac{r_{\max}^2}{2\sigma^2}}\left(\frac{r_{\max}^2}{2\sigma^2}(1+\mu)^2 + \mu^2\right)\left(\frac{r_{\max}}{\sqrt{2}\sigma}\right)\right]. \qquad (9)$$

Starting with the expression (4), and using approximation (5), we obtain:

$$D_{g2} = \frac{\pi^2}{6M^2}\sum_{i=1}^{L} m_i f(m_i)\int_{r_{i-1}}^{r_i} rdr = \frac{\pi^2}{6M^2}\sum_{i=1}^{L} m_i f(m_i)\frac{(r_i + r_{i-1})(r_i - r_{i-1})}{2}. \qquad (10)$$

Using approximation (7) and knowing that $\Delta r_i = r_i - r_{i-1}$, we have that

$$D_{g2} = \frac{\pi^2}{6M^2}\sum_{i=1}^{L} m_i^2 f(m_i)\Delta r_i \cdot$$

Changing summation with integration, it is obtained that

$$D_{g2} = \frac{\pi^2}{6M^2}\int_0^{r_{\max}} r^2 f(r)dr \cdot \qquad (11)$$

After the integration, the following expression for D_{g2} is obtained:

$$D_{g2} = \sigma^2\frac{\pi^2}{3M^2}\left[1 - \left(1+\frac{r_{\max}^2}{2\sigma^2}\right)e^{-\frac{r_{\max}^2}{2\sigma^2}}\right]. \qquad (12)$$

When $r > r_{\max}$, the amplitude r is mapped to m_L. In that way the overload distortion D_{ov} is made. Using the procedure applied for the granular distortion in [10], it is obtained that

$$D_{ov} = \frac{1}{2}\int_{r_{\max}}^{+\infty}\left[(r-m_L)^2 + \frac{rm_L\pi^2}{3M^2}\right] f(r)dr \cdot$$

For large L, approximation $m_L \approx r_{\max}$ is valid. Applying this, after the integration, the following expression is obtained:

$$D_{ov} = \frac{\sigma^2}{6M^2}\left[2e^{-\frac{r_{\max}^2}{2\sigma^2}}\left(\pi^2\frac{r_{\max}^2}{2\sigma^2} + 3M^2\right) + \sqrt{\pi}\left(-6M^2 + \pi^2\right)\frac{r_{\max}}{\sqrt{2}\sigma}\operatorname{Erf}\left(\frac{r_{\max}}{\sqrt{2}\sigma}\right)\right]. \qquad (13)$$

The total distortion D is equal to the sum of the expressions (9), (12) and (13). $SQNR$ is defined as

$$SQNR = 10\log_{10}(\sigma^2/D) \text{ [dB]}. \qquad (14)$$

The design of quantizers is done for one referent input variance, denoted with σ_0^2. The maximal amplitude range of the quantizer $r_{\max}$, is proportional to σ_0, i.e. $r_{\max} = \alpha\sigma_0$. The values for the parameter α and referent variance σ_0^2 will be defined in Section 4.

The bit-rate of the log-polar quantizer, denoted with $R^{\log\text{-}pol}$, is defined as:

$$R^{\log-pol} = \frac{1}{2}\log_2 N = \frac{1}{2}\log_2 LM \text{ [bits/sample]}. \qquad (15)$$

Simplified expressions for the signals with moderate amplitude. For these signals it is valid that $\mu r \gg r_{\max}$ and $r < r_{\max}$. The overload distortion can be neglected, which means that the total distortion is equal to the granular distortion, i.e. $D = D_g = D_{g1} + D_{g2}$. We will see that the expression for the distortion can be significantly simplified. Due to approximation $\mu r \gg r_{\max}$, it is valid that $g'(r) = [r_{\max}/\ln(\mu+1)]/r$. Since $\Delta r_i = r_{\max}/[L\, g'(m_i)]$, we have that $\Delta r_i = [\ln(\mu+1)/L]\, m_i$. Based on (8) it follows that

$$D_{g1} = \frac{\ln^2(\mu+1)}{24L^2}\sum_{i=1}^{L} m_i^2 f(m_i)\Delta r_i \,.$$

Changing summation with integration, it is obtained that

$$D_{g1} = \frac{\ln^2(\mu+1)}{24L^2}\int_0^{r_{\max}} r^2 f(r)dr \cdot$$

For moderate signals it is valid

$$\int_0^{r_{\max}} r^2 f(r)dr = 2\sigma^2 . \tag{16}$$

Using this, it is obtained that $D_{g1} = \sigma^2 \ln^2(\mu + 1) /(12 L^2)$. Based on (11), and using (16), it is obtained that $D_{g2} = \sigma^2 \pi^2 /(3 M^2)$. Finally, the total distortion is equal to

$$D = D_{g1} + D_{g2} = \sigma^2 \left[\frac{\ln^2(\mu+1)}{12L^2} + \frac{\pi^2}{3M^2} \right].$$

SQNR is given with the following expression:

$$SQNR[\mathrm{dB}] = -10\log_{10}\left(\frac{\ln^2(\mu+1)}{12L^2} + \frac{\pi^2}{3M^2} \right). \tag{17}$$

From (17) we can see that *SQNR* is constant in the range of the moderate signals since it does not depend on the input variance σ^2.

4. Numerical Results and Comparison between the Log-polar and the Scalar G.711 Quantizer

Simulation. The simulation of the log-polar quantizer is done in MATLAB. As an input signal, we use the random variable with Gaussian distribution, with zero mean value and variance $\sigma^2 = 1$, which has 160000 samples and which is generated using MATLAB function:

```
x = random('Normal',0,1,1,160000).
```

In Tab. 1 numerical results are given for three log-polar quantizers. We give *SQNR* obtained by theory, for $\sigma^2 = 1$. Also, we give *SQNR* obtained by simulation. We can see that theoretical and simulation results are almost identical (the maximal difference is only 0.023 dB), which proves the theory developed in Sections 2 and 3.

L	M	SQNR[dB] theory	SQNR[dB] simulation	SQNR[dB] experiment
256	256	40.1595	40.1749	40.2802
256	128	36.0732	36.0864	36.1157
128	128	34.1389	34.1626	34.2403

Tab. 1. *SQNR* [dB] for three log-polar quantizers, obtained by theory and by simulation.

Experiment. Now, we will apply the log-polar quantizer on the real speech signal (sampling rate is 8 kHz, the signal consists of 320000 speech samples). To do this, we form small frames of length $F = 40$ speech samples. Samples within one frame are denoted with $x_1,\ldots, x_F$. Then, two-dimensional vectors are formed in the following way: two samples x_i and $x_{F/2+i}$, $i = 1,\ldots, F/2$ are joined into one two-dimensional vector. So, we join two samples separated for $F/2$ samples, instead of joining two consecutive samples. This is done to eliminate correlation between consecutive samples. Since our two-dimensional model should be compatible with the G.711 standard (which was developed for one-dimensional quantization) uncorrelated samples should be used. So, if we want compatibility with the G.711 standard, correlation should be eliminated. Because of that, our model is developed for uncorrelated samples. Forming the frames, a small delay of $\tau = 5$ ms is produced (for sampling rate of 8 kHz), but this delay is almost negligible since an allowed delay for the speech signal is 150 ms, according to the ITU G.114 recommendation.

Values of *SQNR* obtained by experiment are presented in Tab. 1. We can see that these values are very close to the values obtained by theory and by simulation. In that way, correctness of our model is proved.

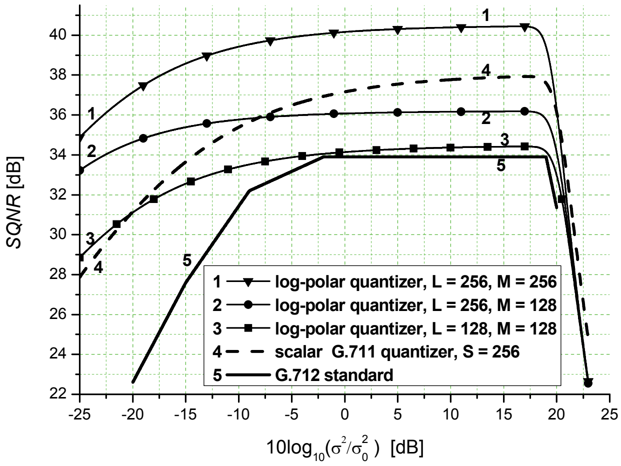

Fig. 1. *SQNR* in the wide range of the input variance.

Numerical results obtained by theory, for the wide range of input variances. We can define the relative input variance $10 \log_{10}(\sigma^2/\sigma_0^2)$ as the logarithmic ratio of the input variance σ^2 and the referent variance σ_0^2. Without losing of generality we can choose that the referent variance is $\sigma^2 = 1$. In Fig. 1, the dependence of *SQNR* on the relative input variance is presented. The scalar quantizer defined with the G.711 standard will be called *the scalar G.711 quantizer*. We have five lines in Fig. 1. Line 5 defines the G.712 standard [13]. Line 4 represents *SQNR* for "the scalar G.711 quantizer". Lines 1, 2 and 3 represent *SQNR* for the two-dimensional log-polar quantizer, for different values of the parameters *L* and *M*. Parameter α for the log-polar quantizer is chosen in the way that all four lines (1, 2, 3 and 4) start to decrease, due to the overload distortion, in the same relative input variance $10 \log_{10}(\sigma^2/\sigma_0^2) = 17$ dB. In that way comparison of these lines will be simplified. Using this condition, we obtain that $\alpha = 35$. We can see from Fig. 1 that lines 1, 2, 3 and 4 are above the line 5, which means that all these quantizers satisfy the G.712 standard.

Now, we will define two performance parameters: $SQNR_{\max}$ and $SQNR_{\mathrm{average}}$. $SQNR_{\max}$ is the maximum of *SQNR*, and it can be read from Fig. 1. Also, $SQNR_{\max}$ for the log-polar quantizer can be obtain using (17), since $SQNR_{\max}$ is achieved for the moderate signals. $SQNR_{\mathrm{average}}$ is the average *SQNR* in some interval I of the relative input variance. We use interval I = (-25 dB, 20 dB). Averaging is done in 450 points, mutually separated by 0.1 dB. For the scalar G.711 quantizer we have that $SQNR_{\max} = 37.93$ dB and $SQNR_{\text{average}} = 35.57$ dB.

Now, we will analyze three cases of the log-polar quantizer, for different values of parameters L and M.

- Log-polar quantizer with $L = 256$ and $M = 256$. Line 1 corresponds to this quantizer. For this quantizer it is valid that $R^{\text{log-}pol}=8$ bits/sample, $SQNR_{\max}=40.4407$ dB and $SQNR_{\text{average}}=39.2932$ dB. This quantizer has the same bit-rate as the scalar G.711 quantizer, but it has for 2.51 dB higher maximal *SQNR*. Also, from Fig. 1 we can see that *SQNR*-line of this log-polar quantizer is much wider (i.e. *SQNR* is constant in much wider range of the input variances) compared to the scalar G.711 quantizer. Therefore, this log-polar quantizer gives the average *SQNR* higher for 3.7242 dB. So, we can conclude that using this log-polar quantizer, much higher maximal and average *SQNR* can be achieved compared to the scalar G.711 quantizer, for the same bit-rate.
- Log-polar quantizer with $L = 256$ and $M = 128$. Line 2 corresponds to this quantizer. For this quantizer it is valid that $R^{\text{log-}pol}=7.5$ bits/sample, $SQNR_{\max}=36.1808$ dB and $SQNR_{\text{average}} = 35.6569$ dB. This quantizer has smaller maximal *SQNR* compared to the scalar G.711 quantizer, but due to the much wider *SQNR*-line (see Fig. 1), its average *SQNR* is higher for 0.09 dB. So, with this log-polar quantizer we can achieve the same average *SQNR* but with bit-rate decrease of 0.5 bits per sample, compared to the scalar G.711 quantizer.
- Log-polar quantizer with $L = 128$ and $M = 128$. Line 3 corresponds to this quantizer. For this quantizer it is valid that $R^{\text{log-}pol}=7$ bits/sample, $SQNR_{\max}= 34.4226$ dB and $SQNR_{\text{average}} = 33.3209$ dB. From Fig. 1 we can see that this quantizer satisfies the G.712 standard and it has wider *SQNR*-line compared to the scalar G.711 quantizer. So, we can conclude that using this log-polar quantizer the G.712 standard can be satisfied with bit-rate decrease of 1 bits/sample compared to the scalar G.711 quantizer (which requires 8 bits per sample to satisfy the G.712 standard).

So, we can conclude that the log-polar quantizer has much better performances, compared to the scalar G.711 quantizer. Firstly, it has much wider *SQNR*-line (i.e. it provides constant *SQNR* in much wider range of input variances). Using the log-polar quantizer we can achieve for 2.51 dB higher maximal *SQNR* and for 3.7242 dB higher the average *SQNR*, for the same bit-rate. Bit-rate decrease of 0.5 bits/sample can be achieved for the same average *SQNR*. Standard G.712 can be satisfied with bit-rate decrease of 1 bit/sample.

Our log-polar quantizer also has some other good characteristics. As it was explained in Section 3, it is very simple for realization (since uniform quantization of the phase is done and the number of phase levels is the same on each amplitude level).

Another very important characteristic of the log-polar quantizer is compatibility with the G.711 standard. Scalar quantizers based on the G.711 standard are widely used, especially in PSTN. With a small modification of these G.711 scalar quantizers which already exist, the log-polar quantizers can be obtained. So, with small investments, log-polar quantizers can be widely implemented. With small costs, significantly better performances can be achieved.

5. Conclusion

In this paper a new vector two-dimensional log-polar quantizer for memoryless Gaussian source was proposed. The quantizer was designed in polar coordinates. For amplitude quantization μ-law companding quantizer, defined with the G.711 standard, was used. Because of that, the log-polar quantizer is compatible with the G.711 standard. Phase quantization was done with uniform quantizer and the number of phase levels is the same for each amplitude level. Therefore, our log-polar quantizer is simple for realization and can be obtained by simple software modification of the existing scalar G.711 quantizers, which are widely used in many systems, especially in PSTN. In that way, the log-polar quantizer can be very easily and with small investments implemented in these systems.

Formulae for performances (distortion, *SQNR*, bit-rate) were derived in the paper. Also, simplified formulae were derived for moderate signals, and it was shown that log-polar quantizer has constant *SQNR* for moderate signals. The simulation for the log-polar quantizer was done in MATLAB. Also, the experiment was done using the real speech signal. Very good matching of theoretic, simulation and experimental results was obtained. It was shown that the log-polar quantizer gives much better performances compared to the scalar G.711 quantizer: it has much wider *SQNR* curve (i.e. the range of input variances where *SQNR* is constant is much wider), for the same bit-rate it can achieve for 2.51 dB higher maximal SQNR and for 3.72 dB higher average *SQNR* (averaging was done in the range (-25 dB, 20dB) of input variances in relation to the referent variance), it can achieve the same average *SQNR* with bit-rate decrease of 0.5 bits/sample, it can achieve the G.712 standard with bit-rate decrease of 1 bit/sample. So, small investments are needed for wide implementation of the log-polar quantizer in PSTN and other systems, but performances will be significantly improved.

References

[1] JAYANT, N. S., NOLL, P. *Digital Coding of Waveforms*. Prentice-Hall, 1984.

[2] *ITU-T Recommendation G.711*. Pulse code modulation (PCM) of voice frequencies, 1972.

[3] LYON, A. D. The μ-law CODEC. *Journal of Object Technology*, 2008, vol. 7, no. 8, p. 17-31.

[4] *ITU-T Recommendation G.711.1*. Wideband embedded extension for G.711 pulse code modulation, 2008.

[5] SASAKI, S., MORI, T., HIWASAKI, Y., OHMURO, H. Global standard for wideband speech coding: ITU-T G.711.1 (G.711 wideband extension). *NTT Technical Review*, vol. 6, no. 8, 2008.

[6] HIWASAKI, Y., MORI, T., SASAKI, S., OHMURO, H., KATAOKA, A. A wideband speech and audio coding candidate for ITU-T G.711 WBE standardization. In *Proceeding of ICASSP2008*. Las Vegas (Nevada, USA), 2008, p. 4017-4020.

[7] KOVESI, B., RAGOT, S., GUYADER, A. A 64-80-96 kbits/s scalable wideband speech coding candidate for ITU-T G.711-WB standardization. In *Proceeding of ICASSP2008*. Las Vegas (Nevada, USA), 2008, p. 4801-4804.

[8] HIWASAKI, Y., OHMURO, H., MORI, T., KURIHARA, S., KATAOKA, A. A G.711 embedded wideband speech coding for VoIP conferences. *IEICE Trans. Inf. & Syst*, 2006, vol. 89, no. 9, p. 2542-2552.

[9] PERIC, Z., DINCIC, M., DENIC, D., JOCIC, A. Forward adaptive logarithmic quantizer with new lossless coding method for Laplacian source. *Wireless Personal Communications*, 2010, published online, DOI: 10.1007/s11277-010-9929-3.

[10] PERIC, Z., STEFANOVIC, M. Asymptotic analysis of optimal uniform polar quantization. *AEU - International Journal of Electronics and Communications*, 2002, vol. 56, no. 5, p. 345-347.

[11] PERIC, Z., DINCIC, M., JOVANOVIC, A. Optimal log-polar image sampling. *Journal of Communications Technology and Electronics*, 2009, vol. 54, no. 12, p. 1397–1402.

[12] PERIC, Z., BOGOSAVLJEVIC, S. Asymptotic analysis of optimal piecewise uniform polar quantization. *Radioengineering*, vol. 13, no. 2, p. 26-30.

[13] *ITU-T Recommendation G.712*. Transmission performance characteristics of Pulse Code Modulation (PCM), 1992.

[14] MATSCHKAL, B., HUBER, J. B. Spherical logarithmic quantization. *IEEE Transaction on Audio, Speech and Language Processing*, 2010, vol. 18, no. 1, p. 126-140.

[15] RAVELLI, E., DAUDET, L. Embedded polar quantization. *IEEE Signal Processing Letters*, 2007, vol. 14, no. 10, p. 657-660.

About Authors ...

Milan R. DINCIC was born in Niš, Serbia, in 1983. He received the BSc degree in Telecommunications from the Faculty of Electronic Engineering, Nis, in 2007. He is currently on doctoral studies on the same faculty, and he is scholar of the Ministry of Science, Republic of Serbia. His current research interests include source coding and quantization of speech signals and images.

Zoran H. PERIC was born in Nis, Serbia, in 1964. He received the B. Sc. degree in Electronics and Telecommunications from the Faculty of Electronic Engineering, Nis, Serbia, Yugoslavia, in 1989, and M. Sc. degree in Telecommunications from the University of Nis, in 1994. He received the Ph. D. degree from the University of Nis, also, in 1999. He is currently Professor at the Department of Telecommunications and vicedean of the Faculty of Electronic Engineering, University of Nis, Serbia. His current research interests include the information theory, source and channel coding and signal processing. He is particularly working on scalar and vector quantization techniques in speech and image coding. He was author and coauthor in over 150 papers in digital communications. Dr Peric has been a Reviewer for IEEE Transactions on Information Theory. He is a member of Editorial Board of Journal “Electronics and Electrical Engineering’.