A Calculation Method of Quantization Level in the Design of Digital Echo Cancellers

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1. Introduction

An echo occurs in long-delayed telecommunications circuits such as satellite telecommunications, TV conference and audio conference circuits. For example, when using the long-haul telephone connection, you sometimes hear your voice from your receiver side after dozens to hundreds ms. And, smooth conversations become difficult. The echo means your voice heard from your receiver side. Figure 1 shows a typical long distance telephone circuit. Local loops near subscribers are 2-wire and long transmission trunks between the local loops are 4-wire for the purpose of signal amplification. Hybrid coils are placed to connect the 2-wire loops to the 4-wire trunks, and to match its impedance to that of the 2-wire loops. However, the part of the speech signal returns by the mismatching of the impedance. This is the echo. The influence of the echo increases with increasing the round-trip delay of networks.

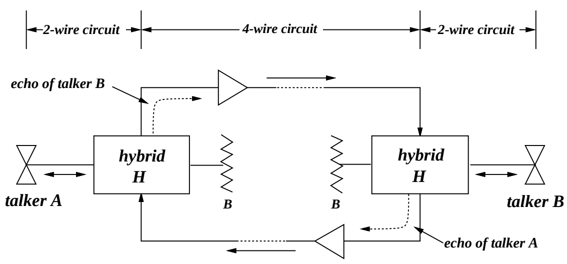

Figure 1: A typical long distance telephone circuit.

The echo disturbs conversations greatly. To supress the echo, echo cancellers have been developed [1]-[8]. In the echo cancellers, an echo path is estimated from an input signal and a real echo, a replica of the echo is generated, and the replica is deducted from the real echo. This process protects telephone conversations from disturbance by the echo.

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Digital technology for telecommunications systems has recently advanced, and most of transmission equipments for these systems have been replaced with digital circuits. The echo cancellers have been also replaced. However, it is not sufficient even if the required design data are available. Because, digital circuits have a new problem, namely, the quantization error introduced by analog-to-digital converters and arithmetic processors.

In this study, a simple extraction method to obtain the design data of the digital echo cancellers is studied. In order to evaluate ERLE that indicates one on the performance of the echo canceller, and a new calculation method to obtain ERLE is proposed. The quantization noise is taken into the equation of ERLE to resolve the problem arisen by digitization. The design data is calculated to obtain the required value of ERLE. Moreover, this expression can be simplified. Then, it is possible to obtain a cancellation value easily. The simple calculation method will be important to design the digital echo canceller.

2. NLMS algorithm

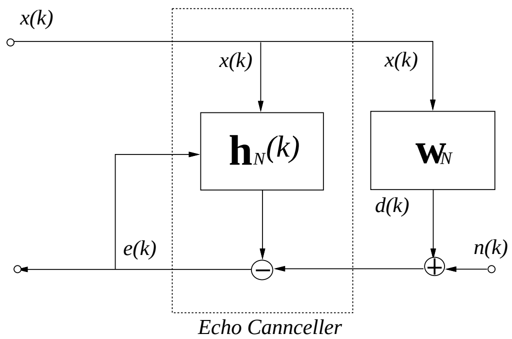

Figure 2: Circuit of echo canceller.

Figure 2 shows the circuit of echo canceller. NLMS has been mainly used as echo cancellation algorithm because of its simple process. Also, NLMS is expressed by the following formulas.

$$\mathbf{h}_N(k+1) = \mathbf{h}_N(k) + \alpha \frac{\mathbf{x}_N(k)}{\|\mathbf{x}_N(k)\|^2} e(k) \tag{1}$$

$$e(k) \;=\; d(k) \;-\; y(k) \;+\; n(k) \tag{2}$$

$$d(k) = \mathbf{W}_N{}^T \mathbf{x}_N(k) \tag{3}$$

$$y(k) = \mathbf{h}_N{}^T \mathbf{x}_N(k) \tag{4}$$

where

$$\mathbf{x}_N(k) \;=\; (x(k-1)\,, x(k-2),\; \cdots,\; x(k-N))^T \tag{5}$$
$$\mathbf{h}_N(k) \;=\; (h_1(k)\,, h_2(k),\; \ldots,\; h_N(k))^T \tag{6}$$

$x(k)$: *input signal*
$d(k)$: *real echo*
$y(k)$: *replica echo*
$e(k)$: *error*
$n(k)$: *noise (near-end talker's speech signal)*
α : *step gain*
$\mathbf{h}_N(k)$: *estimated impulse response*
$\mathbf{W}_N$: *impulse response of unknown system*
N : *tap length*

3. Digital echo canceller

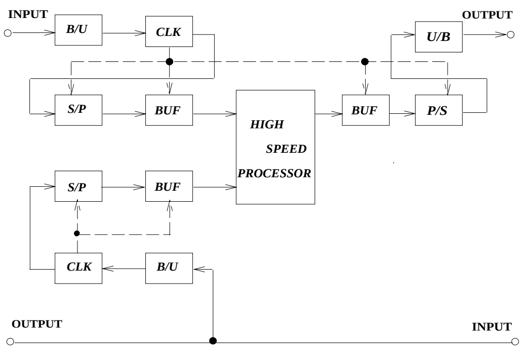

Figure 3: Digital echo canceller.

B/U : *bipolar to unipolar converter*
U/B : *unipolar to bipolar converter*
S/P : *serial to parallel converter*
P/S : *parallel to serial converter*
BUF : *buffer*
CLK : *clock pulse generator*

Figure 3 shows the composition of digital echo canceller. It is fundamentally the same as the analog one. In digital echo cancellers, problems on the quantization noise occurs. The quantity of this noise depends on the number of quantization bits. If the number of quantization bits for processing becomes larger, the accuracy becomes better, or the quantization noise becomes smaller. The quantization errors of both analog-to-digital converter and convolution operation influence greatly the echo cancellation performance.

4. ERLE

An actual communications circuit is considered below. First, the quantization noise of analog-to-digital converter $u(k)$ is taken in. From Eq. (3), the following equation is obtained.

$$d(k) = \mathbf{W}_N{}^T \mathbf{x}_N(k) + u(k) \tag{7}$$

where T denotes the transpose of a vector. From Eq. (2), the following equation is obtained.

$$e(k) = (\mathbf{W}_N - \mathbf{h}_N(k))^T \mathbf{x}_N(k) + u(k). \tag{8}$$

Therefore, Eq. (1) becomes the following equation.

$$\mathbf{h}_N(k+1) = \mathbf{h}_N(k) + \alpha \frac{\mathbf{x}_N(k)\{(\mathbf{W}_N - \mathbf{h}_N(k))^T \mathbf{x}_N(k) + u(k)\}}{\|\mathbf{x}_N(k)\|^2} \tag{9}$$

Next, the quantization noise of convolution operation $v(k)$ is taken in. From Eq. (9), the following equation is obtained.

$$\mathbf{h}_N(k+1) = \mathbf{h}_N(k) + \alpha \frac{\mathbf{x}_N(k)\{(\mathbf{W}_N - \mathbf{h}_N(k))^T \mathbf{x}_N(k) + u(k)\}}{\|\mathbf{x}_N(k)\|^2} + \mathbf{V}_N(k). \tag{10}$$

ERLE as shown in Eq. (11) means echo return loss enhancement, which shows the electric power ratio of error (residual echo) and real echo at the k-th point in time. It is usually used in order to evaluate the performance of the echo canceller.

$$ERLE(k) = 10 \log_{10} \frac{\|d(k)\|^2}{\|e^*(k)\|^2} \tag{11}$$

where $e^*(k)$ is error without quantization noise, that is, $e(k) - u(k)$. S/N_q is a signal-to-noise ratio of analog-to-digital converter. The following equation shows S/N_q.

$$S/N_q = 10 \log_{10} \frac{\|d(k)\|^2}{\|u(k)\|^2}. \tag{12}$$

Now, let k be infinity. This $ERLE(\infty)$ is given with the next equation from Eq. (11).

$$ERLE(\infty)$$

$$= \lim_{k\to\infty}\left[10\log_{10}\|d(k)\|^2 - 10\log_{10}\left\{\frac{\alpha}{2-\alpha}\|u(k)\|^2 + \frac{1}{\alpha(2-\alpha)}\|\mathbf{V}_N(k)^T\mathbf{V}_N(k)\mathbf{x}_N(k)^T\mathbf{x}_N(k)\|\right\}\right]. \quad (13)$$

Two cases are considered as follows.

(A) When the quantization noise of analog-to-digital converter $u(k)$ is sufficiently large, namely,

$$\frac{\alpha}{2-\alpha}\|u(k)\|^2 \gg \frac{1}{\alpha(2-\alpha)}\|\mathbf{V}_N(k)^T\mathbf{V}_N(k)\mathbf{x}_N(k)^T\mathbf{x}_N(k)\|,$$

Eq. (13) becomes very simple,

$$ERLE(\infty) = 10\log_{10}\frac{2-\alpha}{\alpha} + S/N_q. \quad (14)$$

(B) When the quantization noise of convolution operation $v(k)$ is sufficiently large, namely,

$$\frac{1}{\alpha(2-\alpha)}\|\mathbf{V}_N(k)^T\mathbf{V}_N(k)\mathbf{x}_N(k)^T\mathbf{x}_N(k)\| \gg \frac{\alpha}{2-\alpha}\|u(k)\|^2,$$

Eq. (13) becomes,

$$ERLE(\infty) = 10\log_{10}\{\alpha(2-\alpha)\} + 10\log_{10}\frac{\|\mathbf{W}_N\|^2}{\|\mathbf{V}_N(k)\|^2}. \quad (15)$$

5. Echo canceller design

How should be the echo canceller designed in order to obtain the required value of ERLE? In this study, we designes the step gain α and the number of quantization bits M for each operation, which can realize a specific cancellation value. Figure 4 shows an impulse response of the echo return path in the actual network.

5.1. Echo return loss

Generally, the waveform of an impulse response decreases and disappears within 40ms. ERL is the amount of signal attenuation through the echo return path. It is expressed with following formulas.

$$ERL = 10\log_{10}\frac{\|\mathbf{x}_N(k)\|^2}{\|d(k)\|^2} = 10\log_{10}\frac{1}{\|\mathbf{W}_N\|^2}. \quad (16)$$

A mean value of ERL is about 11dB in the actual echo return paths. So, ERL is set to 11dB for the calculations.

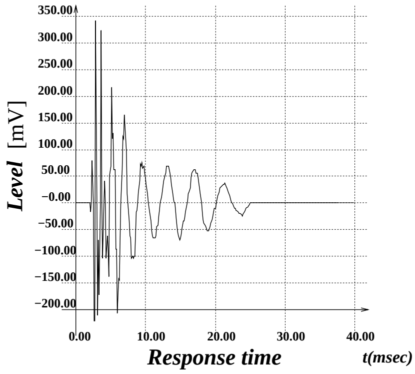

Figure 4: Impulse response.

5.2. Convolution operation

When M bits are used for convolution operation, a quantization noise $v(k)$ is shown as follows.

$$2^{-M} \le \ | v(k) | \ \le 2^{-M+1} \quad (17)$$

The mean value of $|v(k)|^2$ is nearly equal to 2^{-2M+1}. Therefore,

$$\|\mathbf{V}_N(k)\|^2 = N \times 2^{-2M+1} \quad (18)$$

In dB indication, Eq. (18) is expressed as follows.

$$10\log_{10}\|\mathbf{V}_N(k)\|^2 = 10\log_{10}N + 10\log_{10}2^{-2M+1} \quad (19)$$

Here, N is the tap length of the impulse response. N is set to 320 because the maximum delay time is 40ms in Japan. S/N_q is set to 33dB because of quantization noise is established between 33 and 36dB by A-law or μ-law [9].

6. Calculation results

Each value of ERL and S/N_q is obtained by the actual measurements. And, the step gain α of the echo canceller is set to $1, 1/2, 1/2^2, 1/2^3.....1/2^7$, then ERLE($\infty$) is calculated.

Figure 5 shows ERLE(∞) in the case of (A). For this calculation, Eq. (14) is used. ERLE increases as the step gain α decreases.

Figure 6 shows ERLE(∞) in the case of (B). For this calculation, Eq. (15) is used. When the number of the bits M decreases by 1, ERLE(∞) decreases by 6dB. On the other hand, ERLE(∞) becomes smaller as α decreases. When α is changed from 1 to 1/8, ERLE(∞) decreases 7dB. In an actual conversation, the required total echo attenuation value is about 40dB. The total

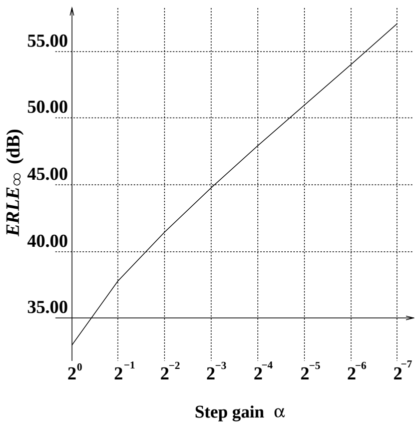

Figure 5: ERLE(∞) in the case of (A).

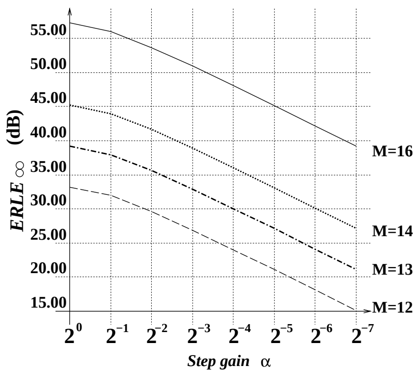

Figure 6: ERLE(∞) in the case of (B).

echo attenuation value is given as a sum of ERL and ERLE(∞). In this calculation, ERLE(∞) should be more than 29dB because the actual measurement value of ERL is about 11dB. Considering the convergence rate and the value of ERLE(∞), the step gain α is recommended to be from 1/8 to 1. Furthermore, the number of the bits M should be more than 13.

7. Conclusions

With recent advances, most of telecommunication systems have been replaced with digital circuits. Therefore, the echo cancellers also have been developed with digital circuits. However, digital circuits have a new problem such as the quantization error introduced by analog-to-digital converters and arithmetic processors. It is important to investigate into these ploblem.

In this study, a new calculation method was proposed, which is easily applicable to the digital echo canceller. How should be the digital echo canceller designed? We took the quantization noise into the equation of ERLE that indicates one of the performance of the echo canceller. And then, we proposed a simple calculation method which can obtain almost correct cancellation values. For example, the number of the quantization bits of the analog-to-digital converter and the arithmetic convolution processor must be over 13, in order to realize 40 dB, the required value of total echo attenuation. Also, the step gain α should be set between 1 and 1/8. Thus, this calculation method would be very important to design the digital echo canceller.

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