PERFORMANCE TESTING OF LOGARITHMIC ANALOG-TO-DIGITAL CONVERTERS

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Abstract - *This paper describes test procedures to characterize the behavior of logarithmic analog-to-digital converters. Logarithmic A/D converters are usually characterized in terms of signal-to-noise ratio (SNR) or in deviation of the ideal characteristic in dB. There are a lack of test methods definition in the literature, as can be observed in the IEEE standard 1241 for these type of converters. Systematic test procedures have been applied to μ-law converters according to the G.711 standard, and to a new type of high-speed true logarithmic pipeline A/D converter. DNL and INL had been defined in the logarithmic domain to allow correct characterization of this class of converters.*

Keywords – Logarithmic converter, companding, μ-Law converter.

1. INTRODUCTION

Logarithmic A/D converters are widely used in communications, instrumentation and hearing aids, among other applications areas, where it is needed to adapt the dynamics of signals to the dynamics of the channels used for transmission. Besides his important use and application for a long time, there are few test definitions for the total characterization of these converters in the literature.

Traditionally, logarithmic A/D converters are characterized in terms of SNR and in the deviation from the ideal curve in dB. Specifications in terms of INL and DNL are very rare and diffuse in the literature. Therefore exists the need to correct define these type of converters in terms of INL and DNL with a coherent method that can give a god evaluation of the converter characteristics.

This paper proposes a new method of characterizing logarithmic A/D converters by a transformation to the logarithmic domain. The transformation linearizes the input-output relationship allowing the use of the same definitions of DNL and INL that are used in linear converters and maintain the integral derivative relation between INL and DNL. In section 2 the standard method of INL and DNL calculations used in linear converters [1] with small modification to the logarithmic case is done to the standard CCITT G.711 μ-law converter. Section 3 describes the method and applies it to the same converter. Section 4 applies the same principles to a high-speed pipeline converter described in the literature.

2. μ-LAW CONVERTER

The μ-Law has a converter characteristic given by [2,3]

$$y = sign(Vin) \cdot \frac{\ln(1+\mu \cdot |Vin|)}{\ln(1+\mu)} \qquad (1)$$

Where y is the digital normalized output, and μ the compression coefficient.

The logarithmic conversion is build from a linear 13 bit digital code, applying the algorithm given by Table1. The converted curve is shown in fig 1.

Table 1: μ-Law input-output characteristic.

Linear code	Compressed code
00000001wxyza	000wxyz
0000001wxyzab	001wxyz
000001wxyzabc	010wxyz
00001wxyzabcd	011wxyz
0001wxyzabcde	100wxyz
001wxyzabcdef	101wxyz
01wxyzabcdefg	110wxyz
1wxyzabcdefgh	111wxyz

The DNL value is the measure of the step size deviation from the ideal one [4]. It is defined as the difference between successive code edges and the ideal code edge of that specific step.

$$DNL = \frac{V_{k+1} - V_k - Lsb_i}{Lsb_i} \qquad (2)$$

$$Lsb_i = \frac{1}{\mu}(1+\mu)^{\frac{i}{2^N}} \qquad (3)$$

Lsb_i is the corresponding ideal LSB of that step. The INL is defined as the deviation, for each segment, of the reconstructed transfer function from the ideal one *Vi*.

$$INL = \frac{V_k - V_i}{Lsb_i} \qquad (4)$$

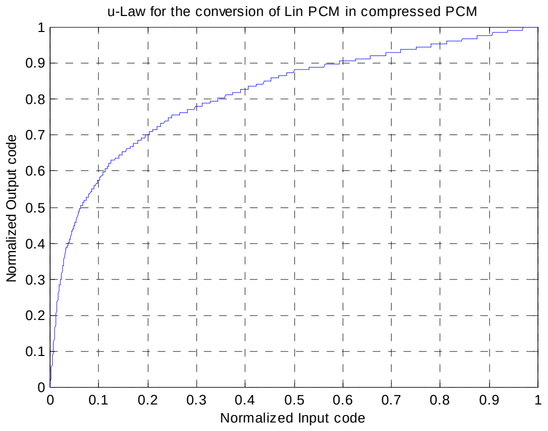

Fig. 1 Half characteristic of a standard CCITT G.711 μ-Law converter.

The corresponding DNL and INL for the μ-law converter is shown in fig. 2 and fig. 3. Fig. 4 shows the error voltage for this converter.

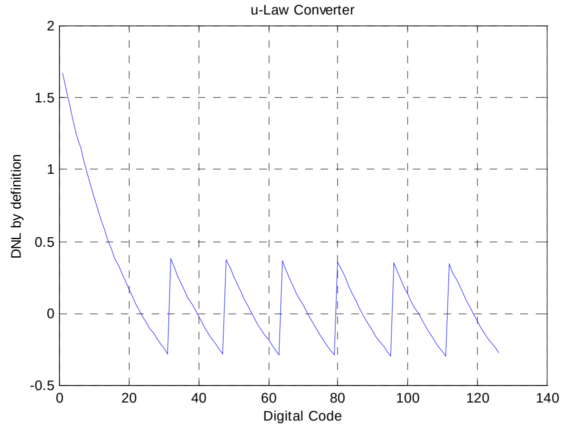

Fig. 2, DNL calculated by definition (2) for the μ-law converter.

In the case of linear A/D converters, the INL can be obtained from the DNL by a simple integration. For the case of these types of converters the integration of the DNL gives an absurd result, since the transition step is different for each code, as can be seen in fig. 5 and so the integration diverge.

To illustrate as the integral of DNL gives a non-consistent result, consider the case of a function given by $y = a \cdot b^{\frac{x}{n}}$, with n=$2^{Nbits}$-1, and an added error of the type $\sin(\pi \cdot \frac{x}{n})$. The cumulative sum of the DNL is given by the first part of (5) and is complete different of the INL expression, second half of (5). The cumulative sum gives a rather large and complex expression that has no relation to the expression of the INL.

$$\sum_{y=0}^{x} \frac{a \cdot b^{\frac{x}{n}} \cdot (b-1) - \sin\left(\pi \cdot \frac{y+1}{n}\right)}{a \cdot b^{\frac{y}{n}} \cdot (b-1)} - 1 \neq \frac{\sin\left(\pi \cdot \frac{y+1}{n}\right)}{a \cdot b^{\frac{y}{n}} \cdot (b-1)} \qquad (5)$$

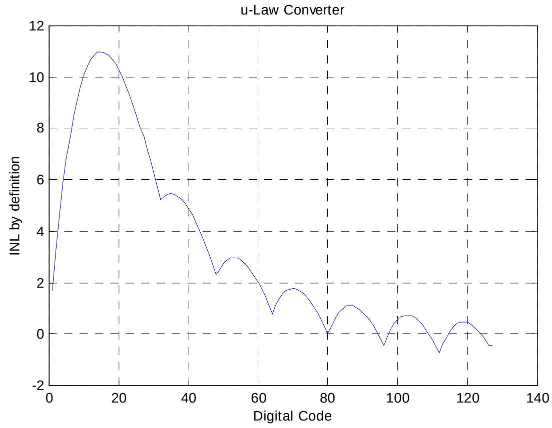

Fig. 3, INL calculated by definition (4) for the μ-law converter.

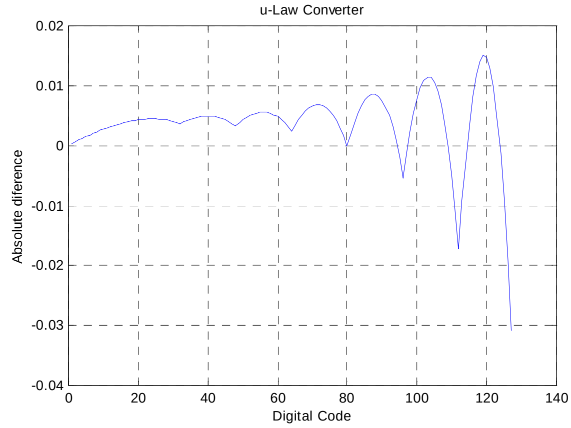

Fig. 4, Error voltage of the μ-law converter.

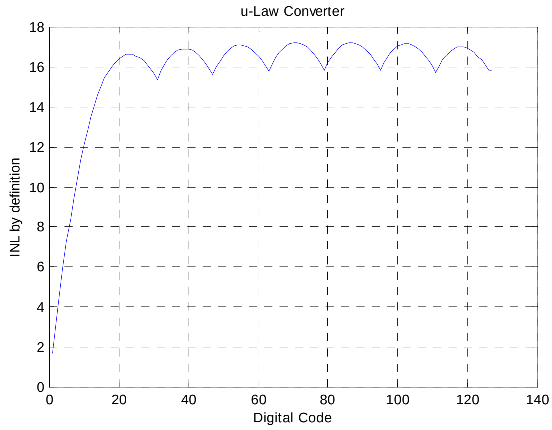

Fig. 5, INL calculated by integration of the DNL.

3. DNL AND INL IN THE LOGARITHMIC DOMAIN

The μ-law curve can be inverted, and is given by

$$Vin = \frac{1}{\mu} \cdot (1+\mu)^{y} - \frac{1}{\mu} \qquad (6)$$

From (6) it can be seen that 1/μ is a simple offset that is added to the input to allow the passage throw zero. If this offset is removed from the input, it is possible to apply logarithms to both sides of equation, and having a linear relation from *Vin* to the digital output (7).

$$\ln(Vin) = y \cdot \ln(1+\mu) - \ln(\mu) \qquad (7)$$

Therefore the non-linear input voltage *Vin* has been transformed in a linear input voltage in the logarithmic domain. The transition step in this case is given by (8). Fig. 6 shows the input and ideal voltage in the logarithmic domain.

$$\Delta Vin = \ln(1+\mu) - \ln(\mu) = \ln\left(\frac{1+\mu}{\mu}\right) \qquad (8)$$

The *Lsb* in the logarithmic domain is given by (8) and is constant for all code steps as is the case of linear converters. With that transformation the DNL and the INL will be given by

$$DNL = \frac{\ln(V_{k+1}) - \ln(V_k) - \Delta Vin}{\Delta Vin} \qquad (9)$$

$$INL = \frac{\ln(V_{k+1}) - \ln(V_i)}{\Delta Vin} \qquad (10)$$

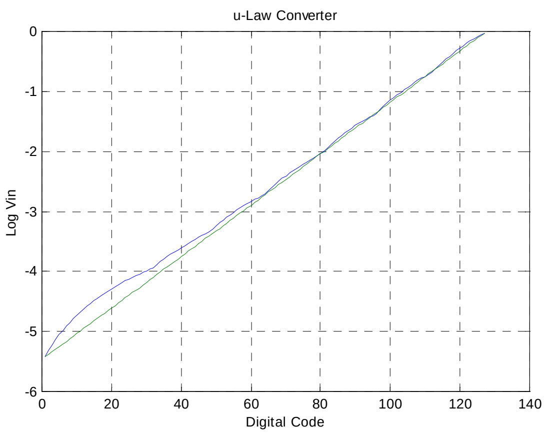

Fig. 6, Input and ideal input voltage in the logarithmic domain.

The INL can be obtained from the DNL by a simple integration, as is the case of linear converters.

$$INL_k = \sum_{i=0}^{k} DNL_i \qquad (11)$$

It can be proven that this relationship is valid besides the use the logarithmic functions in the calculations.

The previous calculations can be done for the same μ-law converter, and they are shown in fig. 7 and fig. 8.

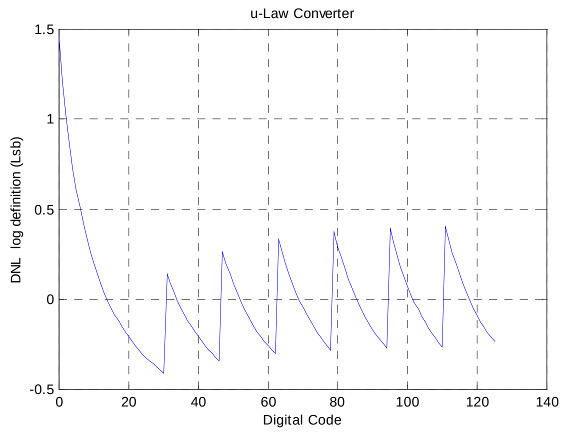

Fig. 7, DNL in the logarithmic domain of the μ-law converter.

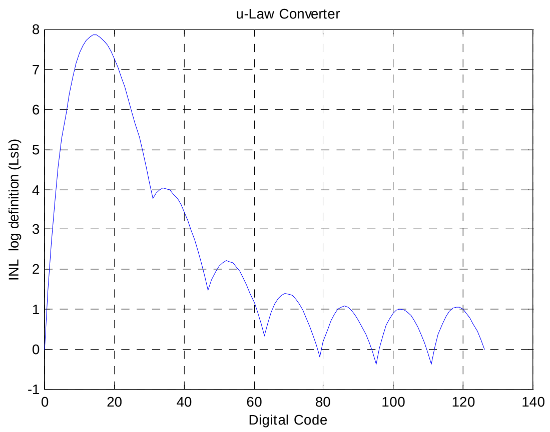

Fig. 8, INL in the logarithmic domain of the μ-law converter.

These results permit the correct definition of the converter characteristics, since in the logarithmic domain there exists a linear relation between input and output, allowing the use of standard procedures for INL and DNL as in the linear case. The definition of the *Lsb* in the logarithmic domain is a direct and logical consequence of the transformation, allowing the correct and direct measure of the INL and DNL in terms of *Lsbs* deviation. At the same time this definition gives better results than the one discussed in section 2.

4. HIGH-SPEED LOGARITHMIC PIPELINE CONVERTER

The same procedure can be applied to a recent high-speed logarithmic pipeline converter [5], described elsewhere. Fig. 9 shows the architecture of the converter. Figs. 10 and 11 shows the matlab simulation of the DNL and INL of the converter.

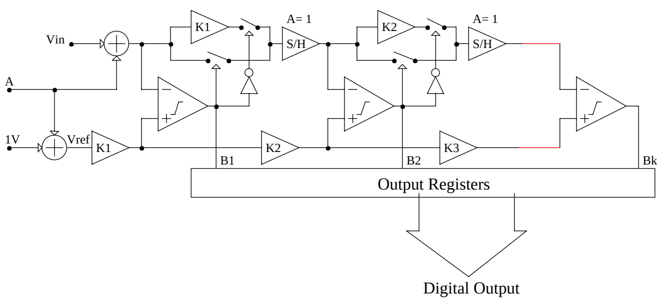

Fig. 9, Architecture of the high-speed logarithmic pipeline converter described in [5].

Component circuit characteristics, as gain, offset voltages and distortion has been modeled as blocks in a matlab simulink model.

An integrated circuit based in this architecture is currently under development in a 0.25 µm CMOS technology.

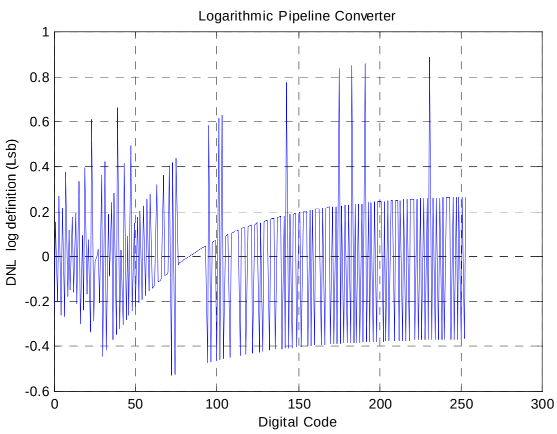

Fig. 10, DNL in the logarithmic domain of the pipeline converter.

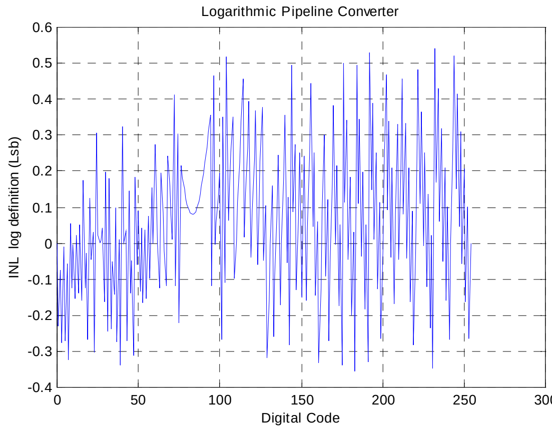

Fig. 11, DNL in the logarithmic domain of the pipeline converter.

5. SUMMARY AND CONCLUSIONS

A new method to characterize logarithmic A/D converters has been described. The method consists in making a transformation of the input transition voltages to the logarithmic domain, to allow a liner relationship between input and output, and therefore use the same DNL and INL definitions that are used for standard linear converters. This method defines correctly the *Lsb* in the logarithmic domain and maintains the integral derivative characteristic of the INL and DNL relationship. The method permits the correct INL and DNL error characterization of logarithmic A/D converters in terms of *Lsbs*.

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