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Study on Multi-tone Signals for Analog/Mixed-Signal IC Testing

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High quality cosine waves and sine waves are relatively easy to generate electrically and are also useful for theoretical analysis. Therefore, they are widely used for analog/mixed-signal IC testing as well as the design and analysis of circuits and systems. In this paper, we investigate the properties of the multi-tone signal (the sum of cosine waves and sine waves of many different frequencies with the same amplitude), and consider its applications.

First, we show simulation results of Kitayoshi algorithm using Eqs.(1), (2) [1] for crest factor reduction and similarity of three algorithms (Kitayoshi, Newman [2], Schroeder [3]). In these equations, the time is from 0 to 8191, and N (the number of tones) is 4 and 1024. The simulation results are shown in Fig. 1 and 5, where T (the number of the sampling points) is 8192.

$$\phi_k = \frac{\pi}{N} k(k+1) \quad \cdots (1) \qquad s(t) = \sum_{n=1}^{N} cos(2\pi nt/T + \phi_n) \quad \cdots (2)$$

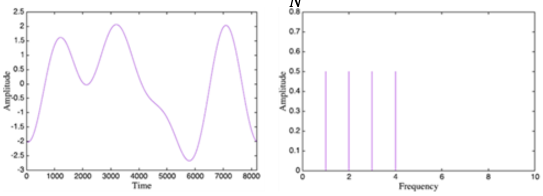

Fig. 1. 4-tone signal using Kitayoshi algorithm

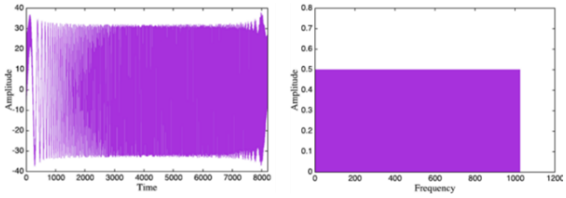

Fig. 2. 1024-tone signal using Kitayoshi algorithm

Next, we show similarity of three algorithms (Kitayoshi, Newman and Schroder). Eq. (3) of Newman and Eq. (4) of Schroeder algorithm are from [2] and [3], respectively. Eq. (2) is common in three algorithms.

$$\phi_k = \frac{\pi}{N}(k-1)^2 \quad \cdots (3) \qquad \phi_k = -\frac{\pi}{N} k(k-1) \quad \cdots (4)$$

Fig. 3 shows the relationship between the number of tones (N) and the crest factor. The simulation results of three algorithms are almost consistent, especially Kitayoshi and Schroeder match exactly. Fig. 4 shows relationship between N and the amplitude of the multi-tone signal. We found that the results of all algorithms match exactly and the amplitude is proportional to $\sqrt{N}$.

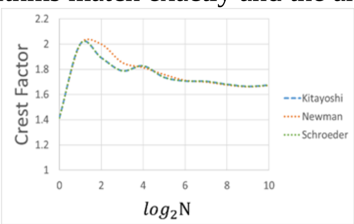

Fig. 3. Relationship between N and crest factor

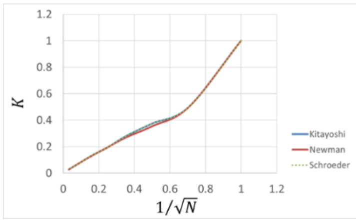

Fig. 4. Relationship between N and amplitude

Then, we have simulated a multi-cosine signal in Eq. (2) where each tone has a random initial phase ϕ_k generated as a Gaussian random number (Figs. 5,6); its crest factor is bigger than the three algorithms.

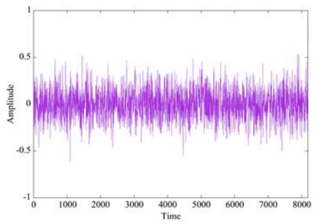

Fig. 5. Multi-tone signal with random initial phases

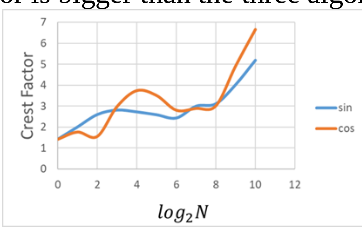

Fig. 6. Relationship between N and crest factor

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[2]D. J. Newman, "An L1 Extremal Problem for Polynomials", American Mathematics Society (Dec.1965).
[3]M. R. Schroeder, "Synthesis of Low-Peak-Factor Signals and Binary Sequences with Low Autocorrelation", IEEE Trans. Information Theory (1970).