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Serial digital interface video signal jitter generator and its calibration method

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ABSTRACT

Jitter is an important factor for serial digital interface video signal (SDI signal) analysis. In this paper, we present the simulated SDI signal generator with certain amount of jitter using a sinusoidal frequency modulation (FM) signal, and propose a calibration method for the jitter value based on modulation index and relative power of sinusoidal FM signal. An experimental system is set up to generate and calibrate SDI signal with specific jitters. High-definition (HD) SDI signal with bit rate of 1.485 Gbit/s is employed to describe the calibration procedure and analyze the uncertainty of measurement.

1. Introduction

Serial digital interface (SDI) is used to transmit serial digital video signals, which was defined by the Society of Motion Picture and Television Engineers (SMPTE) in 1989. Serial digital video signals that conform to the standards published by SMPTE (SMPTE standards) for SDI are called SDI signals. Nowadays, SDI signals are transmitted at higher and higher speed. Jitter becomes one of the key elements that limit bit rate and quality of SDI signal.

Jitter mainly includes two components: deterministic jitter and random jitter [1]. Jitter is introduced by electromagnetic interference noise of environment [2], instrument bandwidth [3], and characteristics of link path [4], etc. Jitter can degrade the signal-to-noise ratio of a system [5] and increase bit-error-rate which has negative influence on the desired signal. In order to guarantee quality of SDI signal, it is important to measure the amount of jitter of video system. Video-specific measurement instrument is employed to measure peak-to-peak jitter amplitude of SDI signal [6]. To ensure such instrument's performance on jitter measurement, it is necessary to have an accurate generator that is able to output SDI signal with certain amount of jitter.

In general, sinusoidal frequency modulation (FM) signal is used to model jitter component [1,7–10]. We use such signal to model SDI signal with certain amount of jitter. The jitter value can be obtained by changing the value of modulation index in sinusoidal FM signal. The relationship between jitter and modulation index is shown in Eq. (2), which will be described in detail in part 3. For SDI signal, jitters below 1 UI are important [11,12]. So to get suitable jitter value, we have investigated the methods that can obtain small modulation index. Refs. [9,10] use Bessel-zero method to calibrate CD/DVD jitter generator. According to Bessel-zero method, the minimum value of modulation index is about 2.4048. According to Eq. (2), the minimum jitter is calculated as about 1.53 UI, which is greater than 1 UI. With the help of frequency multiplier that multiplies the frequency of sinusoidal FM signal's carrier, Bessel-zero method can achieve jitter below 1 UI. Because Bessel zero points are discrete, to get more jitters, frequency multiplier should have a number of multiples which will add more sophisticated work. Ref. [13] mentions that modulation index can be calculated based on the amplitude of modulating signal, frequency modulator proportionality coefficient and root value of Bessel function. However, in real system, frequency modulator proportionality coefficient cannot keep the same when the ampli-

Abbreviations: SDI, serial digital interface; SDI signal, serial digital interface video signal; HD, high-definition; FM signal, frequency modulation signal; SMPTE, Society of Motion Picture and Television Engineers; SMPTE standards, standards published by Society of Motion Picture and Television Engineers; UI, unit interval.

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tude of modulating signal is changing. Refs. [14,15] mentions that modulation index can be calculated through the amplitudes of three frequency components shown on spectrum analyzer based on the characteristics of Bessel function [16]. When modulation index is small, the amplitudes of frequency components are too small which will decrease the measurement accuracy.

According to the studies mentioned above, in this paper, we present a method to get small modulation index and calibrate jitter value for SDI signal modeled by sinusoidal FM signal. The method is based on modulation index and relative power of sinusoidal FM signal. Such method can obtain jitter below 1 UI which is proper for the calibration of the SDI signal source for reliable jitter generation. In the experiment, a system is set up to generate and calibrate SDI signal with certain amount of jitter. The 1.485 Gbit/s signal conforming to SMPTE 292 M specifications for high-definition video formats (HD-SDI signals) is used to describe the calibration procedure and analyze the uncertainty of measurement.

2. SDI signal jitter

Ideally, the time interval between transitions in SDI signals should equal to an integer multiple of the unit interval (UI) [6]. UI is the period of one clock cycle [17]. It corresponds to the nominal minimum time between transitions of SDI signals [18]. The SMPTE standards specify that the clock frequency used to create SDI signal equals SDI signal bit rate. So UI is inversely proportional to SDI signal bit rate. That is, if the bit rate of SDI signal is 270 Mbit/s, 1 UI = (1/270) s = 3.7×10^{-9} s. In real systems, the transitions of SDI signal may vary from their ideal locations in time. Such variations are called time interval errors and referred to as jitter [6].

SDI signal jitter consists of random jitter and deterministic jitter. Random jitter is caused by thermal, shot, flicker noise, etc. Deterministic jitter is caused by switching power supply, frequency response of cables or devices, differences in the rise and fall times of transition, line and field structure of video data, etc. SDI signal jitter is measured by video-specific measurement instrument: First, SDI signal is transmitted through equalization and transition detection; Next instrument demodulates and detects the phase related variations; Finally, through filter and peak-to-peak detection, jitter value is obtained.

3. SDI signal jitter generator

Eq. (1) shows a sinusoidal FM signal $S_{FM}(t)$ whose carrier and modulating signal are single sinusoid. $S_{FM}(t)$ is employed to model SDI signal with certain amount of jitter. A is the amplitude of carrier which represents the peak-to-peak amplitude of SDI signal; ω_c is the radian frequency of carrier which represents the frequency of desired SDI signal; ω_m is the radian frequency of modulating signal which represents the frequency of jitter in SDI signal; β is the modulation index which represents the peak value of phase variation in SDI signal.

$$S_{FM}(t) = A\cos[\omega_c t + \beta\sin\omega_m t] = A\cos\omega_c t\cos(\beta\sin\omega_m t) - A\sin\omega_c t\sin(\beta\sin\omega_m t) \quad (1)$$

The relationship between ideal SDI signal and sinusoidal FM signal is shown in Fig. 1: Sinusoidal FM signal's carrier frequency f_c is one half of SDI signal's bit rate and 1 UI corresponds to π rad. If bit rate of SDI signal is 270 Mbit/s, f_c equals 135 MHz. Fig. 2 shows simulated SDI signal with certain amount of jitter: Sine wave with solid line represents desired SDI signal while sine waves with dashed line represent the maximum phase variation introduced by jitter. Video-specific measurement instruments detect the peak-to-peak value of SDI signal's phase variation, so jitter corresponds to 2β rad. Then SDI signal's jitter can be calculated by Eq. (2) where J represents jitter whose unit is UI.

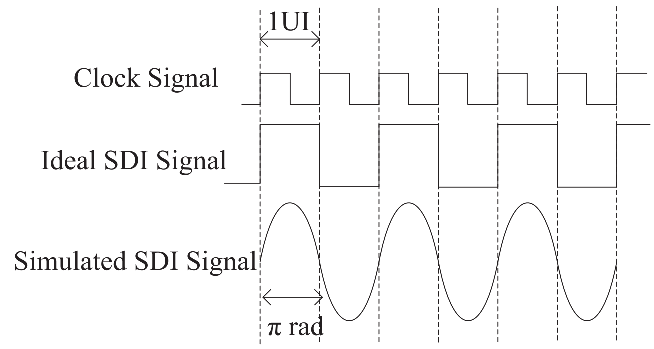

Fig. 1. The relationship between SDI signal and sinusoidal FM signal.

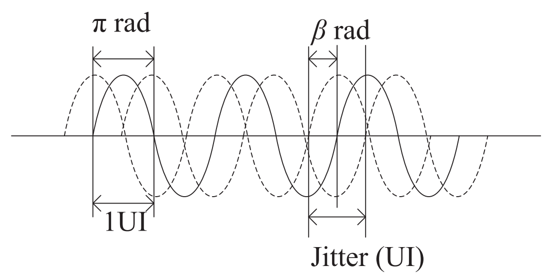

Fig. 2. Simulated SDI signal with certain amount of jitter.

$$\frac{\pi}{2\beta} = \frac{1\text{ UI}}{J}, \quad J = \frac{2}{\pi}\beta \quad (2)$$

4. Calibration method

According to Eq. (2), to obtain jitter value, accurate value of β should be calculated. We replace $\cos(\beta\sin\omega_m t)$ and $\sin(\beta\sin\omega_m t)$ in Eq. (1) by Fourier series and get Eq. (3) and Eq. (4), respectively. Based on Eq. (3) and Eq. (4), Eq. (1) is rewrote as Eq. (5) [19] where $J_n(\beta)$ is Bessel function of the first kind and n is integer. If $n = 0$, $AJ_n(\beta)$ is the amplitude of carrier component; If $n = 1,2,3\ldots$, $AJ_n(\beta)$ is the amplitude of frequency component of first side band, second side band, third side band...

$$\cos(\beta\sin\omega_m t) = J_0(\beta) + \sum_{n=1}^{\infty} 2J_{2n}(\beta)\cos 2n\omega_m t \quad (3)$$

$$\sin(\beta\sin\omega_m t) = 2\sum_{n=1}^{\infty} J_{2n-1}(\beta)\sin(2n-1)\omega_m t \quad (4)$$

$$S_{FM}(t) = A\sum_{n=-\infty}^{\infty} J_n(\beta)\cos(\omega_c t + n\omega_m t) \quad (5)$$

Eq. (6) is obtained based on Eq. (1) and Parseval's theorem [20]. P_f is the average power of $S_{FM}(t)$. Two components of P_f, P_{f0} and P_{f1}, are expressed in Eq. (7) and Eq. (8) respectively where $n1$ and $n2$ represent two components of sinusoidal FM signal and $n1 \neq n2$.

$$P_f = \overline{S_{FM}^2(t)} = \overline{A^2\sum_{n=-\infty}^{\infty} J_n^2(\beta)\cos^2[\omega_c t + n\omega_m t]} = \frac{1}{2}A^2\sum_{n=-\infty}^{\infty} J_n^2(\beta) \quad (6)$$

$$P_{f_0} = \frac{1}{2}A^2 J_{n1}^2(\beta) \quad (7)$$