A Novel Structure Design Method of Delta-Sigma Modulator based on Genetic Algorithm for Mobile Fronthaul

Dayong Tan[1], Linsheng Zhong[1], Yang Zou[1], Jie Zhang[1], Weiqi Lu[1], Xiaoxiao Dai[1], Qi Yang[1,*], Songnian Fu[2], Mengfan Cheng[1], Lei Deng[1], Deming Liu[1]

1 School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China,

2 Advanced Institute of Photonics Technology, School of Information Engineering, Guangdong University of Technology, Guangzhou, China

yangqi@hust.edu.cn

Abstract: We proposed a novel structure design method of delta-sigma modulator based on genetic algorithm. Compared to the traditional method, SNR of the restored signal under the optimized structure at the receiver is increased by ~6dB.

1. Introduction

In 2016, delta-sigma modulation technology was first applied in optical communication in the realization of 5G digital transmitter in mobile fronthaul [1], which is called delta-sigma radio over fiber (DSRoF). Compared with traditional digital radio over fiber (DRoF) based on the Common Public Radio Interface (CPRI), DSRoF has higher spectrum utilization efficiency. Moreover, the carrier frequency and modulation format are adaptive and compatible, which is convenient for subsequent upgrades. Meanwhile, only one electrical filter can restore the analog signal, which greatly reduces the construction cost and is very conducive to the deployment of mobile fronthaul networks. Recently, various types of delta-sigma modulators (DSM), baseband, band-pass, and multi-band, have been reported [2-5]. The distribution of quantization noise is determined by the structure and parameters of the DSM. Better noise shaping performance of DSM requires higher order, which means more parameters needs to be determined, largely increasing the difficulty of modulator design. Thus, optimized structure design appears quite important for the modulator. The R. Schreier DSM structure design package, which can design DSM structure in any order, with any oversampling rate (OSR) and at any center frequency, is the most commonly used platform in MATLAB program [6]. However, since the requirement of signal-to-noise ratio (SNR) and the error vector amplitude (EVM) is relatively high in the mobile fronthaul, structure of the R. Schreier designed DSM still has room to be improved. The parameters traversal method is usually used to design the DSM structure. However, the amount of calculation is huge, especially for the higher order structure. For instance, to deal with 6-order DSM structure, the parameters traversal method with 1000 values per parameter acquires $1\text{x}10^9$ of calculations. Thus, quick searching method for optimized DSM structure and parameters is worthy to be investigated.

In this paper, we propose a novel DSM structure design method, which uses genetic algorithm (GA) to search for various parameters combination to design a DSM structure. We use both of GA and R. Schreier's design package to design a 6-order bandpass DSM structure with an OSR of 8, and the central frequency is 2GHz. We also use these two DSMs to carry out a 64-QAM 312.5MBaud mobile fronthaul transmission experiment. The results show that compared to the R. Schreier's method, the DSM structure designed by GA improves the SNR of the recovered signal by ~6dB.

2. Principle

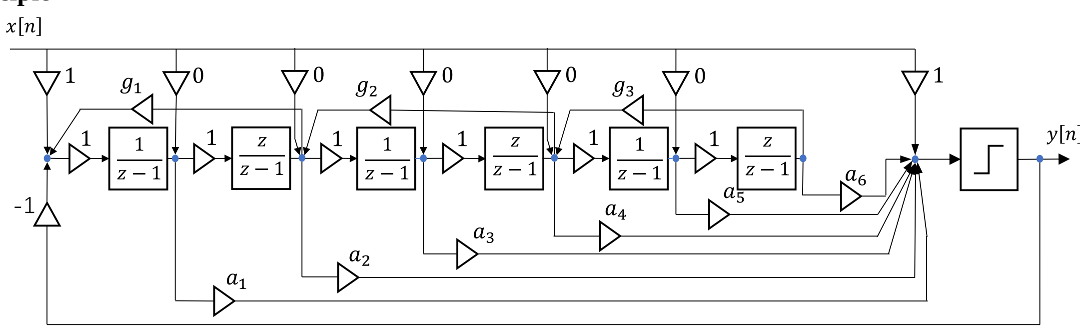

Fig. 1. The z-domain structure and a, g parameters of a six-order CRFF-DSM structure diagram

When designing any sort of DSM structure, the two design requirements, stability and practicability, are of essence. Stability ensures that the DSM can work stably without overload, which means the output is all +1 or -1. According to Lee's rule [7], the stability of DSM is easily satisfied when the maximum value of its noise transfer function (NTF) is less than 4.24dB. Meanwhile, when all poles of a system are located within the unit circle, the system is stable. Practicability means the DSM can meet the requirements of desired center frequency, bandwidth and SNR. For any DSM structures, it can be uniquely represented by four arrays of a, g, b, and c mathematically. The DSM structure of the cascade of resonators weighted feedforward and distributed input coupling (CRFF) architecture has the most stable and low distortion characteristic. Fig.1 shows a 6-order CRFF architecture DSM, whose b and c parameters are fixed. (b = [1 0 0 0 0 0 1], c = [1 1 1 1 1 1]). The arrays a and g are undetermined, $a = \{a_i\}, i = 1,2,3,4,5,6.$ $g = \{g_j\}, j = 1,2,3$ respectively. The g parameter uniquely determines the numerator of the NTF, in which the bandwidth of the DSM is decided. Therefore, only the unknown a and g arrays need to be searched to uniquely optimize the DSM structure.

When designing a CRFF-DSM structure with a specified bandwidth and central frequency, firstly we need to select the range of the g parameter according to the bandwidth and center frequency. Then, numbers of random arrays a and g are input as individuals to form the first-round population, and set basic conditions, such as crossover and mutation factor, population number, evolutionary algebra, etc. The stability of DSM is strictly taken as the optimization constraint. And SNR is selected as the optimization objective, i.e. individual fitness. GA can search for array a and g in the direction of high fitness. After the evolutionary algebra is completed, the remaining individuals are the DSM structures with the highest SNR value.

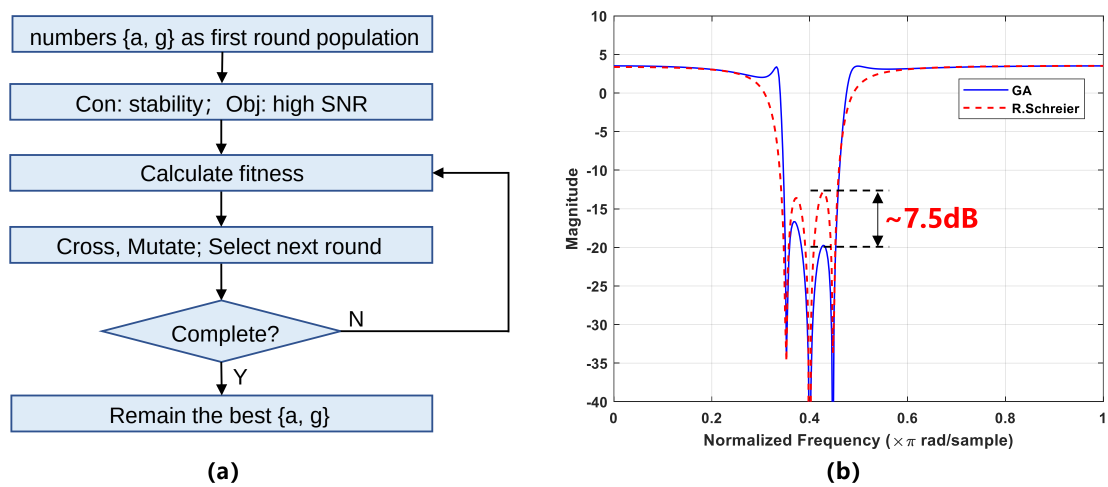

Fig. 2. (a) Flow chart of GA searching, (b) Comparison of NTF curves of the two delta-sigma modulators

3. Experiment and results

We have designed a 6-order bandpass CRFF-DSM with an OSR of 8 based on the two methods mentioned above, the central frequency is 2GHz. Fig. 2(b) displays the NTF curves of the two structure. Compared with the structure designed by R. Schreier's method, the maximum SNR of CRFF-DSM structure designed by GA is increased by 7.5dB in the signal band.

Table 1. Detailed parameters of the DSM structure

	a_1	a_2	a_3	a_4	a_5	a_6	g_1	g_2	g_3
GA	0.5871	-0.3505	0.0254	-0.1822	-0.0289	-0.0033	-1.3846	-1.6703	-1.1100
R. Schreier	0.5710	-0.3217	0.0157	-0.1639	0.0080	-0.0483	-1.3820	-1.6773	-1.1009

We also experimentally show the performance comparison between these two delta-sigma modulators in mobile fronthaul, and the experimental setup is shown in Fig. 3(a). At the transmitting end, we map the original data into a 64-QAM signal with a baud rate of 312.5Mbaud. The signal is then processed with a series of digital signal processing (DSP) procedures, such as up-sampling and up-conversion, finally be converted into a 1-bit signal through a DSM. We use an arbitrary waveform generator (AWG) Keysight M8195A to transmit the 1-bit signal to the Mach-Zehnder Modulator (MZM), and transmit it through a 20-km single-mode fiber (SMF). At the receiving end, a variable optical attenuator (VOA) is used to control the received optical power. After the optical signal is converted into an electrical signal by an optical detector (PD), the signal is collected by an oscilloscope Lecroy LabMaster 10-59Zi for digital signal processing such as digital bandpass filtering, down-conversion and down-sampling.

We measured the SNR of the received signal at different received optical powers. As is shown in Fig. 3(d), under the same received optical power of -1dBm, the structure designed by GA method shows ~6dB SNR improvement compared with the structure designed by R. Schreier. Meanwhile, In order to obtain the same SNR value for the received signal, the received optical power (P_{rec}) required by the structure designed by GA method is ~ 5.5dBm lower than that of the structure designed by R. Schreier.

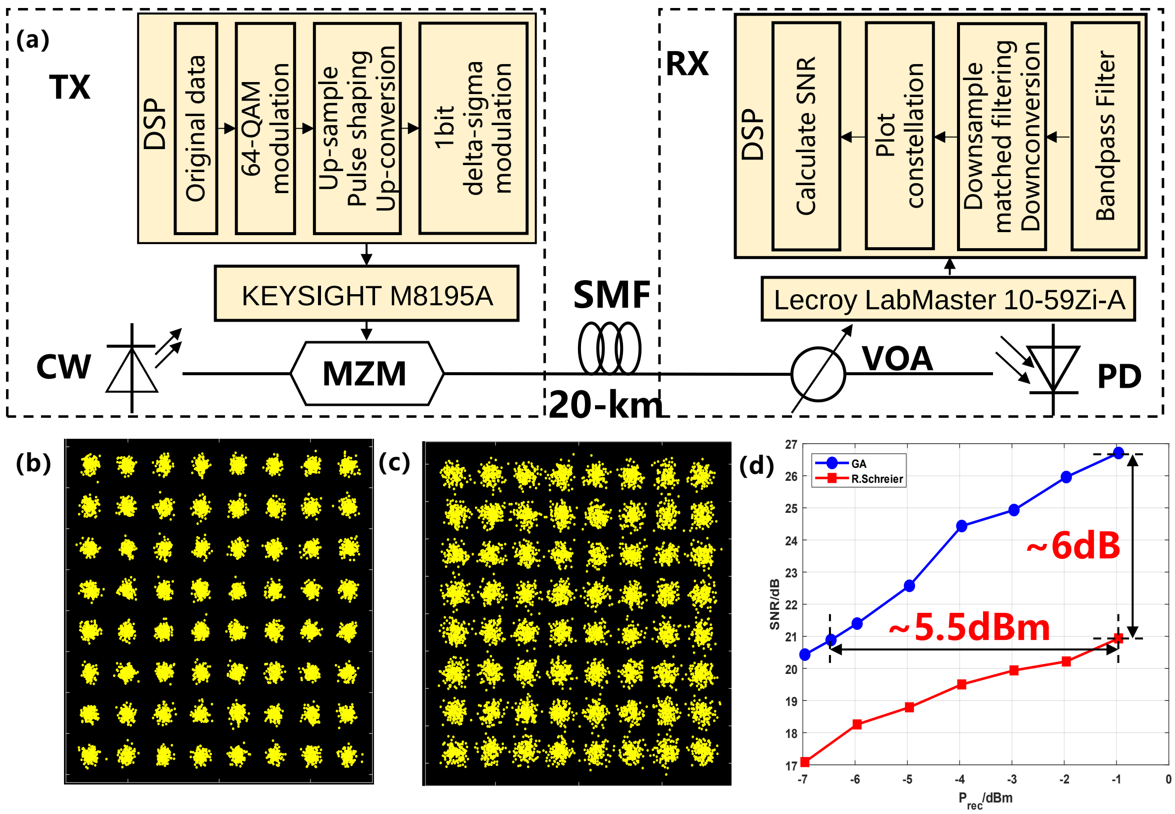

Fig. 3. (a) Experiment set up, (b)-(c) Constellation of the restored signal **P_{rec}** = -1dBm after 20-km SMF with GA designed DSM and R. Schreier's DSM, (d) SNR of the restored signal versus **P_{rec}** .

4. Conclusion

We have proposed a novel DSM structure design method, which uses genetic algorithm to search for optimized parameters combination to design a DSM structure. The GA based delta-sigma modulator structure outperforms R. Schreier's. Loading with 64-QAM signals, the output performance of GA based DSM shows a significant SNR improvement of ~6dB.

5. Acknowledgements

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6. Reference

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