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Coherent accumulation by using sequence shifting and genetic algorithm

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ABSTRACT

We propose to eliminate the random phases in the coherent accumulation by shifting the sampling sequences of the accumulation pulses. Because there is a certain phase difference between the adjacent two samples of analog-to-digital converter (ADC) for a heterodyne signal, the random phases may be eliminated in the sum of these sequences shifted with different steps. Genetic Algorithm (GA) is used to determine the appropriate shifting steps of each sequence. Numerical calculations confirm that the combination of GA and our method is effective to increase the coherence of the accumulation pulses. Thereby, the signal-to-noise ratio (SNR) can be increased notably. These random phases both in transmitter and reception can be eliminated by our approach, which make it has great advantage compared with the existing technologies. Our approach can be realized in a conventional microcontroller unit (MCU). Without the need of reserving the random phase by sampling the transmitter pulse, our approach is easier to realize in practice.

1. Introduction

Pulse coherent accumulation is an effective approach to detect very weak signals in optical heterodyne technology [1–3]. Theoretically, by use of coherent accumulation, the SNR of the weak signal may increase linearly with the number of the laser pulse [4]. This approach is quite attractive, but it is effective only when the echo pulses are coherent. In fact, various factors may cause the accumulation to be incoherent by attaching a random phase to the pulses. In the transmitter part of a system, the random phase may be caused by the time jitter of the Q switch [5]. In addition, the arrival of the echo pulse is usually judged by a range gate [6], so in the reception part, the opening-time jitter of the range gate can also lead to a random phase. Thereby, it is necessary to eliminate them both in the transmitter and reception for realizing the coherent accumulation.

In the transmitter, the random phase caused by the time jitter of the Q switch is difficult to avoid. So, In 1970s, coherent on receive processing (CORP) [7] was proposed to solve the problem. Based on the fundamental of CORP, some technologies have been developed for improving the performance of CORP, such as injection phase-locking [8], digital phase correction [9], digital coherence correction [10], digital coherent reception with amplitude and phase combination [11]. In these technologies, the common property is to "remember" the random phase by sampling the transmitter pulse. Then, by using analog or digital means, the random phase may be eliminated by considering the sample pulse as a reference.

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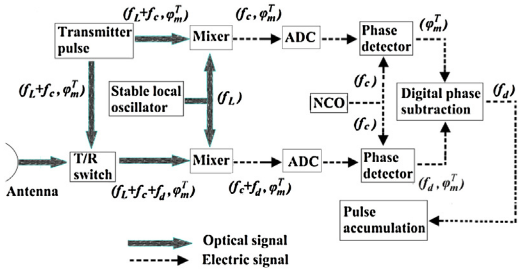

Fig. 1. Schematic of digital coherence correction.

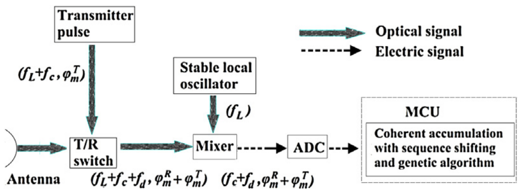

Fig. 2. System of coherent accumulation based on sequence shifting and genetic algorithm.

Take digital coherence correction as example whose schematic is shown in Fig. 1. In this technology, a small amount of transmitter energy with frequency $f_L + f_c$ and random phase φ_m^T is diverted as the sample, where f_L and f_c is the frequency of the stable local oscillator and intermediate frequency, respectively, and φ_m^T is the random phase of the mth pulse resulted from the jitter of Q switch. The frequency of the echo pulse is $f_L + f_c + f_d$ where f_d is the Doppler frequency. After the sample and the echo pulse are mixed with the local oscillator beams, two digital signals with frequencies f_c and $f_c + f_d$ are obtained by ADCs. By use of two phase detectors and a numerically controlled oscillator (NCO) working in the frequency f_c, φ_m^T may be eliminated in a digital phase subtraction. Further, all echo pulses are accumulated coherently based on the results of the subtraction.

From above introduction, one may find that it is necessary to add extra optical paths for "remembering" the random phase. Corresponding, extra optical and electronic components are also needed, which makes the system to be quite complicated and results in the difficulty of installation and adjustment. Because the processes of the echo and sample pulses are analogous, there is a high requirement of the conformity, stability and accuracy of related electronic components. In general, such technology is not easy to realize in practice. In addition, because the sample of transmitter pulse only "remembers" the random phases in the transmitter, this technology is invalid for these random phases yielded in the reception, such as these caused by the opening time jitter of the range gate.

In this paper, a new approach for eliminating these random phases is presented. It is easy to realize and effective for all random phases caused in the transmitter and reception. Based on the fact that there is a certain phase difference between the two adjacent samples of ADC, we propose to eliminate the random phases by shifting the data sequences of the accumulation pulses with different steps. Then when all sequences are summed, an approximate equiphase superimposition can be realized. The appropriate shifting steps of each sequence may be determined by GA, which is proved to be effective by numeral simulation. The accumulation system in our approach is shown in Fig. 2 where the random phases in the reception is denote by φ_m^R. The eliminations of φ_m^T and φ_m^R may be performed in a conventional microcontroller unit (MCU). Without the need of "remembering" the random phase, our system is greatly simplified compared with that in Fig. 1.

2. Fundamental theory of pulse heterodyne detection

The accurate derivation of an echo field is quite complicated, because it is related to the impulse response based on the geometrical and reflectance properties of an object [12]. Because the main purpose of this paper is to demonstrate the effectiveness of our approach, we may simplify the expression of the mth echo field as following

$$E_m(t) = E_{m0}(t)\cos\left[\omega_s(t - mT) + \varphi_m\right], \tag{1}$$

where $m = 0, 1, 2, \ldots$, T is the pulse period, ω_S is the angular frequency of the echo signal, $\varphi_m = \varphi_m^T + \varphi_m^R$ is the sum of the random phases caused in the transmitter and reception, $E_{m0}(t)$ is a heavy-tailed function and

$$E_{m0}(t) = E_0\left(\frac{t}{\tau_m^2}\right)\exp\left(-\frac{t}{\tau_m}\right), \tag{2}$$

where E_0, τ_m are constants. Fig. 3(a) gives an example of $E_{m0}(t)$. The term $\omega_S mT$ in Eq. (1) will not affect the accumulation when T is stable, so we may omit it in the subsequent part. Even if T is unstable, it can be written by $T = T' + \Delta T_m$, where T' is