

An algorithm for adaptive cancellation of phase jitter

by R. A. Nobakht

Proposed here is a new algorithm for adaptive cancellation of phase jitter. If all of the possible sources of phase jitter are known *a priori* for a given system, it should be possible to adaptively filter out their effects through use of the algorithm. In addition to offering a cost-effective solution for combating the effects of severe phase jitter, the algorithm should respond rapidly to varying sources of phase jitter and should not encounter any noise/bandwidth conflicts. Hence, it should be applicable with no sacrifice in performance.

Introduction

Adaptive carrier recovery systems are essential in high-performance quadrature amplitude modulated (QAM) data communications systems to correct for phase jitter and frequency offset. Present schemes adapt their structure to match the spectral properties of the impairments. However, their use involves a conflict between wide bandwidth to track fast jitter and narrow bandwidth to minimize output noise. In addition, their convergence time for effective phase jitter cancellation can be too long for intermittent sources of phase jitter [1-5]. Incorporation of powerful and cost-effective adaptive carrier recovery systems is essential in achieving reliable operation of high-performance (5-8 bits/s/Hz) data communications systems. Such high-speed data communications systems are

essential in the realization of remote access multimedia and the ability to transmit different types of digital data (e.g., speech, image, fax, e-mail) over existing voice-band channels.

In the work described here, the well-known data-directed second-order phase-locked loop has been used to compensate for the effects of frequency offset. Seven second-order IIR narrow-band filters have been used to compensate for 20-, 50-, 60-, 100-, 120-, 150-, and 180-Hz sources of phase jitter. However, since these sources of phase jitter are not present continuously at all times, a fast and cost-effective adaptive algorithm has been designed in order to minimize the output noise and improve the performance of the communication system. The 50-Hz and 60-Hz jitter harmonics, if present, stay active during the entire communication session. Therefore, the algorithm has been designed to disable the specific jitter filters whose jitter source does not exist. This task can be performed during the start-up procedure. Unlike the other types of jitter, the 20-Hz phase jitter can be intermittent. The 20-Hz phase jitter is caused by the ring frequency. The algorithm has been designed, in this case, to adaptively probe for the presence of this jitter; if it is present, the algorithm activates the 20-Hz jitter filter. On the other hand, once the source of this 20-Hz phase jitter disappears, the algorithm deactivates the 20-Hz jitter filter. This methodology yields the fastest and the most cost-effective solution for combating the effects of severe phase jitter with no sacrifice in performance.

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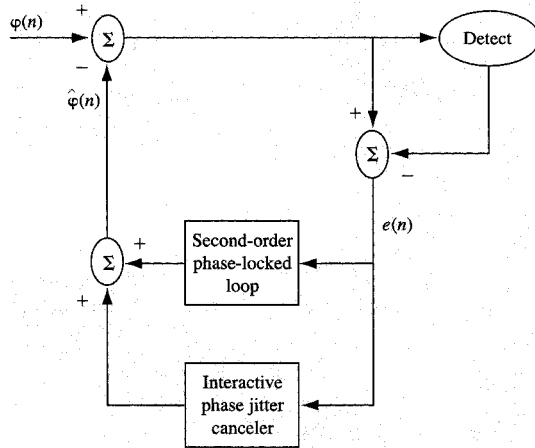


Figure 1

Block diagram of carrier recovery system.

The adaptive solution

Figure 1 shows the structure of the carrier recovery system which is designed to combat the effects of frequency offset and phase jitter. In this diagram $\varphi(n)$ represents the complex input signal; $\hat{\varphi}(n)$ represents the combined estimate of the phase jitter, frequency, and phase offset; and $e(n)$ represents the detected error in phase. As mentioned above, the block representing the second-order phase-locked loop used for combating frequency offset is a well-known structure; hence, its algorithmic characteristics are of no interest to this paper. We discuss in detail the characteristics of the adaptive phase jitter canceler depicted in Figure 2. The blocks designated as "narrow-band" are composed of second-order IIR filters whose block diagram is shown in Figure 3. The frequency response, $H(z)$, of the narrow-band jitter filters, where f_c is the jitter frequency and f_s is the symbol rate, is given by

$$H(z) = \frac{\xi(z^{-1} + \rho z^{-2})}{1 - 2kz^{-1} + z^{-2}}, \quad (1)$$

where

$$\begin{aligned} k &= \cos \alpha, \\ \xi &= 0.01k, \\ \rho &= (\xi - 4k)/4k^2, \\ \alpha &= 2\pi f_c / f_s. \end{aligned}$$

Each of these filters is designed to filter out the effects of phase jitter occurring at a single frequency. However, an adaptive mechanism must be designed in order to systematically enable or disable these filters depending on the presence of their corresponding jitter frequency. The

blocks designated "vargain" in Figure 2 are interactive switches which multiply the incoming signal by a 0 or a 1 depending on the input from the "adaptms" block. In effect, these vargain switches turn the corresponding narrow-band filters on or off depending on the input from the adaptms block.

The algorithm employed in the execution of the adaptms block is the main focus of the work presented here. As can be seen from Figure 2, the adaptms block contains eight inputs and eight outputs. The eight inputs are as follows: the error signal $\Delta\varphi(n)$, and the seven estimated phase signals $\hat{\varphi}_1(n)$, $\hat{\varphi}_2(n)$, $\hat{\varphi}_3(n)$, $\hat{\varphi}_4(n)$, $\hat{\varphi}_5(n)$, $\hat{\varphi}_6(n)$, $\hat{\varphi}_7(n)$, where $\hat{\varphi}_1(n)$ corresponds to the estimated 50-Hz jitter, $\hat{\varphi}_2(n)$ corresponds to the estimated 100-Hz jitter, $\hat{\varphi}_3(n)$ corresponds to the estimated 150-Hz jitter, $\hat{\varphi}_4(n)$ corresponds to the estimated 60-Hz jitter, $\hat{\varphi}_5(n)$ corresponds to the estimated 120-Hz jitter, $\hat{\varphi}_6(n)$ corresponds to the estimated 180-Hz jitter, and $\hat{\varphi}_7(n)$ corresponds to the estimated 20-Hz jitter.

Algorithmic methodology

In this algorithm, the total estimated phase jitter can be expressed as

$$\hat{\varphi}(n) = \sum_{i=1}^7 \hat{\varphi}_i(n). \quad (2)$$

The eight outputs are as follows: the error signal $\Delta\varphi(n)$ (same as the input signal), and seven on/off output signals, g_i , corresponding to the gain of the switches (vargain). During the start-up, all seven narrow-band jitter filters are activated, and their output energies E_i are determined as follows over N symbol intervals:

$$E_i = \sum_{n=0}^{N-1} \hat{\varphi}_i^2(n), \quad \text{where } 1 \leq i \leq 7. \quad (3)$$

If, for any given jitter filter, its corresponding source of jitter also exists, the output energy of this filter will be significantly larger than the estimated output noise energy N_i . Therefore, the following logic applies for the disabling of a phase jitter filter:

$$g_i = 0 \quad \text{if} \quad E_i \leq N_i \quad \text{for} \quad 1 \leq i \leq 7. \quad (4)$$

Once the initial existence of all sources of phase jitter is determined during the start-up, this adaptive algorithm must track the presence of the 20-Hz phase jitter in a continuous fashion over M periodic symbol intervals. Equation (3) can be modified for the tracking of the 20-Hz phase jitter, where k is the iteration number for the periodic intervals:

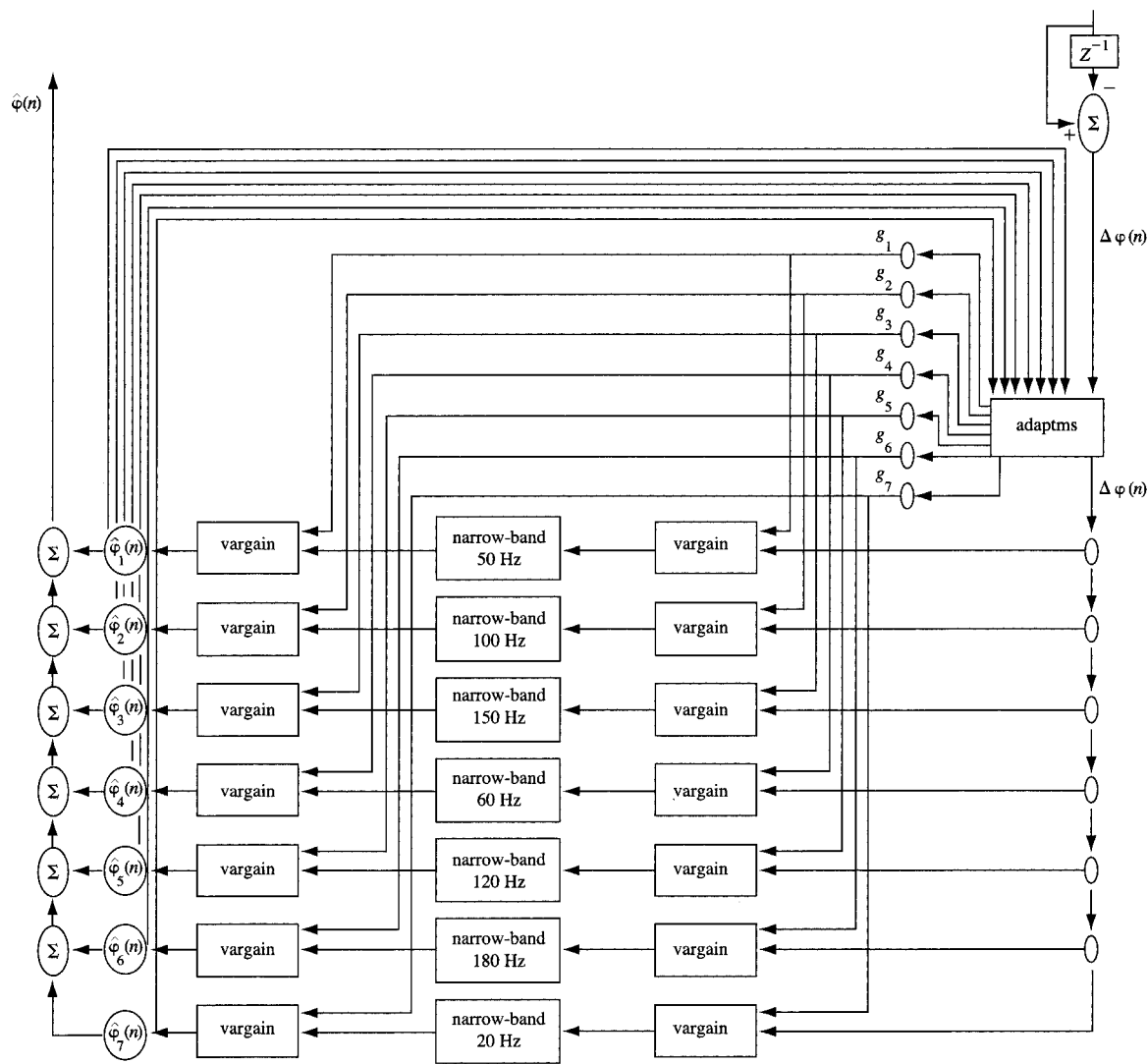


Figure 2

Block diagram of interactive phase jitter canceler.

$$E(k) = \sum_{n=kM}^{[(k+1)M]-1} \hat{\phi}_7^2(n). \quad (5)$$

Using Equation (6), one can determine whether 20-Hz phase jitter is present. This can be applied for the deactivation of the 20-Hz narrow-band jitter filter, where N_7 is its maximum output noise energy. Thus,

$$g_7 = 0 \quad \text{if} \quad E(k) \leq N_7. \quad (6)$$

On the other hand, this algorithm must also determine the presence of the 20-Hz phase jitter while the 20-Hz narrow-

band jitter filter is off. This requires that the input energy $J(k)$ be determined continuously over $N + 1$ periodic symbol intervals, where k is the iteration number for the periodic intervals:

$$J(k) = \sum_{n=kN}^{[(k+1)N]-1} \Delta\phi^2(n). \quad (7)$$

In Equation (7), $k = k + 1$ every N symbol intervals. Hence, the following logic applies for the activation of the 20-Hz phase jitter filter:

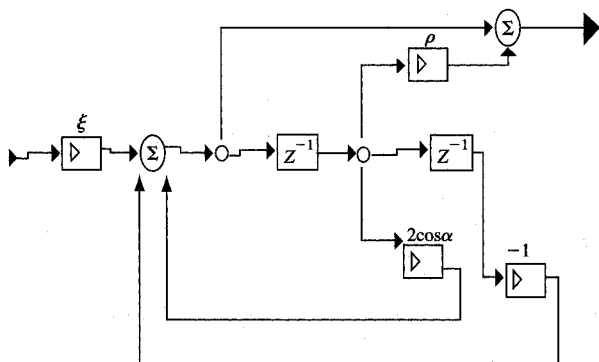


Figure 3

Block diagram of narrow-band filter.

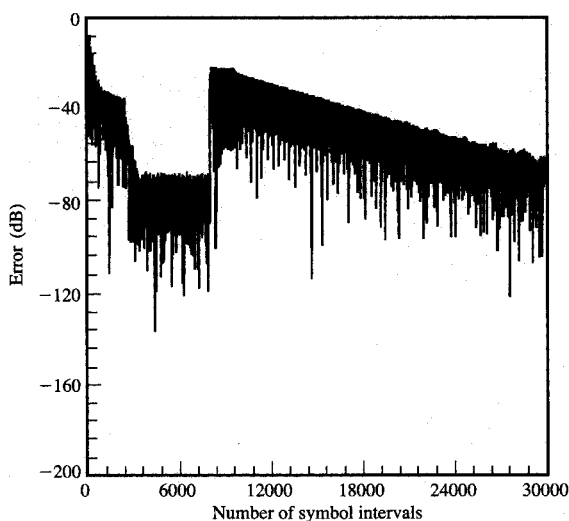


Figure 4

Error curve vs. number of symbol intervals for proposed adaptive phase jitter canceler.

$$g_7 = 1 \quad \text{if} \quad J(k) \geq J(k-1) + \gamma, \quad (8)$$

where γ is the offset input noise energy. The above equation indicates that if the input energy (system error) of the 20-Hz narrow-band jitter filter is increased above an offset noise energy γ , the 20-Hz narrow-band jitter filter should be activated due to the existence of the 20-Hz phase jitter. The algorithm for the deactivation of the

appropriate narrow-band jitter filters and the adaptive tracking of the 20-Hz phase jitter filter is thus completed.

It should be noted that in the algorithm N_i and γ are estimated off-line during the modem start-up mode and assumed invariant during the modem data (steady-state) mode. This is a valid assumption for PSTN channels, since the noise levels do not change drastically for a given channel.

Simulation results

The proposed scheme was implemented in a 2400-symbol-per-second full duplex modem. It was assumed that the 50-Hz and 60-Hz power line harmonics did not change during a communication session. Therefore, all of the related phase jitter frequencies could be determined during the modem start-up training period. At this point the algorithm disables the specific jitter filters whose jitter source did not exist. For this specific example all six possible phase jitter sources were activated. Since the 20-Hz phase jitter is intermittent, it might not be present during the modem start-up period. For this example, the 20-Hz phase jitter source was activated after 8000 symbol intervals. The magnitude of all of the sources of phase jitter was set at 15 degrees. Also, in the simulation, a three-degree continuous phase offset was introduced. As was discussed in the previous section, the effects of this offset can be effectively eliminated by the second-order phase-locked loop. In simulations, the proposed algorithm was compared to an adaptive FIR phase jitter canceler similar to one proposed in [1]. Since a minimum of 120 FIR filter taps are necessary to effectively remove a 20-Hz phase jitter in a symbol rate of 2400 Hz, the number of adaptive FIR filter taps was set to 120.

Figure 4 shows the error curve versus the number of symbol intervals for the proposed algorithm. As can be seen, the algorithm was able to converge to -70 dB phase error in about 3600 symbol intervals. Additionally, after the 20-Hz phase jitter source was activated at the 8000th symbol interval, the effective phase error was reduced to -62 dB after 22000 iterations. In comparison, Figure 5 shows the error curve versus the number of symbol intervals for the adaptive FIR phase jitter canceler. As can be seen from the figure, this algorithm was able to converge to -70 dB phase error in about 7300 symbol intervals. This translates to about 3700 more symbol intervals necessary to achieve the same level of performance than were required using the proposed algorithm. Also, after the 20-Hz phase jitter source was activated at the 8000th symbol interval, the corresponding phase error was reduced to -45 dB after 22000 iterations. This translates to about 17 dB reduction in performance compared to that achieved with the proposed algorithm. This demonstrates the faster convergence property of the proposed algorithm in comparison to the adaptive FIR

phase jitter canceler. In addition to these superior performance characteristics, the proposed algorithm has a much smaller numerical complexity. There are only 28 coefficients used in the proposed algorithm compared to the 120 FIR filter taps used in the adaptive FIR phase jitter canceler. Also, the proposed adaptive algorithm is less complex than the LMS algorithm used in that technique.

Summary

An adaptive algorithm for cancellation of phase jitter has been proposed. It has been shown that if all the possible sources of phase jitter are known *a priori* for a certain system, it should be possible to adaptively filter out their effects through its use. Because of its unique nature, noise/bandwidth conflicts should not occur, and, hence, no sacrifice in performance should be necessary. Performance analysis has indicated that in addition to offering a cost-effective solution for combating the effects of severe phase jitter, the algorithm should facilitate a relatively fast response time to varying sources of phase jitter.

Note

The work described in this paper was carried out while the author was a member of the Digital Communications Development Department at the IBM Microelectronics Division facility in Research Triangle Park, North Carolina.

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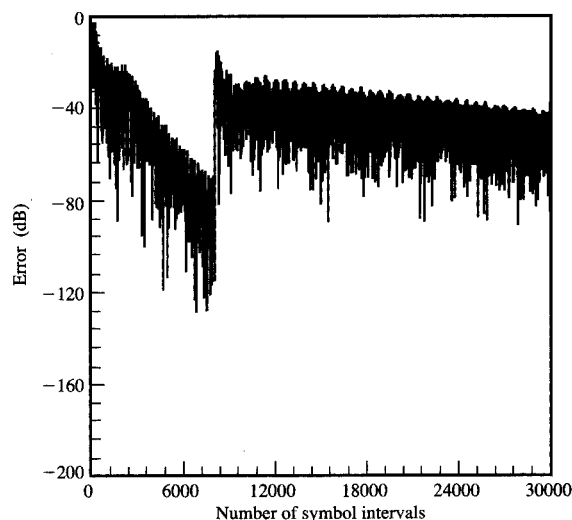


Figure 5

Error curve vs. number of symbol intervals for adaptive FIR phase jitter canceler.

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