**Lab 2：Pulse shaping and matched filtering**

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| **Introduction**  1. Experimental goal: master pulse shaping and matched filtering techniques  2. Fundamentals of pulse shaping and matched filtering:  **Pulse shaping** is a signal processing technique designed to alter the spectral and temporal characteristics of an input signal to make it more suitable for a particular application or system. Pulse shaping is usually related to the characteristics of the transmission medium and channel between the sending and receiving signals. For a transmit signal, pulse shaping can be achieved by selecting an appropriate signal shape and frequency response. This is done to provide the signal with better transmission characteristics, such as reduced power loss, increased bandwidth utilization, etc. For received signals, pulse shaping is typically used to suppress noise, interference and other unwanted signal components for better detection and extraction of the target signal of interest. By selecting appropriate filters to tune the frequency response and time domain characteristics of the received signal, the signal-to-noise ratio can be optimized to improve the system performance.    **Matched filter** is a special type of filter designed to maximize the correlation between a target signal and a known reference signal. The frequency response of a matched filter is opposite to the spectral conjugate of the target signal. The basic principle is to perform a convolution operation between the target signal and the reference signal to achieve optimal signal enhancement and noise rejection. By selecting an appropriate reference signal, matched filtering improves the signal-to-noise ratio of the signal and makes the target signal easier to detect and extract in the background noise.    (1). Nyquist First Guidelines  When transmitting a code element over a channel with bandwidth B, to achieve no inter-code crosstalk, the code element rate Rs cannot exceed 2 times the bandwidth. That is, Rs≤ 2B. To achieve the maximum transmission rate (Nyquist rate) of 2B, an ideal low-pass filter with a bandwidth of B must be used for filtering.  To avoid aliasing during sampling, the sampling frequency must be at least twice the highest frequency of the signal being sampled. Aliasing occurs when the high frequency components of a signal interact with the sampling frequency. If the sampling frequency is too low to capture the high-frequency portion of the signal, these high-frequency components will appear as errors in the sampled signal. This erroneous representation makes signal recovery and subsequent processing difficult. According to Nyquist's first criterion, when the sampling frequency is at least twice the highest frequency of the signal, it is ensured that all signal components can be recovered. This is because in this case the spectra of the signal do not overlap and each frequency component can be recovered independently.    **Nyquist pulse**    (2). Root ascending cosine function waveform bandwidth、Roll-off factor、inter-symbol interference:  The Root Rise Cosine Function (RRC) waveform is a baseband waveform commonly used in digital communication modulation techniques to minimize isi under certain bandwidth requirements, and it has anti-interference and anti-multipath fading properties during transmission. The bandwidth depends on two parameters: the Roll-off factor and the Symbol interval. Roll-off factor (α) indicates the steepness of the frequency response of the filter and ranges from 0 to 1. A smaller roll-off factor indicates a smoother frequency response, while a larger roll-off factor indicates a steeper frequency response. Symbol interval (T) indicates the time interval between neighboring symbols. Bandwidth = (1 + α) / T    (3). The paradoxical problem of signal bandwidth and inter-symbol interference  1. **signal bandwidth:**  **PULSE SHAPING:** In pulse shaping, we try to tune the frequency response of the signal by selecting appropriate filters to reduce power loss, increase bandwidth utilization, etc. To achieve these goals, we may choose a signal shape with a wider bandwidth.  **Matched Filtering:** Matched filtering improves the signal detection performance by maximizing the correlation with the target signal. To achieve optimal matching, we need to select a filter with a narrower bandwidth to ensure that the signal matches the frequency response of the matched filter.  2. **Inter-symbol interference:**  **Pulse Shaping:** To reduce inter-symbol interference, longer pulse shapes are often used to minimize overlap between adjacent symbols. This increases the duration of the signal and reduces the effect of intersymbol interference.  **Matched Filtering:** Matched filtering typically introduces inter-symbol interference because the frequency response of the filter is the opposite of the spectral conjugate of the target signal. This improves the correlation of the signal with the target signal, but may also increase inter-symbol interference.  Paradoxically, pulse shaping typically selects a wider bandwidth and longer pulse shape to reduce inter-symbol interference, but this may result in a larger bandwidth footprint and reduced bandwidth utilization. Matched filtering usually selects a narrower bandwidth to improve the correlation between the signal and the target signal, but this may increase inter-symbol interference, especially in the case of multi-symbol interference. Trade-offs and optimization in practical system design are required to select appropriate roll-off coefficients, symbol spacing, filter types, and other parameters to balance the relationship between signal bandwidth and inter-symbol interference for best performance.  (4). Optimal receiver requirements  1. **Matched Filter Design**: The optimal receiver requires a matched filter design with a frequency response that matches the pulse shaping filter used at the transmitter. This maximizes the correlation between the signal and the target signal and improves signal detection.  2. **Clock Synchronization**: The receiver needs to maintain clock synchronization that matches the transmitter to ensure proper sample timing and symbol spacing. Clock synchronization is critical to the performance of the matched filter as it affects parameters such as filter interpolation and delay.  3. **BER Performance Evaluation**: The optimal receiver requires a BER performance evaluation of the received signal to determine the reliability and performance of the system. This can be accomplished by comparing the difference between the received signal and the original signal.  **Lab results & Analysis**：   1. Pulse Shaping and Matched Filtering (Block Diagram, Programming Process, Simulation Results):   **Pulse Shaping**  **Block Diagram**    **Programming Process**  First, up sampling the datas put into the model, then use raised-cosine function to pulse shaping the data（use convolution model）， then we get the filter coefficients to put out.  **Simulation Results**  **RRC**    **Matched Filtering**  **Block Diagram**    **Programming Process**  **Simulation Results**  **RRC**         1. Curve of SNR as a function of receiver root-lift cosine roll-off factor for a certain transmitter root-lift cosine roll-off factor:      1. The USRP collects real-world data, observes eye diagrams, constellation diagrams (performance), and signal bandwidth (resources) under different root-raised cosine roll-off factors, and analyzes the relationship between them:   **When alpha=0:**  eye diagrams:    Signal constellation:    signal bandwidth    **When alpha=0.5:**  eye diagrams:  Signal constellation:    signal bandwidth:    **When alpha=1:**  eye diagrams:    Signal constellation:    signal bandwidth:    By observing and analyzing the eye diagrams, constellation diagrams and signal bandwidth, the following relationship can be derived:  A smaller roll-off factor produces a narrower signal bandwidth, but may result in a narrower eye diagram and a more compact distribution of constellation diagrams.  A larger roll-off factor produces a wider signal bandwidth, but may result in a wider eye diagram and a more scattered distribution of constellation diagrams.  **Note**: Please indicate meaning of the symbols in all expressions. Please indicate the coordinate and unit in all figures. | |
| **Experience**   1. **Screenshots**   蔡浩宇            曹子惠    **2, Problems encountered in simulation or hardware experiments, and experience gained.**  Some computers in the 410 classroom have problems with the linked usrp hardware, resulting in many computers where the receiver cannot receive the signal and can only see a dot at the origin position of the constellation diagram, which does not belong to any of the white noise interference, phase noise, gain compression, carrier suppression, I, Q amplitude imbalance, I, Q quadrature imbalance.  Through this experiment, I understood more clearly that the role of the pulse shaping filter is to keep the symbol period of the signal from being aliased, while the role of the matched filter is to filter out the interference caused by the reflection of the signal during the transmission process. At the same time, I have gained a more skillful knowledge of the errors that may occur in hardware experiments and the solutions. | |
| **Score** | 100 |