**Project：OFDM**

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| **Introduction**  **1.Experimental objective**：  Understand Orthogonal Frequency Division Multiplexing (OFDM) techniques and be able to verify experimentally using LabVIEW.  **2.Fundamentals of OFDM：**  High spectrum utilization efficiency: OFDM splits the high-speed data stream into multiple low-speed data streams and modulates these low-speed data streams into different subcarriers. This can make full use of spectrum resources and improve spectrum utilization efficiency. Anti-multipath fading: As signals propagate through space they may encounter multipath effects, resulting in the receiver receiving multiple versions of the signal from different paths. The use of OFDMreduces the impact of multipath effects on the communication system.  Spectral isolation: The different subcarriers are orthogonal (perpendicular to each other), making them independent of each other, thus reducing interference between subcarriers and improving the system's immunity to interference.  Long symbol period: As the symbol period of each subcarrier is long, the interval time within the symbol period is reduced, which is conducive to resisting interference in transmission such as frequency deviation and phase noise.    **3.Problems caused by multipath channels in broadband transmission：**  Multipath effect refers to the electromagnetic wave propagation through different paths, the component fields arrive at the receiving end at different times, according to their respective phases superimposed on each other and caused by interference, making the original signal distortion, or error. For example, the electromagnetic wave propagation along two different paths, and the length of the two paths exactly half a wavelength difference, then the two signals to reach the end of exactly cancel each other out (peaks and valleys overlap). Therefore, multipath effect is an important cause of fading.  Time-domain spreading: Multipath transmission causes different versions of a signal to arrive at the receiver with different delays. This leads to interference between symbols, making the received signal blurry and difficult to decode correctly, thus affecting the quality of communication.  Frequency Selective Fading: Signals on different paths may be weakened or strengthened by frequency selective fading. This phenomenon is known as frequency selective fading, which is particularly evident in broadband transmission and can lead to signal distortion and demodulation difficulties.  Phase distortion: Multipath transmission can cause different versions of a signal to differ in phase, called phase distortion. This can lead to signal overlap, making it difficult for the receiver to properly recognize and reproduce the original signal.  Inter-symbol interference: The superposition of signals under multipath transmission results in inter-symbol interference, which causes interference between the individual symbols of the received signal and reduces the system's immunity to interference.    **4.Frequency selective fading:**  Frequency-selective fading means that signals with different frequency components experience different attenuation and phase delay in a channel. This will cause different frequency components of the transmitted signal to be interfered with different degrees at the receiving end, resulting in signal distortion and demodulation difficulties. Frequency-selective fading usually occurs in mobile communication systems or broadband communication systems, where the bandwidth of the signal is very wide, resulting in significant differences in propagation characteristics between different frequency components. This fading can cause the spectrum shape of the received signal to change, and even serious distortion. In order to overcome frequency selective fading, some techniques are widely used, including:  Equalization technique: by equalizer to offset the distortion caused by frequency selective fading, so that the received signal returns to the original spectral shape.  Adaptive modulation technology: According to the channel state adaptively adjust the modulation mode to adapt to the influence of frequency selective fading, improve the anti-interference ability of the signal.  Coding and interweaving techniques: error-correcting coding and interweaving techniques are used to enhance tolerance for frequency-selective fading and improve signal reliability.  **5. The fundamental concept of OFDM technology:**  The fundamental concept of OFDM technology is to partition the channel into multiple orthogonal sub-channels and divide the high-speed data stream into numerous low-speed sub-carriers for transmission, each of which is orthogonal (perpendicular) and non-overlapping. This approach enables efficient spectrum utilization and anti-multipath interference capability. Specifically, OFDM technology divides the raw data stream into parallel low-speed subcarriers with relatively narrow spectrum widths, resulting in a lower transmission rate per subcarrier. Each signal block on every sub-channel is smaller than the relevant bandwidth of the channel, allowing each sub-channel to be considered flat fading and eliminating inter-code crosstalk. Additionally, because each sub-channel's bandwidth represents only a small portion of the original channel's bandwidth, channel equalization becomes more manageable. Narrow-band carriers are frequency-domain orthogonal; their spectra do not overlap one another, enabling simultaneous transmission of different data streams. This orthogonality allows OFDM systems to effectively resist time-domain interference caused by multipath propagation while improving system anti-interference performance. At the receiving end, demodulation and merging of each subcarrier restore the original high-speed data stream. Since each carrier's transmission rate is relatively low, corresponding modulation and demodulation techniques are simple to implement.  **6. IFFT/FFT:**  FFT is an efficient algorithm for calculating DFT, which converts a discrete sequence of N points into its frequency domain representation. The Fourier transform is a mathematical transformation that converts a signal in the time domain to a signal in the frequency domain. It represents a continuous or discrete time-domain signal as a series of complex frequency-domain components, each representing the amplitude and phase of the signal at a different frequency. The DFT is a generalization of the Fourier transform on discrete sequences. For a discrete sequence of N points, the DFT converts it into the frequency-domain components of N complex numbers. The core idea of FFT algorithm is to decompose DFT into several smaller scale DFT, which can be decomposed and merged recursively, thus greatly reducing the computation amount. The FFT algorithm uses the divide-and-conquer idea to decompose an n-point DFT into two N/ 2-point DFT, and then combine these two DFT into one n-point DFT. The key operation in FFT algorithm is butterfly operation. Butterfly operation is a kind of multiplication and addition operation based on rotation factor, which combines two frequency domain components to obtain a new frequency domain component. The FFT algorithm realizes the decomposition and merging process of DFT through the iteration and exchange operation of butterfly operation. The FFT algorithm uses the iterative method to calculate, thus avoiding the extra overhead brought by recursion. In the iterative calculation, the FFT algorithm calculates each frequency domain component in turn according to different butterfly operation order. The time complexity of FFT algorithm is O(NlogN). Compared with the time complexity O(N^2) of direct DFT calculation, FFT has higher computational efficiency. IFFT and FFT are a pair of algorithms that operate inversely to each other. IFFT is the inverse of FFT, which converts a sequence of frequency-domain representations back into time-domain representations. IFFT algorithm and FFT algorithm have the same basic idea, but some adjustments are made in the calculation process, so that the result of the inverse transformation is consistent with the original sequence. The time complexity of the IFFT algorithm is also O(NlogN).    **7. Cyclic prefixes and cyclic convolution:**  Cyclic prefix: In an OFDM system, in order to offset the interference between symbols caused by multipath propagation, the sender inserts a cyclic prefix at the beginning of each OFDM symbol that is the same as the end of the symbol. The length of this loop prefix is usually greater than or equal to the maximum delay of the channel to ensure that the receiver can eliminate the interference caused by the multipath by simply stripping the loop prefix. The addition of the loop prefix makes the frequency selective fading of the channel irrelevant and simplifies the processing on the receiving end. Cyclic convolution: Cyclic convolution is a special kind of convolution operation, which has the characteristics of periodicity. In digital communication system, cyclic convolution is usually used to realize linear equalizer, and the receiver uses cyclic convolution operation to offset the interference of the signal in the frequency selective fading channel, so as to restore the original data. Cyclic convolution is also widely used in digital filter design and channel equalization due to its periodic characteristics. Cyclic prefixes and cyclic convolution play an important role in digital communication systems. They enable the receiver to deal with the interference caused by multipath more effectively, and improve the robustness and anti-interference ability of the system.    **8. Subcarrier and null carrier mapping:**  Subcarriers: In OFDM system, the entire spectrum bandwidth is divided into multiple subcarriers, each of which has a relatively narrow spectrum width and is orthogonal and non-overlapping. Each subcarrier can carry data independently, so multiple data streams can be transmitted simultaneously. The number and distribution of subcarriers can be adjusted according to system requirements to achieve higher data transmission rates and spectrum utilization efficiency.  Null carrier: A null carrier is a subcarrier that does not carry valid data and, in some cases, can be used to transmit control information, enhance channel estimation, or other system management purposes. In some cases, for purposes such as specific system design or channel estimation, some subcarriers can be set as empty carriers, i.e. no data is transmitted. By properly configuring the null carrier, flexible resource allocation and interference suppression can be achieved in OFDM systems. A null carrier is inserted at a specific location to perform operations such as channel estimation, synchronization, and control information transmission.    Subcarrier and null carrier mapping describe how data is distributed on these carriers, which mainly includes the following ways:  Uniform distribution: Data is distributed evenly across all available subcarriers, which is simple and efficient, but may not take full advantage of channel and spectrum characteristics.  Bit allocation: Dynamically allocate data of different bit rates to different subcarriers according to their spectral characteristics and channel states to maximize the throughput and robustness of the overall system.  Mapping: In OFDM system, mapping data to subcarriers is a key step to achieve data transmission. The mapping process assigns the data to be transmitted to different subcarriers, usually using modulation techniques to convert digital data into analog signals. Common modulation methods include quadrature amplitude modulation (QAM) and phase shift keying (PSK). The mapping process can also be dynamically adjusted according to channel conditions and system requirements to improve transmission performance and anti-interference capability.    **Lab results & Analysis**：  **1.OFDM modulation/demodulation simulation (program block diagram, programming process, simulation results, note: serial/parallel conversion, insertion of empty carrier wave and other modules can be used in the library file provided modules):**  student\_OFDM\_FEQ.vi  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\TH[{IRT]@H{ER}O6~S)}4_U.png  OFDM\_modulator.vi    OFDM\_demodulator.vi      **2. Experimentally investigate the sensitivity of OFDM technology to frequency deviation.**  [20,20,4,4] N=64 f=50 100 150 200  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\`_IL1G_22GR_ZE0OC4TX@@A.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\4SSXQTMEM~X$HXW5YSVJ2%O.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\PR844CWAA2G[)C9G4UK(B_T.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\N2OU38QO`O~`J7B]5AZ]DAD.png  [20,20,4,4] N=1024 f=50 100 150 200  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\4@0E4SO]LFORRV{Y6JTV_6K.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\7OSGT6LBCU4SH~0{164XZPM.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\$KY_5(MFI0O$110EVZBY6SX.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\TBITY2`K)KXAHR9`BVEE_O9.png  [4,4,4,4] N=64 f=50 100 150 200  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\_A@9[)K9CBD0RQEQV8}HW0D.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\CV$OOX9O]M{1Z@8IF9`3635.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\)02A9$DOXL{RG4FY)J(EF3R.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\XL`NX1$6EY)Z)%JUISDC`J8.png  **3. To investigate the effect of the number of subcarriers on the system through experiments**  频偏frequency offset= 0Hz 10Hz 50Hz 100Hz 150Hz  子载波数N=64 循环前缀Lc=8 上采样因子=10 采样率=4MHz  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\8RQS$1I}[@TO$WOP(P@EFXX.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\JKY]4EA((_0D3YX@TGJ~1{W.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\S2F4P409E5K`WYM[SRP`0%U.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\WSQ7$0_E6XA{I5TX4XQHCPV.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\R[I6~_SP(NMPVHE}_7{}1]W.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\@K$@2MWB}T]HMFJ59GQL~QW.png  子载波数N=512 循环前缀Lc=16 上采样因子=10 采样率=4MHz  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\@J4F[DZ(YMCCKS[F(Q3$OKO.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\OEMX3FCI($6))HFN26FVQAS.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\LU5@809NJ]TWB6$~QH@219R.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\MSP_BW2ZQM`3UF@YC[3Q$ZV.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\S%EAOJ3@TFV}}$T`SR[O)20.pngC:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\_~64F27%6H7I{RBNQP7XD6A.png  子载波数N=1024 循环前缀Lc=32 上采样因子=10 采样率=4MHz  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\J3}D(A~0B}EQ~T[V4T@WR80.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\BSCW4LC89RLJC0JBBYLB1WC.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\Z`0VEZS55L3C5$CHKEO%W@L.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\F9DSP1~J})_3P)1IO@S)JGP.png  C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\`JF7FXV9CX5ZH0WKZN)H4R5.png C:\Users\Administrator\AppData\Roaming\Tencent\Users\328786803\QQ\WinTemp\RichOle\`S$(HNHO2E]72K]HABZFL75.png  **4. Prototype validation using USRP**  Test USRP    **5 Improvement:**  **(1) High-order Modulation of Subcarrier.**  **modulate.vi**      **decode.vi**      **receiver\_init(SubVI).vi**      **transmitter\_init(SubVI).vi**      **Result**  **BPSK**    QPSK    **16QAM**    **64QAM**    **(2).Image Transmission with OFDM.**  **OFDM\_transmitter.vi**      **top\_ofdm\_rx.vi**    **Result**    **（4）Utilizing MIMO transmission cable for two USRP data transmission**    Using A1 and A2 two usrps and link them using MIMO. Check the device, find two ip is same, so change one decive ip from 192.168.10.2 to 192.168.10.5 | |
| **Experience**  1. During the modulation process, the absence of noise initialization initially prevented the removal of noise in high-order modulation. This issue was resolved by later incorporating noise initialization.  2. To address the incomplete transmission issue with 64QAM, we adjusted the packet length, ensuring a complete transmission signal.  3. Finally, combining Expansions 1 and 4, we successfully achieved the transmission of high-order modulation signals between two USRP devices using MIMO over cable, yielding satisfactory results. | |
| **Score** | 100 |