THE APPLICATION OF DIGITAL DEMODULATION TECHNIQUE FOR FREQUENCY MODULATION SIGNAL IN TELEMETRY RECEIVER

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ABSTRACT

Combined with an example of digital telemetry receiver design, this paper mainly discusses the application of software radio in telemetry receiver. The paper begins with an introduction of applying high efficiency digital filter and math analysis in quadrature digital frequency modulation and demodulation to digital frequency conversion technique. Next, Simulink/Matlab is used to simulate digital telemetry receiver. The method of simulation, analysis and calculation of performance and result of simulation are all available. In the end, the paper discusses digital telemetry receiver design and implement by making use of software radio technique, the circuits apply HSP50214 chip of Intersil Co., CPLD implements of Altera Co. and PC Bus. The sample is an expansion card for personal computer. Result of test, performance of the receiver and conclusion are given out, which show fine performance of receiver and can be apply to practice. The lever of this technology has reached first class in the world.

KEY WORDS

Software radio, telemetry receiver, digital frequency modulation and demodulation

PREFACE

There are two directions in the development of telemetry receive system. One of them is large-scale integration telemetry ground receiver station, which characteristics are excellent performance and complete function. Another one is miniaturized, portable telemetry receiving equipment, its characteristics are small volume and low price, which is suitable for lab test, outfield test and small-scale telemetry receiving mission. It is very important equipments in need in telemetry of guided missile too.

In the past and at present, the telemetry receivers developed, manufactured or used in China and abroad are all analog. That means besides the part of radio frequency (RF), the part of intermediate frequency (IF) is also analog. According to the development of software radio technique, DSP technique and CPLD technique, the after part of IF in telemetry receiver can be completed by digital technique, which means applying software radio technique to digital down converter and digital demodulation in telemetry receiver.

Digital telemetry receiver which is applied software radio has flexible application, strong opening, small hardware volume and low cost. For example, the demodulation modules in telemetry receiver used in the past and at present must be replaced before changing to other demodulation methods. If the software radio technique is applied, the same functions can be accomplished by simple setups.

THE DIGITAL DEMODULATION FOR FREQUENCY MODULATION SIGNAL

A. Sequence Decimation and High-efficient Digital Filters

In telemetry receiver, decimation is needed in sampling signal to meet the demands of following signal processing. Decimation rate is decided by the IF bandwidth of useful signal. In high bit rate, decimation rate is lower to satisfy no distortion in signal. On the other hand, raising decimation rate and reducing sampling rate in low bit rate in order to gain higher order of digital filter and improve system performance.

High-efficient digital filters used in software radio are mainly FIR Filter, HB Filter and CIC Decimating Filter.

B. Quadrature Digital Demodulation for Frequency Modulation Signal

Demodulation methods can be roughly divided into two kinds: coherent demodulation and incoherent demodulation. Generally speaking, the performance of coherent demodulation is better than incoherent demodulation. In digital domain, coherent demodulation is commonly used. Digital coherent demodulation is similar to analog coherent demodulation in principle; both of them need a local carrier which has exactly the identical frequency and phase as modulation signal to coherent demodulate. The output of demodulation will be seriously distorted with the unsatisfied identical frequency and phase. Because quadrature digital demodulation can overcome these weaknesses to a certain extent, so it is usually used.

a. Quadrature Transforming Adopted the Digital Mixing Method

The so-called digital mixing quadrature transforming is that the orthogonal local oscillators $\cos(\omega_0 n)$ and $\sin(\ _0 n)$ are both multiplied by the input signal sequence, then let them pass through the low-pass filter to achieve orthogonality, as Fig.1 shows.

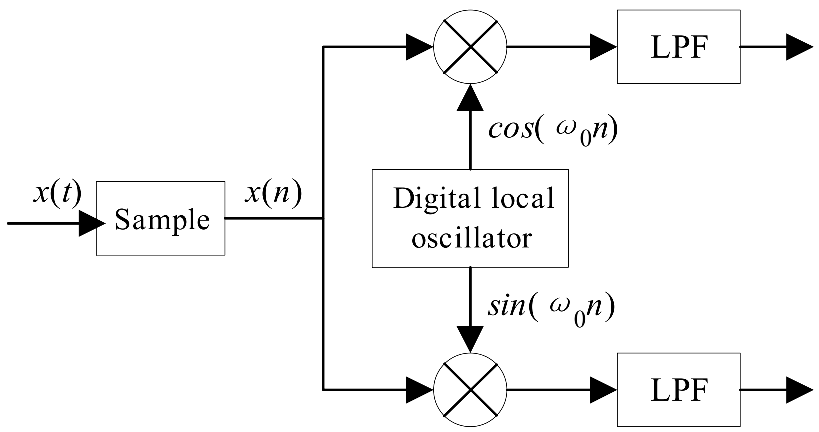


Fig.1 Baseband Quadrature Transforming for Real Signal

From the figure above, it can be seen that the generation and multiplication of the two orthogonal local oscillators is the result of mathematical operation which means orthogonality can be guaranteed completely. In addition, signal spectrum will be moved to zero frequency through quadrature transforming adopted the digital mixing method, which is beneficial to the following filter and demodulation.

b. Digital quadrature demodulation for frequency modulation signal

The expression of frequency modulation signal:

$$S(n) = A_0 \cos[\omega_c n + k\sum m(n) + \phi_0] \qquad (1)$$

In the expression, k is a factor of proportionality, ϕ_0 is constant. The signal will be moved to zero frequency by digital mixing quadrature transforming and after the orthogonal decomposition, the result is:

Inphase component: $X_I(n) = A_0 \cos[k\sum m(n) + \phi_0]$ (2)

Orthogonal component: $X_Q(n) = A_0 \sin[k\sum m(n) + \phi_0]$ (3)

The ratio of orthogonal component to inphase component make arc tangent operation will get the phase information:

$$\phi(n) = arctg\left[\frac{X_Q(n)}{X_I(n)}\right] = k\sum m(n) + \phi_0 \qquad (4)$$

Then carrying on difference to phase can get modulation signal.

$$\phi(n) - \phi(n-1) = m(n) \qquad (5)$$

FM signal has strong ability of resisting mismatch of carrier when the method of quadrature demodulation is used to demodulate. And when there are differences in frequency and phase between the local carrier and the carrier of the signal, the inphase component and orthogonal component can be expressed as:

$$X_I(n) = A_0 \cos[\Delta\omega \cdot n + k\sum m(n) + \Delta\phi] \qquad (6)$$

$$X_Q(n) = A_0 \sin[\Delta\omega \cdot n + k\sum m(n) + \Delta\phi] \qquad (7)$$

Similarly, the ratio of orthogonal component and inphase component make arc tangent operation will get modulation signal:

$$arctg\left[\frac{X_Q(n)}{X_I(n)}\right] - arctg\left[\frac{X_Q(n-1)}{X_I(n-1)}\right] \qquad (8)$$

$$= [\Delta\omega \cdot n + k\sum m(n) + \Delta\phi] - [\Delta\omega \cdot (n-1) + k\sum m(n-1) + \Delta\phi]$$

$$= \Delta\omega + m(n) \qquad (9)$$

Therefore, when there are constant difference in frequency and phase in carrier, demodulation output will increase a direct-current component $\Delta\omega$, so subtract the direct-current component from the output can get the original modulation signal.

USE SIMULINK/MATLAB TO SIMULATE DIGITAL DOWN CONVERSION AND DIGITAL FREQUENCY MODULATION AND DEMODULATION

The digital demodulation part mainly includes the following three segments: digital down conversion, digital filter and digital frequency discriminator. All of them can be realized by the special-purpose devices, they can also be realized by programmable devices such as DSP and FPGA. The development period will be shorter if the special-purpose devices are used, but it is limited by conditions, such as function of the device and speed, etc. At the same time, it can be designed flexibly by the programmable devices, the quick development of the device provides very good guarantee to the speed, but on the other side, the design period is relatively longer. Considering the system designing requirements and factors above synthetically, the HSP50214 of Intersil Co. was used as the digital demodulation chip in this system.

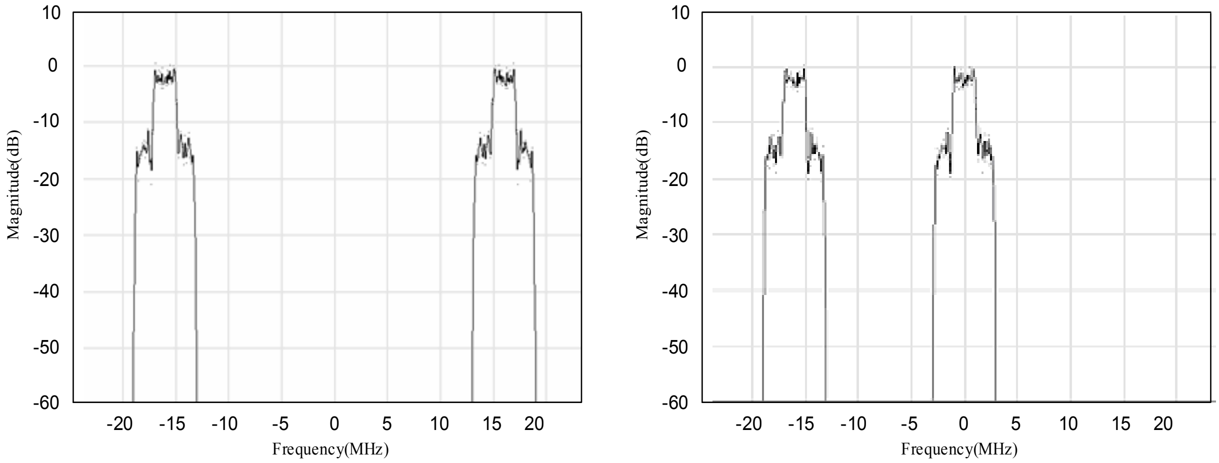
A.System Performance

According to the system request of missile telemetry system and the level of techniques at present, the technical performance are following:

- Bit Rate: ≤2Mbps
- Output of IF: 160MHz (first frequency of down converter)
- Sampling Rate of Band-pass：48Mbps
- Demodulation Type: FM
- Video Bandwidth: ≤1.4MHz adjustable in succession
- IF Bandwidth: ≤4MHz adjustable in succession
- Size (the part of RF included): full-size ISA, which can be put in computer
- Control Bus: ISA Bus
- Control Functions of Computer: Tuning of local oscillator, IF and video bandwidth, AGC time constant

B. Sample and Orthogonalize of Signal

In this system, 160MHZ IF signal is acquired to digital domain by sampling rate of 48Mbps at first. Take the highest bit rate of 2Mbps as the example, the following will explain the process of sampling and orthogonalize of signal.



(a)Spectrum of Signal Sampling at48Mbps (b)Spectrum of the Signal after it multiplies the Quadrature Local Oscillator

Fig.2 Sampling of the Signal and Orthogonality of the Spectrum

As Fig. 2(a) shows, the centre frequency of the signal is 16MHZ after 48Mbps sampling. Because the signal is real signal, there will be mirror image frequency on －16MHZ. Then superheterodyne mixing is carried on in the analog part, in fact the signal of －16MHZ is the original signal spectrum and the signal of 16MHZ is the mirror spectrum of the original signal.

In order to move centre frequency of original signal to zero frequency, here the signal is multiplied by orthogonal local oscillator（the frequency of which is 16MHz）. Because the signal multiplied by $e^{j\omega}$ in time domain is equivalent to signal ads ω in frequency domain, so after the signal multiplied by 16MHZ orthogonal local oscillator the spectrum is as Fig. 2(b) shows. From the figure, the centre frequency of original signal is zero, and on －16MHZ there is an inhibitory mirror image frequency needed.

C. Decimation and Filter of Signal

In HSP50214, the AGC loop needs six clock periods to make operation, so the sampling rate of signal must be reduced, and the maximum order of real symmetrical FIR filter is:

$$\mathrm{N}_{\mathrm{Taps}} = (\mathrm{PROGCLK}/\, f_{\mathrm{SAMP}} - 1)\times 2 \qquad (9)$$

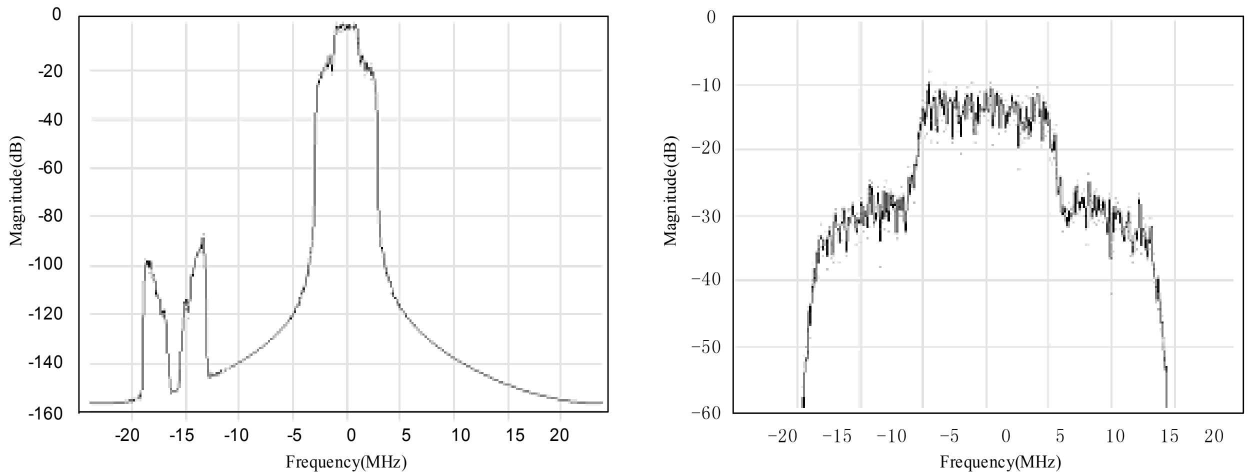
In the expression, PROGCLK is the processing clock speed, f_{SAMP} is the sampling rate of the signal dealt by FIR. So:

$$\mathrm{N}_{\mathrm{Taps}} = (R-1)\times 2 \qquad (10)$$

R is the decimation rate before FIR filtering for the system. It can be seen that the decimation rate is bigger in earlier stage; the FIR filter order is higher in later stage.

In order to suppress the mirror frequency and noise out of useful band, resisting aliasing filter should be adopted before decimation. Both CIC decimation structure and HB decimation structure require the bandwidth of the signal to try their best to be narrow, usually useful signal bandwidth should not exceed 1/8 of sampling rate after decimation in CIC, 1/4 of sampling rate after decimation in HB.

As to 2Mbps bit rate, signal spectrum is concentrating on the inside bandwidth of [－1Mz, 1MHz]. Because the signal will be decimated 6 times at least, the useful bandwidth of signal has already been 1/8 of the sampling rate after decimating 6 times of CIC, so it will skip over HB decimation at this moment. The spectrum is as Fig.3 shows after six orders of CIC filtering and decimation.



(a)Spectrum of the Signal after Six Orders of CIC Filtering (b)Spectrum of the Signal after Six Times of Decimation

Fig.3 CIC Filter and Decimation

There are many decimation methods when modulation terminal is the signal in low bit rate, which can still keep the low decimation rate, increase CIC decimation rate or use HB decimation after CIC decimation. The system performance will be different depending on the decimation method; the best method of different bit rate must be decided by practice.

Different windows function leads differences in characteristics of stopband and transition band of filter. The transition band of Rectangular window is the narrowest in common use, but there is rise and fall in pass-band and relatively bad suppression in stopband. The stopband of Blackman window is the best in suppression, but at the same time the transition band is the widest. Because there are more factors which will influence actual signal, what kind of window function will have better function is also decided by practice.

D. Digital Quadrature Demodulation

Carry on pole coordinate conversion of signal in plural domain; it will get the phase information of signal as Fig.4 (a) shows:

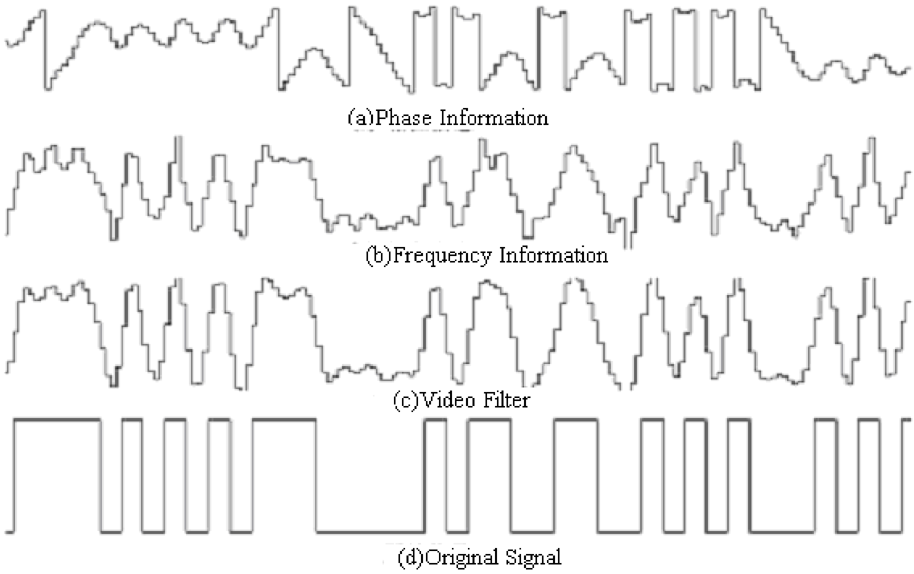


Fig.4 Waveform of Digital Modulation and Demodulation

Go on difference for phase, it will get the frequency information of signal as Fig.4 (b) shows. Go on video filter by FIR filter, it will get demodulation output signal as Fig.4(c) shows. Comparing Fig.4(c) with Fig.4 (d), it can be found out that demodulation output signal is the result of limiting bandwidth of original modulation signal then adding to noise. There is not obvious distortion in the waveform.

IMPLEMENT OF DIGITAL DEMODULATION TECHNIQUE FOR SIGNAL IN FREQUENCY MODULATION IN TELEMETRY RECEIVER

A. Circuit Design and Implement

The structure diagram of the circuit is as Fig.5 shows:

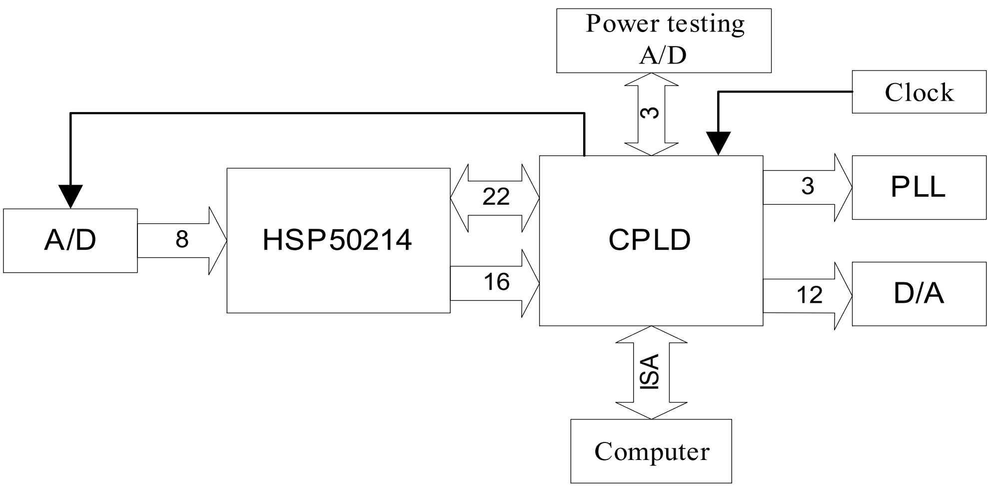


Fig.5 Structure of the Circuit

B. Test results and Analysis of Performance

The signal with only 100 KHz frequency is inputted in modulation, and amplitude of which is invariable. Change the frequency deviation of the signal generator then observe the virtual value of the output voltage, the result is as Fig.6 shows, except that voltmeter changes the rang of measurement which causes the jump of the output amplitude with 600 kHz frequency deviation, the virtual value of output voltage that measured in voltmeter at the same rang has the linear relationship with frequency deviation of the signal.

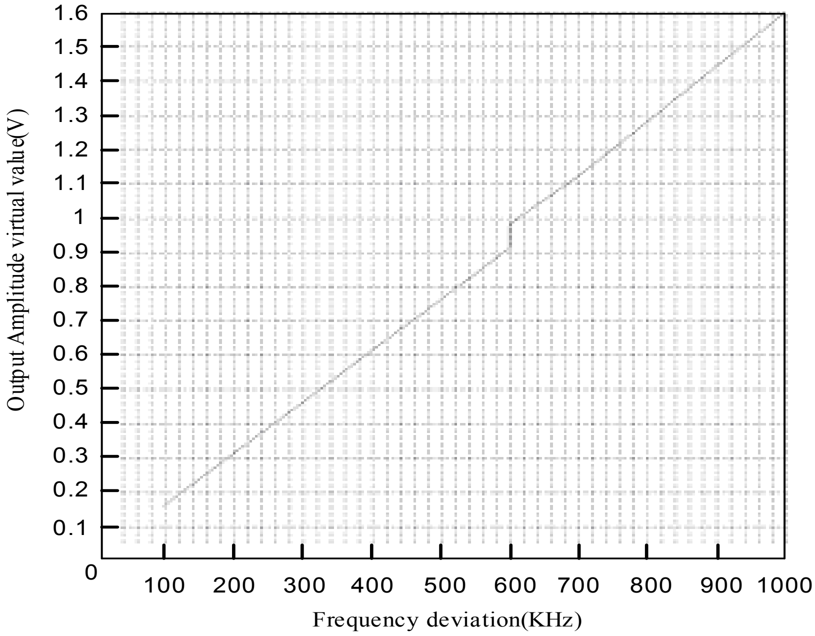


Fig.6 Test of Demodulation Linearity

CONCLUSION

In the telemetry receive station based on PC bus; telemetry receiver is important assembly. With expending of the telemetry application domain, the demand for the small volume, low price portable telemetry receiving equipments is increasing day by day. Thus, we have developed the telemetry receiver based on ISA bus: according to the development of receiver techniques and combining to software radio techniques, the systematic design plan of only one down frequency conversion in preceding analog circuits have proposed. With the application of software radio theory confirming the digital demodulation algorithm and the simulation of full process of digital demodulation by Matlab in the after part of IF, Debugging of the primary product and performance testing have been finished. The test results indicate its technique level has already reached the international advanced level.

The next job can be add demodulation modes, such as PM, BPSK, QPSK, etc, raise the bit rate of demodulation output further and realize PCI bus controls the interface. The final target of the development is making the function of the receiver more perfect.

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