

A DIRECT CONVERSION RECEIVER FOR GMSK IN DIGITAL MOBILE COMMUNICATIONS

Bo Wu, Jing Wang and Yan Yao

Department of Electronic Engineering, Tsinghua University
Beijing 100084, P. R. China

ABSTRACT

The direct conversion (Zero-IF) receiver has drawn much attention recently in digital mobile communications since it is suitable for integration and digital signal processing technology can be used in it to realize complex algorithms. In this paper, a common technique --- quadrature detection is applied to the direct conversion receiver for GMSK signal which is implemented by one DSP chip TMS320C25 and some supporting components at the bit rate of 72kbit/s. The frequency error estimation, timing recovery and decision are all completed by software, which makes the receiver simple and flexible. Computer simulation results and test performance of the actual system are satisfactory. The system is easy to be modified for different requirements and is suitable for discrete realization and integration.

1. INTRODUCTION

The direct conversion receiver has drawn much attention recently due to its suitability for integration. If it is combined with the digital signal processing technology, many functions and complex algorithms can be realized in software. There are many applications of this kind of receiver in different fields.

GMSK or prefiltered FSK is widely used in mobile radio (GSM, CT2, DECT etc.) for its features such as narrow power spectra, constant envelope, coherent/non-coherent detection capabilities and good BER performance^[1]. Generally it can be demodulated by FM discriminator detection, differential detection and coherent detection. In this paper, we use the direct conversion structure and apply quadrature detection which is a common technique used in direct conversion receiver to GMSK signal. After the analysis of its

application to ideal system, we get a simple method which can be realized by general DSP chip. The computer simulation results show that its BER performance for MSK and GMSK signals against AWGN in ideal state is satisfactory.

In the actual system, for the bit rate of 72kbit/s, a Texas Instruments TMS320C25 chip is chosen to complete the frequency error estimation, timing recovery and decision. Its test performance of BER is degraded nearly 2 dB compared to the computer simulation results for GMSK signal at the BER of 1E-3 when BT is equal to 1.0. After some developments, some complex algorithms can be realized and the performance can be improved. The system is easy to be modified in software for different requirements and is suitable for discrete realization and integration.

2. DIRECT CONVERSION RECEIVER AND QUADRATURE DETECTION

The structure of direct conversion receiver is illustrated by Fig.1. The input signal is equally divided into two parts. One part is multiplied by a sinusoidal signal from a local oscillator, this part is denoted the "in-phase" or I component, the other part is multiplied by the same local oscillator signal after it has been phase shifted by 90°. This part is denoted the "quadrature" or Q component. The two parts are then low-pass filtered to remove the mixer products. The resulting baseband signal is then digitally processed after analog-to-digital converted.

For a carrier wave at frequency ω_c arbitrarily modulated, we obtain a signal of the form^[5]

$$s(t) = a(t) \cos(\omega_c t + \varphi(t)) \quad (1)$$

which can be rewritten as

$$s(t) = \text{Re} \{ u(t) e^{j\omega_c t} \} \quad (2)$$

where $u(t) = a(t)e^{j\varphi(t)}$ is known as the complex envelope of the signal $s(t)$. The complex received signal after the low-pass filter is

$$r(t) = x(t) + jy(t) \quad (3)$$

where the in-phase component $x(t)$ is

$$\begin{aligned} x(t) &= s(t) \cos \omega_L t \Big|_{\text{baseband}} \\ &= \text{Re} \left\{ \frac{1}{2} u(t) e^{j(\omega_c - \omega_L) t} \right\} \end{aligned} \quad (4)$$

and the quadrature component $y(t)$ is

$$\begin{aligned} y(t) &= s(t) * (-\sin \omega_L t) \Big|_{\text{baseband}} \\ &= \text{Im} \left\{ \frac{1}{2} u(t) e^{j(\omega_c - \omega_L) t} \right\} \end{aligned} \quad (5)$$

ω_L is the local oscillator frequency. So the complex valued signal $r(t)$ is

$$r(t) = \frac{1}{2} u(t) e^{j(\omega_c - \omega_L) t} \quad (6)$$

The complex signal resulting from the quadrature detection consists of the complex envelope of the signal $s(t)$ multiplied by a vector rotating at the frequency of the difference between the carrier frequency of the signal and the local oscillator frequency. We call this difference frequency error.

From equation (6), we can get the conclusions: for arbitrarily modulated signal after direct conversion quadrature detection, we can first estimate the frequency error using some algorithms such as statistical averaging or Kalman filtering and then process the timing recovery and decision using different algorithms for different modulated signals.

In a complex plane, the amplitude of the signal is given by the magnitude of the vector, and its phase at any time is described by the angle between the vector and the positive I (real) axis. In principle, this structure can be used to demodulate any amplitude or phase modulated signal. As a special case, it is possible to distinguish between vectors rotating in the anticlockwise and clockwise direction, thus input frequencies above the local oscillator frequency are distinct from those below. For MSK and GMSK signals after direct conversion quadrature detection, binary signal 1 corresponds to positive frequency and the vector rotates a positive angle; binary signal 0 corresponds to negative frequency and the

vector rotates a negative angle. So we can make the one-bit decision from the sign of the angle a vector rotates during one period. The one-bit detection only utilize the information of one bit period. For MSK and GMSK, each symbol is spread in time over at least two symbols. Thus using two-bit detection or maximum-likelihood detection, the performance can be improved. This kind of one-bit or two-bit method is so simple that we can realize it in software using general DSP chip.

The direct conversion architecture possesses several advantages over the normal superheterodyne approach^[4]. Firstly, because the IF is at zero frequency the image response frequency is coincident with the wanted signal frequency. This results in the selectivity requirement for the RF filter being greatly eased. Secondly, the choice of zero frequency means that the bandwidth for the IF paths is only half the wanted signal bandwidth. Thirdly, the channel selectivity filtering can be performed using simply a pair of low-bandwidth low-pass filters.

This method can also be used in general CPM signals since it can access the instantaneous phase of the input signal. The DSP implementation makes it possible to realize adaptive channel equalization, matched filter, maximum-likelihood detection etc. in software.

3.SIMULATION RESULTS

To compare the performance of this method in ideal state, the computer simulation structure is constructed using the TOPL communication system simulation software package^[6].

For the low-pass filter, after comparison we select the sixth order Butterworth filter and its 3dB bandwidth is $0.55 f_c$. Fig.3 is the BER performance of the one-bit and two-bit detection for the MSK signal in ideal state. One-bit detection is making decision on the sign of the phase difference of one period. Its performance is similar to the coherent detection of FSK signal. Two-bit differential detection is making decision on the phase difference of two periods after some modifications of algorithm for one-bit detection(the transmitted signal is differential coded). Its performance is degraded about 1.5 dB compared to that of differential coherent detection of 2PSK at the BER of $1E-3$.

Fig.4 and Fig.5 are simulation results of the BER performance of two-bit differential detection of GMSK signal when BT is 1.0 and 0.5 respectively. Compared to the results of the limiter discriminator detection, the performance is improved. In order to improve the performance more, maximum-likelihood detection is needed especially when BT is small. Some work is doing now in this aspect.

4.SYSTEM STRUCTURE

For experiment, we select the modulation signal to be GMSK which is widely used and the bit rate to be 72kbit/s which is specified in CAI (Common Air Interface) [2] of CT2 and implement the actual system.

In transmitter, we adopt quadrature modulator to realize the modulation of GMSK signal, for it has many advantages such as suitability for VLSI implementation, ROM modification flexibility, no accumulations of phase error etc. The structure is shown in Fig.2.

For the receiver, we adopt the direct conversion receiver introduced above. The structure of the receiver is similar to Fig 1. The low-pass filter is the fourth-order Butterworth filter and its 3dB bandwidth is $0.55f_c$. The analog-to-digital converter is a dual 18-bit low power CMOS A/D converter, its min conversion time is $4.5 \mu s$. The resolution of the A/D is so high that the external AGC is not needed. The DSP chip is TMS320C25 [7], the cycle of which is 100 ns. It contains 544 words RAM, 16 bits data bus and address bus, a timer and a serial port. It completes these functions^[9]

- a. Estimating the frequency error and correcting it;
- b. Synchronizing a clock oscillator to the incoming data;
- c. Making one-bit or two-bit decision.

The instantaneous phase is obtained by computing the I and Q data and looking up the table. For simplicity, the statistical averaging method is used to estimate the frequency error. The timing recovery is realized by program control digital PLL. The digital PLL has the advantages of fast acquisition and long time holding. Two sampling points are required in one data period. For the bit rate of 72kbit/s, the sampling rate is 144kbit/s, that is, decision, timing recovery and frequency error estimation must be processed in every two 69 instructions. During one sampling period, the abstract of timing error and adjust of timing are processed. And during the other sampling period, the estimation and correction of the frequency error and decision are processed.

The test performance when BT is equal to 1.0 is shown in Fig.6. Compared to the simulation results, its BER performance is degraded nearly 2 dB at BER of $1E-3$. The reason of this disadvantage is that the system is experimental --- the experimental board and C25 developing board are used, which bring many interferences in the system.

5.CONCLUSIONS

Quadrature detection is a common technique used in

direct conversion receiver for the demodulations of radio and microwave signals. In this paper, we apply it to the demodulation of GMSK signal and the BER simulation result of two-bit differential detection for MSK is degraded about 1.5dB compared to that of coherent detection of DPSK at the BER of $1E-3$. This method can also be used in general CPM signals and complex algorithms can be used to improve the performance. For the bit rate of 72kbit/s, the direct conversion receiver is realized by one chip of TMS320C25 and other simple supporting components. The test results show that the system performance is satisfactory. For high bit rate or other uses, high speed DSP, parallel processing, discrete realization or ASIC technologies can be used.

References

- [1] S.Mc Gruth, C.J.Burkley "Low Complexity GMSK Modulator and Demodulator for Integrated Circuit Implementation",1990 IEEE 40th Vehicular Technology, pp.559-563
- [2] MPT 1375:1989. Second Generation Cordless Telephone Common Air Interface (CAI) Service. The Department of Trade and Industry, London
- [3] S.J.Roome,"Analysis of Quadrature Detectors Using Complex Envelope Notation", IEE Proceedings, Vol.136, Pt.F, No.2, April 1989
- [4]W.H.W.Tuttlebee(Ed.)"Cordless Telecommunications In Europe",Springer-Verlag,London,1990
- [5] J.B.Anderson, T.Aulin and C.E.Sundberg,"Digital Phase Modulation", Plenum Press,New York,1986
- [6] "TOPL User's Manual", Dept. of Electronic Engineering, Tsinghua Univ., 1988
- [7] "Second-Generation TMS320 User's Guide", Texas Instruments Inc.,1987
- [8] B.Wu, Y.Yao and J.Wang, "A Direct Conversion Transceiver For GMSK In Digital Mobile Communications", Proc.ICCT'92, Beijing, 1992
- [9] B.Wu, "Research and Implementation of Zero-IF Receiver",Master's thesis (in Chinese), Department of Electronic Engineering, Tsinghua University, June 1992

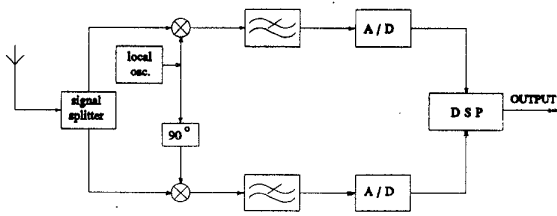


Fig.1 Structure of Direct Conversion Quadrature Detector

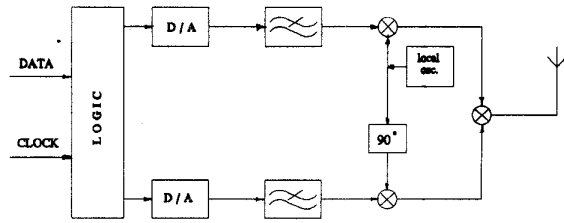


Fig.2 Structure of Quadrature Digital Modulator

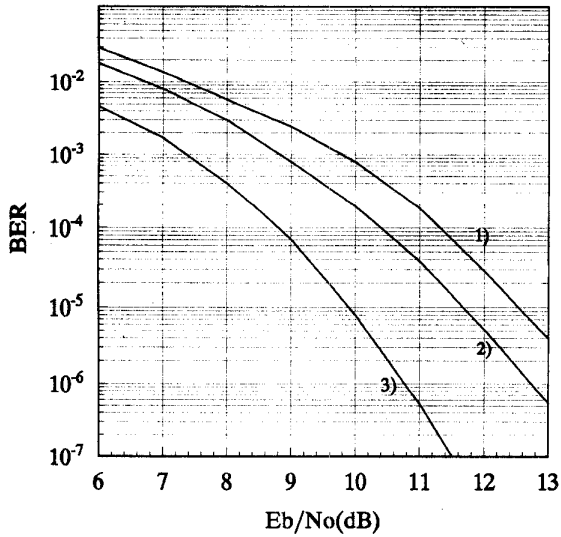


Fig.3 Simulation Results for MSK
 1)One-bit Detection; 2)Two-bit Differential Detection;
 3)Differential Coherent Detection of 2PSK

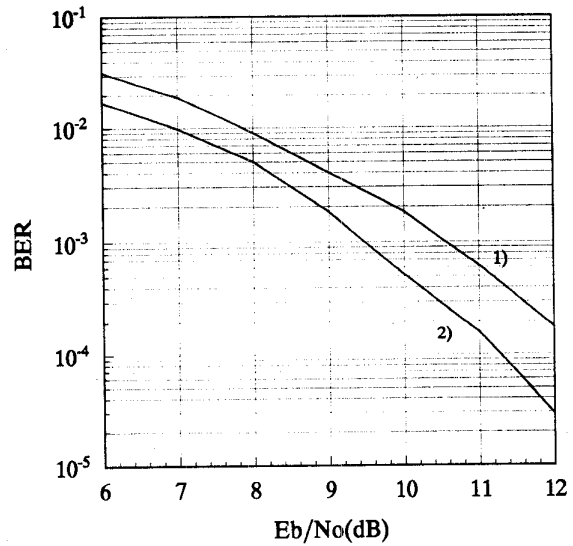


Fig.4 Simulation Results for GMSK (BT = 1.0)
 1)Limiter Discriminator Detection; 2)Two-bit Differential Detection

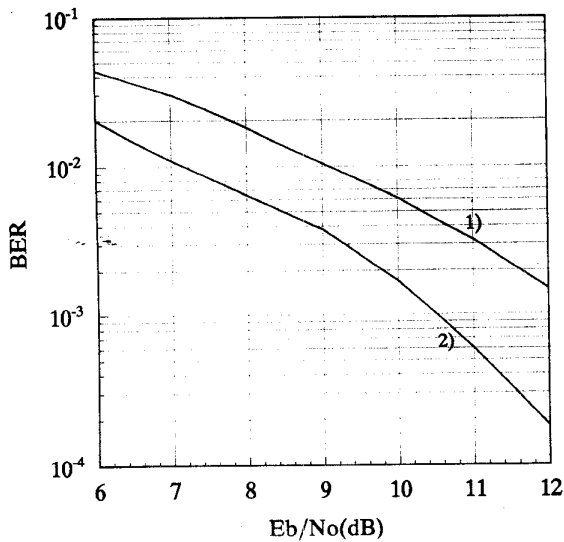


Fig.5 Simulation Results for GMSK (BT = 0.5)
 1)Limiter Discriminator Detection; 2)Two-bit Differential Detection

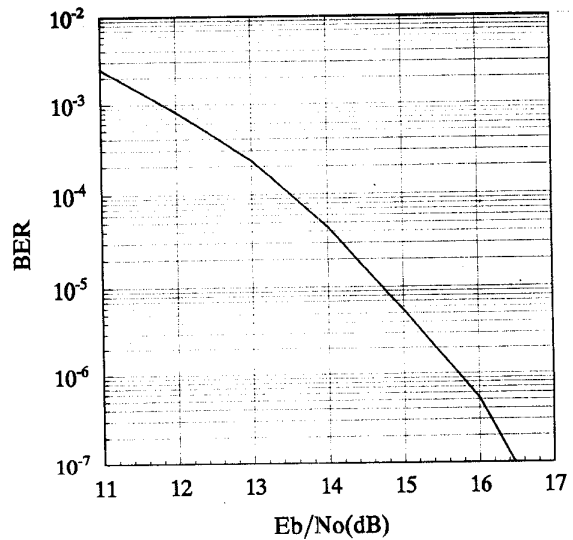


Fig.6 Test Performance of GMSK (BT = 1.0)