A NEW DIRECT DIGITAL RECEIVER PERFORMING COHERENT PSK RECEPTION

Ji Li, R.G.Bosisio and Ke Wu

POLY-GRAMES Research Center
École Polytechnique, C. P. 6079, Succ. Centre Ville
Montréal, Canada H3C 3A7
FAX: (514) 340-5892
Email: liji@grmes.polymtl.ca

Abstract

Coherent reception provides better CNR performance over its differential counterpart. However, this is generally obtained at the expense of increasing complexity of the receiver and more stringent specifications of circuits. In this paper, we describe a new coherent PSK direct receiver, in which a 'soft' phase reference is established by DSP, while the detection is performed directly at mm-wave frequencies. Both measurements and computer simulations validate the proposed new approach.

Introduction

It has been recently shown that a six-port circuit in conjunction with DSP (Digital Signal Processor) is capable of performing digital demodulation directly at frequencies ranging from microwave to mm-wave bands [1]. This new direct digital receiver promises reduced receiver complexity, loose fabrication requirements and fair performance in providing a cost effective alternative to the conventional heterodyne structure used in various digital terminals.

The most widely used modulation schemes in digital communication systems, such as satellite and personal communication systems, are PSK (Phase Shift Keying). There are two types of demodulation techniques: coherent and non-coherent (differential) [2]. In general, the differential detection brings about less complicated receiver configuration whereas the coherent detection is superior in error performance. However the complexity of a coherent receiver may be increased significantly due to the carrier recovery requirement. This task becomes particularly difficult when the carrier recovery has to be performed directly at microwave and millimeter-wave frequencies.

The presence of DSP in the six-port receiver gives us a flexibility of implementing receiver functions using simple software algorithms. In this work we introduce a simple method to establish a 'soft' phase reference needed for the coherent detection. In this way, only AFC (Automatic Frequency Control) is required for the local oscillator. Once the LO frequency is within the 'catching up' range of the receiver, the 'soft' phase reference tracks down and compensates the phase drift

This work is supported by the Natural Science and Engineering Council of Canada (NSERC)

introduced by residual frequency difference such that the detected signal constellation becomes fixed as though the carrier recovery is achieved.

Description of the Method

A block diagram of the six-port direct digital demodulator is shown in Fig. 1. The RF signal is fed into a six-port circuit. From the outputs of the four diode power detectors, the instant phase and frequency of the input RF signal are calculated by the DSP. The DSP controls the local oscillator to perform AFC. Once the carrier and clock recovery are achieved, the modulated data will be readily recovered.

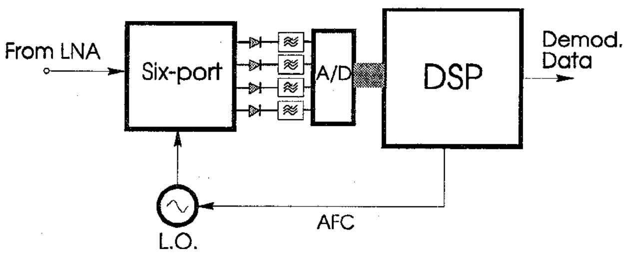

Figure 1. Block diagram of the six-port direct digital demodulator.

A received PSK signal is given by the following expression:

$$s(t) = A_c \cos(2\pi f_0 t + \Phi(t,a)) \quad (1)$$

where f_0 is the carrier frequency and the instant phase $\Phi(t,a)$ is a function of time t and the modulation data sequence a. Taking QPSK as an example and disregarding the band-limit, we have

$$\Phi(t,a) = 2\pi \cdot \frac{a_i}{4} + \phi_0 \quad (2)$$

where $a_i = \{0, 1, 2, 3\}$, $\phi_0 = 0$ or $\pi/4$, a_i is the ith symbol during $iT < t < (i+1)T$, and T is the duration of one symbol.

Suppose the LO frequency is very close to the incoming carrier frequency and the symbol clock synchronization is achieved, then samples detected by the six-port receiver are given by

$$s(i) = A_c \cos(2\pi \Delta f t_i + 2\pi \cdot \frac{a_i}{4} + \phi_0) \quad (3)$$

where $\Delta f = f_c - f_{LO}$, and to simplify the problem, only one sample is taken for each symbol.

It is observed from (3) that due to the presence of residual Δf the sampled constellation is still rotating at an angular speed of $2\pi\Delta ft$. In order to enable a coherent detection, a phase reference must be set up to counter this rotation.

For the case where f_{LO} is sufficiently close to f_c , the phase drift introduced by the term $2\pi\Delta ft$ can be considered negligible during a certain period of time NT, and in this case the instantaneous samples θ_i represent the modulation data. Taking a sample θ_0 as reference and denoting it by P_0 , for every subsequent sample θ_i , let $\varphi_i = \theta_i - P_0$ $(0 \le \varphi_i < 2\pi)$, such that the 4 states of data sequence can be recovered as follows:

$$a_i = (\varphi_i + \tfrac{\pi}{4}) / (\pi/2) \quad (4)$$

In order to eliminate the noise, a FIFO (First-In-First-Out) register of length N is set up, and every latest θ_i that makes $a_i = 0$ is pushed into the register. Let the phase reference P_0 be the average of θ_i 's in the register:

$$P_0 = \frac{\sum_{j=0}^{N-1} \theta_i}{N} \quad (5)$$

In the stable state,

$$P_0 = P_0 + (\theta_{i.latest} - \theta_{i.earliest}) / N \quad (6)$$

Obviously, P_0 will follow the $2\pi\Delta ft$ term and the φ_i 's will become relatively fixed regardless of Δf. In this way, once the test sequence is detected, the a_i 's will be mapped into corresponding bits in conformity to the transmitting end. Although the example is given for QPSK demodulation, this method also applies to all other PSK and even QAM modulations.

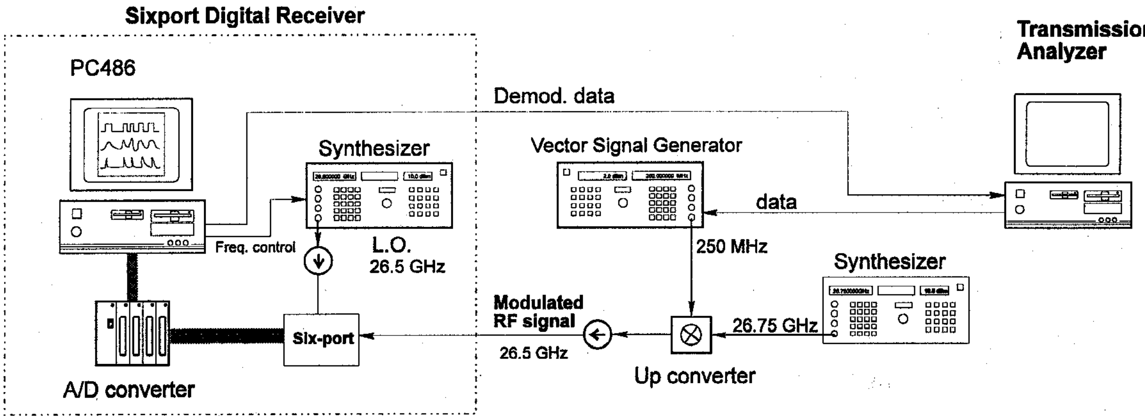

Figure 2. Block diagram of the test setup for measurement simulation.

Results

A measurement simulation was made to verify the above procedure. Figure 2 is the block diagram of the test setup. The transmitter is composed of a HP8782B vector signal generator, a upconvertor and a RF source. The 26.5 GHz PSK is fed into the six-port receiver. No additional amplifier is placed before the six-port junction. The receiver LO power was -1.5 dBm. A PC486 was used to simulate the DSP functions. The input power level of the receiver was controlled by the internal attenuator of the vector signal generator which provides over 160 dB of variation in output level. Five basic PSK demodulations were tested: differential and coherent BPSK, QPSK and coherent 8PSK. A small random variable frequency deviation of the receiver LO was intentionally made to simulate the residual Δf.

A statistical computer simulation was also performed to verify the measurement results. It takes into account the phase noise of the signal generators and LO, the ADC quantitized noise. The interference brought in by DC path was also considered. It is noticed that for this measurement simulation the effect of Gaussian white noise is negligible. BER (Bit Error Rate) was simulated as a function of input power level, and a perfect carrier recovery was assumed during the coherent PSK simulation.

Figure 3 shows the measured and simulated BER versus input powers. It is found that the coherent PSK reception presents about 1 dB (BPSK) to 2 dB (QPSK) better than their differential counterparts. The agreement between measured and calculated data suggests a good performance of the proposed coherent demodulation method. It also shows that the demodulation can be performed at a power level as low as -35 to -45 dBm. It must be mentioned that the measurement results are by far not optimized. A significant improvement in performance can be expected once the six-port junction design and system configuration are optimized.

Conclusion

A novel approach is proposed, which enables the coherent PSK demodulation directly at millimeter wave frequencies using a new receiver concept. This makes it possible for new six-port digital receiver to deal with various coherent and differential PSK modulation schemes. The receiver can be used in various wireless microwave/mm wave digital terminals to provide a cost-effective alternative to conventional heterodyne receivers.

References

[1] Ji.Li, R.G.Bosisio and K.Wu, "A Six-port Direct Digital Receiver", Digest of IEEE MTT Symposium, Vol. 3, pp.1659-1662, San Diego, May, 1994

[2] F. Xiong, "Modem Techniques in Satellite Communications", IEEE Communication Magazine, pp 84-98, August, 1994

[3] Gerhard Schultes *et al*, "A New Incoherent Direct Conversion Receiver", IEEE Vehicular Technology Conference 1990, pp.668-674

[4] T.E.Hodgettes and E.J.Griffin, "A Unified Treatment of the theory of six-port re-flectometer calibration using the minimum of standards", Report No. 83003 R.S.R.E Malvern, Aug. 1983

[5] Ji.Li, R.G.Bosisio and K.Wu, "A Collision Avoidance Radar Using Six-port Phase /Frequency Discriminator (SPFD)", Proc. of 1994 IEEE National Tele-systems Conference, pp55-58, San Diego, May, 1994

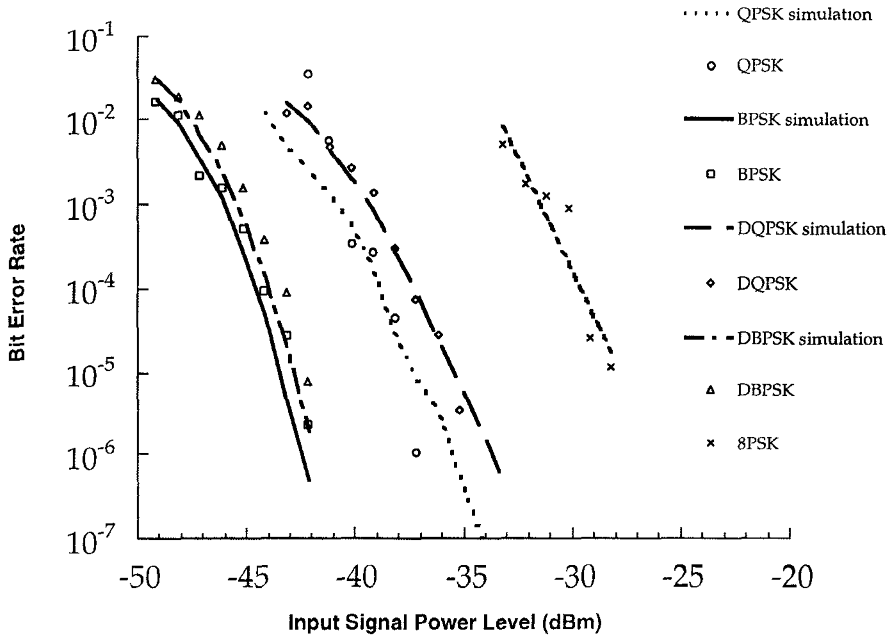

Figure 3. Measured and computer simulated BER performance