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MULTICARRIER MODULATION RECEIVER BASED ON DIGITAL FOURIER TRANSFORM

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Abstract. Multicarrier modulation has a potential of high performance in a hostile RF environment. The major obstacle is the design of an economical receiver which can separate closely spaced subchannels. This paper describes an experimental receiver designed for a narrowband personal communication service network using eight subcarriers per channel. Subcarrier detection is done by an optimized 24 point discrete Fourier transform algorithm. It operates with only 14 integer multiplication, and makes 14.4 % processor load for a state-of-the-art IBM PC. Further, a brief description of the frequency control of the local oscillator by a digital processing is given.

Key words: Multicarrier modulation, Fourier transform, subcarrier detection, receiver design, radio frequency.

1. Introduction

The Multicarrier Modulation (MCM) can be described as splitting the channel bandwidth into M subchannels, each carrying independent data stream. This data streams can be bit- interleaved to produce a single channel with a capacity M times that of a subchannel. This technique enables large bit rate to symbol rate ratios and gives a long symbol interval for the given bit rates. This is important in order to increase the signal immunity against impulse noise and fast fades, and eliminates need for an equalization [1]. It also provides a very compact signal spectrum, with flat top and sharp roll-of in transition region, which indicate good spectrum utilization and potentially high receiver sensitivity.

The major problem for MCM techniques is separation of subchannels at a receiver. Analog techniques, based on a battery of filters, are impractical for large M and for symbol rate close to subchannel bandwidth [2].

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Development of inexpensive and powerful A/D converters and DSP processors enabled a practical receiver design based on Digital Fourier Transform (DFT), which is the subject of this paper.

Specific application discussed here is developed for Nationwide Wireless Network (NWN), on behalf of MTEL Technologies, Jackson, and submitted to the FCC [2,3]. In its ruling in July 1992 the FCC has granted a tentative pioneer preference for application of the proposal, as a Narrowband Personal Communication Service (NPCS) [4].

2. System description

The NPCS has spectrum allocated in the 930 MHz band. The individual channels have 50 kHz bandwidth with emission spectrum mask defined by the FCC as shown by the dashed line in Fig.1. This sharp transition region is necessary in order to avoid interchannel interference even if an adjacent channel transmitter is much closer than any of the transmitters of the monitored channel. Fig. 1 shows also the spectrum of the signal of an NWN transmitter, which is under the mask and follows closely the boundaries.

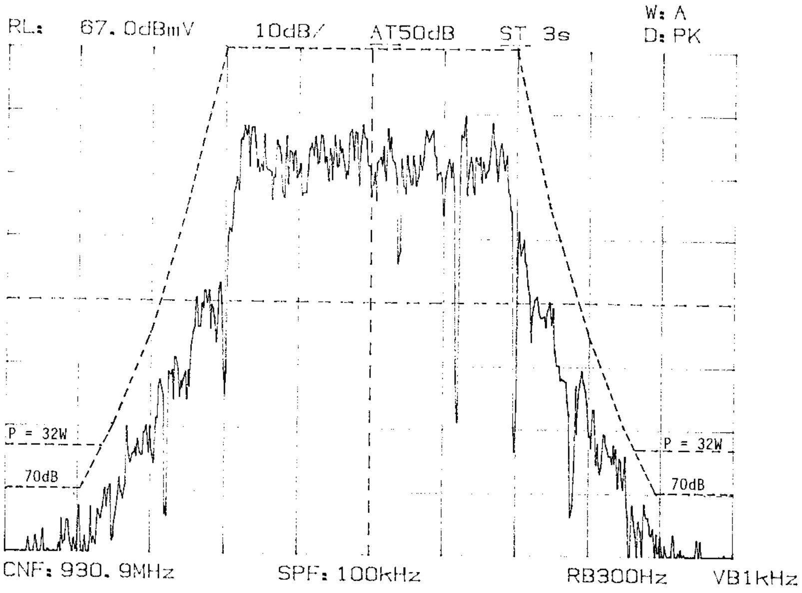

Fig. 1 Spectrum of the MCM signal with 8 subchannels carrying random data at 4 kbaud rate.

Our decision to use MCM technique is related also to the requirement of the simulcast operation of the NWN network transmitters. This means that a number of transmitters simultaneously send the same information in mutually overlapping area. This technique increases coverage area, improves building penetration and reduces the effect of shading and multipath fades. It also imposes restruction to a minimum symbol interval in order to accommodate differential propagation delay in overlap area. We have chosen 4 kbaud rate (250 μs symbol interval) in line with relevant measurements [5].

Symbol transition interval is limited to 50 μs , so that stable symbol parameters are expected for 200 μs, which corresponds to time window for DFT. The frequency resolution is, therefore, $\Delta f = 1/200\mu s = 5$ kHz, so that subcarrier separation (subchannel bandwidth) is also 5 kHz. Since the channel pass-band is 40 kHz the number of subchannels is M=40/5=8.

Further we opted for a variant of MCM called Permutation Modulation (PM) [6], which has features of constant energy per symbol, efficient spectrum utilization and low requirement of SNR [7]. In our system four out of eight carriers are ON and four are OFF in any symbol.

3. Experimental receiver design

The experimental receiver block diagram is shown in Fig. 2. The RF down-converter with intermediate frequency 45 MHz is used to bring the signal into a desired frequency band, typically below 100 kHz. The A/D converter has 16 bit/sample resolution, so that no AGC in RF block is needed. The DSP board, connected to the PC bus, has C 30 floating point processor. The PC is IBM compatible, 50 MHz, 486 processor. This receiver design provided flexibility nesessary to investigate many design options as well as to simulate potential signal distortions.

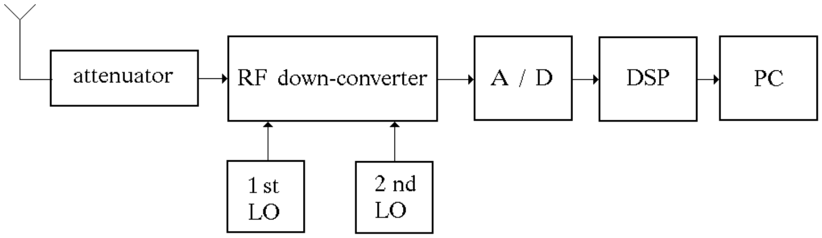

Fig.2. Experimental receiver block diagram

3.1 Symbol detection

Symbol detection is based on DFT with 200 μs window, i.e. 5 kHz resolution. Subcarrier frequencies should be positioned at 5 i kHz, where i is an integer. The number of samples per window should be larger than 16 in order to avoid aliasing. If exactly 16 samples per window are used, the minimum of one subcarrier is aliased to itself with random phase causing potentially destructive interference. The choice of the number of samples per window is governed by the minimum processing requirement, as well as the rejection of the interference due to intermodulation products.

Table 1. Minimum number of multiplications versus number of samples

Samples per window	integer multiplications
18	22
20	32
24	14
32	44

Minimum number of multiplication per a DFT is analyzed for several numbers of samples per window, and results are given in Table 1. In this analysis we restricted DFT calculation only to 8 bins, coinciding with subcarrier frequencies. In this analysis we used different optimization techniques, such as substitution multiplication by 0.5 with shift right and eliminating it from multiplication count etc. Please note that standard $N = 32$ point FFT operates with $N/2 * \log 2N = 80$ complex multiplication (or 320 real multiplication), so that any of the optimized algorithms brings large gains.

The number of additions linearly depends on N and it is less then $8 * N$ (e.g. 142 additions for 24 point DFT). Although the optimum processing algorithm strongly depends on the type of processor used, e.g. on the number of cycles per multiplication and addition, we see no reason for going with less than 24 samples per window.

Taking more than 24 samples can bring a couple of benefits. First, it can reduce nonlinear distortion due to so called triplebeat effect. This distortion produces noise at frequencies $f_i + f_j - f_k$, where f_i, f_j, and f_k are subcarrier frequencies. The intermod products failling outside signal spectrum can be rejected, instead of being aliased back into signal spectrum. Our signal has seven triple-beat components on each side, and they can be all avoided by a

32 sample DFT. Unfortunately most of the triple-beat components fall into a signal spectrum directly (not through aliasing) and therefore AGC in RF section is necessary for high dynamic range.

Another advantage of a larger number of samples per window is in finer symbol synchronization. The sample clock is asynchronous with respect to the symbol boundaries, so that the optimal window position has inherently ±1/2 sampling interval precision. On the other hand, a much larger error is expected while switching between signals from different transmitters in a simulcast overlap, so that the above mentioned effect is marginal.

We have implemented 24 points DFT into an assembly language routine in 486 PC and found that approximately 1800 clock cycles is enough for DFT, followed by a magnitude square calculation, sorting of bins, and decoding from a look-up table. This corresponds to 14.4% of the processor load on our 50 MHz 486 PC.

3.2 Frequency offset control

Our experiments have shown that for good receiver sensitivity the frequency offset of the subcarrier positions should not exceed 200 Hz. This means that our local oscillator, normally at 885 MHz should have stability better then 0.25 ppm. Crystals with this stability are expensive, and it can be advantageous to introduce digital control of the local oscillator frequency. The block diagram of the control loop is shown in Fig.3. The frequency offset is extracted by DFT performed by five Goertzel filter distributed around a subcarrier frequency which is kept constant during the preamble. By comparing the signal amplitude at the output of these filters the frequency offset is detected by the control module. Further, a control signal is generated by D/A converter to make correction of the local oscillator.

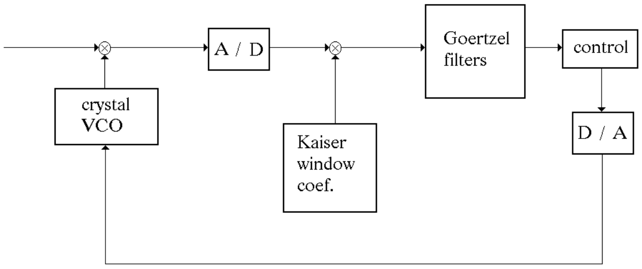

Fig.3. Block diagram for digital control of frequency offset

4. Conclusion

The multicarrier modulation technique improves signal immunity against impulse noise and fast fades, eliminates need for equalization, and enables simulcast operation. It also provides high sensitivity for a non-coherent detector. These features make it attractive for application in a narrowband PCS. The major issue is a design of a relatively simple and compact receiver. This paper gives an example of the receiver design based on digital signal processing. It is shown that optimized DFT algorithms can largely outperform general purpose FFT algorithms.

This paper also considers a method for frequency stabilization of the local oscillators by digital processing in a non-coherent receiver.

Field tests with the receiver described here proved the feasibility of the proposed technique. The next step is a design of integrated circuits which would implement the described algorithms in a compact receiver.

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