IEEE P802.11
Wireless LANs

Low-Cost, High-Rate Minimum-Shift-Keyed Modem Technique

Date: November 3, 1997

Author: John H. Cafarella
MICRILOR, Inc.
17 Lakeside Office Park, Wakefield, MA 01880
Phone: 781-246-0103
Fax: 781:246-0157
e-Mail: JohnCafarella@worldnet.att.net

Abstract

Minimum-Shift-Keyed modulation has long been attractive for modern communications, both spread-spectrum and conventional, because it offers nearly constant-envelope in the time domain while maintaining excellent confinement in the frequency domain. A large variety of techniques exist for generation and for processing of MSK waveforms; these suffer from limitations, mainly reproducibility and cost. The present approach combines effective means for modulation and demodulation of MSK waveforms requiring very little departure, in current-generation technology, from more traditional Bi-Phase-Shift or Quadri-Phase-Shift Keying (BPSK or QPSK).

The motivation for the technique was the development of low-power, low-cost implementations of direct-sequence spread-spectrum radio modems for wireless Local Area Networks (LANs). The application is particularly stressing on cost and power. The main advantages gained by using MSK are:

a) spectral confinement - MSK has lower spectral side lobes than BPSK, thus avoiding the need for expensive filters, and only moderate amplitude modulation is induced by filtering;

b) bandpass limiting on receive - MSK exhibits nearly constant envelope in the time domain; filtered BPSK would exhibit dips in envelope which would exaggerate interference when passed through a bandpass limiter;

c) power amplifier saturation on transmit - The nearly constant-envelope of MSK while at the same time possessing spectral confinement means that the output power amplifier could be operated nearly into saturation without spectral regeneration which would occur using filtered BPSK.

Low-Cost, High-Rate Minimum-Shift-Keyed Modem Technique

Introduction

Minimum-Shift-Keyed modulation has long been attractive for modern communications, both spread-spectrum and conventional, because it offers nearly constant-envelope in the time domain while maintaining excellent confinement in the frequency domain. A large variety of techniques exist for generation and for processing of MSK waveforms; these suffer from limitations, mainly reproducibility and cost. The present approach combines effective new means for modulation and demodulation of MSK waveforms requiring very little departure, in current-generation technology, from more traditional Bi-Phase-Shift or Quadri-Phase-Shift Keying (BPSK or QPSK).

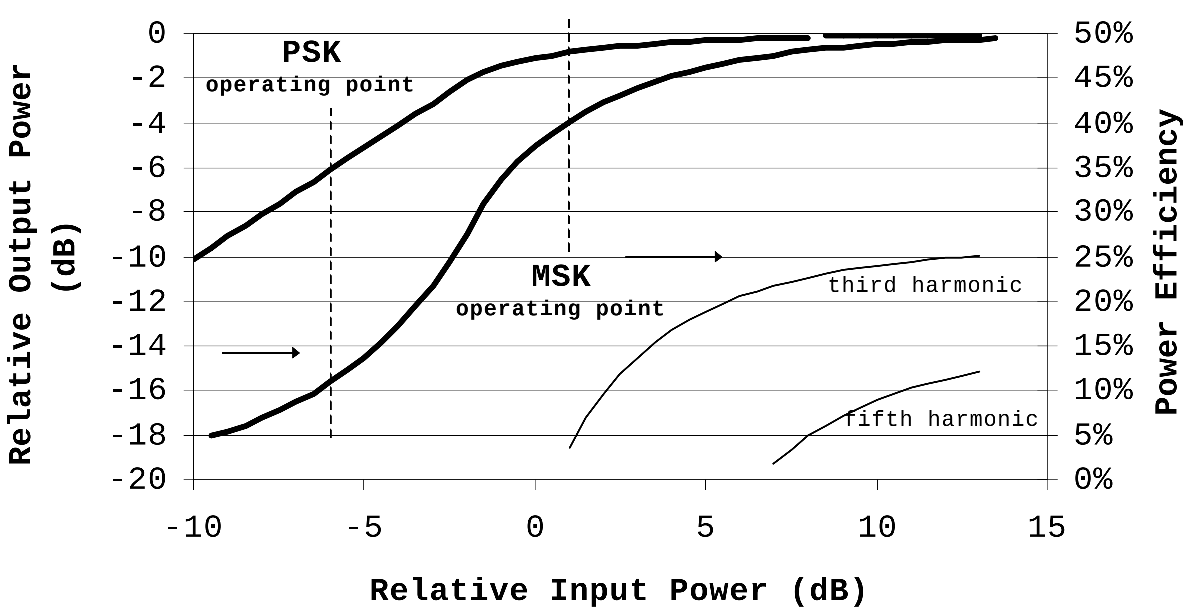
The motivation for the technique was the development of low-power, low-cost implementations of direct-sequence spread-spectrum radio modems for wireless Local Area Networks (LANs). The application is particularly stressing on cost and power. The main advantages gained by using MSK are:

a) spectral confinement - MSK has lower spectral side lobes than BPSK, thus avoiding the need for expensive filters, and only moderate amplitude modulation is induced by filtering;

b) bandpass limiting on receive - MSK exhibits nearly constant envelope in the time domain; filtered BPSK would exhibit dips in envelope which would exaggerate interference when passed through a bandpass limiter;

c) power amplifier saturation on transmit - The nearly constant-envelope of MSK while at the same time possessing spectral confinement means that the output power amplifier could be operated nearly into saturation without spectral regeneration which would occur using filtered PSK.

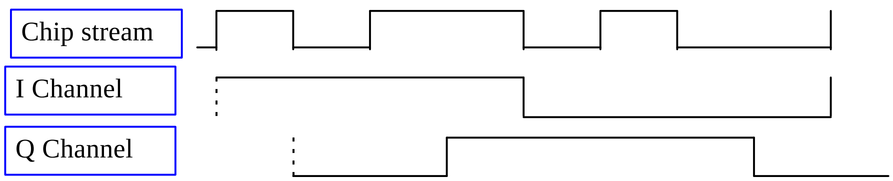
Power dissipation is of utmost importance for PC card implementations of wireless LAN devices. The figure below shows the output power and power efficiency vs. input power (relative to the level which would cause a 1-dB



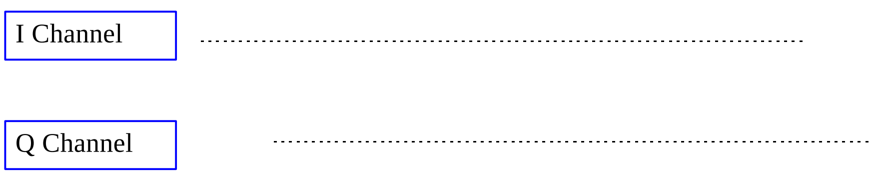
gain compression). The operating point for filtered PSK is typically 6-dB below the 1-dB compression point. A PC card using MSK can be operated with the power amplifier running into saturation for much improved efficiency.

MSK Waveform Generation

Because available Baseband-to-IF modulators anticipate the possible use of Differential QPSK, these modulators make available both I and Q channels. A simple technique for generating MSK is to shape Offset QPSK, which is well known. The even chips feed the I channel, while the odd chips feed the Q channel. For a chit duration T_c, each of these streams consists of digital pulses if duration $2T_c$, and the streams are offset by the original chip time T_c.

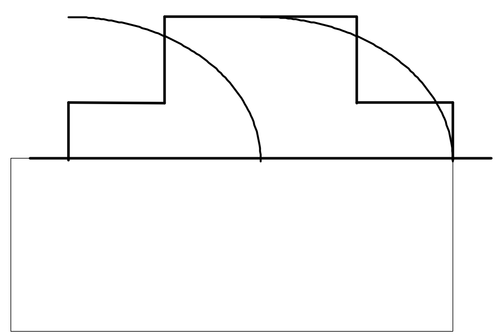


Each $2T_c$ pulse must be re-shaped to a half-sinusoidal pulse whose amplitude is positive or negative, respectively, depending upon whether the digital pulse is 1 or 0.

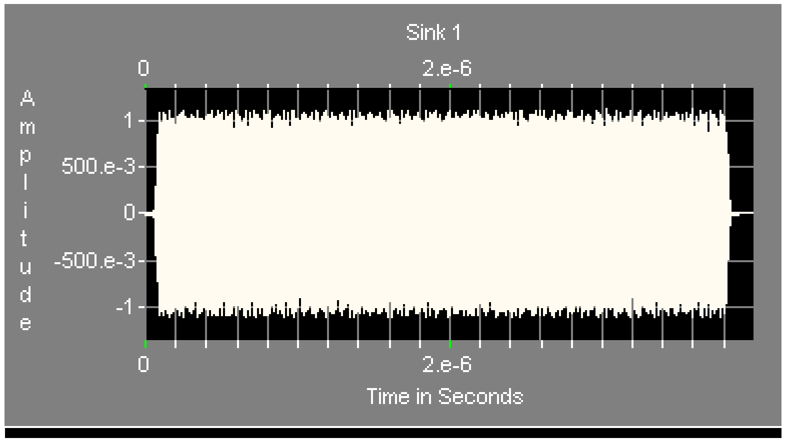


The waveform generator herein consists of a digital/analog MSK-pulse approximation followed by analog fitering. The MSK-pulse approximator employs a staircase function which, when filtered, closely approximates the half-cosine shape of the ideal MSK chip waveform. The staircase approximation causes the errors to be far out in frequency, hence easily filterable. The staircase is produced by the action of logic gates which drive resistive summing networks. Thus, the critically timed digital circuitry is contained inside the digital chip, and is small compared to other digital functions. The summing requires eight package pins for digital outputs; this supports the I and Q channels as well as balanced outputs.

The staircase set the first and last $T_c/4$ portions at .37, and the middle $T_c/2$ portion at level 1. A more-general solution (using four independent parameters) would produce a somewhat better spectrum, but would require a more complex implementation.

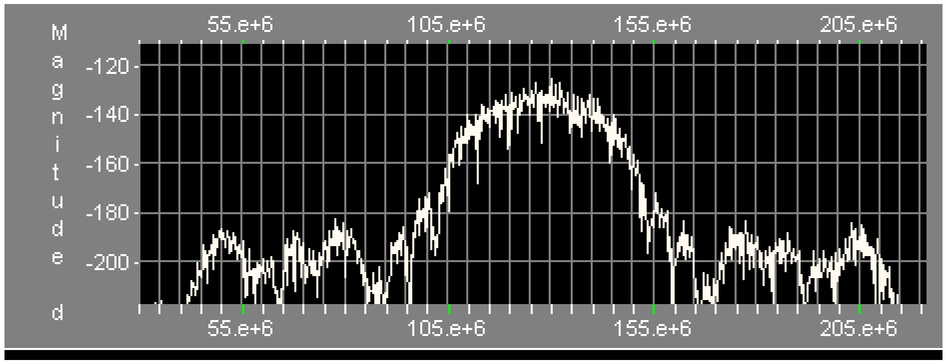


A SAW bandpass filter, used for calculation purposes, was specified to have .25-dB in-band ripple, 48-Mhz bandwidth, and 16-Mhz transition bands. This is overkill, in terms of filtering performance, but a SAW filter would be much smaller than other alternatives.

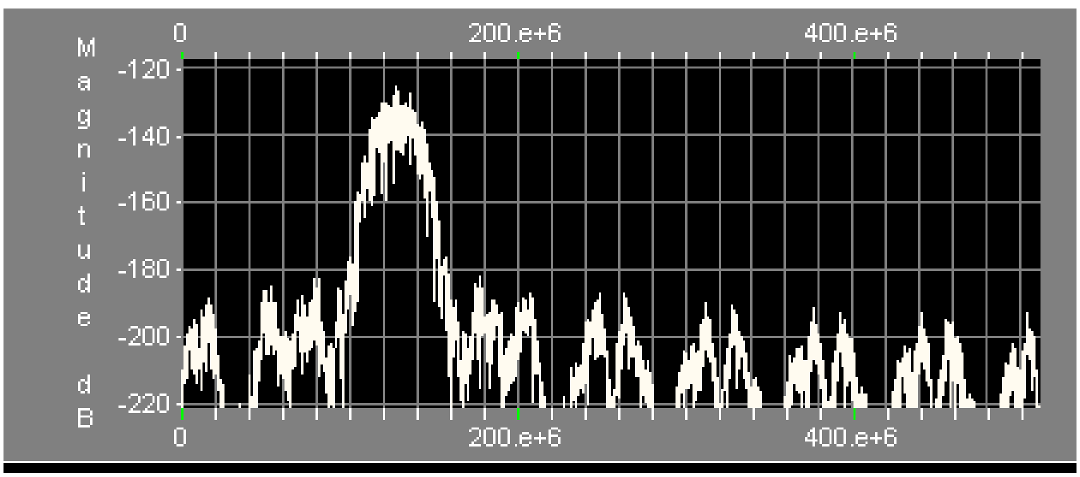


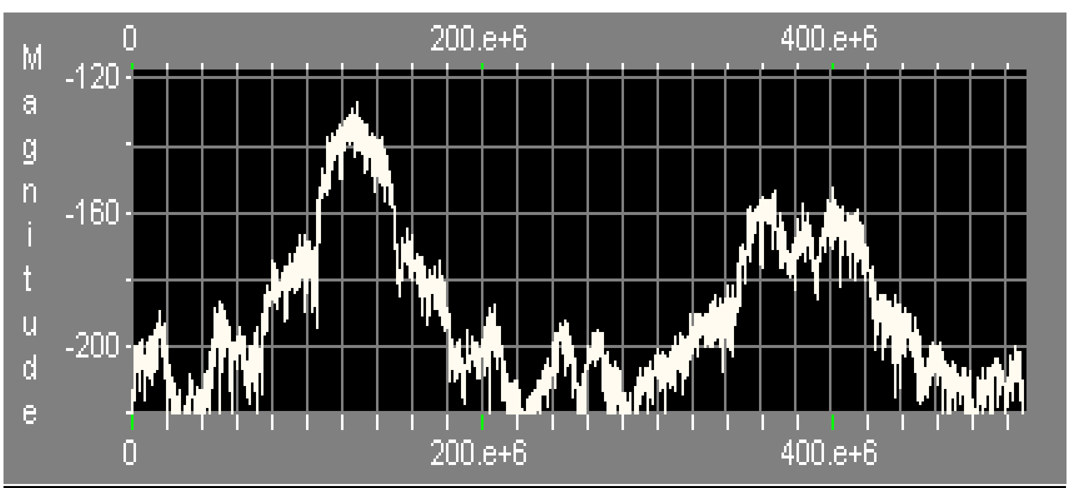
A key issue in employing MSK is the behavior of the transmitted signal in the presence of power-amplifier nonlinearities. To explore this, we begin by showing the time-domain amplitude ripple and transmitter spectrum of the baseline design in the absense of amplifier nonlinearities. The amplitude ripple is about 10%; numerical averaging revealed the average ripple to be 1.25 dB. This is considerably lower than the roughly 3 dB that would be experienced with BPSK

The spectrum shows the spectral sidelobes approximately 50 dB down from the main lobe. This is about 20 dB lower than that of unfiltered MSK. This level, imposed by the SAW filter, is maintained over a wide range of frequencies.



Using MSK instead of BPSK enables the power amplifier to be driven nearly into compression; this, in turn, means that a much more efficient power amplification can be achieved using MSK. The next two spectra contrast the linear case to that which incorporates a soft saturation effect. The presence of the third harmonic reflects the nonlinearity, although the near-in spectral side lobes are quite tolerable. (Note that the third-harmonic distortion is easily removed in practice by filtering, but that near-in spectral components would not be.)



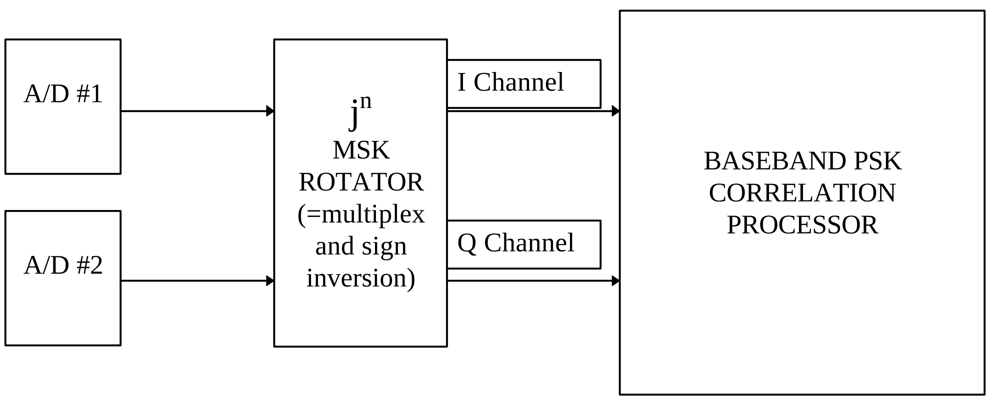


The transmit amplifier operating point was approximately 1.7 dB into gain compression.

Receive Processing

There is a well-known relationship between receiver hardware implementations for use with BPSK and MSK. Amaroso's technique[1] used an LO offset by a quarter of the chip rate, with PSK matched filters in the processing channels. The offset LO provided 90° rotation between samples which were separated by a chip, although the matched filter was operated at twice the chip rate.

In the case of correlation reception, the receiver operates at the chip. The correction for using MSK can be effected via a multiplex operation combined with sign inversions. Specifically, since MSK alternates the complex samples between I and Q channels, a receiver designed for PSK and which has I and Q channels in order to handle the unknown propagation phase can also be made to process MSK. If alternate receive samples of an MSK signal are swapped between the I and Q samples with sign changes every other alternation, then the sequence of compled samples is, in effect, multiplied by j^n. The correlation sum is carried out in the baseband (I & Q) channels, and the presence of both channels accommodates the unknown carrier phase. The multiplexing technique described herein is considerably easiler to implement than an offset LO.



With this technique, an existing correlation processor for PSK signals can be made to process MSK waveforms with no other changes than the "rotator" shown.

[1] Frank Amoroso and James A. Kivett, "Simplified MSK Signaling Technique," IEEE Trans. Commun. (Concise Papers), vol. COM-25, pp. 433-441, April, 1977.