GMSK in a nutshell

Thierry Turletti
Telemedia Networks and Systems Group
Laboratory for Computer Science
Massachussets Institute of Technology
turletti@lcs.mit.edu

April, 96

Abstract

This report presents a brief overview of the GMSK modulation scheme.

1 What is GMSK ?

GMSK stands for *Gaussian Minimum Shift Keying*. This is a modulation scheme in which the phase of the carrier is instantaneously varied by the "modulating" signal (i.e. the information to transmit). GMSK differs from MSK (*Minimum Shift Keying*) in that a Gaussian Filter of an appropriate bandwidth (defined by the BT product) is used before the modulation stage. The time-domain impulse response of the filter is described in Equation 1, where $k_1 = \frac{\pi}{\sqrt{2 \ln 2}}$ and B is the half-power bandwidth.

$$h(t) = \frac{k_1 B}{\sqrt{\pi}} e^{-k_1^2 B^2 t^2} \tag{1}$$

MSK is binary digital FM with a modulation index of 0.5. It has the following important characteristics: constant envelope, relatively narrow bandwidth and coherent detection capability. The most important characteristic of MSK is that it is a constant-envelope variety of modulation. This makes the modulation scheme more immune to noise than the *Amplitude Shift Keying* (ASK) scheme. However, MSK does not satisfy the requirements with respect to out-of-band radiation for single-channel-per-carrier (SCPC) mobile radio. GMSK uses a pre-modulation Gaussian filter which makes the output power spectrum more compact. The pre-modulation Gaussian filter has narrow bandwidth and sharp cutoff properties which are required to suppress the high-frequency components. Moreover, it has a lower overshoot impulse response which allows to protect against excessive instantaneous deviation.

Figure 1 shows the 16-bit NRZ (Non-Return-to-Zero) sequence $(-1, -1, -1, +1, +1, -1, +1, +1, +1, +1, -1, +1, -1, +1, -1, -1)$ and the corresponding phase trajectory of MSK (left) and GMSK (right) signals. The phase increment per symbol is $\pm \frac{\pi}{2}$ for the MSK signal. Figure 2 shows the in phase I (real) and quadrature Q (imaginary) components of the MSK (left) and GMSK (right) corresponding baseband equivalent signals. Finally, figure 3 shows the MSK and GMSK modulated signals for two different symbols. Notice the slight difference of frequency between the modulated signal of symbol (-1) and symbol (1). This shows the FM nature of MSK and GMSK signals.

2 How to implement a GMSK modulator ?

There are many ways to implement a GMSK modulator. A block diagram of such a modulator is shown in Figure 4.

An algorithm of a GMSK modulator is described below:

- Create the NRZ $(-1, 1)$ sequence from the binary (0,1) input sequence.
- Create N samples per symbols (N depends of FsT).
- Integrate the NRZ sequence.
- Convolute with a Gaussian function.
- Compute the corresponding I and Q components. At this stage, we have the quadrature components of the baseband GMSK equivalent signal.
- Multiply the I and Q components by the corresponding $cos(n\ w_0)$, and $-sin(n\ w_0)$ carriers.
- Add the two resulting flows.

3 How to implement a GMSK demodulator ?

A coherent detector can be used to demodulate GMSK signal, see Figure 5.

However, to avoid the need for the receiver to have its own reference, (i.e. the necessity of a coherent demodulation) a differential encoding can be used to create the NRZ signal at the input of the demodulator. Table 1 shows how to convert the binary input (0,1) to differential $(-1, 1)$ symbols. It can be easily computed using the following operations:

$$X = x[n] \oplus x[n-1], \quad Y = 1 - 2\,X \tag{2}$$

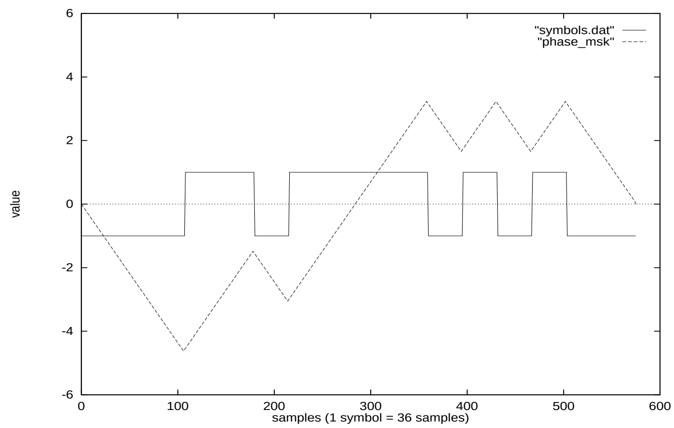

Figure 1: Symbols and phase (in radians) of MSK and GMSK signal vs samples

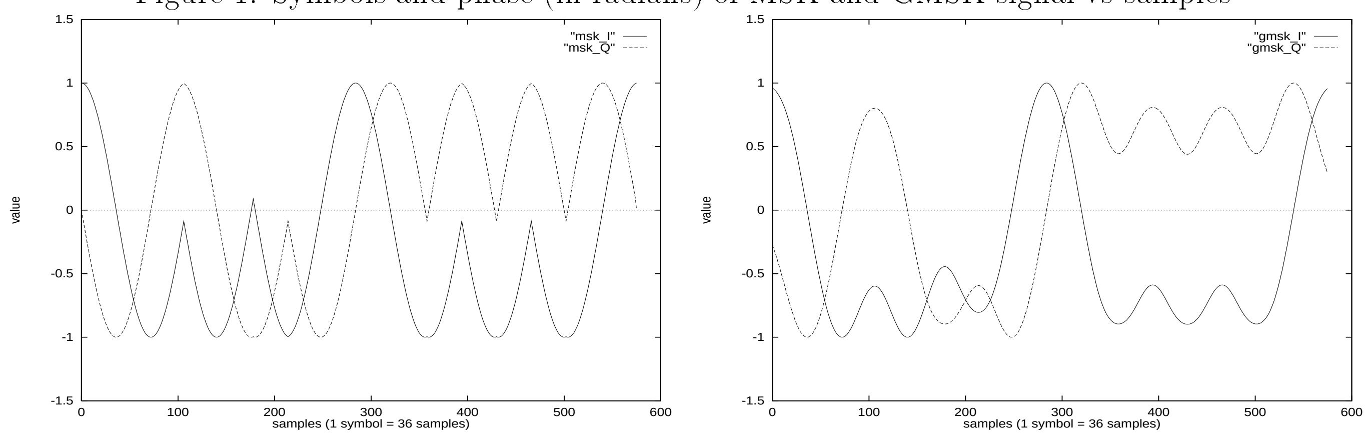

Figure 2: Baseband (I,Q) MSK and GMSK signals vs samples for fsT=36

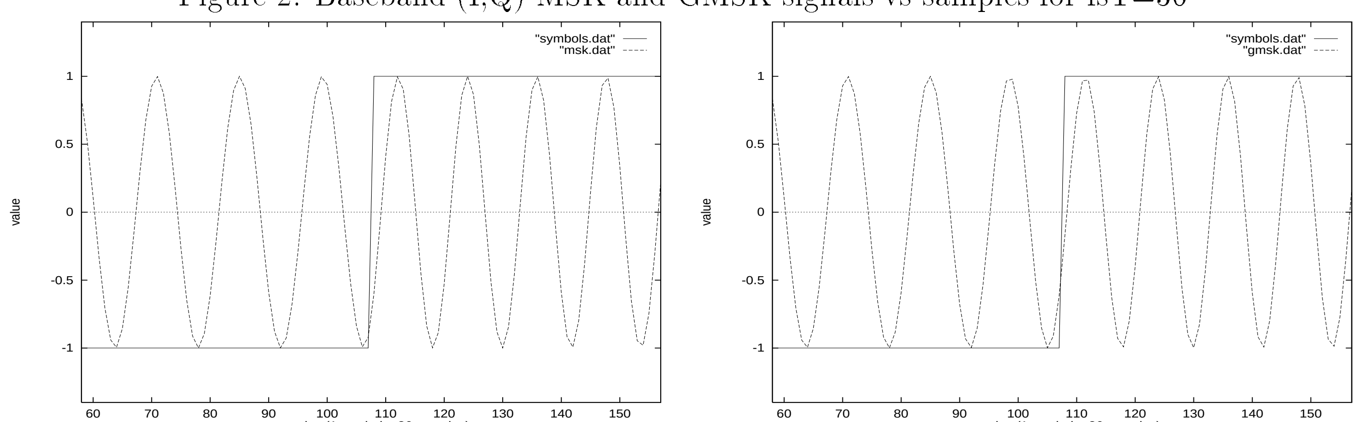

Figure 3: MSK and GMSK signal vs samples for fsT=36

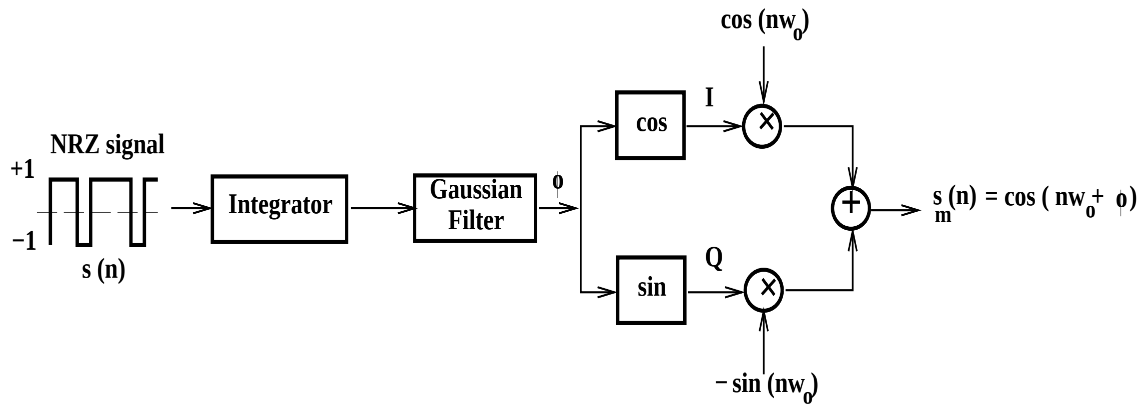

Figure 4: GMSK modulation block diagram

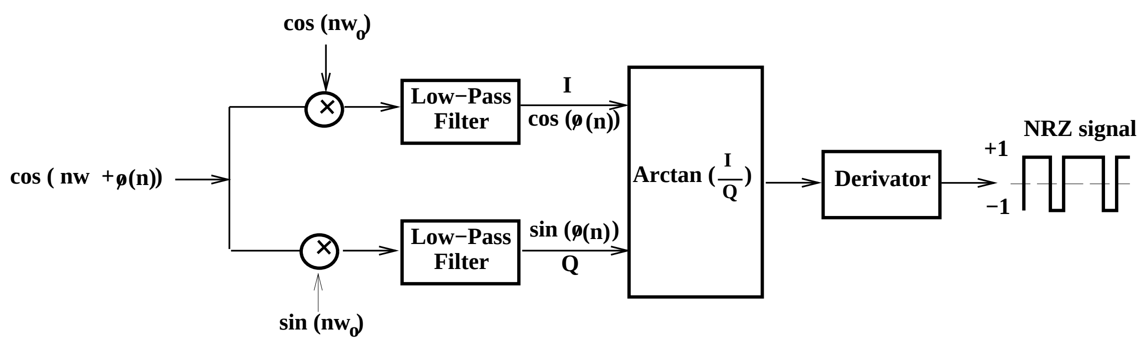

Figure 5: GMSK Demodulation block diagram

4 A specific GMSK scheme for GSM

GSM uses GMSK with modulation index $h = 0.5$, BT (filter bandwidth times bit period) equal to 0.3 and a modulation rate of 271 (270 5/6) kbauds. That makes $B = 81.3$ kHz when T is about $3.7\,\mu s$. The GMSK modulation has been chosen as a compromise between a fairly high spectrum efficiency (of the order of 1 bit/Hz) and a reasonable demodulation complexity. The constant envelope allows the use of simple power amplifiers and the low out-of-band radiation minimizes the effect of adjacent channel interference.

Theoretically, a modulating symbol influences the signal during an infinite period. Luckily, this influence becomes negligible outside a period during $3\,T$. This source of interference can be limited by separating geographically the usage of adjacent frequencies. The protocol for frequency use in GSM is an operator dependent function of frequency planning activities. The GSM specifications leave these issues to manufacturers who can incorporate clever dynamic channel allocation schemes within their equipment.

This source of interference is not the only one a receiver is confronted to: a GSM receiver has also to tackle the following problems:

x[n]	x[n-1]	X	Y
0	0	0	$+1$
0	1	1	-1
1	0	1	-1
1	1	0	$+1$

Table 1: Logical table for differential encoding

- *variable signal attenuation*: because of free space loss and also because of the attenuation due to the presence of obstacles along the way.
- *multipath propagation:* incoming RF signals results from reflections of the transmitted signal from the environment (houses, mountains and various obstacles) where each path yields valid signals with different relative time delays.
- *adding noise:* co-channel interference (interferences from other GSM emitters using the same frequency band at the same time), adjacent band interference (as discussed before), thermal noise, etc.

The GSM specifications do not impose one particular demodulation algorithm. However, they impose minimal performance figures measured after correction of errors by channel decoding. The algorithm used must be able to cope with two multipaths of equal power received at an interval of up to 16 μs (i.e. more than four symbols). With such a level of intersymbol interference, simple demodulation techniques are ineffective and an equalizer is required. The aim of the equalizer is to separate the different signals, to sharpen and recover the original signal. It is a filter that uses the 26-bit training sequence included in each burst transmitted[1] to clear up the distorted signals. The longer the possible delays, the fancier the equalizer should be. Viterbi demodulation is a maximum likelihood technique which finds the most probable emitted sequence, according to assumptions on the possible signals and on the adding noise [1]. The algorithm uses a finite set of possible signal shapes received during one bit period. The received signal shapes is influenced by several modulating bits. If the signal depends on n bits, 2^n different shapes have to be stored in memory. In order to be able to cope with two multipaths of equal power received at an interval of up to 16 μs, 5 bits (i.e. 32 different shapes) are required.

References

[1] Forney, G.D. JR. "The Viterbi Algorithm" *Proc. of the IEEE*, Vol. 61, No 3, Mar. 1973, pp. 268-278.

[1] All the signals in a particular cell share the same training sequence.

[2] Mouly, M. and Pautet, M-B. "The GSM System for Mobile", ISBN: 2-9507190-0-7, 1992.

[3] Murota, K., Hirade, K. "GMSK Modulation for Digital Mobile Radio Telephony", *IEEE Trans. on Communications*, Vol. com-29, No 7, July 1981.

[4] Redl, S.H., Weber, M.K., Oliphant, M.W. "An Introduction to GSM", *The Artech House Mobile Communications Series*, ISBN 0-89006-785-6, 1995.