Linear vs. Constant Envelope Modulation Schemes in Wireless
Communication Systems

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Abstract

There are a number of factors that enter into the choice of a modulation scheme for use in a wireless application. Performance of a cellular system is dependent on the efficiency of the modulation scheme in use. Linear and constant envelope modulation techniques, such as QPSK and GMSK, will be used to examine the features of each scheme and illustrate their uses in the cellular environment. The study of QPSK and GMSK is crucial to second and third generation cellular systems where achieving high capacity is the supreme factor. The goal of a modulation technique is not only to transport a message signal through a radio channel, but to achieve this with the best quality, power efficiency, and the least amount of bandwidth possible. In order to study the techniques for occupying less bandwidth and reducing power consumption per channel, a closer study of transmission techniques are explored in order to determine a favorable modulation technique for a particular wireless application.

Introduction

The importance of modulation schemes in wireless systems has led to advancements in digital signal processors (DSPs), microprocessor design, and various cellular standards. Much of the success of wireless standards is due to the contribution of modulation schemes that allow power efficient mobiles that require minimal bandwidth and battery size and provide crisper voice technology. Thus, modulators are fundamental components in wireless systems. This paper focuses on two techniques to illustrate the issues in both linear and constant envelope modulations.

Background: QPSK and GMSK

Quadrature Phase Shift Keying (QPSK) is currently used in applications such as cable modems and the IS-95 (CDMA) system. QPSK is predominantly noted for its power efficiency and robustness against phase noise. Another type of modulation scheme used in mobile radio systems is Gaussian Minimum Shift Keying (GMSK), which is vastly popular in Europe's GSM cellular standard. In addition, narrow bandwidth and its ability to use coherent detection characterize GMSK, a constant envelope modulation technique.

QPSK originates from Quadrature Amplitude Modulation (QAM). QAM combines phase changes with signal amplitude variations that enable more information to be carried over a limited channel bandwidth. Several varieties of QAM modulation exist, such as PSK, BPSK, and QPSK, providing various levels of bandwidth efficiency. In QPSK, two data channels modulate the carrier. Transitions in the data cause the carrier to shift by either 90° or 180°. This allows two discrete data streams, identified as I channel (in phase) and Q channel (quadrature) data.

GMSK is from the Minimum Shift Keying (MSK) modulation family. GMSK differs from MSK in the aspect of filter use, hence the name Gaussian MSK. GMSK resulted from an attempt to improve the MSK power spectrum. However, one of the advantages of MSK is that it does not produce Intersymbol Interference (ISI). The transmitted pulse is confined within its bit duration resulting in no adjacent channel interference. Nevertheless, GMSK possesses a more compact spectrum, with the application of a lowpass filter, helping to reduce its spectral sidelobes.

Problems: Issues in Digital Modulation

Most digital transmitters operate their power amplifiers at or near saturation to achieve maximum power efficiency. At saturation, it poses a threat to the signal, exposing it to phase and angle distortions. These distortions spread the transmitted signal into the adjacent channel, causing interference. To resolve this issue, a filter is used to suppress the sideband lobes. Nyquist pulse-shaping techniques, such as the Raised Cosine (RC) filter and Gaussian filter, are used to reduce ISI.

Filtering

Taking a closer look at the respective modulation schemes reveals a need for a filter. Shown below is the block diagram for generating a QPSK signal.
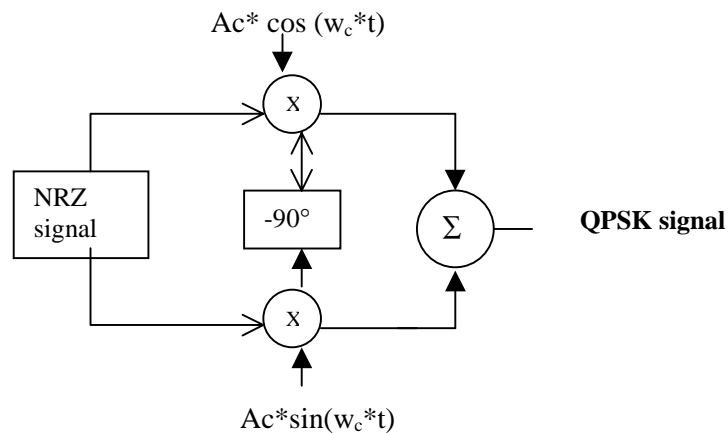
$$Ac* \cos (w_c*t)$$

NRZ signal

-90°

Σ   **QPSK signal**

$$Ac*\sin(w_c*t)$$

Figure 1: Generating a QPSK signal

First, the system converts a bit stream into a Non-Return-to-Zero (NRZ) signal which is multiplied by an in-phase (I) and quadrature (Q) signal, keeping in mind that each carrier phase is separated by 90°. The two components are then summed to achieve the desired QPSK signal output. In order to optimize the signal, QPSK uses the RC filter. This prevents the signal from spreading its energy into the adjacent channels.

Ideally, the Nyquist filter is free of ISI. However, all practical Low Pass Filters (LPF) exhibit phase and amplitude distortions so special pulse shaping filters are needed to ensure that the total transmitted signal arrives at the receiver. For the case of QPSK, the RC filter is used for the ideal LPF since the roll-off factor, r, controls the bandwidth of the Nyquist filter. The formula used to calculate the RC filter is shown below.

$$\text{Hrc}(t) := \left(\frac{\sin\left(\pi \cdot \frac{t}{Ts}\right)}{\pi \cdot t} \right) \cdot \left[\frac{\cos\left(\pi \cdot r \cdot \frac{t}{Ts}\right)}{1 - \left[4 \cdot r \cdot \frac{t}{(2 \cdot Ts)} \right]^2} \right]$$

This formula signifies the impulse response of the RC filter for changing values of r, the roll-off factor. According to the equation, as r increases, the bandwidth of the filter also increases while maintaining low sidelobes. As the roll-off factor decreases, the spectrum becomes more compact. This requires a more complex receiver at demodulation.

In order to create a Gaussian modulator, an NRZ signal comprised of –1's and 1's is made from a binary sequence of 0's and 1's and passed through an integrator. Then the signal is convoluted via a Gaussian filter, as shown in Figure 2. The I and Q components are multiplied with their respective carriers to get the resulting output.
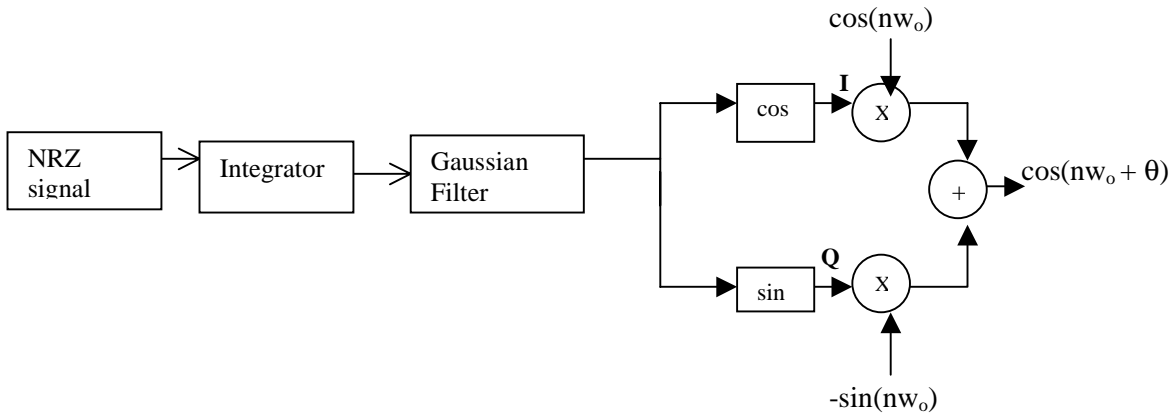
Figure 2: Generating a GMSK signal

In the case of GMSK, a Gaussian filter is applied prior to modulation so as to maintain

the constant envelope property of the modulation scheme. The impulse response

equation of the Gaussian filter, h(t), is show below.

$$h(t) := K \cdot \sqrt{2 \cdot \frac{\pi}{\ln(2)} \cdot (BT)} \cdot e^{-2 \cdot \frac{((BT) \cdot t \cdot \pi)^2}{\ln(2)}}$$

In order to reduce the sidelobes and produce a compact spectrum, the BT factor controls

the effects of the Gaussian filter. In the BT product, B is the 3 Db (or half-power)

bandwidth, while T is the symbol period.

Results and Performance Analysis

Using the RC and Gaussian filter, the linear and constant envelope modulation

schemes are implemented in Matlab to yield its performance and drawback issues. All

of the following results show simulations for values of BT and roll-off factor r equal to

0.2 and 0.9. For the case of GMSK, as BT decreases, the sidelobe levels fall off very

rapidly causing an increase in bandwidth efficiency, as seen in Figure 3. However, as

BT increases in the Power Spectral Density (PSD) implementation, as in the case of

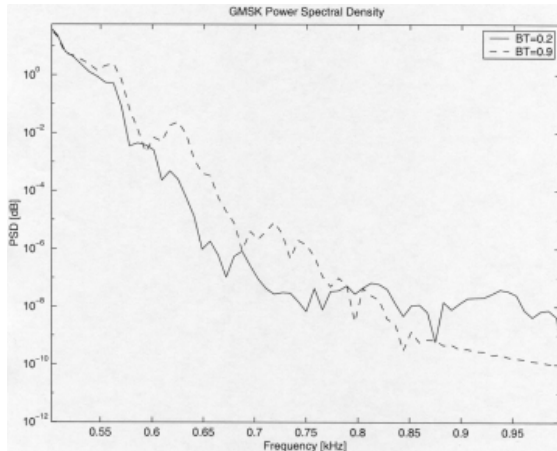BT=0.9, the graph yields a wider spectrum, indicating a loss in power efficiency.

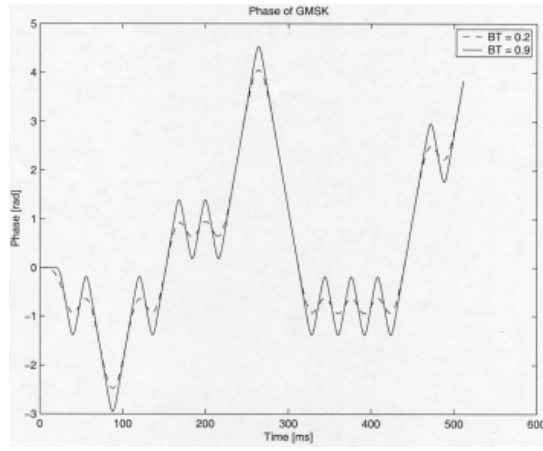**Figure 3: GMSK Power Spectral Density**

Figure 4: GMSK Phase Transitions

With regards to the phase of GMSK, illustrated in Figure 4, the spectrum becomes more

compressed, the phase transitions tracing a smoother curve, for decreasing values of BT.

This is beneficial because it better utilizes the power spectrum.

Next, referring to the total GMSK signal output, the graph reveals a wider eye diagram

for a increasing BT, as shown in Figures 5 and 6.   This means that it is easier to recover
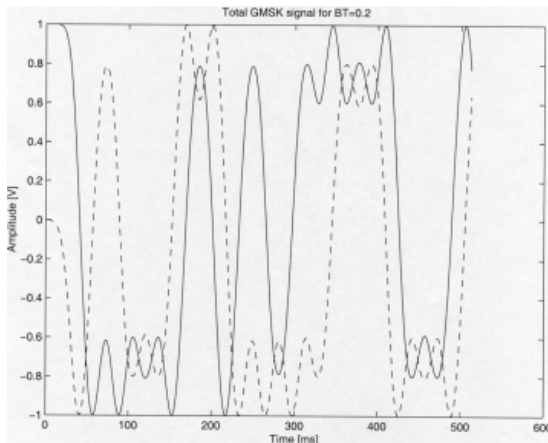
the carrier at the demodulator.

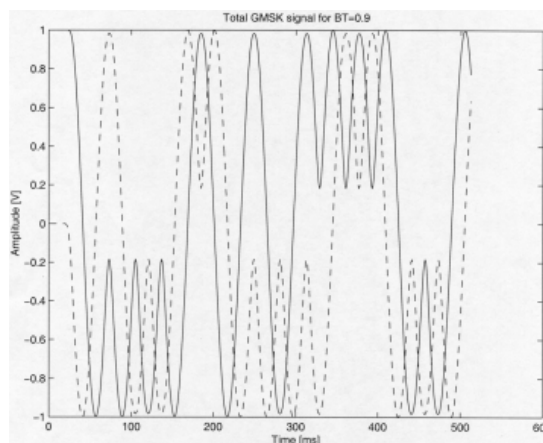
Figure 5: Total GMSK Signal, BT=0.2

Figure 6: Total GMSK Signal, BT=0.9

Implementing QPSK's RC filter shows that increasing the roll-off factor r, makes the spectrum more compact, causing a faster decay of the signal response as seen in Figure 7. However, our interest lies in the slow decay and this exists for smaller roll-off values, where ISI is fought more effectively.
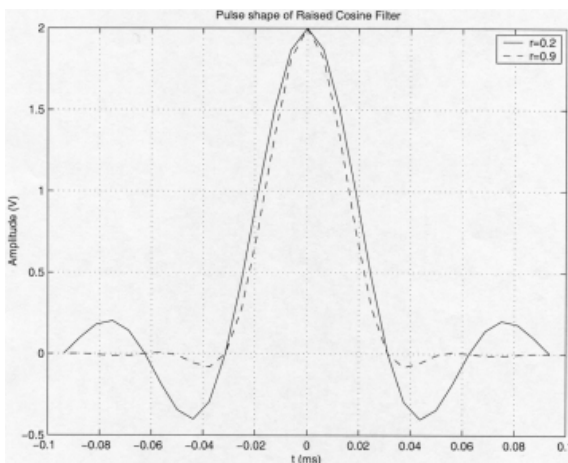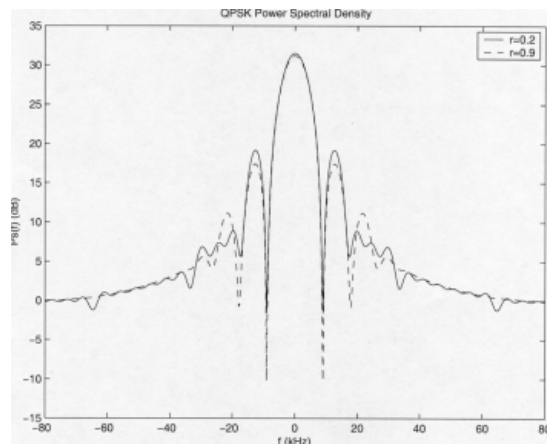

Figure 7: QPSK RC Filter Response

Figure 8: QPSK Power Spectral Density

Examining the PSD of QPSK in Figure 8, decreasing the roll-off factor r expands the spectrum, requiring more bandwidth, and thus, more power. However, since QPSK is predominantly noted for its bandwidth efficient feature, it is preferable to operate at higher values of roll-off in order to accommodate for the increasing demand for more users within a limited channel bandwidth. Nevertheless, another tradeoff is that a complex receiver is needed at the end of the filter to recover the carrier. In order to achieve easier carrier recovery, a wider eye diagram is necessary as shown in Figure 9 with a roll-off factor decreasing from 0.9 to 0.2.
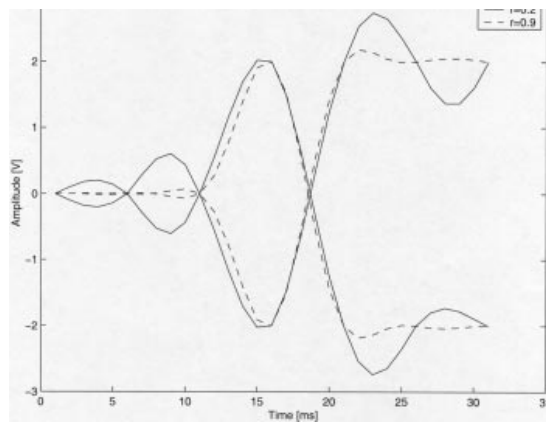
Figure 9: Total QPSK Signal

This effect yields less power efficiency; yet since the eye is wide, this shows that minimal ISI is present.

Conclusion

The results above indicate that there is no one prominent modulation scheme between linear and constant envelope modulation methods. Both QPSK and GMSK have strong features that provide a desirable cellular environment. When it comes to any one particular application, it is important to look at the tradeoffs involved. Most mobile products are designed with Class C power amplifiers, which offer the highest power efficiency, yet because they are nonlinear, require the amplified signal to have a constant envelope. This reduces the desirability of implementing QPSK in this situation. However, QPSK effectively utilizes bandwidth; whereas, GMSK requires more bandwidth to effectively recover the carrier.

Due to its linear amplification feature, QPSK is able to maintain low spectral sidelobes; thus providing good adjacent channel performance. This is an important contribution to wireless systems because it enables a higher channel reuse factor. Furthermore, QPSK's importance in CDMA is evident with its efficient bandwidth use, enabling more users within a limited channel bandwidth. GMSK makes its contribution to cellular systems in communications from the mobile to the base station. In the case of uplink, power is drained significantly from the mobile, necessitating a power efficient

amplifier. GMSK fulfills this need.   Furthermore, due to its frequency modulating

characteristic, GMSK shows a greater immunity to signal fluctuations. QPSK and

GMSK each provide beneficial features, and although neither dominates the other, both

contribute to the advancement of wireless telecommunication systems.

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