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EXPERIMENTAL TEST AND EVALUATION OF A GMSK CHIPSET COMPATIBLE WITH THE GSM AND PCS STANDARDS

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Abstract

This paper presents experimental test and evaluation results of a baseband processor chipset of Gaussian Minimum Shift Keyed (GMSK) quadrature modulator. Quadrature GMSK and related quadrature Feher's QPSK (FQPSK) modulator structure have been of interest to digital communication engineers. In this contribution we hightlighted the cross-correlation properties of the in-phase(I) and the quadrature-phase(Q) signals, described some of the advantages of cross-correlation, gave a simple analytical expression, and discussed correlated signal processors initiated by Kato/Feher[2] and also described in[1] and other recent references.

1. Introduction

The Gaussian Filtered Minimum Shift Keyed (GMSK) modulation format has very important applications in digital wireless communications. European digital cellular systems specified it for the Global Mobil System (GSM) standard with normalized Gaussian lowpass filter bandwidth BT_b = 0.3. In the Cellular Digital Packet Data (CDPD) standard GMSK is specified with BT_b=0.5. One of the advantages of GMSK is, besides Frequency Shift Keyed (FSK) modulation, it can be realized by quadrature phase shift keyed modulation. This property makes GMSK more attractive for applications which requires a robust performance.

GMSK has a non-obvious property. There is cross-correlation between the In-phase (I) and Quadrature-phase (Q) signal when it is implemented by a Quadrature Baseband Processor/QUAD modulation architecture, such as illustrated in fig 1(b). This property reveals that in quadrature modulated GMSK, the baseband I and Q signals are not independent signals. Many of the GMSK advantages are related to this property. For example, cross-correlation lead to GMSK constant magnitude, so the subsequent RF power amplifier can operate in non-linear mode with a greatly improved power efficiency. In today's wireless cellular PCS systems, many devices are driven by battery, and large amount of power is consumed by RF power amplifier, so power efficient modulation becoming key factor for power saving.

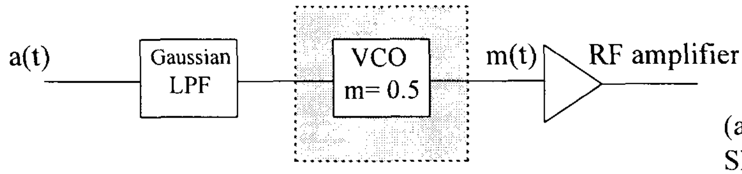
The cross-correlation property could be described as a discovery that is "*against*" the well-established wisdom of classical linear communication system theories and principles. In classical theory such as in Haykin's[9] textbook, it is demonstrated that for theoretical optimum QPSK system, at the end of a signaling interval T, the output of the correlater in the in-phase channel is

$$l_1 = \pm\frac{1}{2}A_cT + \int_0^T w(t)\cos(2\pi f_c t)dt$$

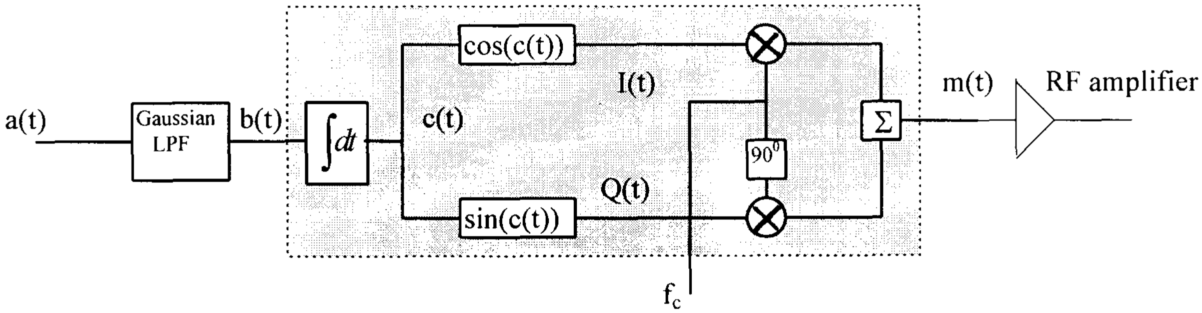
whereas the output of the correlater in the quadrature phase channel is

$$l_2 = \pm\frac{1}{2}A_cT + \int_0^T w(t)\sin(2\pi f_c t)dt$$

For optimal performance the random variables L_1 and L_2, whose values are denoted by l_1 and l_2, are *uncorrelated*. They are also Gaussian because they are derived from the Gaussian process w(t) by a linear filtering operation. Accordingly, they are



(a) GMSK implemented by Frequency Shift Keying modulation with FM-VCO



(b) GMSK implemented a by quadrature baseband correlated architecture

Figure 1. Two methods to generate the GMSK signal, the shaded areas in (a) and (b) have the same function. The GMSK signal m(t) is same both in (a) and (b).

statistically independent, thus any form of cross-correlation between I and Q will cause performance degradation. However, as pointed out in this paper, instead of keeping I and Q channel signals independent, we introduced cross-correlation between them, and it will improve some characteristics in certain applications, especially when the application requires non-linear amplification environment.

This cross-correlation property was initiated and included in the Kato/Feher's patent, "The correlated signal processor,"[2] which gives a good description of this property. This patent has many impacts on modulation and overall digital communication system designs. In this paper, we use the measurement results of a commercial GMSK baseband processor chipset to demonstrate the GMSK cross-correlation property

2. Cross-correlation

There are two methods to generate GMSK, one is frequency shift keyed modulation, the other is quadrature phase shift keyed modulation. Fig 1 shows the two methods. The first method requires the frequency deviation factor exactly equals to 0.5, that is m= 0.500. It is difficult to meet this demand by VCO that must maintain high precision on frequency deviation. The second method looks complicated, but it is relatively easy to implement. The second method has another advantage of being able to extended to another modulation mode, to form the dual compatibility modulation format. Most of the practical applications use quadrature modulation method to generate GMSK.

In figure 1,

$$a(t) = \sum_{n=-\infty}^{+\infty} a_n \prod \left(\frac{t-nT}{T}\right)$$

b(t) can be expressed as:

$$b(t) = \frac{1}{2}\left(erf\left(-\sqrt{\frac{2}{\ln 2}}\pi B t\right) + erf\left(\sqrt{\frac{2}{\ln 2}}\pi B (t+T)\right)\right)$$

where

$$erf(t) = \frac{2}{\sqrt{\pi}} \int_0^t \exp(-u^2)\,du$$

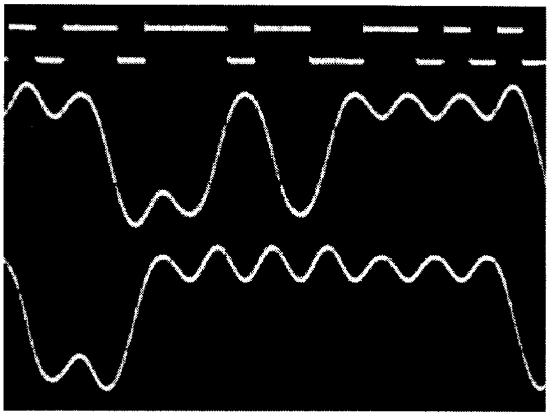


Figure 2. GMSK(BT_b =0.3) baseband waveforms, the top is PRBS NRZ input data, in the middle is the I signal, and bottom is the Q signal.

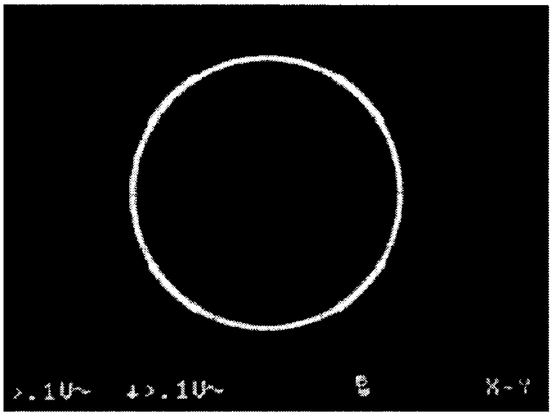


Figure 3. Constellation of I and Q signals. There are 4 shiny lines in the constellation graph, it means the signal phases stay here longer than other state. The shiny lines are well constrained in a circle due to cross-correlation property.

and c(t) is

$$c(t) = \int_{-\infty}^{t} b(\tau)d\tau$$

I(t), Q(t) signals are,

$$I(t) = \cos(c(t))$$
$$Q(t) = \sin(c(t))$$

I and Q are generated by sin( ) and cos( ) of c(t). c(t) is used both by I and Q. From our point of view, we deliberately introduce cross-correlation here. I and Q start from the same signal c(t). We noted that the I and Q signals are cross-correlated. The reason is that we can express the I(t) in term of Q(t).

$$I(t) = \cos(\sin^{-1}(Q(t)))$$

and also express Q(t) in term of I(t).

$$Q(t) = \sin(\cos^{-1}(I(t)))$$

The experimental GMSK baseband processor chipset uses the above approach to generate its baseband signals with Gaussian LPF BT_b=0.3. The output baseband waveforms are shown in figure 2. In these waveforms, there are ripples whenever the signals have consecutive '0's or '1's. The signal magnitudes are not equal, with ripple bottom is about 0.85 of the maximum magnitude. From study of this phenomenon, we can observe the effects of cross-correlation. The quadrature signal Q reaches its highest magnitude if and only if the in-phase I is crossing zero, and the quadrature signal Q is at lower amplitude when the inphase signal I is at bottom of the ripple, or vice versa.

Figure 3 shows the constellation of I and Q baseband signals. The encoded output signals have amplitudes such that the vector sum of I and Q signals are approximately the same at virtually all phases of each bit period. The vector magnitude can be expressed as,

$$m(t) = \sqrt{I^2 + Q^2} = \sqrt{COS^2(c(t)) + SIN^2(c(t))} = 1$$

Because of the phase ambiguity, we can not tell the phase of Q(t) when we know I(t), but we know the amplitude of Q(t) if we know I(t). So the normalized m(t) will always have the same value as results of quadrature modulation.

3. Power efficiency and BER improvement

One of the advantages of cross-correlation is it lead to power efficiency. In GMSK, cross-correlation makes the modulated RF signal constant envelope, suitable for nonlinear power amplification. This overcomes the crucial problem of output power backoff (OBO). OBO normally reduce 6-8 dB output power in non-constant envelope modulation

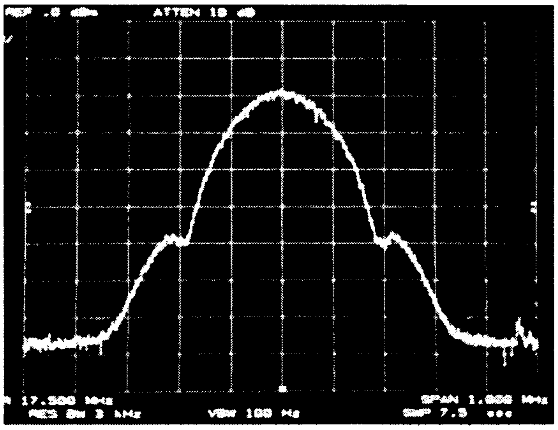


Figure 4. GSMK (BT_b=0.3) power spectrum density. The modulation method is quadrature phase shift key. The solid line is linear amplified GMSK PSD, and the background line, which is only visible under 55dB, is non-linearly amplified spectrum. The non-linear spectrum is well confined with in 55dB.

format, like QPSK, $\frac{\pi}{4}QPSK$ etc.. We measure the spectrum spread in several cases, such as class C amplifier, hardlimiter, power amplifier at 1dB compression point and fully saturated state. All of the results show that the GMSK is superior to other modulation format. Figure 4 is the measured power spectrum of GMSK, where the RF power amplifier is working at fully saturated state.

The BER measurement is also satisfactory. Under additive Gaussian white noise, E_b/N_o is about 10.0 dB, the measured P_e is 1×10^{-4}. This result is very close to the results of computer simulation of GMSK performance, which is about 9.8dB when error rate is 1×10^{-4}. It is important to point out that this is partly due to the cross-correlation property.

4. Conclusion

In this paper we discussed a neglected fact that there is cross-correlation between I and Q signals in GMSK modulation format, when implemented by quadrature phase shift keyed modulation. The experimental measurement of a commercial GMSK chipset demonstrate this property. The importance of these results is related to the GSM world-wide PCS standard, and power efficiency in digital wireless cellular systems.

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