COMMUNICATIONS

Wireless communication system based on GMSK modulation scheme

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SUMMARY. – *To investigate the techniques for occupying less bandwidth and power for a given probability of error, a closer study of transmission techniques are explored during this work in order to determine a suitable modulation technique for a particular wireless application. A mobile communication system is modeled and simulated using GSM standards, including the Gaussian Minimum Shift Keying (GMSK) modulation scheme and a Gaussian filter of bandwidth – symbol duration product of 0.3, with a carrier frequency of 900 MHz. The effect of Raleigh fading is studied and simulated using a model based on a spectral analysis of the fading envelope. The Probability of error in the received signal is used in the comparison between various systems, by calculating an appropriate level of noise for particular signal strength. Simulation work has been done using MATLAB software package.*

Key words: Digital Communication System, GMSK, Wireless Communication, Cellular system, Computer Simulation, Raleigh Fading Channel.

1. Introduction

There are a number of factors that influence the choice of a modulation scheme for use in a wireless communication. The performance of a mobile communication system is dependent on the efficiency of the used modulation method. Linear and constant envelope modulation techniques, such as BPSK, QPSK, GMSK, etc…, were used to examine the features of the required modulation scheme, and to illustrate their use in the cellular environments. The goal of a modulation technique is not only to transport message signal through a radio channel, but also to achieve this with the best quality, power efficiency, and with the least possible amount of bandwidth (1).

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Cellular mobile radio systems enable high-density geographical cochannel reuse and are effective for achieving efficient spectrum utilization. These systems are adopted in advanced mobile radio system plans. Digital technologies are also effectively applied to achieve not only high-speed, highly reliable data transmission but also high-grade, highly flexible system control (2).

In 1974 Federal Communication Commission (FCC) used 40 MHz bandwidth allocation in the (800-900) MHz range and released cellular land mobile phone service for commercial operation in 1981(3). The distribution of channels and channel frequency must be ensures that assignments within one geographical cell area will not interfere with channels assigned in adjacent cell locations (4).

The special characteristics of the mobile-radio environment can have an adverse effect upon radio propagation, and consequently can affect this quality of services provided (5). It is therefore essential to know the cause, extent, and methods for minimizing these effects in order to improve the quality and reliability of mobile-radio telephone communication.

In light of many problems, many observers are now begin to look toward a next generation of mobile radio based on the digital signal processing and voice coding technology that have come so far under the impetus of increasingly powerful processors.

Digital mobile radio shares three basic characters: coding, modulation, and multiplexing. Modulation is the technique by which the digital bit stream is transferred onto radio carrier. Any modulation technique can be used to carry a digital signal of particular interest are the highly spectrum efficiency. The choice of modulation technique for a mobile radio system will rest on two considerations. First, it should be spectrum-efficient and should occupy as narrow a transmission bandwidth as possible with a sharp power roll-off (6). Second, as with the voice coders, it should be able to withstand a high error environment. Some spectrum-efficient techniques like QAM are highly efficient, but are not suitable for modulation applications because they require a stable amplitude reference not present in a fluctuating mobile signal. Conventional PSK also is unsuitable because it requires an absolute phase reference (7).

K. Murota (8) presented a paper concerned with digital modulation for future mobile radiotelephone services. First, the specific requirements on the digital modulation for mobile radio use are described. Then, premodulation Gaussian filtered minimum shift keying (GMSK) with coherent detection is proposed as an effective digital modulation for the present purpose, and its fundamental properties are clarified.

GMSK demodulator was simulated to evaluate its performance. They simulated the 4-state linearized Viterbi demodulator in AWGN under two scenarios. Both scenarios, then performed blind demodulation in the sense that no training signal was used. It is clear that the adaptive 4-state MLSE demodulator achieved optimal performance (the same as MSK) (9).

A closed form expressions for computing the power spectrum using vector-matrix techniques was presented in (10). The Power Spectral density (PSD) is expressed in a compact Hermitian form suitable for numerical computation. Results were given for various Gaussian base band filter Bandwidth-Time products and modulation pulse truncation lengths.

Both QPSK and GMSK have strong features that provide a desirable cellular environment (11). 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 (12).

The purpose of this paper is to modeling and simulate a GMSK system and exploited this system in the mobile wireless applications. To achieve this we studied the behavior of radio waves during propagation in the radio channel, from the transmitting antenna to the receiving antenna. The majority of signal degradation occurs, and so to develop effective transmission methods it is necessary to have a knowledge of what actually happens in the channel. So we simulated this channel using MATLAB package. In order to fulfill this task we modeled and simulate the transmitter and the receiver. The use of computer simulation has greatly aided this process. The adaptability of simulated communication systems is of a great advantage. Simulation also allows ease of comparison between various models.

Section two discusses briefly the GMSK modulation technique. Section three represents modeling of a GMSK modulator, demodulator and the channel . The result of computer simulation tests and their assessment are given in section four. Finally, the conclusion of the work and the suggestions for further investigation are given in section five.

2. GMSK simulated system

There are two methods to generate GMSK, as shown in Figs.1 and 2.

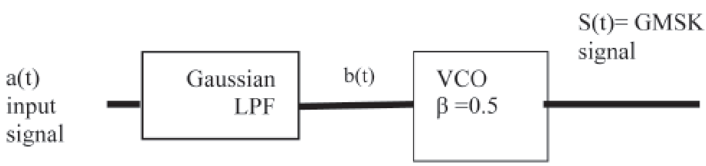

FIG. 1

GMSK implemented by Frequency Shift Keying modulation with FM-VCO.

The MSK VCO-modulator architecture as shown in the Fig. 1 is simple but is not suitable for coherent demodulation due to component tolerance problems. This method requires that the frequency deviation factor of the VCO exactly equals 0.5, but the modulation index of conventional VCO based transmitter drifts over time and temperature. The implementation in the Fig. 2 employs a quadrature baseband process followed by a quadrature modulator. With this implementation, the modulation index can be maintained at exactly 0.5. This method is also cheaper to implement. Both methods lead to the same GMSK modulated signal. We are going to look at the second method.

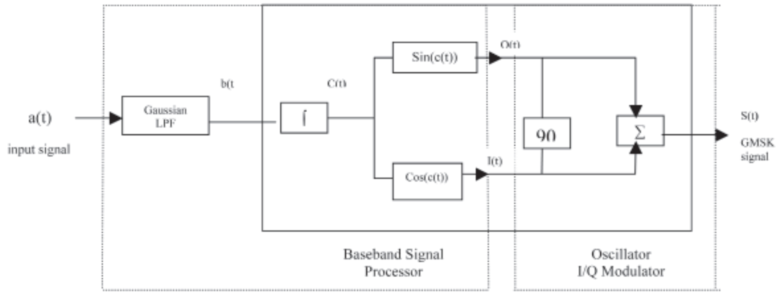

FIG. 2

GMSK implemented by a quadrature baseband method.

In this paper, GMSK system has been simulated, evaluated and represented by a series of equations. Non-Return-to-zero data is passed a Gaussian pulse-shaping filter, then it modulates a carrier signal using MSK. The modeling of the different sections is performed as follows.

2.1 – *Transmitter modeling*

As shown in Fig. 3, the transmitter consists of the input data source, the modulation process, the transmission channel, and the demodulation process. To test the computer model, random data must be produced. This is done by generating a set of uniform values between 0 and 1, and assigning the greater half as positive, and the rest as negative, to form the required set of values, {1, –1}.

For the purposes of a computer simulation, the modulator can be modeled as given in Eq.[1]:

[1] $$S(t) = \cos\phi(t,\alpha)\cos\left(2\pi f_c t\right) + \sin\phi(t,\alpha)\sin\left(2\pi f_c t\right)$$

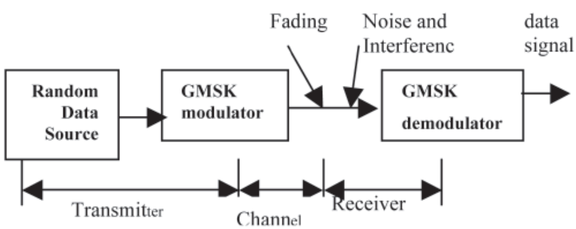

FIG. 3

Block diagram of system to be simulated.

Here $\cos\Phi(t,\alpha)$ is called the in-phase component and $\sin\Phi(t,\alpha)$ is the quadrature component.

The phase can be calculated directly using 50 data samples and a sampling rate of 4 samples/second. The phase is then fed into the two arms of the system shown in Fig. 4.

Each signal is then multiplied by the carrier with frequency f_c. Finally the signals are summed and transmitted.

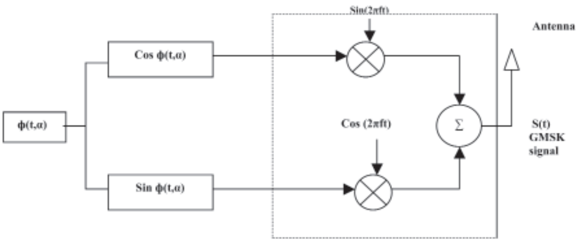

FIG. 4

Block diagram of a quadrate modulating system.

2.2 – *Channel modeling*

The PSD is depending on the distribution of the incident angle α, and on the gain of the receiver antenna $G(\alpha)$, which can be given as (13)

[2] $$S(f) = \frac{A\left[p(\alpha)G(\alpha) + p(-\alpha)G(-\alpha)\right]}{f_m\sqrt{1-\left(\frac{f-f_c}{f_m}\right)^2}}$$

where $p(\alpha)$ is the variation of incoming power with angle, A is the average received power with respect to an isotropic antenna and so $AG(\alpha)p(\alpha)$ is the total received power. The frequency f_m is the maximum Doppler shift. The maximum baseband spectrum for the fading signal will be $2f_m$.

The spectrum is centered on $f=f_c$, the carrier frequency, and is zero for $f<f_c-f_m$ and for $f>f_c+f_m$.

At the boundaries of $\alpha=0$ and $\alpha=\pi$, $f=f_c \pm f_m$, and the components at this frequency have infinite power spectral density.

The algorithm to be implemented by the computer simulation of a Rayleigh fading channel was first developed in (14). A block diagram of this algorithm is shown in Fig. (5). Two independent Gaussian noise sources are shaped by the spectral filter, and then added in time quadrature.

Specifically, the model consists of two complex Gaussian random number generators used to produce a baseband line spectrum of noise. The in-phase and quadrature components are then multiplied by the fading spectrum,

$$\sqrt{S_{E_s}(f)}$$

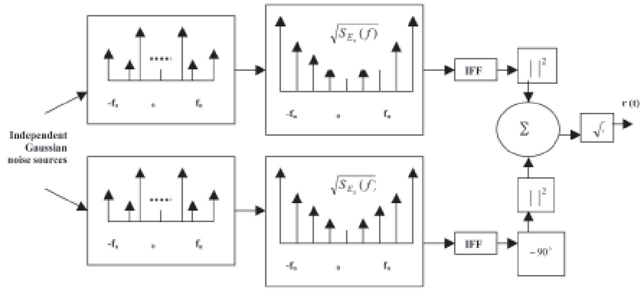

FIG. 5

Computer Simulator of Rayleigh Fading Channel.

The shape of the filter created by the power spectra is shown in Fig. 6. This graph has been created by using the values $G(\alpha)=1.5$ and $p(\alpha)=1/2\pi$ over 0 to 2π.

The resulting signal is converted to the time domain using an Inverse Fast Fourier Transform (IFFT), and the squares of the two components are summed. The square root of this result is then taken to give a series of simulated Rayleigh fading signals. The Gaussian noise source is created in several steps. First the maximum Doppler shift frequency is chosen, or calculated from a given velocity. The number of frequency domain points in between f_m and $-f_m$, must be chosen preferably a multiple of 2 to allow faster Fourier calculations. Gaussian random variables are generated to form the positive frequency components. Then, the negative components are formed by conjugating their positive counterparts. To avoid discontinuities at the limits of $\alpha=0$ and $\alpha=2\pi$, the values $S_{Ex}(f)$ near the boundaries are calculated using the slope of the curve near those points.

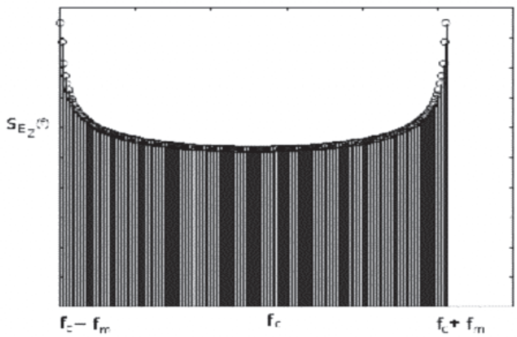

FIG. 6

Filter formed by fading spectrum.

2.3 – *Simulation of AWGN*

The bit energy is defined as the ratio of received power to the transmission rate in bits/second. Consider the complex form of the signal envelope. If the power of the signal envelope is normalized to 1, then the signal energy of each bit is

[3] $$E_b = \int_0^T P(t)\,dt = T$$

A complex Gaussian noise can be generated in the same way as in the Rayleigh fading simulation algorithm. So, consider a noise source.

[4] $$N_S = q + jb$$

where *a* and *b* are Gaussian random variables. Since the in-phase and quadrature components of the noise source are independent and have equal power (i.e., 1), the total noise power is equal to the sum of the power of these components (i.e., 2). However, the mean power of the noise, must equal N_0B. The bandwidth, or Δf, is equal to f_s, where f_s is the sampling frequency per data symbol. This gives a noise power spectral density of

[5] $$N_0 = 2/f_s$$

The sampling rate will be some number *r* divided by the duration of the bit *T* that is, $f_s = r/T$. Combining Eqs.[5] and [3] gives a SNR of $E_b/N_0 = r/2$. For example, the sampling rate used in the final simulation was 16 samples/bit, so the SNR was $E_b/N_0 = 8$.

However, because of the normalization of the signal envelope, the complex noise source will have to be adjusted by some factor *K*, such that

$$N = KN_S$$

Now the noise spectral density is

$$N_0 = \frac{2T}{r}K^2$$

and the SNR becomes

$$\frac{E_b}{N_0} = \frac{r}{2K^2} \quad \text{or} \quad \frac{E_b}{N_0} = \frac{8}{K^2}$$

Producing *a BER* vs. *SNR* graph, is now a simple process to calculate a value of *K* for a number of different values of E_b/N_0, and adding the corresponding value of noise to the fading signal during the channel stage.

2.4 – *Receiver modeling*

Filtering the input data through a pre-modulation Gaussian pulse-shaping filter needs not affect the demodulation process. GMSK signals are generally demodulated as a simple MSK signal in the following fashion. The signal is first split into the in-phase and the quadrature components and down-converted from the carrier, then passed through a Gaussian low pass filter.

Finally, the data is retrieved by alternatively sampling the in-phase and quadrature signals with a time interval of 2*T*, where *T* is the symbol period, as shown in Fig. 7.

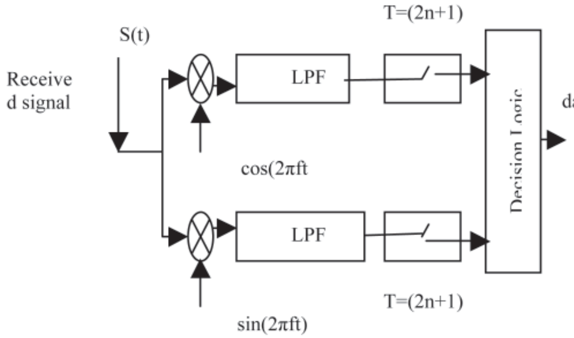

FIG. 7

Block diagram of the receiver.

3. Results of GMSK simulation

According to Fig. 4 the truncated filter response is represented graphically in the Fig. 8.

Ensuring that the response of the filter to a single 1 is a phase change of $\pi/2$, is equivalent to choosing the constant K to satisfy the following equation

$$\int_{-T}^{T} Kg(t)\,dt = \frac{\pi}{2}$$

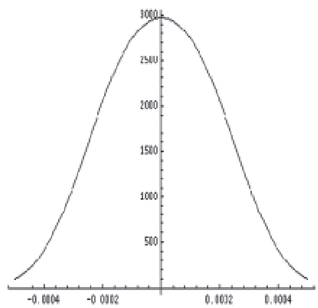

FIG. 8

The truncated and scaled impulse response of the Gaussian low-pass filter.

To demonstrate the GMSK modulation, we are using the following randomly chosen binary data stream.

$$\{1,1,-1,1,1,-1,-1,1,-1,1,-1,-1, \quad 1,1,-1,1,1,-1,-1,1,-1,1,-1,-1,\ldots\}.$$

The beginning of this data stream can be represented graphically by Fig. 9.

As the data passes through the filter it is shaped and ISI (Inter Symbol Interference) is introduced since more than one bit are passing through the filter at any time. For $BN = 0.5$, since the bits are spread over two bit periods, the second bit enters the filter as the first is half way through, the third enters as the first leaves etc. This can be represented graphically as shown in Fig. 10.

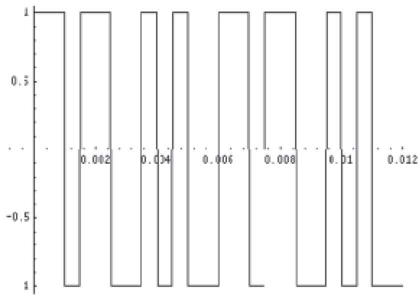

FIG. 9

The beginning of the data stream being sent through the filter.

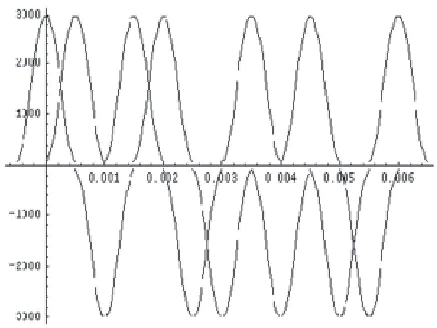

FIG. 10

The individual shape pulses representing the data stream.

These individual shaped pulses are then added together to give a function which is denoted by $b(t)$ as shown in Fig. 11.

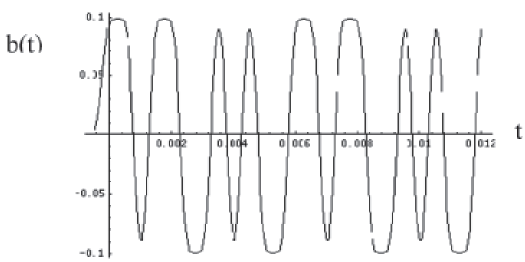

FIG. 11

The function $b(t)$.

This function $b(t)$ is then integrated, with respect to time from $t=0$ to ∞, to give the function c(t) as shown in Fig. 12.

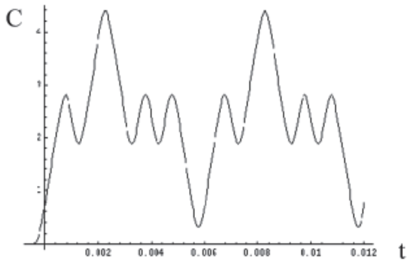

FIG. 12

The function $c(t)$.

Once we have obtained the function $c(t)$, its sine and cosine functions are found to produce the I and Q-baseband signals. Taking the cosine of $c(t)$ produces the I-baseband signal $I(t)$, i.e., $I(t) = \cos(c(t))$, which can be represented graphically as shown in Fig. 13.

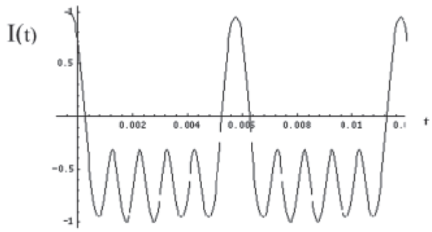

FIG. 13

The I-baseband signal, i.e. the function $I(t)$.

Taking the sine of $c(t)$ produces the Q-baseband signal $Q(t)$, i.e., $Q(t) = \sin(c(t))$, which again can be represented graphically as in Fig.14.

These two functions $I(t)$ and $Q(t)$ are then passed through the I/Q modulator which leads to the output signal $S(t)$:

$$S(t) = \sin(2\pi f_c t) I(t) + \cos(2\pi f_c t) Q(t)$$

where f_c is the carrier frequency used. Hence a GMSK signal is obtained as shown in Fig. 15.

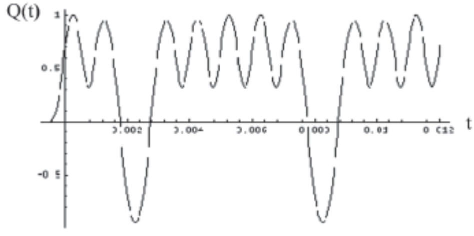

FIG. 14

The Q-baseband signal, i.e. the function $Q(t)$.

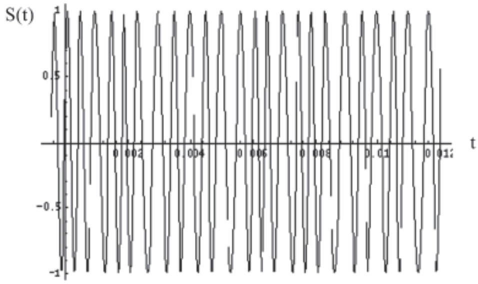

FIG. 15

The GMSK modulated signal $S(t)$.

4. Results of fading channel simulation

The simulation of the Rayleigh fading envelope, described in the section II, resulted in graphs such as that of Fig. 8. A visual inspection clearly shows a strong similarity between the two graphs indicating that the method used was successful. The graph of Fig. 16 is less smooth than the other, which probably indicates the use of less data points per millisecond. However, the average number of occurrences of various fade levels appears very similar.

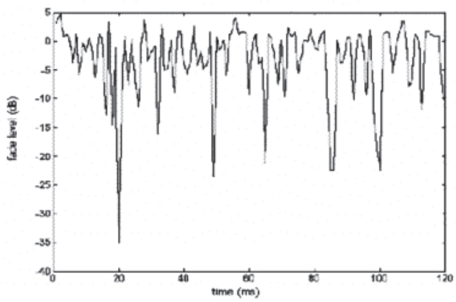

FIG. 16

Simulation of Rayleigh fading envelope for a velocity of 120 km/h and a carrier frequency of 100 MHz.

Figure 17 shows a plot of the distribution of the simulated results. Added to this plot is a Rayleigh curve for comparison. It is obvious from this that the simulated results fit a Rayleigh curve as required.

5. Conclusions

GMSK modulation was modeled and simulated and it is found to be an efficient form of modulation, both in bandwidth and power use. The modulated waveform was formed by passing the data through a pulse-shaping Gaussian filter, then modulated using a form of frequency modulation called Minimum Shift

Keying. Simulation of the MSK transmitter was achieved directly by modeling the shape filter and the modulator.

Rayleigh fading was summarized as the interference effect because when several reflections of a plane wave signal arrive at the receiver separated by only small differences in time or distance. The resulting signal envelope was found to have a Rayleigh distribution. The simulation has been used a two Gaussian noise sources, filtered using the spectrum of the fading envelope and added in time quadrature.

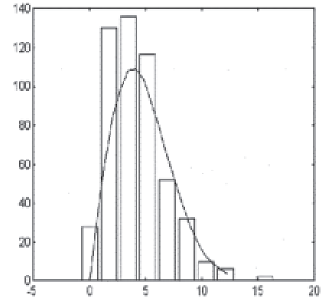

FIG. 17

Distribution of simulated results compared to a Rayleigh curve.

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