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Manchester-Coded Minimum Shift Keying (MCMSK)

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Abstract Minimum (frequency) Shift Keying (MSK) is a spectrally efficient modulation scheme compared with other constant envelope modulation schemes. However, its main sidelobe can be of some worry in digital data transmission, particularly over nonlinear channels. Therefore, it is practically of interest to search for pulse shaping schemes, largely proposed through baseband pulse shaping to reduce sideband power, which in turn reduces out-of-band interference between signal carriers in adjacent frequency channels. In this paper a pulse shaping method based on a Manchester coded signaling is proposed to be used in MSK-type signaling. A methodology is proposed for comparing the MCMSK with MSK; and the proposed pulse shaping does not attain improvement in spectral efficiency over straight MSK, for the same channel bandwidth. The fractional out-of-band power and error rate performance are used to compare the behavior of the system under the new proposed technique. The obtained results reveal that the application of Manchester-coded signaling in MSK attains good improvement in symbol synchronization; but the spectral and power efficiencies are less than that of MSK.

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***Index Terms*—Minimum Shift Keying (MSK), Pulse Shaping, Manchester Code, MCMSK.**

I. INTRODUCTION

The increasing move toward digital communication and away from analog communication have several reasons. In the late 1940s it was recognized that regenerative repeaters, at appropriately spaced intervals, could be used to reconstruct the digital signal error-free. A second advantage of digital representation of information is the flexibility inherent in the handling of digital signals. This means an essentially unlimited range of signal conditioning and processing options becoming available to the designer. The third major reason for the increasing popularity of digital data transmission is that it can be used to exploit the cost effectiveness of digital integrated circuits.

In most communication system designs, a general objective is to use as efficiently as possible the resources of bandwidth and transmitted power. In many applications, one of these resources is scarcer than the other, which results in most channels being classified as either bandwidth limited or power limited. Thus we are interested in both a modulation scheme's *bandwidth efficiency*, defined as the ratio of data rate to signal bandwidth (bps/Hz), and its *power efficiency*, characterized by the error probability which is a function of signal-to-noise ratio (SNR) [1,2] .

Minimum (frequency) Shift Keying (MSK) is a spectrally efficient modulation scheme compared with other constant envelope modulation schemes. However, its main sidelobe can be of some worry in digital data transmission, particularly over nonlinear channels. Therefore, it is practically of interest to search for pulse shaping schemes, largely proposed through baseband pulse shaping to reduce sideband power, which in turn reduces out-of-band interference between signal carriers in adjacent frequency channels. This paper will consider investigations into such approaches for application of Manchester-coded signaling to MSK. In considering the proposed pulse shaping scheme, the modulation performance will be evaluated using the following combined criteria :

- *Spectral Efficiency* : measured by better spectral roll-off , and fractional out- of-band energy content.
- *Error Performance* : measured by the detected (probability of) transmission errors in linear channels.

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II. REPRESENTATION OF MINIMUM SHIFT KEYING (MSK)

A digital frequency modulated signal *x(t)* can be written as [3,4].

$$x(t) = \cos[2\pi f_c\, t + \Phi(t)] \tag{1}$$

where

$$\Phi(t) = \omega_d \int_{-\infty}^{t} \sum_{k=-\infty}^{\infty} a_k . b(u - kT)\, du \tag{2}$$

is the phase deviation, f_c is the carrier frequency, ω_d is the peak angular frequency deviation, a_k is the random acquirable data assuming the values +1 or -1, T is the bit duration, and *b(t)* is the modulating pulse shape.

The signal *x(t)* can be rewritten as :

$$x(t) = \cos\left(2\pi f_c\, t + \sum_{k=-\infty}^{\infty} a_k . g(t - kT)\right) \tag{3}$$

where

$$g(t) = \omega_d \int_{-\infty}^{t} b(u)\, du \tag{4}$$

and the peak angular frequency deviation is given by ($\omega_d = \pi h / T$), *h* is the deviation ratio (modulation index), and is defined as the ratio of the frequency deviation to the bit rate .

Minimum Shift Keying (MSK) can be viewed as a special case of continuous-phase frequency shift keying (CPFSK) with modulation index *h*=0.5 and a rectangular pulse shape.

$$b(t) = \begin{cases} 1 & ; 0 \le t \le T \\ 0 & ; elsewhere \end{cases} \tag{5}$$

Then

$$g(t) = \int_0^t \frac{\pi}{2T}\, dt = \frac{\pi}{2T} t \ , \quad 0 \le t \le T \tag{6}$$

and according to (3) the signal *x(t)* can be defined in the *k*th interval $kT \le t \le (k+1)T$ as [5,6]:

$$x(t) = \cos\left(2\pi f_c t + a_k \frac{\pi}{2T} t + x_k\right), \quad kT \le t \le (k+1)T \tag{7}$$

where x_k is a phase constant which is valid over the *k*-th binary data interval. The value of x_k is a constant during *T* interval, that is, $x_k = 0$ or π modulo 2π, determined by the requirement that the phase of the waveform be continuous at *t*=*kT* , as follows [5,6]:

$$x_k = x_{k-1} + (a_{k-1} - a_k)\frac{\pi k}{2} \tag{8}$$

Without loss of generality we can take the initial phase $x_0 = 0$. The phase $\Phi(t)$ in (1) is then given by:

$$\Phi(t) = \frac{\pi . a_k}{2T} t + x_k \tag{9}$$

Using trigonometric identities and the property that $x_k = 0, \pi$ (modulo 2π), the MSK waveform representation (7) can be rewritten in a quadrature form as:

$$x(t) = a_I \cos\left(\frac{\pi t}{2T}\right)\cos(2\pi f_c t) + a_Q \sin\left(\frac{\pi t}{2T}\right)\sin(2\pi f_c t), \quad kT \le t \le (k+1)T \tag{10}$$

where $a_I = \cos(x_k) = \pm 1$ and $a_Q = -a_k \cos(x_k) = \pm 1$ and the in-phase and quadrature symbol weightings are

$$c(t) = \cos\left(\frac{\pi t}{2T}\right), \quad -T \le t \le T \tag{11}$$

$$s(t) = \sin\left(\frac{\pi t}{2T}\right), \quad 0 \le t \le 2T \tag{12}$$

MSK can be viewed as an Offset-QPSK (OQPSK) with sinusoidal symbol weighting. The in-phase and quadrature channels with the half sinusoidal symbol weighting imposed by *c(t)* and *s(t)* respectively. In the case of OQPSK a rectangular symbol weighting used, i.e.,

$$c(t) = \frac{1}{\sqrt{2}}, \quad -T \le t \le T$$

and

$$s(t) = \frac{1}{\sqrt{2}}, \quad 0 \le t \le 2T$$

From the above discussion we can see that MSK and OQPSK can be generated by de-multiplexing the data

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stream a_k into odd and even data streams which are used to determine the symbol pulse signs of the in-phase and quadrature channels during odd intervals: $(2k-1)T \le t \le (2k+1)T$, and even intervals: $2kT \le t \le (2k+2)T$, respectively. The MSK signal *x(t)* has a complex (low-pass) envelope of the form:

$$\tilde{x}(t) = \exp[\,j\Phi(t)] = \cos[\Phi(t)] + j\sin[\Phi(t)] \qquad (13)$$

where

$$x(t) = \mathrm{Re}\left[\tilde{x}(t)\exp(j2\pi f_c t)\right] \qquad (14)$$

where Re[.] denotes the real part of the quantity in brackets. It follows that the baseband power spectral density of *x(t)* is given by [1]:

$$G(f) = \frac{|C(f)|^2 + |S(f)|^2}{2T} \qquad (15)$$

where *C*(*f*) and *S*(*f*) are the Fourier transform of *c*(*t*) and *s*(*t*) respectively. From (15), the baseband spectrum of MSK signal is then given by:

$$G(f) = \frac{16T}{\pi^2}\left[\frac{\cos(2\pi fT)}{1-16f^2T^2}\right]^2 \qquad (16)$$

A better comparison of bandwidth requirements for these modulation schemes is given in terms of fractional out-of-band power (F.O.B.P), which is given in terms of the baseband power spectrum, *G (f)*, by:

$$\text{F.O.B.P} = \frac{\int_W^\infty G(f)\,df}{\int_0^\infty G(f)\,df} \qquad (17)$$

where *W* is the one-sided bandwidth. This bandwidth criterion states that the occupied bandwidth is the band that leaves exactly a certain specified percentage outside this bandwidth. For example we will adopt that the bandwidth as the band by which 99% of the total power is inside the bandwidth (i.e., 1% of the total power is outside the band). The fractional out-of-band power for MSK is shown in Fig. 1. From Fig. 1 we can see that the RF bandwidth, *B*=2*W*, which contains 99% of the total power is $B \cong 1.2\,R_b$ for MSK. The bandwidth (spectral) efficiency is defined as $\eta = R_b/B$, where $R_b = 1/T$ is the bit rate. The bandwidth efficiency for MSK with respect to 99% power bandwidth can be found as $\eta \cong 0.833\,bps/Hz$.

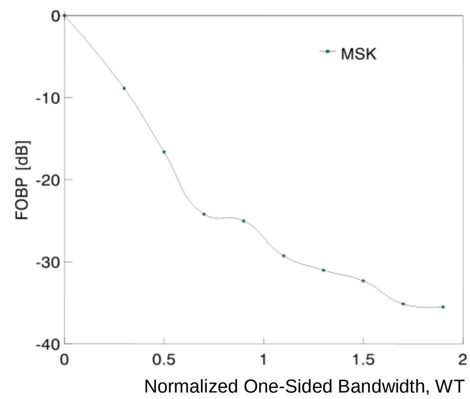

Fig. 1. Fractional Out-Of-Band Power for MSK.

III. MANCHESTER-CODED SIGNALING

The Manchester-coded signaling is often used for digital information transmission owing to easy ac coupling and its ability to provide symbol synchronization [7]. The spectrum of Manchester-Coded FSK (MCFSK) can be easily found. We start with Manchester pulse shape *b(t)* instead of rectangular one in Eq.(5) with h=0.5, and proceed as in the case of MSK.

$$b(t) = \begin{cases} 1\ , & 0 \le t < T/2 \\ -1, & T/2 \le t \le T \\ 0\ , & \text{elsewhere} \end{cases} \qquad (18)$$

Then, *g(t)* in Eq.(6) becomes:

$$g(t) = \frac{\pi}{2T}\int_0^t b(u)\,du \quad , \ 0 \le t \le T$$

$$= \begin{cases} \frac{\pi}{2T}t & , \ 0 \le t < T/2 \\ \frac{-\pi}{2T}(t-T) & , \ T/2 \le t \le T \end{cases} \qquad (19)$$

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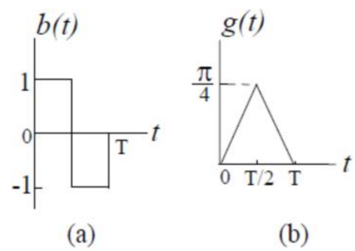

Fig. 2. (a) The modulating pulse shape b(t) and (b) its integral g(t).

According to Eq.(3) the MCMSK signal *x(t)* can be defined in the *k*-th interval, $kT \le t \le (k+1)T$, as follows :

$$\begin{aligned} x(t) &= \cos\left(2\pi f_c t + a_k .g(t-kT)\right) \\ &= a_I \cos\left[g(t-kT)\right]\cos\left(2\pi f_c t\right) \\ &+ a_Q \sin\left[g(t-kT)\right]\sin\left(2\pi f_c t\right) \\ &= a_I\ c(t-kT)\cos\left(2\pi f_c t\right) \\ &+ a_Q\ s(t-kT)\sin\left(2\pi f_c t\right), \qquad T \le t \le (k+1)T \end{aligned} \tag{20}$$

where the in-phase and quadrature data are :

$$a_I = \cos\left(a_k\right) = +1$$
$$a_Q = -\sin\left(a_k\right) = -a_k = \mp 1$$

and the in-phase and quadrature channel symbol weightings *c(t)* and *s(t)* are

$$c(t) = \begin{cases} \cos\left(\dfrac{\pi t}{2T}\right) & ,0 \le t < T/2 \\ \sin\left(\dfrac{\pi t}{2T}\right) & ,T/2 \le t \le T \end{cases} \quad , \quad s(t) = \begin{cases} \sin\left(\dfrac{\pi t}{2T}\right) & ,0 \le t < T/2 \\ \cos\left(\dfrac{\pi t}{2T}\right) & ,T/2 \le t \le T \end{cases}$$

In the above representation of Eq.(20), the signal *x(t)* can be viewed as sum of two quadrature components. The in-phase component (deterministic) with symbol weighting *c(t)* represents the timing (synchronization) term, while the quadrature component (random) with symbol weighting *s(t)* carries the information data a_k. Then the power spectral density (PSD) of MCMSK contains discrete spectral lines corresponding to the deterministic periodic sequence of pulses of period *T* seconds defined by *c(t)*:

$$G_d(f) = \sum_{n=-\infty}^{\infty} \left|C_n\right|^2 \cdot \delta\left(fT - n\right) \tag{21}$$

where $\delta(\cdot)$ is the Dirac impulse function and *n* is an integer; C_n is the coefficient of the Fourier series expansion of the modulating pulse sequence *c(t)*, that is:

$$C_n = \frac{1}{T}\int_0^T c(t)\cdot \exp(-j\frac{2\pi n}{T}t)$$

The discrete spectral lines are then given by:

$$G_d(f) = \sum_{n=-\infty}^{\infty} 8\left[\frac{\cos(n\pi)}{\pi(16n^2-1)}\right]^2 \cdot \delta\left(fT - n\right) \tag{22}$$

The second component of the PSD corresponding to the random modulating pulse sequence *s(t)* for *T* seconds, is continuous, and is given by :

$$G_c(f) = \frac{\left|S(f)\right|^2}{T} \tag{23}$$

where, *S(f)* is the Fourier transform of *s(t)*. Substituting *S(f)* in Eq.(23), we get the continuous component of the PSD:

$$\begin{aligned} G_c(f) &= \frac{8T\left[2 - \sqrt{2}\cos(\pi f T)\cos(2\pi f T) + \cos(2\pi f T)\right]}{\pi^2(16f^2T^2-1)^2} \\ &+ \frac{8T\left[-\sqrt{2}\sin(\pi f T)\sin(2\pi f T) - \sqrt{2}\cos(\pi f T)\right]}{\pi^2(16f^2T^2-1)^2} \end{aligned} \tag{24}$$

Finally, the baseband PSD of MCFSK is given by the sum of two components Eq.(22) and Eq.(24) as follows:

$$G(f) = G_c(f) + G_d(f) \tag{25}$$

The spectrum of MCMSK is shown in Fig.3 while the fractional out-of-band power is shown in Fig.4. From these figures we can conclude that the 99% RF bandwidth for MCFSK is $B \cong 2.4R_b$ and the bandwidth (spectral) efficiency is $\eta \cong 0.417$ bps / Hz. Consequently the bandwidth of MCFSK is double the bandwidth of MSK. Thus in using the Manchester-coded signaling, the efficiency is half the efficiency of MSK.

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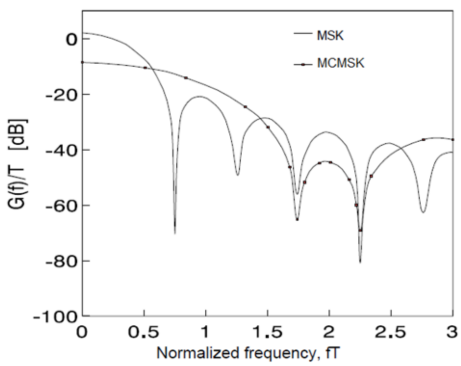

Fig.3 Baseband power spectral density for MSK and MCMSK

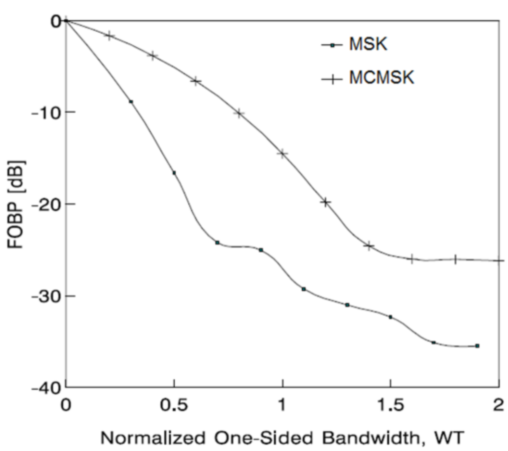

Fig.4 Baseband power spectral density for MSK and MCMSK

IV. RESULTS & CONCLUSION

The obtained results of the proposed pulse shaping show that of the application of Manchester-coded signaling in minimum (frequency) shift keying (MSK) attains good improvement in symbol synchronization; but the spectral and power efficiencies are less than that of MSK.

Another pulse shaping methods can be proposed and compared with MSK and MCMSK, an optimum pulse shaping application of Walsh function was proposed and attained good results compared to MCMSK [4].

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