ELEX 7860 : Wireless System Design
2013 Winter Session

Constant-Envelope Modulation

The QAM modulation techniques have a sinc$()^2$ spectrum that drops off as $\frac{1}{f^2}$. This spectrum would cause interference to users on adjacent channels. The QAM signal can be filtered to reduce its bandwidth but this must be done at baseband since there is no technology available to do narrow-band tunable filtering at RF. The filtered signal must also be amplified by linear amplifiers to avoid inter-modulation distortion which would cause the spectrum to widen and cause adjacent-channel interference.

Another alternative is to use signals which have constant amplitude and thus can be amplified by non-linear (Class C) RF amplifiers which will not distort the signal. These amplifiers are more efficient than linear amplifiers. For this reason constant envelope modulation is used by most digital wireless systems.

FSK

Binary frequency shift keying (FSK) is the simplest constant-envelope digital modulation technique.

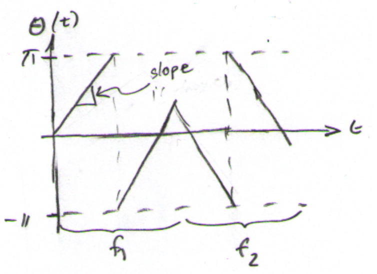
Since discontinuities in the phase would needlessly increase the spectrum of the signal, it is typical to use continuous-phase FSK where the phase of the carrier is continuous and only the rate of change of phase (i.e. the frequency) is changed.

Since phase is the integral over time of frequency, we can express the FSK signal as two time-varying phase components, one due to the carrier frequency and the other due to the modulation:

$$\begin{aligned} s_{FSK}(t) &= \sqrt{\frac{2E_b}{T_b}}\cos\left[2\pi f_c t + \phi_m(t)\right] \\ &= \sqrt{\frac{2E_b}{T_b}}\cos\left[2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(\tau)d\tau\right] \end{aligned}$$

In this equation $m(\tau)$ is the modulating signal (for example ± 1) and k_f is a modulation constant that depends on the frequency deviation (difference between the two carrier frequencies).

We can plot the value of the phase to show the phase as a function of time:

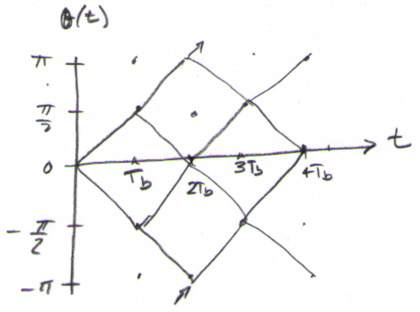


on this diagram the slope of the phase curve is the frequency. In this case there are two phases and two frequencies.

MSK

MSK, Minimum Shift Keying is binary FSK where the frequency difference between the two frequencies is equal to half of the bit rate. This results in the carrier shifting phase by ± 90 degrees every bit period.

Since the phase always ends up at $\pm\pi/2$ or $\pm\pi$ at the end of each bit period there are a limited number of phase trajectories. We can plot all of the various possible phase versus time trajectories. This diagram is called a phase trellis:



we can see that the phase is continuous and changes linearly during the bit interval but the direction changes abruptly at the end of a bit period if the frequency changes.

The following diagram compares the spectrum of MSK and QPSK:

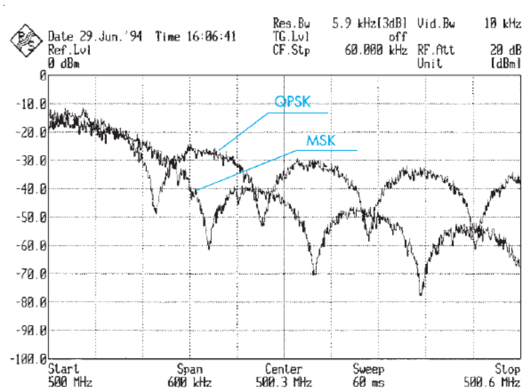
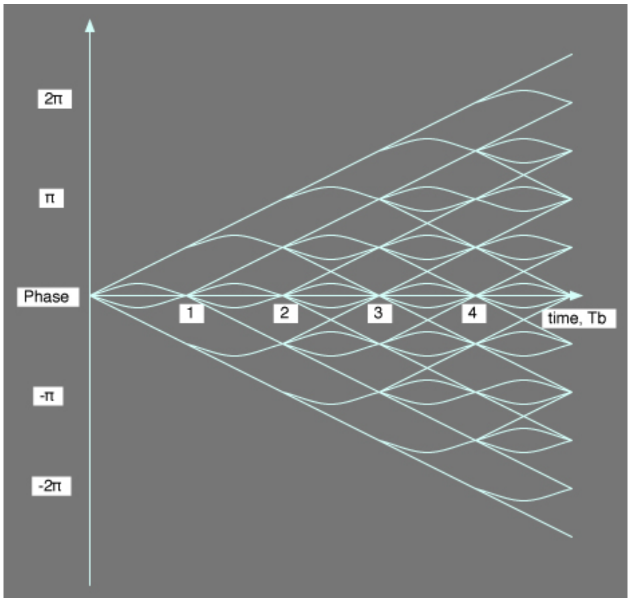


FIG 14 Spectra for QPSK and MSK

The MSK spectrum rolls off more quickly than that of QPSK.

GMSK

If we use a filter with a Gaussian impulse response to shape the modulating signal (the phase vs time signal) we can eliminate these discontinuities as shown in the phase trellis after filtering[1]:



and reduce the bandwidth even further at the expense of creating ISI. This ISI will reduce the BER performance.

The bandwidth of the Gaussian filter can be varied to trade off ISI for bandwidth. A typical value is $BT = 0.3$ which is the value used for GSM. $BT = \infty$ corresponds to no filtering which is MSK.

The following diagram compares the spectrum of GMSK for various amounts of pre-modulation filtering[2]:

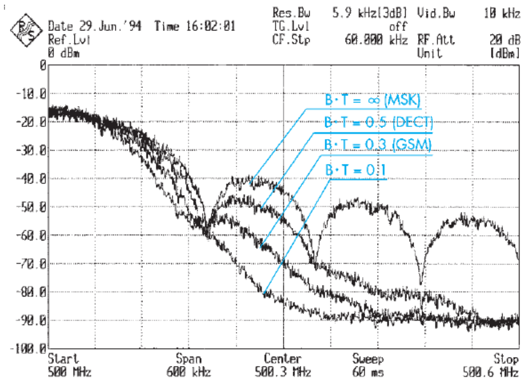
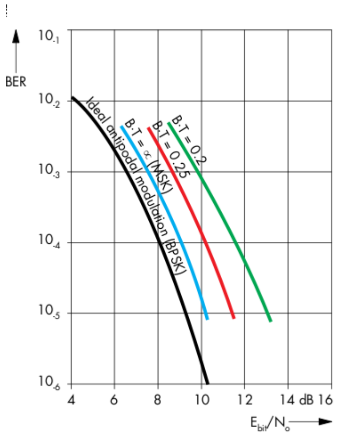


FIG 16 GMSK spectra for various values of bandwidth · bit duration

and the following diagram show the BER penalty as the filtering increases:



Because it has good BER performance and a compact spectrum GMSK is one of the common RF modulation techniques.

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[1] From face-paging.com

[2] From "News from Rohde & Schwartz", Number 155 (1997/III)