RTT TECHNOLOGY TOPIC
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Modulation and multiplexing- the 3G to 4G transition

There has always been an intimate relationship between modulation and bandwidth efficiency. In first generation cellular phones, the FM modulation depth determined the occupied RF bandwidth and practical channel spacing. Increasing the modulation depth (more FM deviation) improved the gain available through the demodulator but increased adjacent channel interference - coverage at the cost of capacity. The advantage of FM was (and is still today) the absence of information carried on the amplitude of the signal, ie you can use power efficient Class C amplification.

A similar approach was adopted for GSM with the decision to use minimum shift keying. Minimum shift keying is phase modulation (i.e. a form of frequency modulation) where the phase changes at a constant rate.

Baseband pulse shaping using a Gaussian filter further 'softens' the modulation to ensure that there are no AM components - the modulation is 'constant envelope'. Power efficient Class C amplification can be used but at the cost of some closure of the eye diagram, ie some residual inter-symbol interference is introduced as a consequence of the choice of modulation. The eye closure (60%) makes it relatively easy to achieve and maintain adjacent channel performance (-60 dBc).

Relaxing the baseband filtering reduces inter-symbol interference but increases the RF bandwidth required (a performance trade off between the time domain and frequency domain).

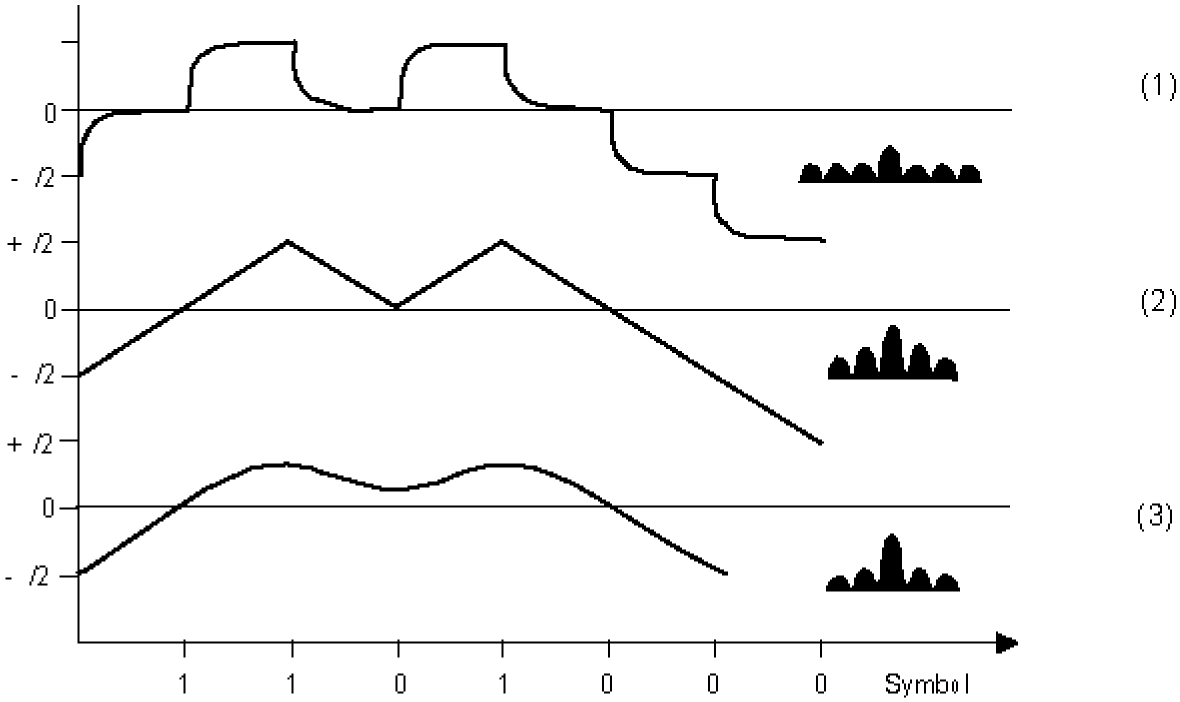

Figure 1 - QPSK, MSK and GMSK Compared

Figure 1 compares GMSK, MSK and QPSK. QPSK (quaternary phase shift keying) has relatively abrupt changes of phase at the symbol boundaries. MSK has less sideband energy but has a fully open eye diagram at the symbol decision points, GMSK has additional filtering (which effectively slows the transition from symbol state to symbol state) and in consequence decision points are not always achieved (a residual demodulated bit error rate).

For US TDMA and IS95, the decision was taken to use QPSK. This had the advantage of delivering twice as many bits per symbol as GMSK but with the disadvantage that the modulation contained AM components that required reasonable linearity to be preserved in the RF PA (i.e. power amplifiers have to be Class A/B devices).

In the case of IS95, the handsets use offset QPSK on the uplink to reduce the need for linearity. Similarly, in US TDMA, p4DQPSK is used - the vector is indexed by 45° at every symbol change.

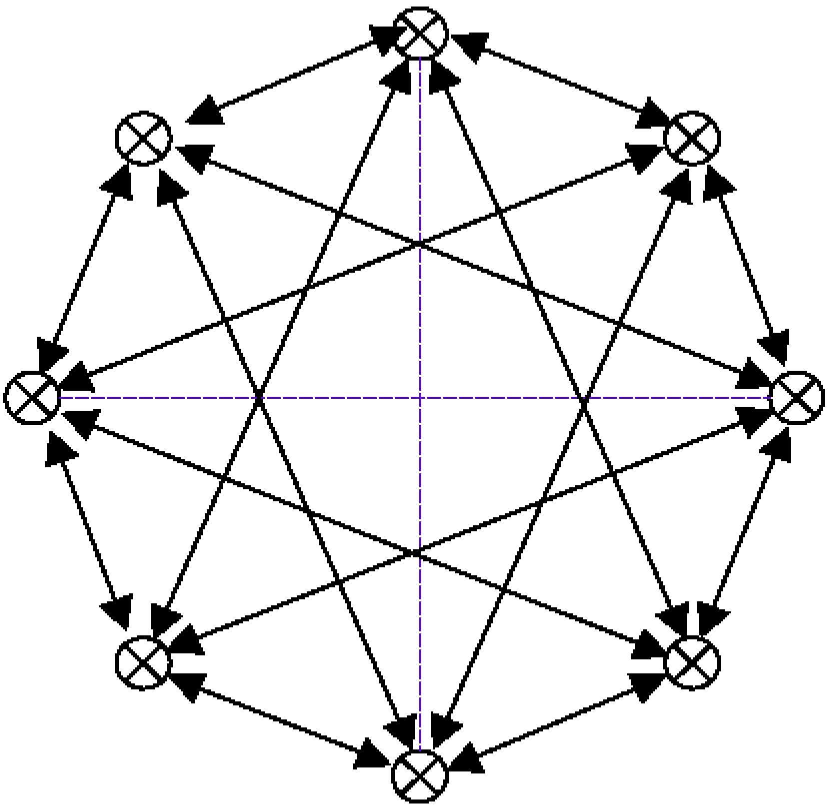

Figure 2 - IS54 TDMA - Modulation Vector - I Q Diagram for p4 DQPSK Modulation

Figure 2 shows how symbol transitions never pass through the zero crossing point (which represents 100% AM modulation) but instead are forced away from the centre (limiting AM depth to approximately 70%).

The additional modulation efficiency (2 bits rather than 1 bit per symbol transmit) makes QPSK a better option **provided** linearity issues can be addressed.

This principle is carried forward in 3G design. IMT2000MC (the evolution of IS95 CDMA) and IMT2000DS (also known as W-CDMA) both use QPSK. A variant of IMT2000MC known as 1xEV, however, also has the option of using 8 PSK (also used in GSM 'EDGE' implementation) and 16 level QAM.

This seems to be a sensible way to increase bandwidth efficiency given that 8 level modulation can carry 3 bits per symbol and 16 level can carry 4 bits per symbol.

It is necessary however to qualify the impact of the choice of modulation on the link budget. For every doubling of modulator state, an additional 3 dB of link budget is required to maintain the same demodulation bit error performance, ie QPSK requires 3 dB more link budget than BPSK, 16 level QAM needs 3 dB more link budget than 8 PSK. Provided you are close to the base station, you can take advantage of higher level modulation but it will not deliver additional capacity at the edge of a cell.

It is also worth verifying the time domain performance of the demodulator.

The usual rule of thumb is that a demodulator can tolerate a ¼ symbol shift in terms of timing ambiguity without causing high demodulator error rates.

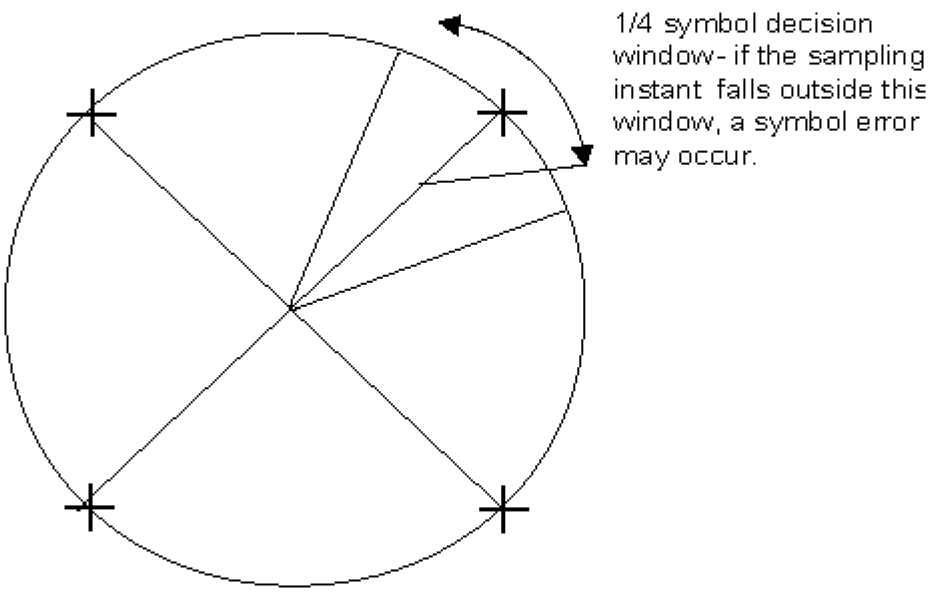

Figure 3 - Symbol Error Window

In higher level modulations, the symbol transition rate stays the same but the number of symbol states increases - the symbol states become closer together in terms of phase and frequency.

Given that the vector is rotating, a timing error translates into a phase or frequency error.

The symbol shift is caused by multipath effects. In CDMA, these are partly, though not totally, taken out by the RAKE receiver. Given that none of these adaptive mechanisms are perfect, timing ambiguity translates into demodulator error rate. This effect becomes more severe as bit rate and symbol rate increases.

Thus, while higher level modulation options promise performance gains, these gains are often hard to realise in larger cells, particularly in edge of cell conditions where power is limited and severe multipath conditions may be encountered.

An alternative is to use OFDM (orthogonal frequency division multiplexing). OFDM is sometimes described incorrectly as a modulation technique. It is more correctly described as a multi-carrier technique. Present examples of OFDM can be found in wireline ADSL/VDSL, fixed access wireless, wireless LANs and digital TV.

Standard terrestrial digital TV broadcasting in Europe and Asia uses QPSK (high definition TV needs 16 or 64 level QAM and presently lacks the link budget for practical implementation). The QPSK modulation yields a 10.6 Mbit data rate in an 8 MHz channel.

The 8 MHz channel is divided into 8000 x 1 kHz sub-carriers which are orthogonal from each other. The OFDM signal is created using a Fast Fourier Transform (historical note - Fast Fourier transforms were first described by Cooley and Tukey in 1963 as an efficient method for representing time domain signals in the frequency domain). As there are now a total of 8000 sub-carriers, the symbol rate per carrier is slow and the symbol period is long compared to any multipath delays encountered on the channel. Continuous pilot bits are spread randomly over each OFDM symbol for synchronisation and phase error estimation, scattered pilot bits are spread evenly in time and frequency across all OFDM symbols for channel sounding.

The advantage of OFDM is that it provides a resilient channel for fixed and mobile users (DVB was always intended to provide support for mobility users). The disadvantage of OFDM is that it requires a relatively complex FFT to be performed in the encoder and decoder. In digital TV, the power budget overheads associated with the complex transform do not matter (in the context of transmitters producing kilowatts of RF power and receivers attached to a 240 volt supply).

Present implementation of an OFDM transceiver in a 3G cellular handset would however not be economic in terms of processor and power budget overhead.

OFDM is however, a legitimate longer term (4G) option providing a bandwidth efficient robust way of multiplexing multiple users across 10, 15 or 20 MHz of contiguous bandwidth. It also provides the basis for converging the 3G TV and cellular radio network bandwidth proposition.

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