# PEAK-TO-AVERAGE POWER RATIO

One of the major problems of OFDM is that the peak amplitude of the emitted signal can be considerably higher than the average amplitude. This Peak-to-Average Power Ratio (PAPR) issue originates from the fact that an OFDM signal is the superposition of N sinusoidal signals on different subcarriers.

On average the emitted power is linearly proportional to N. However, sometimes, the signals on the subcarriers add up constructively, so that the amplitude of the signal is proportional to *N*, and the power thus goes with $N^2$.

If the number of subcarriers is large, we can invoke the central limit theorem to show
that the distribution of the amplitudes of in-phase components is Gaussian, with a standard deviation $\sigma = 1/\sqrt{2}$ (and similarly for the quadrature components) such that mean power is unity. Since both in-phase and quadrature components are Gaussian, the absolute amplitude is Rayleigh distributed.

**There are three main methods** to deal with the Peak-to-Average Power Ratio (PAPR):

1. Put a power amplifier into the transmitter that can amplify linearly up to the possible peak value of the transmit signal. This is usually not practical, as it requires expensive and power-consuming class-A amplifiers. The larger the number of subcarriers *N*, the more difficult this solution becomes.
2. Use a nonlinear amplifier, and accept the fact that amplifier characteristics will lead to distortions in the output signal. Those nonlinear distortions destroy orthogonality between subcarriers, and also lead to increased out-of-band emissions (spectral regrowth – similar to third-order intermodulation products – such that the power emitted outside the nominal band is increased).

The first effect increases the BER of the desired signal (see Figure 3.4.3), while the latter effect causes interference to other users and thus decreases the cellular capacity of an OFDM system (see Figure 3.4.4). This means that in order to have constant adjacent channel interference we can trade off power amplifier performance against spectral efficiency (note that increased carrier separation decreases spectral efficiency).

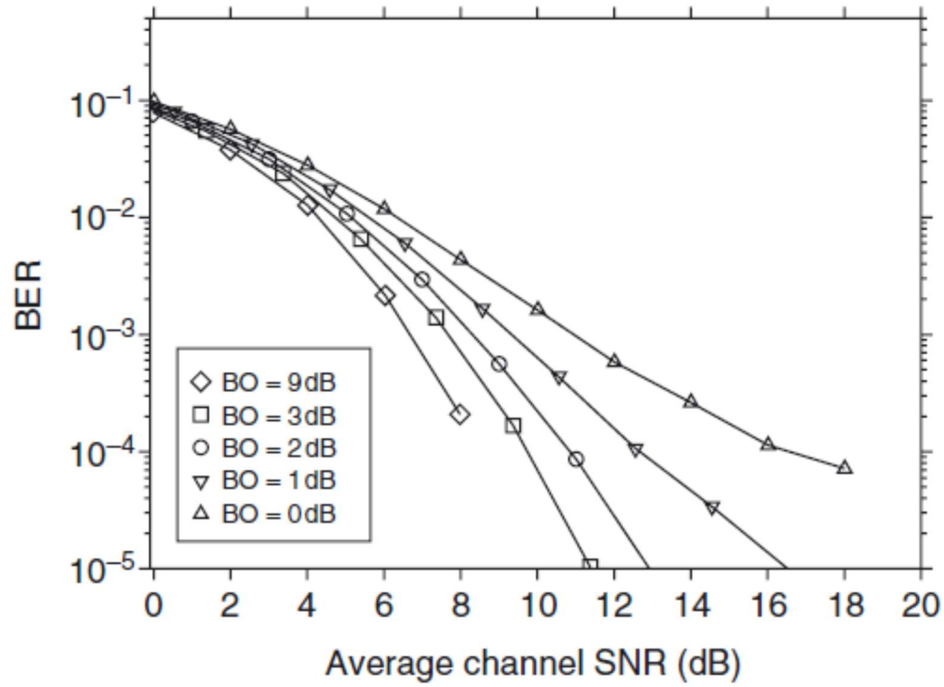


**Fig 3.4.3 Bit error rate as a function of the signal-to-noise ratio, for different backoff levels of the transmit amplifier**.

*[Source : "Wireless communications" by Andreas F.Molisch,Page-430]*

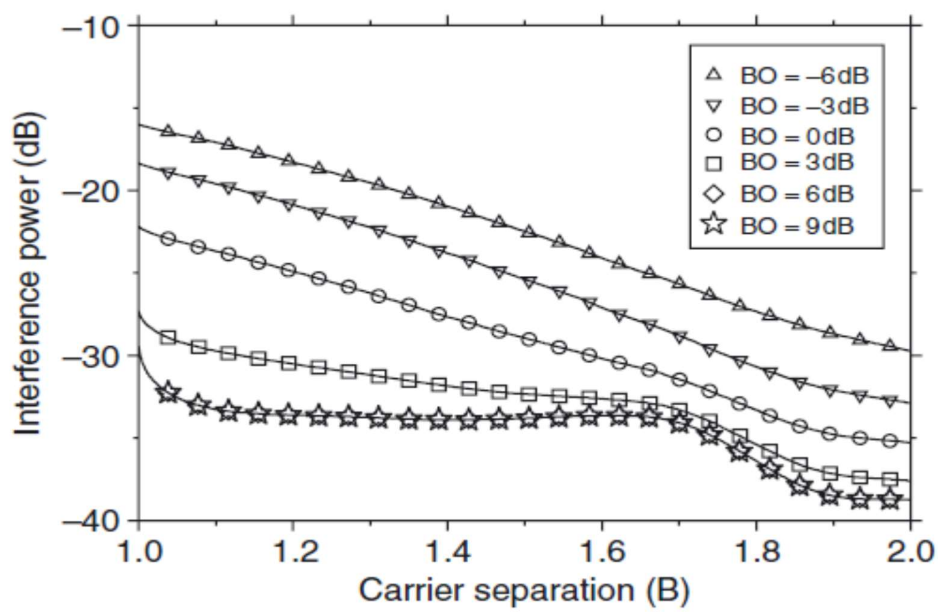


**Fig 3.4.4 Interference power to adjacent bands (OFDM users), as a function of carrier separation**

*[Source : "Wireless communications" by Andreas F.Molisch,Page-430]*

3. Use PAR reduction techniques.

1.Coding for PAR reduction: Under normal circumstances, each OFDM symbol can represent one of $2N$ codewords (assuming BPSK modulation). Now, of these codewords only a subset of size $2K$ is acceptable in the sense that its PAR is lower than a given threshold. Both the transmitter and the receiver know the mapping between a bit combination of length $K$, and the codeword of length $N$ that is chosen to represent it, and which has an admissible PAR.

The transmission scheme is thus the following: (i) parse the incoming bitstream into blocks of length $K$; (ii) select the associated codeword of length $N$; (iii) transmit this codeword via the OFDM modulator.The coding scheme can guarantee a certain value for the PAR.

2.Correction by multiplicative function: Here we multiply the OFDM signal by a time-dependent function whenever the peak value is very high. The simplest example for such an approach is the clipping we mentioned in the previous subsection: if the signal attains a level sk >A0, it is multiplied by a factor A0/sk. In other words, the transmit signal becomes

$$\hat{s}(t) = s(t)\left[1 - \sum_k \max\left(0, \frac{|s_k| - A_0}{|s_k|}\right)\right]$$

A less radical method is to multiply the signal by a Gaussian function centered at times when the level exceeds the threshold:

$$\hat{s}(t) = s(t)\left[1 - \sum_n \max\left(0, \frac{|s_k| - A_0}{|s_k|}\right)\exp\left(-\frac{t^2}{2\sigma_t^2}\right)\right]$$

Multiplication by a Gaussian function of variance $\sigma_t{}^2$ in the time domain implies convolution with a Gaussian function in the frequency domain with variance $\sigma_f{}^2 = 1/(2\pi\sigma_t{}^2)$. Thus, the amount of out-of-band interference can be influenced by the judicious choice of $\sigma_t{}^2$ .