RF Design - Performance Requirements

Introduction

The challenge of designing radio receivers and transmitters is to meet the requirements imposed by government regulations, wireless standards and customers at the lowest cost.

We will study the design of receivers in more detail than transmitters because the design of transmitters is somewhat simpler. Transmitters do not have to separate out the desired signal from interference and noise and do not have to deal with as wide a range of signal levels. Transmitters can also use many of the same components and design principles as receivers.

The technology and architectures used to implement receivers change very quickly because of constant improvements in IC technology and cost pressures. For example, increases in ADC sample rates and DSP processing power have made low-IF architectures more practical. Adoption of techniques such as switched-capacitor filters that allow components to be integrated into ICs have also affected receiver architectures.

Bands vs Channels

Spectrum regulatory agencies (ITU, FCC, IC) allocate certain frequency bands for different purposes (cellular, TV broadcast, unlicensed, etc). Wireless standards (3GPP, ATSC, 802.11, etc) typically divide up each of these bands into channels. Each channel can be used independently by a different user.

Regulatory agencies put limits on out-of-band emissions to ensure different services don't interfere with each other and wireless standards put limits on adjacent- and alternate-channel emissions to ensure different users don't interfere with each other.

In addition, standards organizations and service providers may have minimum performance requirements to ensure that bandwidth is not wasted (for example, due to excessive retransmissions).

Signal Levels

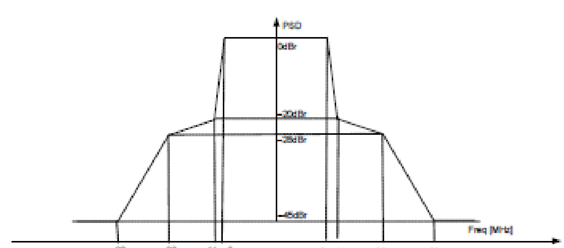
It is important to appreciate the very large dynamic range that receivers must cope with. The received signal level can range from just a few dB above the noise floor (-174 dBm/Hz) to perhaps -20dBm when a transmitter is operating only a meter or so from the receiver (for example two people standing next to each other each using a cell phones two WLAN card). It is not unusual to have to cope with an unwanted signal that is more than 60dB stronger than the desired signal.

Frequency bands are allocated to different services, in part, to minimize the range of signal levels that receivers must deal with. For example, most cellular frequencies are allocated in two bands, one band for forward links and one band for reverse links. This prevents cell phones from transmitting in the same band as they receive in which would require very high adjacent channel selectivity.

Typical Transmitter Performance Specifications

Transmitter specifications typically include frequency and modulation accuracy as well as transmit masks.

The transmit masks specify the allowable power spectral density under specified operating conditions (modulation, data rate, transmit power, etc). For example, the transmit mask for one mode of the 802.11 specification is:



Typical Receiver Performance Specifications

Sensitivity is the maximum input power required to achieve a specified error rate under specific conditions (type of noise or interference, modulation, coding, etc).

A receiver may also be required to operate with a certain input power level on the adjacent and alternate in-band channels or perhaps even out-of-band signals (at cellular or broadcast frequencies, for example).

Issues Affecting Receiver Performance

Images

Some receiver architectures mix the RF input signal with a local oscillator (LO) signal to produce a signal at the IF frequency. However for any given LO frequency there are two RF frequencies that can be mixed down to the IF: the sum and difference of the LO and IF frequencies. For example, if the LO is at 736 MHz and the IF is at 100 MHz then signals at both 836 MHz and 636 MHz will get mixed to 100 MHz.

Only one of these is the desired signal the other frequency is called the image frequency. If there is a signal at this frequency it will also get mixed down to the IF frequency and cause interference. The solution is to use a band-pass or band-stop filter to attenuate the image frequency.

Phase Noise

Phase noise refers to the random frequency modulation of the local oscillator due to noise in the oscillator circuit. This results in the LO signal having sidebands which can potentially mix undesired signal into the IF. Although the phase noise power is typically quite low, the effect can be significant when the unwanted signal is very strong.

Intermodulation Products

Intermodulation distortion products may fall in the frequency range of the desired signal. The solution is to use components with appropriate IP3 specifications or use filtering to attenuate the undesired signal.

Amplifier Desensitization

When an amplifier input contains a strong and weak signal, the operating point of the amplifier may shift and cause a reduction in gain for the weaker signal. This is called "desensing" or "blocking". Amplifiers must be designed to cope with the expected range of input signal levels or a filter must be used before the amplifier to reduce the levels of unwanted signals.

Leakage

Although we typically treat devices such as amplifiers, mixers and filters as operating in one direction only, in fact they have reverse gain (or loss) that can be significant. This can lead to signal components "leaking" out of the receiver or into other parts of the receiver causing unexpected interactions.

ADC Clipping and Quantization Noise

AGC