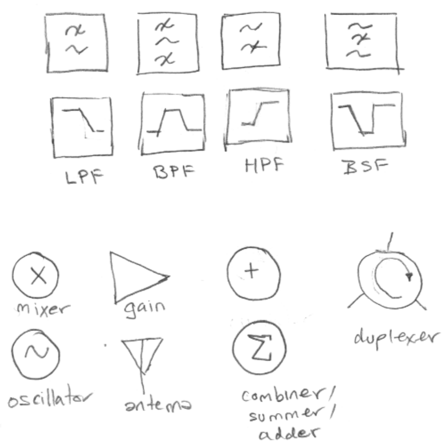
RF Design - Receiver Architectures

Block Diagrams

Some symbols that are commonly used in RF block diagrams are shown below. There are two conventions for drawing filters. The four types shown below are Low-Pass Filter (LPF, common), Band-Pass (BPF, very common), High-Pass (HPF, rare) and Band-Stop (BSF) or "notch" filter (depending on the bandwidth, neither is very common). The other commonly used blocks are for mixers, oscillators, amplifiers, antennas and summers. Standard schematic symbols for switches, connectors, etc are also commonly used.



Mixed Signal Design

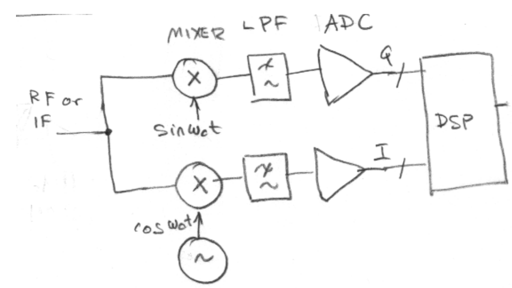
The term "mixed signal" refers to a design that incorporates both analog and digital signals. Most modern receivers use an analog "front-end" (AFE) to down-convert the signal to a lower frequency, often baseband, where it can be digitized by an A/D converter. The remainder of the processing is then done digitally.

The digital portion can be implemented using fixed-function logic, programmable logic or a combination depending on the throughput requirements, complexity of the algorithms and any need to allow for future changes.

Achieving isolation between the analog and digital portions of the receiver can be challenging. Digital signals are at high power compared to the weak received signals and the fast transitions between logic levels result in high harmonic content. Typically the analog and digital portions of the receiver are physically isolated and have separate grounds and power supplies.

Quadrature Demodulator

Most demodulators operate on both the amplitude and phase of the signal. This is usually accomplished with a quadrature down-converter that converts the IF (or RF) signal to separate in-phase and quadrature baseband components:



This architecture has some practical disadvantages related to the non-ideal performance of the analog mixers and oscillators. For example, it is difficult to maintain low LO leakage and quadrature between the I and Q branches and over a range of frequencies, operating temperatures and voltages. However, because this architecture lends itself to fully integrated implementation much effort has been put into overcoming these problems. Receivers and transmitters using this architecture typically use adaptive algorithms to "trim" the operating point of the analog components.

Another option is to convert the RF or IF signal to a low-frequency IF signal, digitize this signal and do the quadrature down-conversion digitally.

The digital quadrature down-conversion can be implemented with arbitrary accuracy and avoids many issues with the analog quadrature down-converters such as gain imbalance, phase quadrature errors, DC offsets in the mixers and leakage.

The disadvantages of this approach are that a more complex down-converter is required to obtain adequate image rejection for low IF frequencies (see below) and that the A/D converter sample rate must be at least twice the rate required by the analog quadrature down-converter.

Gain Distribution

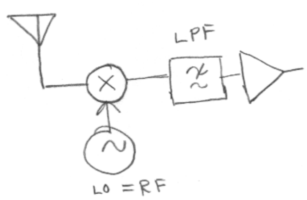
Gain (amplifiers) may be required before, after and between the mixers and filters that down-convert the signal to baseband. The allocation of gain between these stages can have a large effect on the sensitivity of the receiver and its susceptibility to undesired signals.

Often it is necessary to compromise between these two criteria: sensitivity (or the overall noise figure) and immunity to undesired signals. The reason is that higher gains in early stages of the receiver reduce the cascaded noise figure but also reduce the cascaded IP3 of subsequent stages.

The gains will also vary depending on the RF signal level (and possibly on the presence of strong unwanted signals). Part of the design process is to allocate gain to different amplifier stages to achieve acceptable performance for the range of expected desired and undesired signal levels.

Direct-Conversion Receiver

This is also known as a Homodyne or Zero-IF receiver. This receiver uses a local oscillator to mix the RF signal directly to baseband.

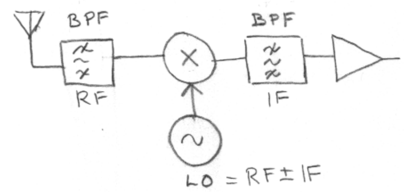


The only tunable component in this architecture is the local oscillator. This provides simplicity and flexibility. By changing the LO frequency the transmitter and receiver can cover a wide range of frequencies. By changing the baseband filter bandwidth the bandwidth of the signal can be changed.

For demodulators that require a complex baseband signal the zero IF receiver is the quadrature down-converter described above with additional gain or filtering.

Superheterodyne Receiver

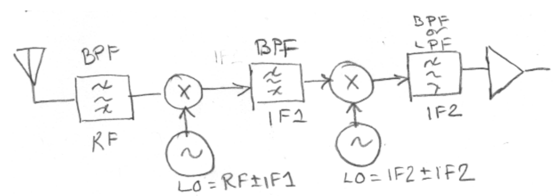
The superheterodyne receiver uses a local oscillator to mix the RF signal to an intermediate frequency (IF) where a channel-select IF filter rejects adjacent-channel signals. This is followed by gain before the IF signal is demodulated. A bandpass or band-reject filter can be used before the mixer to improve image rejection.



Although it requires an additional mixer stage, this architecture allows the majority of the amplification to be done after the IF filter. This means that only the desired signal is being amplified and the IF gain can be set to the minimum value required. This can improve the cascade noise figure and IP3 compared to a direct-conversion receiver.

Dual-Conversion Superheterodyne Receiver

This version of the superheterodyne receiver uses an additional down-conversion stage. One reason is to allow the use of a higher first IF frequency which relaxes the requirements on the image-reject filter. This also allows the use a lower second IF frequency where some types of IF filters are more effective.



A dual-conversion architecture can also generate a low (just above DC) IF frequency which allows for use of a digital quadrature down-converter.

Performance Analysis

For simple designs the calculations of the noise figure, IP3 and the frequencies and levels of various frequency components can be done by hand or using a spreadsheet.

Parameters such as signal frequencies, levels and gains can be varied and the impact on the baseband signal, noise and intermod levels can be studied. The designer can iterate the design by choosing components with different specifications or adjusting the gains between stages to see the impact on receiver performance.