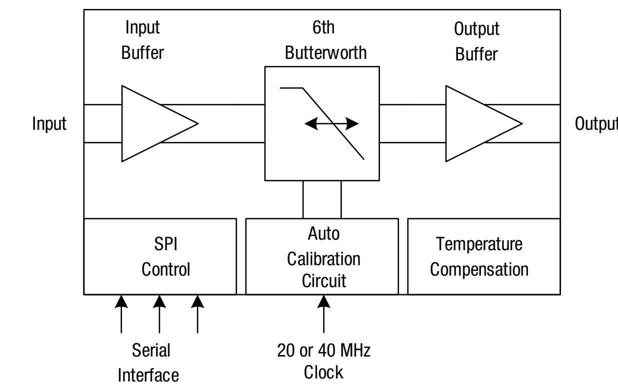
WHITE PAPER

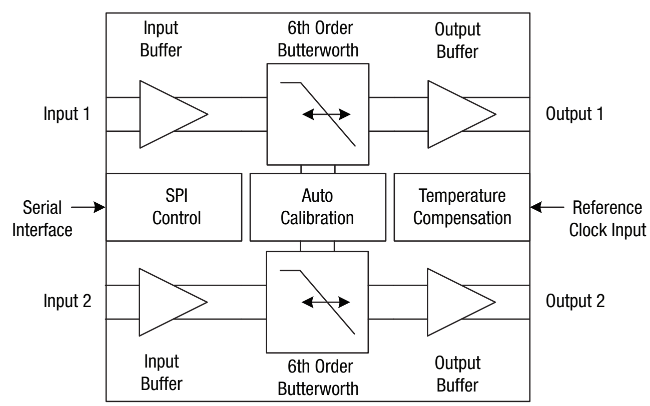
Designing Flexible Software-Defined Radio Architectures

Modern high-performance radio/microwave communications systems utilize digital baseband signal processing (coupled with complex up/down conversion), where very little of the signal processing is performed in the analog/RF domain. Such signal processing includes filtering, phase/frequency de-rotation, channel equalization, pulse shaping, and modulation/demodulation. When sampling rates and numeric precision are accounted for, digital signal processing provides ideal and deterministic functionality. In fact, there exists no more accurate or controllable filtering technique. However, even the most powerful signal processing engines and algorithms are incapable of processing sampled waveforms that have undergone most forms of non-linear distortion. Therefore, even modern digital communications systems still require high-order analog filters to control the non-idealities of the radio and data conversion processes.

Programmable baseband filters (such as the SKY73201-364LF and SKY73202-364LF—See Figure 1), which provide the necessary RF channel selectivity, offer software-defined flexibility. This allows one single radio system to easily adapt to multiple modes (such as the many WiMAX bandwidths) and radio standards, without any change in hardware. This, of course, implies direct conversion operation rather than the superheterodyne approach (which achieves its channel selectivity via intermediate frequency filtering—such filters are expensive, not programmable, and it is difficult to bank multiple filters).



SKY73201-364LF Functional Block Diagram



SKY73202-364LF Functional Block Diagram

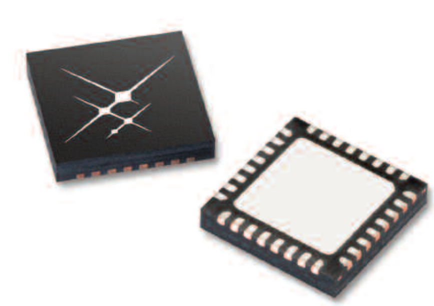


Figure 1. The SKY73201-364LF (Single) and SKY73202-364LF (Dual) 6th Order Programmable Butterworth Filters In a 32-lead, 5 x 5 mm MLP Package

The Transmitter

The function of the transmitter is to produce an accurately modulated Radio Frequency (RF) waveform, while meeting or exceeding regulatory and standards-based emissions requirements. Emissions requirements are defined in the form of spectral mask (a spectral profile relative to the center frequency), out of band spurious emissions, harmonics, and frequency-specific noise density profiles. Modulation accuracy, which is constrained by both system performance and standards-based requirements, refers to the deviation of the transmitted signal, measured at the symbol sampling points, from that of an ideal reference waveform.

A typical transmitter chain (see Figure 2) begins with a digital modulator, which produces a complex digital representation of the modulation waveform that is either DC-centered or rotated with some frequency offset. Then Digital to Analog Converters (DACs) convert this sequence in discrete sample points, of finite numeric precision, to an analog signal. The resultant analog signal is approximated as discrete steps—this is observed in the frequency domain as a repetition of the DC-centered spectra about each multiple of the sampling rate (see Figure 3). Furthermore, inherent to their design, DACs produce broadband noise that extends, in frequency, well beyond that of the desired signal content. Although the "in-band" signal was filtered in the digital domain using nearly ideal digital signal processing functions, the ADC produces analog artifacts such as broadband data noise, spurs, and quantization error.

Reconstruction filters (shown in Figure 2) are placed between the DACs and the mixers of the RF upconverter. These filters, particularly when high-order active filters are used, closely fit the desired spectra, while minimizing broadband noise and spurious responses. Additionally, active filters are capable of driving low impedance loads, which is typical of RF mixers, while presenting a high-impedance load to the DAC. It is very important, however, that such high-order active filters produce an accurate and well-behaved magnitude and phase response in order to preserve signaling integrity. The proper choice and matching (between I and Q channels) of reconstruction filters is crucial in order to achieve both acceptable emissions levels as well as modulation accuracy.

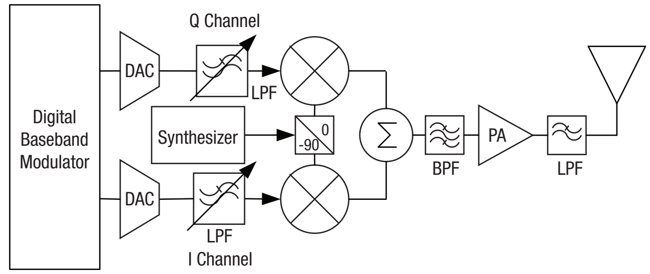


Figure 2. A Typical Direct Conversion Transmitter Chain with Programmable Reconstruction Filters

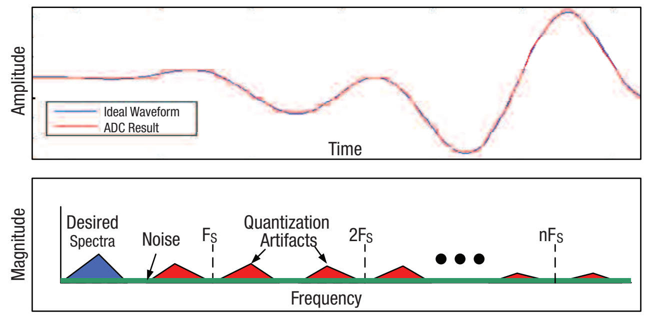


Figure 3. Time and Frequency Domain Representations of a Quantized Analog Waveform—A Unique Reconstruction Filter Setting is Required for Each Sampling Rate

The Receiver

The function of the receiver is to amplify and demodulate radio signals over a wide dynamic range. Dynamic range, and selectivity, i.e. the ability to receive weak signals in the presence of strong signals, are critical specifications of a radio receiver. Additionally, sensitivity and demodulation accuracy are also key performance concerns.

A flexible-channel direct conversion receiver (See Figure 4) achieves its selectivity via the baseband low pass analog filters. This means that the gain of LNA (Low Noise Amplifier) and mixers should be only enough to overcome the receiver's input-referred noise; excessive gain would allow adjacent channel energy to drive the mixers into saturation before any channel selectivity has been applied.

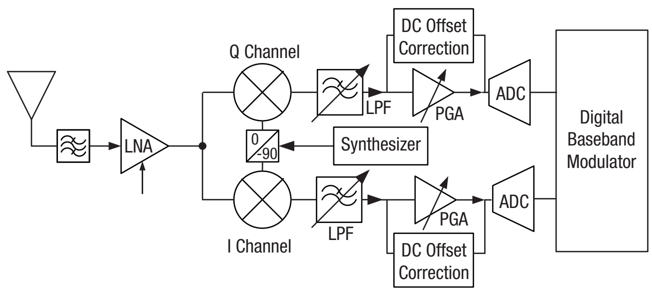
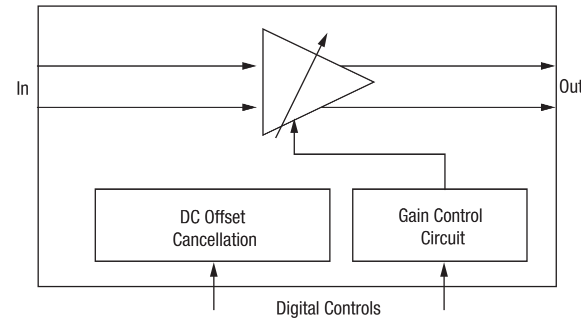


Figure 4. A Flexible Channel Direct Conversion Receiver

Although the digital baseband demodulator contains ideal digital-domain filters, these do not replace the analog baseband filters. Adjacent channel energy is often strong enough to drive the PGAs and ADCs into saturation—digital domain filtering is ineffective if the waveform is not linearly sampled. These analog filters must have a very high dynamic range (the ability to operate in the presence of large signals, while having a small input-referred noise contribution) so that they may remove very strong off-channel energy while passing possible weak desired-channel energy. It is also very important that both the I and Q filters are well matched to each other, and exhibit accurate phase and amplitude responses—this ensures accurate signal down-conversion.

Once the filters strip the undesired (and potentially large magnitude) adjacent and non-adjacent channel energy from the signal path, it is now possible to amplify the desired signal to that of the input dynamic range of the ADC. Since a typical ADCs full-scale input level is about one volt (peak-to-peak), and the front-end mixer and LNA gain is kept to a minimum to preserve linearity, the PGA must produce a very large amount of gain (60 dB or more is common).

Small DC offsets (tens of millivolts), caused mostly by the mixers, are removed at the input of the PGAs by either an adaptive DC offset correction circuit (as shown in Figure 4) or by feedback from digital baseband demodulator. Simple DC offset removal, which is functionally identical to AC coupling, requires a tradeoff between the settling time and the high pass “hole” that is created in the signaling spectra. More advanced techniques, such as those implemented by the SKY65321-364LF Programmable Gain Amplifier (see Figure 5), and custom DSP feedback algorithms, utilize adaptive convergence loops that allow both fast settling time while preserving low frequency signaling content.



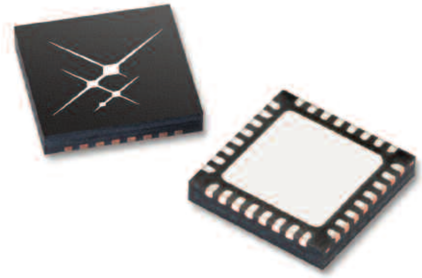


Figure 5. The SKY65321-364LF Programmable Gain Amplifier in a 32-lead, 5 x 5 mm MLP package

Conclusion

Analog filters are an important element in modern high-performance radio/microwave communications systems. Filters are necessary building blocks employed to control the inherent non-idealities of radio and data conversion which even the most capable DSP engines and algorithms cannot address. The SKY73201-364LF 6th Order Programmable Butterworth Filter and the SKY73202-364LF Dual 6th Order Programmable Butterworth Filter can be used in the transmit path or receive path of a radio transceiver as anti-aliasing filters and to remove undesired adjacent-channel energy. The two filters in the SKY73202-364LF are inherently well matched, making them exceptionally well-suited for filtering of I and Q baseband signals.

A baseband amplifier such as the SKY65321-364LF PGA is often placed ahead of the ADC to match its input dynamic range requirements.