High-Q variable bandwidth passive filters for Software Defined Radio

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Abstract

An important aspect of Software Defined Radio is the ability to define the bandwidth of the filter that selects the desired channel. This paper describes a technique for channel filtering, in which two passive filters are combined to obtain a variable bandwidth. Passive filters have the advantage of high linearity, low noise and inherent energy efficiency. After an explanation of the concept, the requirements on the subsequent analog-to-digital conversion are compared with those in a system where (part of) the channel selection is performed digitally. Some drawbacks of the concept are discussed. Finally, conclusions are drawn and our ideas for further research are presented.

Keywords

Software Defined Radio, analog front-end, passive filter, flexibility

1. Introduction

In recent years, interest for Software Defined Radio has been increasing, as evidenced for example by [1]. Software Defined Radio implies that important radio characteristics can be defined by software. One important characteristic of every radio receiver is the bandwidth of the filter that selects the desired channel.

Various ways exist for this filtering. In a conventional single-standard receiver, often a passive filter is used in the form of a ceramic, crystal or surface acoustic wave (SAW) filter. These filters are very linear, exhibit low noise, and require no external power.

One problem however, is their lack of flexibility. Both center frequency and bandwidth are fixed for one particular device. This is a problem in a multi-standard receiver. Other filtering solutions, like active analog filtering or digital filtering are programmable, but consume power.

This paper describes a concept which uses passive filters, but still gives a programmable bandwidth. The idea itself is not new (see for instance [2]), but its application to software defined radio is.

2. System description

A conventional super heterodyne receiver setup is shown in figure 1. The IF filter in such a receiver usually selects only the desired channel, and attenuates all other signals. This greatly reduces the dynamic range of the signal. However, when this system is used in a multi-standard receiver, for most standards the channel bandwidth will be smaller than the bandwidth of the IF filter (because the filter bandwidth will be chosen to accommodate for the standard with the highest channel bandwidth). This means that more than one channel has to be digitized and the remaining channel selection is performed digitally. As the received power in adjacent channels can be far greater than the power of the desired signal, this has a significant impact on the dynamic range, and hence on the number of bits required for the ADC.

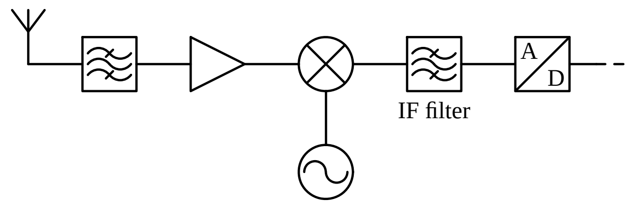

Figure 1: conventional super heterodyne receiver, with fixed bandwidth IF filter

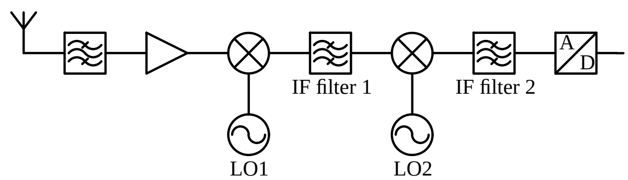

Figure 2: super heterodyne receiver with variable bandwidth IF filter

A different approach is shown in figure 2. This system could be regarded as a standard double super heterodyne receiver, but contrary to a normal implementation, the frequency of the second local oscillator (LO2) can be varied. By doing this, the (band limited) output signal of the first IF filter can be shifted in frequency. This shifted signal is then filtered by the second IF filter. By adjusting the frequency of LO2, a different portion of the signal filtered by the first IF filter can be made to fall within the passband of the second IF filter. In this way, the bandwidth of the signal at the output of the second IF filter can be varied, from the smaller of the two IF filters' bandwidth, theoretically down to zero.

Figure 3 shows the transfer characteristic of two 14^{th} order Butterworth filters, one of which is shifted in frequency, and the resultant filter.

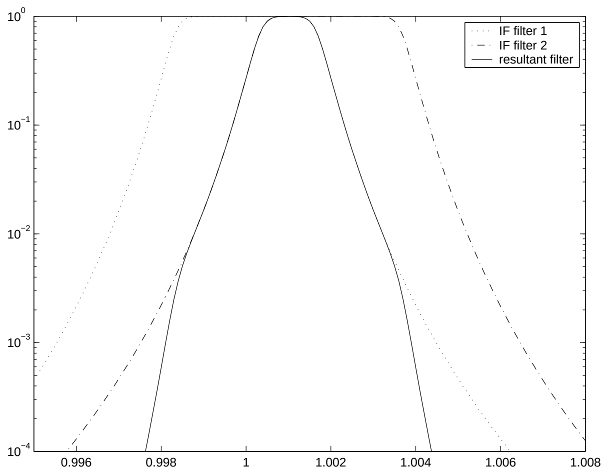

Figure 3: transfer characteristic of two 14^{th} order Butterworth band pass filters, one shifted in frequency, and the resultant filter

standard	ch. BW (Hz)	Δ DR (dB)	Δ # bits
GSM [3]	200k	66	11
DECT [3]	1728k	40	7
Bluetooth [4]	1M	40	7
Hiperlan 2 [5]	20M	0	0

Table 1: various wireless standards, their channel bandwidth, and the effect of analog channel filtering on dynamic range and equivalent ADC resolution

3. Impact on ADC requirements

As mentioned earlier, channel filtering greatly reduces the dynamic range of a signal. Therefore, the required resolution for the analog-to-digital conversion is far lower when channel filtering is performed in front of the ADC.

To estimate the amount of difference, consider two receivers, both designed to receive all the standards listed in table 1. One receiver has a fixed bandwidth IF filter (as depicted in figure 1), while the other has a variable bandwidth IF filter (figure 2). Since the largest channel bandwidth of the selected standards is 20 MHz (for Hiperlan), all IF filters are chosen to have this bandwidth.

Clearly, for Hiperlan the two systems are equivalent. For the other standards, the blocking specifications were examined to obtain the ratio (in dB) between the power of the desired signal and the maximum amount of power inside a 20 MHz bandwidth. The results are shown in table 1.

These results clearly show that channel filtering prior to the ADC affects the required resolution for the ADC. And since the power consumption of an ADC is approximately proportional to $2^{\#bits}$ [6], this drastically reduces power requirements for the ADC.

4. Limitations

Nothing is perfect, and the concept described in this paper is no exception. One drawback is the transfer characteristic of the resultant filter. Usually, a narrower filter has steeper skirts. With this systems however, the slope does not depend on the selected bandwidth. So, when a narrow bandwidth is selected, the filter has a relatively modest roll-off. Also, the transfer function in the pass band is far from flat anymore.

Another issue is the insertion loss of passive filters. SAW filters, which are often used for this application, typically have an insertion loss of up to around 20 dB. An amplifier with a gain of 40 dB to compensate for the loss of two of these filters consumes considerable power.

A last point mentioned here is the need for external components. Although research has shown that integrating SAW filters on-chip is feasible [7], standard IC processes do not accommodate this. Consequently, these filters are located off-chip, and have to be connected to the rest of the circuit using bond wires and PCB traces. This may result in more cross talk which degrades filter performance. On a side note, RF MEMS technologies [8] could in the future lead to integrated passive filters.

5. Conclusions

A circuit technique has been described with which a variable bandwidth filter can be achieved using two fixed bandwidth passive filters. It was shown that analog variable bandwidth filtering lowers the required resolution of ADC in a multi-standard receiver.

As mentioned in the introduction, other methods for channel filtering with a programmable bandwidth exist. Therefore, our next step will be to compare the power consumption of the system described in this paper both with that of digital channel filtering and with analog active filtering on a low or zero IF.

6. Acknowledgement

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7. References

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