

Adaptive Receive Filtering in FDD UMTS

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Abstract— One of the purposes of receive filtering in the Universal Mobile Telecommunication System (UMTS) terminal receiver is to provide channel selection selectivity. This enables the terminal to receive a desired signal in the presence of interfering signals. The worst case interference conditions in which an UMTS terminal still has to operate are defined by a number of conformance tests in the UMTS standard. The interference conditions in which the terminal has to operate in practice are however not always worst case. Based on the required number of operations it is determined when an adaptive digital receive filter is more computationally efficient than a Finite Impulse Response (FIR) receive filter in a terminal where a large part of the receive filtering is performed in the digital back-end. This turns out to be the case when the Adjacent Channel Interference (ACI) conditions are 10 dB or more below worst-case.

Keywords— adaptive signal processing, receive filtering, UMTS

I. INTRODUCTION

One of the purposes of receive filtering in the Universal Mobile Telecommunication System (UMTS) terminal receiver is to provide channel selection selectivity. This enables the terminal to receive a desired signal in the presence of interfering signals. Receive filtering in cellular receivers is usually performed partially in the analog front-end and partially in the digital back-end.

It is likely that most commercial UMTS terminals will use a homodyne receiver architecture (also called direct conversion or zero IF receiver) [1], such as the one presented in Fig. 1. The elimination of an Intermediate Frequency (IF) removes the need for a Surface Acoustic Wave (SAW) filter and an IF synthesizer and mixer, reducing the cost of the receiver. The removal of IF however also means that all the receive filtering will have to be performed in either analog or digital baseband.

In the Freeband Adaptive Wireless Networking (AWgN) project [2] we develop algorithms that implement functions in the Frequency Division Duplex

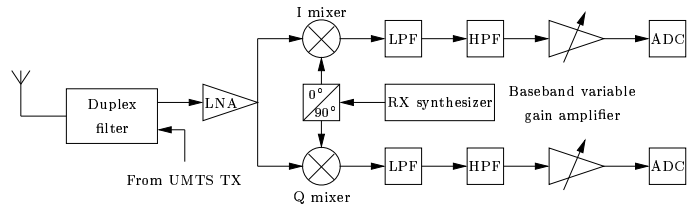


Fig. 1. Homodyne receiver.

(FDD) UMTS terminal receiver by means of Digital Signal Processing (DSP) with a focus on adaptivity [3]. In this paper we study the practicality of making the amount of receive filtering performed in the UMTS terminal adaptive on the interference conditions by using an adaptive digital receive filter.

The paper is organized as follows: In Section II we determine the channel selection selectivity requirements for the worst case interference conditions in which the UMTS terminal has to operate. Section III studies the tradeoffs between performing receive filtering in the analog front-end or the digital back-end. Section IV introduces an adaptive digital receive filter architecture that is found in literature. In Section V we analyze the variation of interference conditions in which an UMTS mobile terminal has to operate. In Section VI the practicality of adaptive digital receive filtering is determined given the range of interference conditions in which the mobile terminal has to operate and the costs of making the receive filtering adaptive. Finally in Section VII the conclusions from this paper are drawn and some directions for future work are given.

II. WORST CASE CHANNEL SELECTION SELECTIVITY REQUIREMENTS

Fig. 2 shows the UMTS downlink receiver channel selection selectivity requirements as a function of the frequency offset from the center frequency of the desired channel. In the figure the solid line indicates the selectivity requirements within the UMTS downlink band, while the dashed line indicates the out-

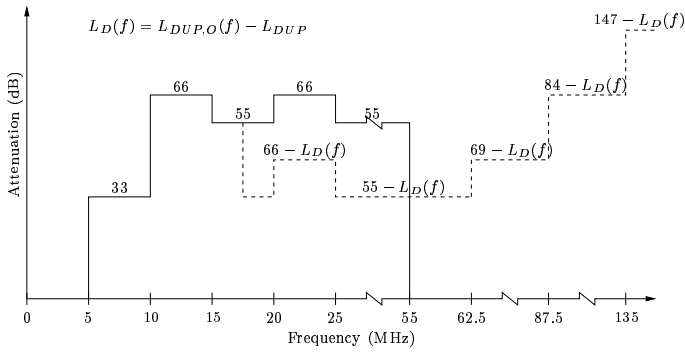


Fig. 2. Channel selection selectivity requirements.

of-band requirements. $L_D(f)$ in the figure represents the duplexer attenuation for a given frequency, which is determined by the out-of-band duplexer attenuation $L_{DUP,O}(f)$ and the in-band duplexer loss L_{DUP} . These requirements were determined in [4] from the UMTS adjacent channel selectivity, in- and out-of-band blocking and intermodulation requirements [5]. Since the duplexer is the only element in a homodyne receiver that performs Radio Frequency (RF) filtering (see Fig. 1) all the attenuation in Fig. 2 will have to be provided by either the analog or the digital base-band filtering.

III. ANALOG - DIGITAL RECEIVE FILTERING TRADEOFFS

Traditionally UMTS direct conversion receivers use analog receive filters with a fifth- or sixth-order Butterworth, Chebychev or elliptical low-pass frequency response for channel selection [6] [7] [8]. These high-order analog receive filters have the advantage that they have high adjacent channel rejection thus reducing the dynamic range requirements of the Variable Gain Amplifier (VGA) and Analog to Digital Converter (ADC) following the analog receive filtering. Disadvantages of these high-order filters are however that they usually require frequency response tuning because of component variations and that they cause Inter Chip Interference (ICI) because of group delay variation which has to be compensated for by equalization in the digital domain.

The current situation of coexisting second- and third-generation cellular systems drives a trend in developing multistandard front-ends for multimode mobile terminals. This makes analog receive filtering more complex because the receive filter has to be made switchable [9], which also means that some of the hardware is not used in all modes. As reuse of hardware is generally easier in the digital rather than

the analog domain this motivates the approach of digitizing as much of the receiver signal processing chain as possible [10] removing the need for complex analog receive filters and VGAs. This requires ADCs with a large dynamic range and a low power consumption. The developments in $\Sigma\Delta$ ADCs make this possible for the signal bandwidths required by UMTS [11].

In [12] for example a $\Sigma\Delta$ ADC for a multimode GSM-EDGE/CDMA2000/UMTS receiver is presented. In UMTS mode it has a dynamic range of 72 dB and a power consumption of 4.5 mW at 1.8 V. The required dynamic range of the ADCs in UMTS mode is determined by the largest input signal, which must be handled and the amount of quantization noise that can be tolerated. The largest input signal that an UMTS receiver should be able to handle is an unmodulated blocking interferer at an offset of 85 MHz with a level of -15 dBm defined in the out-of-band blocking test [5]. In [10] the amount of quantization noise that can be tolerated is determined to be -110 dBm. This would mean that the ADC dynamic range requirement $DR_{adc} = -15 - (-110) = 95$ dB. This is larger than the dynamic range of 72 dB of the ADC in [12]. The out-of-band interferer at an offset of 85 MHz is however attenuated by the RF duplexer because it falls outside of the 60 MHz UMTS downlink signal band and it can be further attenuated by a passive first-order analog receive filter. In [10] it is determined that in this way the required ADC dynamic range is reduced to 66 dB.

Fig. 3 shows the magnitude and phase responses of two first order Butterworth filters. The first filter has a cutoff frequency f_c of 8.5 MHz, while the cutoff frequency of the second filter is placed directly at the edge of the UMTS desired signal band at 1.92 MHz. The phase responses show that moving the cutoff frequency to 8.5 MHz reduces the phase variation and thus the group delay variation in the desired signal band which reduces the intersymbol interference. This however also means that the analog filter does hardly provide any adjacent channel attenuation, so the required maximum attenuation for in-band interfering signals of 66 dB (see Fig. 2) will have to be provided entirely by the digital receive filter.

IV. ADAPTIVE DIGITAL RECEIVE FILTER ARCHITECTURE

UMTS uses a Root Raised Cosine (RRC) transmitter pulse-shaping filter with a roll-off factor of 0.22. This means that ideally the receiver pulse-shaping filter will also have a RRC impulse response. In practice the receiver pulse-shaping filter is often combined

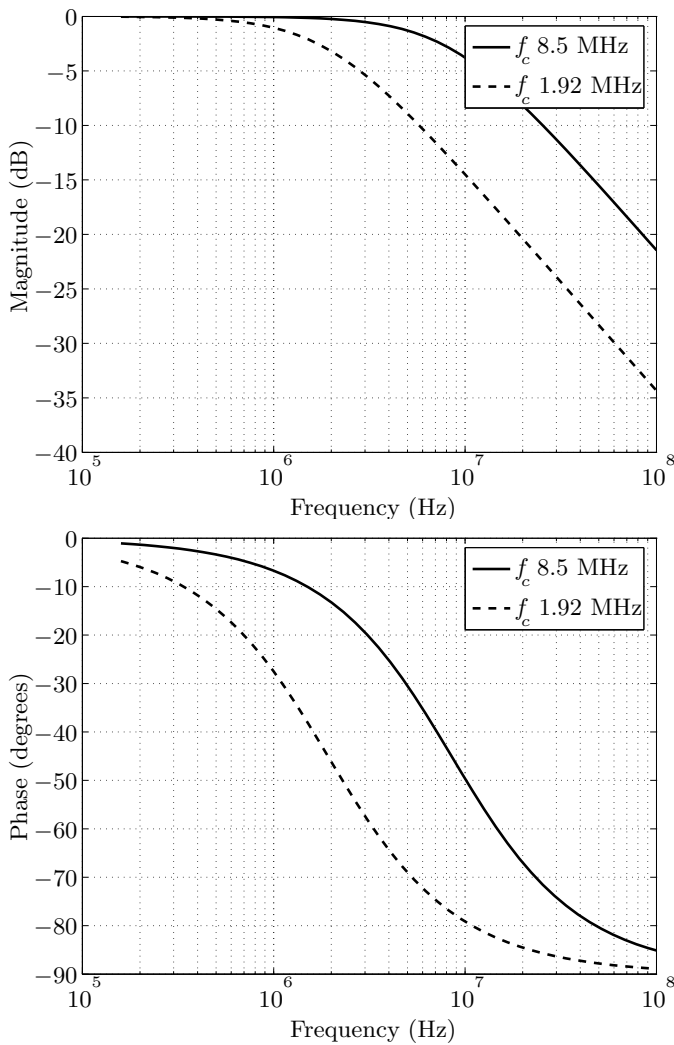


Fig. 3. Magnitude and phase response of first order analog Butterworth filters.

with the channel selection filter and is implemented as a fixed length Finite Impulse Response (FIR) digital filter. This digital receive filter will have to approximate the RRC impulse response closely enough to not cause a lot of ICI and it will have to provide sufficient adjacent channel attenuation for suppression of in-band interfering signals.

In [13] Veljanovski et. al. have proposed an adaptive digital receive filter for a Time Division Duplex (TDD) UMTS terminals receiver which stop-band attenuation is adjusted to the measured in-band interference. It is based on the effect that the stop band attenuation of a low-pass Finite Impulse Response (FIR) filter reduces when taps are shaved off of the tails of its impulse response. This architecture can also be used in FDD UMTS terminals and is shown in Fig. 4. It consists of a folded FIR filter structure with an adjustable number of taps and a low-pass and a

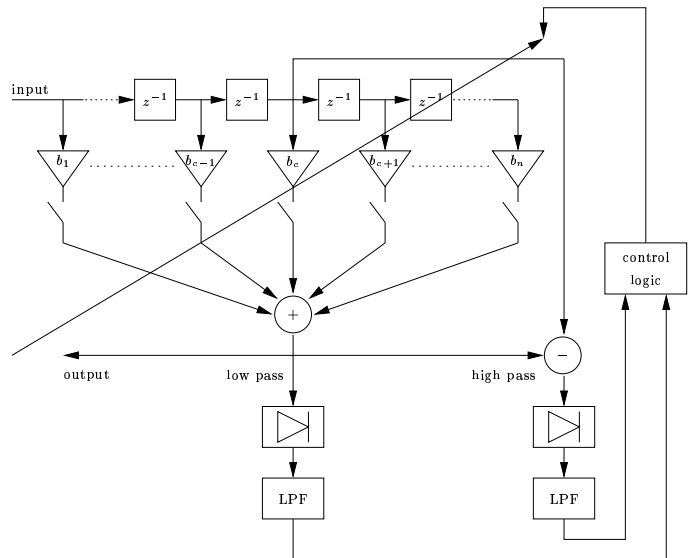


Fig. 4. Adaptive digital receive filter

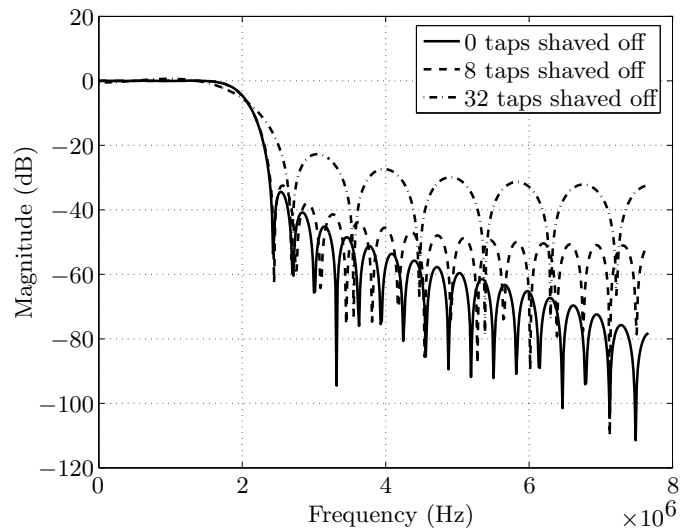


Fig. 5. Magnitude response of a 49 tap adaptive digital receive filter

high-pass output, two rectifiers, two Infinite Impulse Response (IIR) low-pass filters and control logic. The rectified and low-pass filtered low-pass and high-pass outputs of the FIR filter are used to respectively measure the power inside and outside of the desired UMTS channel. Based on these measurements the controller determines the required attenuation and the corresponding number of taps.

Fig. 5 shows the magnitude response of a 49 tap adaptive digital receive filter. When 0 taps are shaved off of the tails of its impulse response (solid line) the filter meets the 33 dB and 66 dB attenuation requirements (see Fig. 2) for in-band interference at frequency offsets of respectively 5 MHz and >10 MHz. Fig. 5 also shows that the stop band attenuation of

the receive filter can be reduced by shaving taps off of the tails of the filters impulse response which reduces the computational complexity of the filter. This is however only useful when the interference conditions vary and the maximum adjacent channel attenuation is thus not required all the time.

V. VARIATION OF INTERFERENCE CONDITIONS

Table I shows the UMTS downlink spectrum assignment in the Netherlands [14]. Each operator has two or three 5 MHz wide UMTS downlink channels available. In thinly populated areas a single channel base station can probably provide sufficient capacity for all the customers of an operator. So in that case the other channels of that operator will not be used in that area. Channels next to an unused channel will experience no Adjacent Channel Interference (ACI) which means that the full 33 dB adjacent channel attenuation (see Fig. 2) is not required in this particular area.

When all UMTS channels are in use in a particular area the ACI can vary as well. The amount of ACI a mobile terminal experiences depends on the difference in distance between the mobile terminal and two base stations transmitting on adjacent frequencies. When a mobile terminal in the network of operator 1 is connected to a far-away base station and is at the same time located close to operator 2's base station it will experience strong ACI. Relative signal power measurements in UMTS networks show that the probability of adjacent channel power differences larger than 41 dB is typically $< 1 \cdot 2\%$ [15]. So the probability that a mobile terminal experiences strong ACI is relatively low. This means that the full 33 dB adjacent channel attenuation (see Fig. 2) is often not required.

VI. PRACTICALITY OF ADAPTIVE DIGITAL RECEIVE FILTERING

In the previous section we have seen that there are conditions in which the full 33 dB adjacent channel attenuation is not required. In a mobile terminal using the adaptive digital receive filter of Section IV this means that a certain number of taps can be shaved off of the tails of the filters impulse response. Shaving a single tap off of each end of the filters impulse response reduces the number of operations that have to be performed per filtered complex sample with two multiplications and four additions, because the adaptive digital receive filter uses a folded FIR structure.

The adaptivity of the adaptive digital receive filter however comes at the cost of some control overhead because the power in- and outside of the desired UMTS channel has to be measured and the number taps that can be shaved off have to be determined. It is assumed that the control loop is only implemented on the in-phase part of the filter but controls the number of shaved taps for both the in-phase as well as the quadrature part of the filter. Measuring the power in- and outside of the desired UMTS channel requires a subtraction per filtered sample to obtain the low-pass and high-pass in-phase FIR filter outputs, see Fig. 4. Rectifying and low-pass filtering these takes respectively two absolute value operations and eight multiplications and four additions per filtered sample (assuming two first-order IIR low-pass filters). Finally the control logic requires a subtraction and a table lookup per filtered sample to determine the number of taps that can be shaved off.

So when it is assumed that the multiplications dominate the complexity the control overhead of the adaptive digital receive filter is compensated for by the reduction in complexity achieved by shaving off taps when in total eight or more taps can be shaved off of the tails of the filters impulse response (four off each end). From Fig. 5 it can be seen that this causes about a 10 dB reduction of the filters stop band attenuation at a frequency offset of 5 MHz. It is likely that in practice there are conditions in which the ACI is 10 dB or more below the maximum allowable ACI of the UMTS adjacent channel selectivity test. So in those conditions the adaptive digital receive filter is more efficient than a fixed FIR receive filter.

Due to time constraints a complete implementation of the adaptive digital receive filter has not yet been finished. So unfortunately complexity comparison numbers using an actual implementation of the filter can not yet be given.

The adaptive digital receive filter is not practical in UMTS terminals where a large part of the receive filtering is performed in analog baseband. In these terminals the remaining adjacent channel attenuation that has to be provided by the digital receive filter can be achieved using a relatively short FIR filter. Not enough taps of these short filters can be shaved off to compensate for the control overhead of the adaptive digital receive filter.

VII. CONCLUSIONS AND FUTURE WORK

In this paper we have shown based on the required number of operations that an adaptive digital receive

TABLE I
UMTS DOWNLINK SPECTRUM ASSIGNMENT IN THE NETHERLANDS.

Operator	Vodafone			KPN			Orange		Telfort		T-Mobile	
Freq. band	2110.3 - 2124.9			2124.9 - 2139.7			2139.7 - 2149.7		2149.7 - 2159.7		2159.7 - 2169.7	
Channels	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz

filter in an UMTS mobile terminal can be computationally more efficient under certain ACI conditions than a fixed length FIR receive filter. This is only the case in terminal receivers where a large part of the receive filtering is performed in the digital baseband. However the general trend in the design of wireless terminal receivers appears to be moving in the direction of making the receivers more and more digital.

In future work we would like to finish the adaptive receive filter implementation. Furthermore we plan to study the effect of shaving off taps of the receive filters impulse response on the ICI, which might degrade the receivers performance. In order to get a better view of the interference conditions in which a UMTS terminal has to operate in practice it would be nice to obtain coverage simulations or measurements in which the relative signal strengths of two UMTS networks transmitting on adjacent channels are shown.

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