The Effect of Filter Type on BER of WCDMA-UMTS Mobile Radio Systems

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Abstract— **This paper investigates the Bit Error Rates (BER) obtained using different filter types for RF front ends for WCDMA-UMTS mobile radio systems. Most Base Stations use Chebychev or Cauer-Chebychev filters. This paper compares the use of Bessel, Butterworth and Chebychev filters for use as single channel filters in a WCDMA-UMTS radio system. It is shown that even though Bessel filters pass more adjacent channel interference, they result in a significantly lower Bit Error Rate (BER) and insertion loss than the other filter types.**

I. INTRODUCTION

Currently most Base Stations use Chebychev or Cauer-Chebychev filters [1, 2]. The paper by Jacob [1] for instance refers to 24 Chebychev, Cauer-Chebychev and Quasi-Elliptic filter designs but not one Butterworth or Bessel filter design. Chebychev filters [3] give the best protection from out of band signals entering the receiver, however as shown in this paper, their poor group delay causes degradation of the waveforms and result in a higher BER for wideband mobile radio systems, where a single RF filter can be used for each channel.

The basic block diagram of a WCDMA modulator is shown in Fig. 1. The data to be transmitted is multiplied by a spreading sequence that has a higher chip rate than the data rate. This spread spectrum signal is then quadrature modulated by multiplying it by an I code and a Q code, both operating at the chip rate. The modulator includes filters ensuring that no signals outside the channel bandwidth are generated. The resulting RF signal can be simulated using a QPSK signal, modulated by random data at the chip rate. An initial investigation on the effects of filter types used a 1 Mcps chip rate [4]. The results presented here are for WCDMA (UMTS), which has a chip rate of 3.84 Mcps, a channel spacing of 5 MHz and a typical Channel Bandwidth of 4.2 MHz.

During demodulation the RF signal is quadrature demodulated, to produce I and Q data streams. The BER of these I and Q data streams is a good performance indicator and is used in this paper. De-spreading and error correcting decoding, will further reduce the BER of the system data. There is a non-linear relationship between the BER of the I and Q data streams and the final BER of the mobile radio system.

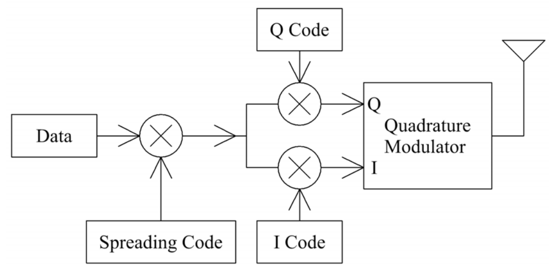

Figure 1. Basic modulation block diagram

II. COMPUTER SIMULATION

Communication system simulation software [5, 6] now makes it possible to investigate the behaviour of the Bessel, Butterworth and Chebychev filter types when used as RF filters protecting the mobile radio base station front end from interference. In this paper, AWR [5] Visual System Simulation (VSS) is used for the computer simulation. The results presented here are for a wideband modulation scheme, where a single filter is used for each channel. To minimise the computational load, the centre frequency of the transmitter is shifted to DC, so that firstly: low pass filters rather than bandpass filters can be used, and secondly: the sampling frequency can be made as low as possible for a given data rate. Since all the waveforms used are complex, the same spectra result, the only difference being the shift in centre frequency. To provide accurate waveform information, a sampling rate of 8 times the chip rate has been used throughout these simulations.

In the block diagram of Fig. 2, the input (IN1) and interferer (IN2) are two different random binary data generators, which generate data at the WCDMA chip rate of 3.84 Mcps. For WCDMA (UMTS), a Root Raised Cosine (RRC) filter with α=0.22 is used in both the transmitter and receiver. In a practical receiver system, the signal from the antenna is filtered by the RF filter being considered in this paper. The output from that filter is then amplified, frequency shifted and digitized. Just prior to demodulation, the complementary RRC filter is used as shown in Fig. 2.

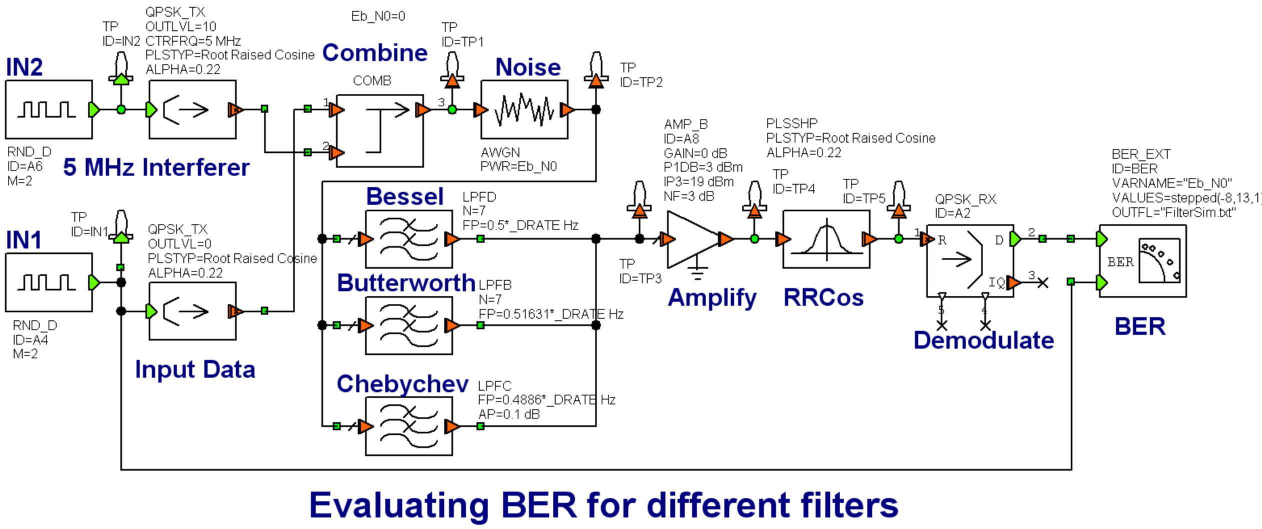

Figure 2. Block diagram of simulation using Visual System Simulator (VSS) [4].

In Fig. 2, the input and interferer data sources are combined and a variable amount of noise is added. The interferer is modulated onto a 5 MHz carrier, corresponding to the channel spacing of WCDMA (UMTS), and its power level is varied to study the effect of adjacent channel interference. The Bit Error Rates are determined using the BER measuring block as the noise and interference is varied. The amplifier block is a general purpose amplifier, where the 1dB compression points and the second and third order intermodulation distortion can be adjusted. The amplifiers are follower by the receiver root raised cosine filters with α=0.22, to provide the raised cosine response for the whole system.

As shown in Fig. 2 only one BER meter is used since due to the different time delays of the signals passing through the 3 different filters and “no filter” configurations being tested, the software has difficulty in accurately evaluating BER if 4 different BER meters were used at the same time. To ensure correct synchronization of the BER meter and thus provide accurate results, only one of the Bessel, Butterworth, Chebychev blocks or “No filter” is enabled at a time. The data from these single trace BER measurements are combined to produce the results shown in this paper. For these results, a minimum of 500 errors or 5 million data samples are required for each plotted data point on the BER curves. Since the error occurrences are random, there are small random variations in the plotted BER curves.

A. Basic filter simulations

Seventh order low pass filters are used for this simulation, which when realized as an RF base station filter, correspond to 7 resonator filters. For the Chebychev filter a passband ripple of 0.1 dB is used to ensure that the increase in receiver noise figure due to the passband insertion loss caused by the ripple is kept to practical limits. Since the BER, depends on the cut-off frequency of the filters, suitable cut-off frequencies have to be selected to allow for a fair comparison between the filter types to be made. The cut off frequencies all filters is chosen such that, if the same uniform spectrum is applied to each of the three filters, the total output power from each filter is the same. This corresponds to a cut-off frequency of 1.92 MHz for the Bessel filter, 1.98 MHz for the Butterworth filter and a cut-off frequency (0.1 dB attenuation) of 1.87 MHz for the Chebychev filter. Fig. 3 shows the resulting frequency responses of the three different filters.

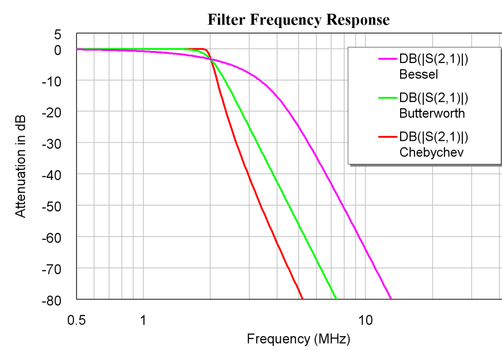

Figure 3. Filter responses for the three filters used in this paper.

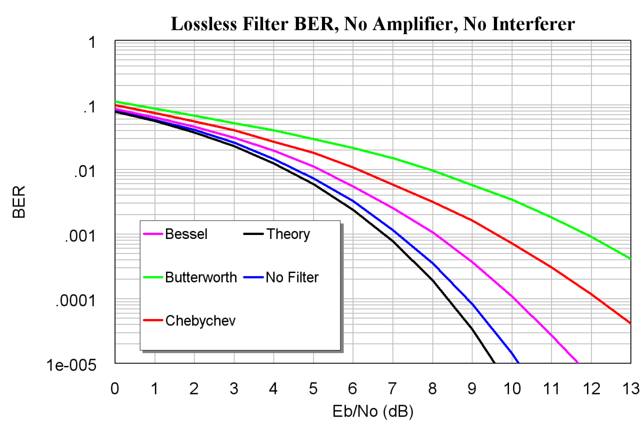

Figure 4. BER of lossles filters, No Interferer, No Amplifier.

Fig. 4 shows the resulting BER for lossless filters. The Bessel filter performs significantly better than the Butterworth filter, and the Chebychev filter performs the worst. For lossless filters and an Eb/N0 ratio of 11 dB, the Chebychev filter has 300 times more errors than the Bessel filter.

B. Practical Filters

The 7th order low pass filters used in this paper, require 7 resonators when they are implemented as RF filters for a mobile radio system. The1920-1980 MHz frequency band is used for a WCDMA (UMTS) uplink. The filter bandwidth is thus 5/1950 = 0.256%. In Australia, the 824-849 MHz band is used for the NextG WCDMA uplink, resulting in a 0.6% filter bandwidth requirement. From filter tables [3], the unloaded Q (Q_0) values required for a filter with a 0.256% RF bandwidth and 1 dB insertion loss is approximately 10000 for the Bessel filter, 20000 for the Butterworth filter and 47000 for the Chebychev filter. Since the resonator diameter is related to the Q_0 of the resonator, Chebychev filters are much larger than Bessel filters for the same insertion loss and a Q_0 of 47000 is very difficult to achieve using low cost technology.

For Combline resonator filters, Q_0 is typically 4000. For coaxial resonator filters, Q_0 is typically 5000. For dielectric resonator filters, Q_0 ranges from 10000 to 40000, with 20000 being typical [7]. A Q_0 of 10000 results in an insertion loss of 1 dB for the 7 resonator Bessel [3], 2.1 dB for the Butterworth and 6.4 dB for the Chebychev filter. Since the RF filter is placed immediately after the antenna, a 6.4 dB insertion loss due to a filter results in a 6.4 dB increase in noise figure of the receiver and a 6.4 dB decrease in Eb/N0, thus shifting the curve for the Chebychev filter in Fig. 4 by 6.4 dB to the right. A 6.4 dB noise figure is too large for a practical mobile radio system. For a Q_0 of 20000 and a 0.256% RF bandwidth, the normalised unloaded Q (q_0) is 51, resulting in an insertion loss of 0.5 dB for the Bessel filter, 1 dB for the Butterworth filter and 2.6 dB for the Chebychev filter. Fig. 5. shows the similar results as shown in Fig. 4, but for practical filters with a Q_0 of 20000. It can be seen that the Butterworth and Chebychev filters have nearly the same performance and that the Bessel filter has 15 times less errors at an Eb/No of 10 dB.

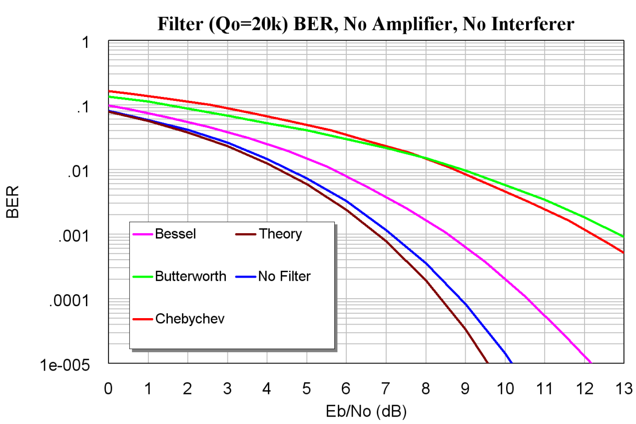

Figure 5. BER of filters (Q_0=20000), No Amplifier, No Interferer.

C. Amplifier Distortion

In practice the RF filters are mounted as close to the base station antenna as possible and an amplifier is used after the filters, to amplify the signals prior to further frequency shifting and demodulation. To investigate the effect of amplifier distortion, a typical amplifier [8] with a 1 dB compression level (P1dB) of +3 dBm, which is 3 dB above the power level produced by the input signal, no second order inter-modulation (IM) and a third order (3IM) intercept point of +19 dBm is included after the filters in Fig. 2. The amplifier gain is set to 0 dB to allow the amplifier to be switched in and out without effecting other parameters.

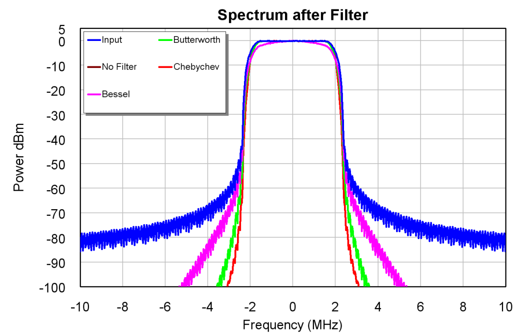

Figure 6. Received spectrum after filters.

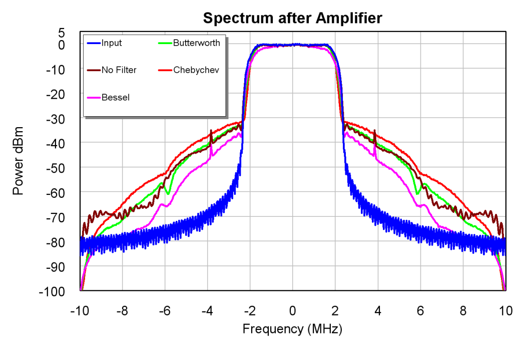

Figure 7. Spectrum of data after amplifiers.

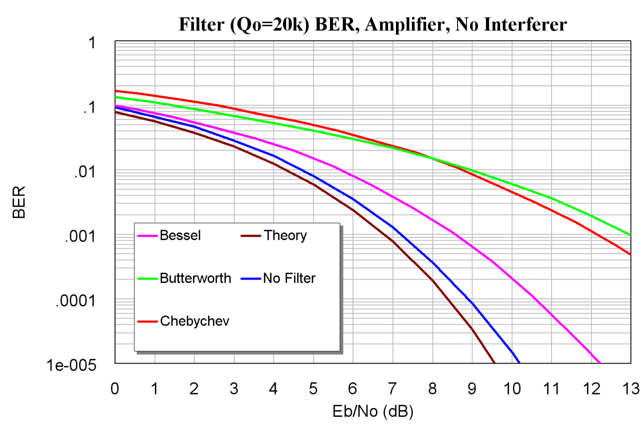

Figure 8. BER of filters (Q_0=20000), Amplifier, No Interferer.

Fig. 6 shows the spectrum of the WCDMA signal after the filters, but before the amplifiers. It can be seen that the Chebychev filter provides the best attenuation to out of band signals. Fig. 7 shows the same spectrum after the amplifier. It can be seen that the Chebychev filter and amplifier combination creates more IM products, because of the poorer transient response of the Chebychev filter.

Fig. 8 shows the BER for filters with a Q_0 of 20000 when amplifiers, which cause the spectrum of Fig. 7 are used. Fig. 5 and 8 are virtually identical and show that in-channel IM distortion caused by the amplifier has little effect when no interference is present.

D. Adjacent Channel Interference

To investigate adjacent channel interference, an interferer with the same power as the input signal and with a carrier frequency of 5 MHz, above the input signal is used. This corresponds to an adjacent radio channel. The spectra of the Bessel filter chain, when no noise is present, is shown in Fig. 9. The blue curve shows the input spectrum, before the filter. The red curve shows the same spectrum after passing through the Bessel filter. It can be seen that the Bessel filter does not remove much of the adjacent channel. The magenta curve shows the signal at the output of the amplifier. The intermodulation distortion generated by the amplifier is clearly visible. The green curve shows the spectrum after this signal at the amplifier output is passed through the RRC filters in the receiver. It is clear that the RRC filters are very effective at removing any adjacent channel interference.

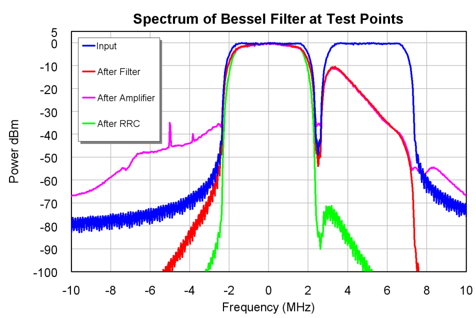

Figure 9. Spectra for Bessel filter with adjacent channel interference.

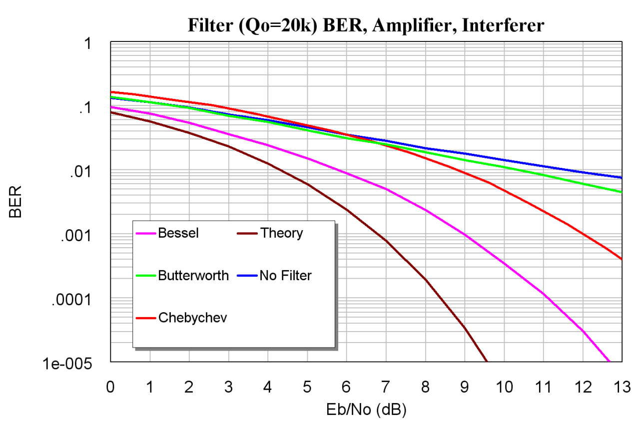

Figure 10. BER of filters (Q_0=20000), Interferer, Amplifier.

Fig. 10 shows the performance of the different filter types in the presence of an equal power adjacent channel interferer corresponding to the spectra shown in Fig. 9. Filters with a Q_0 of 20000 are used and amplifiers are included. This plot again shows that the Bessel filter results in a significantly lower BER than the other filters, even though they remove much less of an interfering signal than Chebychev or Butterworth filters. Fig. 10 shows that RF filters are required, since when an interference is present and typical amplifiers are used, not using any filter results in the poorest performance.

When the amplifier is removed in Fig. 2, or the IM performance of the amplifier is improved, so that no significant distortion results, then a virtually identical plot to Fig. 5 and Fig. 8 results. Increasing the interference by 10 dB under these conditions, results in no noticeable change in BER. This shows that when an interference is present, the performance of the front end amplifier is critical.

Conclusion

This paper shows that Bessel filters give a significantly lower BER and a lower insertion loss than the Chebychev filters currently used in WCDMA mobile radio base stations. The group delay is thus more important that the amplitude response for WCDMA signals. A combination of Bessel RF filters and highly linear input amplifiers will thus result in the best Base Station performance.

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