Project	**IEEE 802.16 Broadband Wireless Access Working Group**	
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Re:	This contribution is submitted in response to the invitation to contribute for Session #6.	
Abstract	Net Filter Discriminator (NFD) values and BER curves for TFM modulation are presented. Also the power amplifier structures for QPSK and TFM are compared.	
Purpose	This contribution tries to clarify some of the issues related to Tamed Frequency Modulation (TFM).	
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TFM (CQPSK) in the 802.16 upstream

Introduction

Tamed frequency modulation (TFM) (also called CQPSK) has been proposed as the upstream modulation scheme for the 802.16.1. Because TFM has generated a lot of discussions and concern about the spectral efficiency, this proposal tries to clarify some issues and to justify the use of TFM in the upstream. One of the reasons for the discussions is perhaps that TFM is not so known and well understood and consequently there is a need for some additional information.

The questions raised have been about spectral efficiency, BER and implementation issues. These are all very relevant and important questions as they address the capacity of the uplink and the price of the terminals.

The coherent qudrature TFM receiver resembles the QPSK receiver although there are some very important differences. First, decisions are made for one bit a time not for a symbol like in QPSK. The second difference is that the optimal receiver filter is different from the filters used in QPSK. This point was not taken into acccount in the contribution 802.16.1.pc-00/11 [4] where a BER curve was presented for TFM.

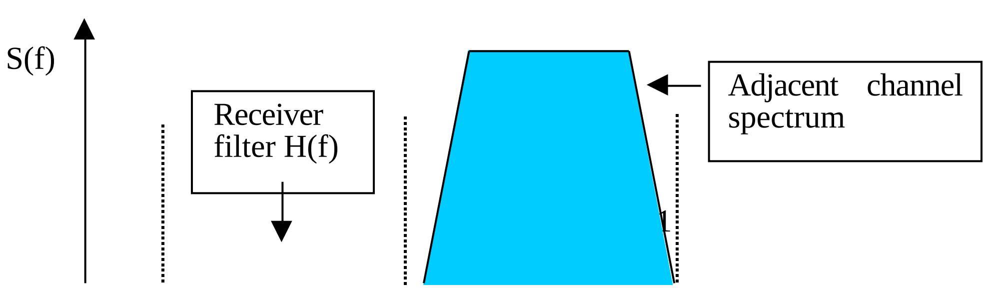
Net Filter Discrimination

Net Filter Discrimination (NFD) indicates how a signal in the adjacent channel interferes with the signal in the wanted channel. It is defined as the ratio between the power transmitted by the interfering system and portion of it that can be measured after the receiver filter in the adjacent channel. The situation is shown in figure 1 where both the spectrum of the interfering signal and receiver filter are presented. The overlapping area represents the part of the interfering spectrum that falls in the receiver filter band and is the source of interference.

The NFD is defined with the following formula

$$NFD = \frac{\int_{-\infty}^{+\infty} S_I(f)\,df}{\int_{-\infty}^{+\infty} S_I(f)\left|H(f)\right|^2 df}$$

where $S_I(f)$ is the power spectrum of the interfering system and H(f) is the transfer function of the receiver filter.



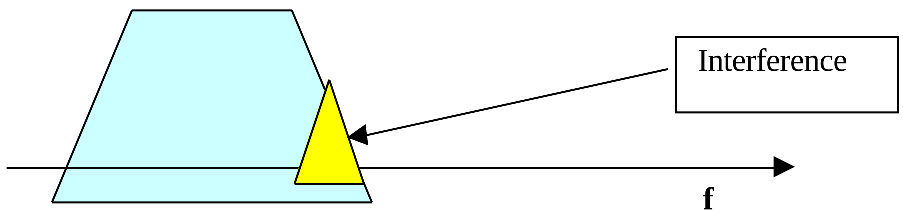


Figure 1. Adjacent Channel Interference (ACI)

In table 1 are the required NFD values (dB) for different upstream scenarios presented. The figures are computed by assuming a required BER of 10^{-4}. The values are based on the assumption that the base station receives all the modulation schemes at the same power level. It is also assumed that there are some tolerances in the components and that there is 1 dB of threshold degradation due to the adjacent channel interference.

	Interferer		
Receiver	**TFM**	**4QAM**	**16QAM**
TFM	20.7 dB	20.7 dB	20.7 dB
4QAM	19.7 dB	19.7 dB	19.7 dB
16QAM	26.7 dB	26.7 dB	26.7 dB

Table 1. Required NFD (dB) for different upstream scenarios.

The NFD between TFM and QAM is shown in figure 2 for different relative bitrates of TFM. Different values of alpha are represented by different curves. Low values of alpha have a lower NFD value than higher. It is seen that at the proposed relative TFM bitrate of 1.33 the NFD is sufficiently high for all the QAM curves except the curve where alpha = 0.1 when a value of 26.7 dB is required.

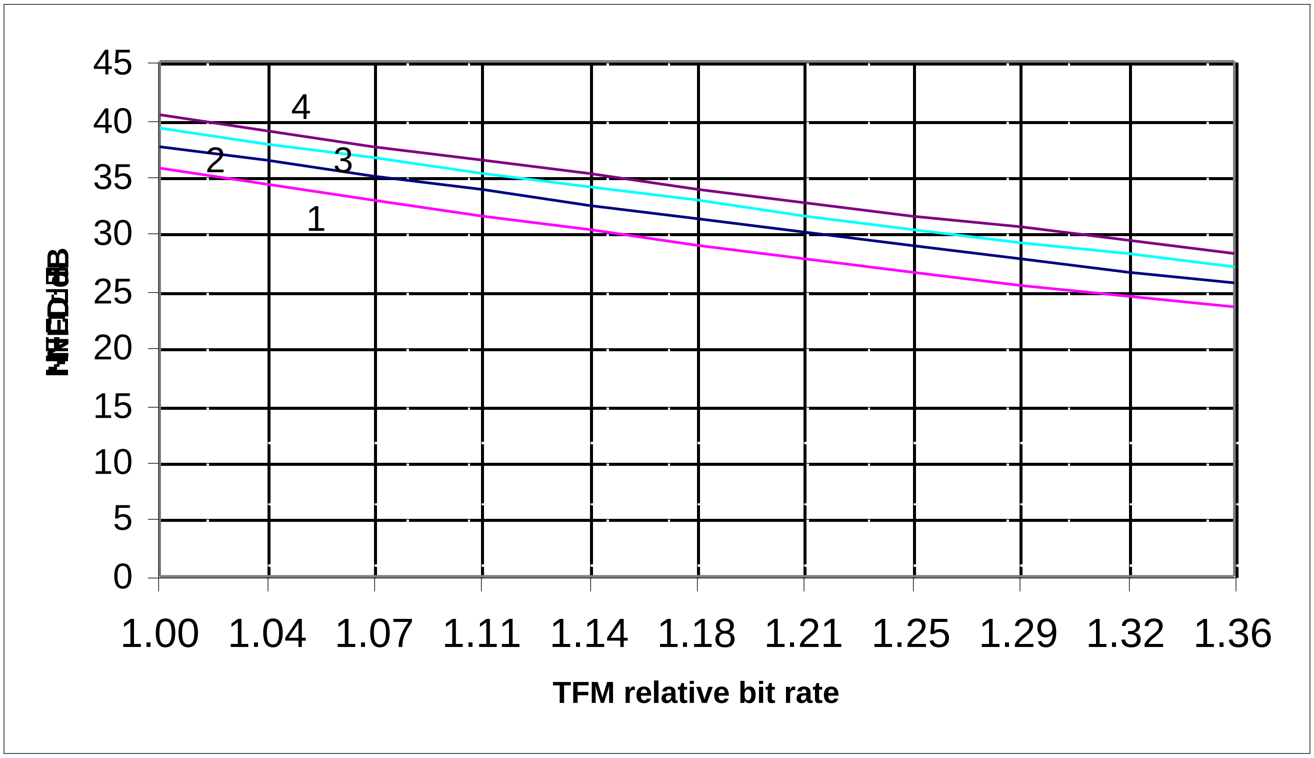


Figure 2. NFD for a TFM transmitter in the adjacent channel. Curves 1 – 4 represent alpha values of 0.1, 0.2, 0.3 and 0.4.

BER performance of TFM

The bit error rate for a modulation scheme depends on the normalized minimum distance between symbol sequences. Table 2 shows the minimum distances for QPSK and TFM. For TFM the minimum distance is found from all possible 6 bit sequences. As seen from the table QPSK has a larger minimum distance and a slightly better performance can also be anticipated. With an optimal receiver the BER can be computed by the formula

$$P_e = Q\left(\sqrt{d_{\min}^2 E_b / N_0}\right)$$

where $d_{\min}^2$ is squared minimum distance and Eb/N0 is the signal to noise ratio in the corresponding band. A TFM receiver with a Viterbi decoder comes close to an optimal receiver.

	N	$d_{\min}^2$
QPSK	1	2.000
TFM	6	1.594

Table 2. Minimum distances

In a real receiver the minimum distance between the symbol sequences will be changed by the receiver filter. Performance of the coherent quadrature TFM receiver is highly sensitive to the filter performance. For TFM receivers there are several approaches for filter design. The AOF-filter (Asymptotically

Optimum Filter) is optimal for high signal to noise ratios. In figure 3 The BER curves for QPSK and different types of TFM receivers are shown. From the curves it also shown that a raised-cosine filter gives a poor performance for TFM.

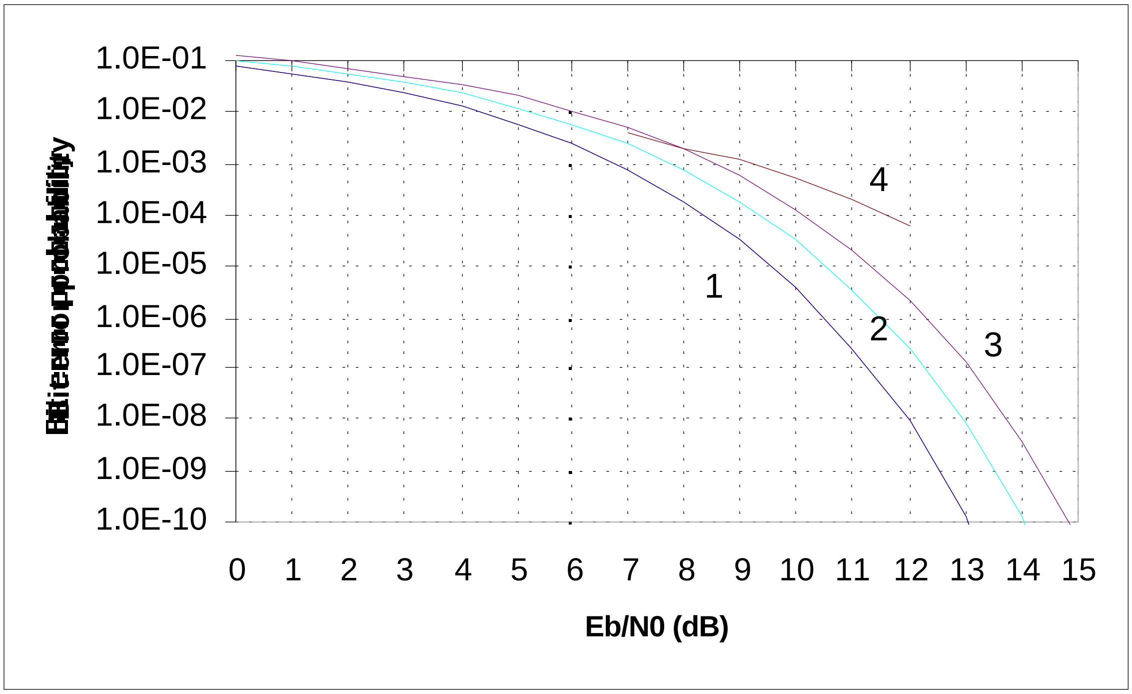


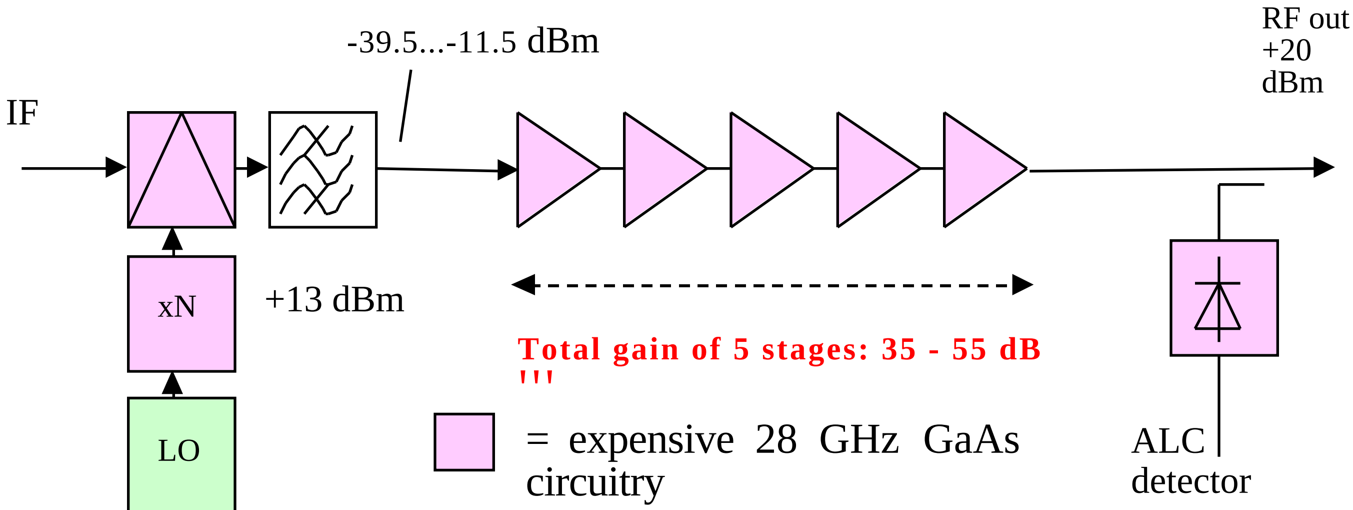
Figure 3. BER curves for TFM and QPSK

1) QPSK with optimal receiver
2) TFM with optimal receiver
3) TFM with MSK-receiver and AOF-filter
4) TFM with MSK-receiver and RC-filtering (roll-off factor 0.4)

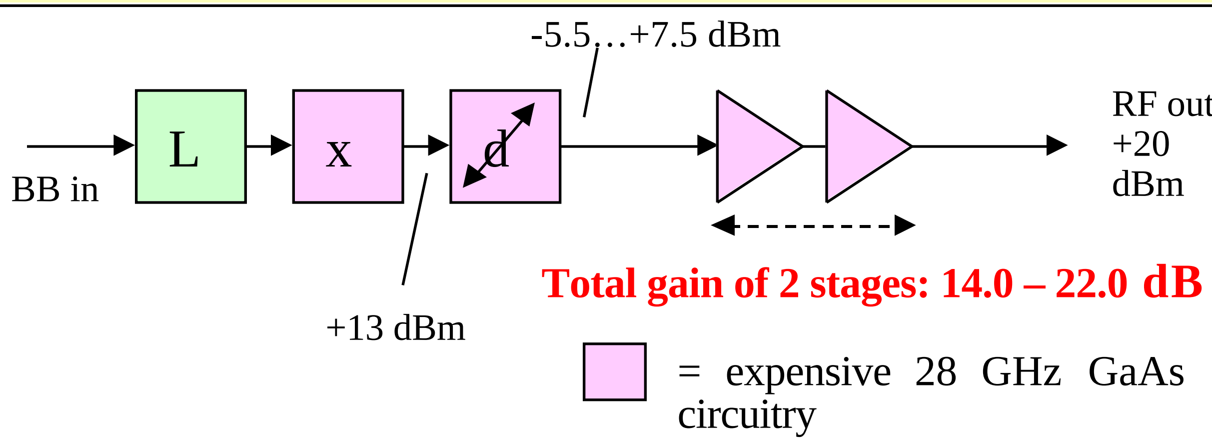
A Comparison between Power Amplifier structures for TFM and QPSK

Not even QPSK will work at an ideal performance level in the microwave frequency bands. The reason is the power amplifier in the transmitter will contain non-linearity which can be reduced by using a large back-off in the amplifier. The non-linearity will make the spectrum grow and spread the constellation points.

The structure of a TFM transmitter is fundamentally different from the QPSK transmitter. The TFM transmitter is based on a VCO which already has a strong signal. The QPSK transmitter includes a mixer which has a weak signal. In addition to that the transmitted signal for QPSK is stronger due to the required back off. All this will lead to that QPSK amplifier will contain considerable more stages. In figures 4 and 5 transmitter stages for QPSK and TFM are shown. The shown cases are for 28 GHz operation. On higher frequencies the difference is even more dramatic.



- The maximum linear output from a mixer is around -10 dBm, after filtering -11.5 dBm
- To reach +20 dBm level 31.5 dB of HPA gain is needed
- The gain of 28 GHz amplifier stage with good yield is 9 +-2 dB (unit, temp, freq)
- **Total of 5 stages are needed**, with max gain of 55 dB, unstability, noise floor, image
- => to compensate tolerances extra 20 dB gain adjustment range is needed, with 50 dB output power range we end up with adjustment range of 70 dB + other tolerances
- Note that ALC detector is needed even with closed loop power control to avoid saturation of non-constant ampitude modulation



- The output from a buffered multiplier is around +13 dBm and to reach +20 dBm level only 13.5 dB of HPA gain is needed
- The gain of 28 GHz amplifier stage with good yield is 9 +-2 dB
- **Total of 2 stages are needed**, with max gain of 22 dB
- => to compensate tolerances extra 8.0 dB gain adjustment range is needed, with 50 dB output power range we end up with adjustment range of 58.0 dB + other tolerances
- Note that ALC detector is not necessary with closed loop power control, since HPA can freely

Figure 5. VCO modulated 28 GHz transmitter.

Conclusions

If we are willing to sacrifice a small percentage of the upstream capacity TFM is an excellent alternative to QPSK. Assuming an asymmetric capacity for residential and small business users the slightly smaller capacity is justified when weighted against the low cost implementation of a TFM terminal. We have also seen that the bit error rate for a properly designed TFM receiver is almost as good as for QPSK. What it really boils down to is whether we are ready to sacrifice a small amount of the *uplink* capacity in order to have low cost terminals working at full *downlink* capacity.

References

[1] Frank de Jager and Cornelis B. Dekker, "Tamed Frequency Modulation, A Novel Method to Achieve Spectrum Economy in Digital Transmission" IEEE Transactions on Communications, May 1978

[2] Sundberg Carl-Erik, 'Continuous Phase Modulation', IEEE Communications Magazine, April 1986, Vol.24, No.4, pp.25-38.

[3] El-Tahany and Mahmoud, "Mean-Square Error Optimization of Quadrature Receivers for CPM with Modulation Index _" IEEE Journal on Selected Areas in Communications, No. 5, June 1987

[4] Eric Jacobsen, "A Brief Examination of CQPSK for CPE PHY Modulation", to be presented at 802.16 Session #6, Albuquerque, NM /