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Title:

**Tamed Frequency Modulation TFM (CQPSK) in the 802.16.1 Upstream**

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Purpose:

This contribution tries to clarify some of the issues related to Tamed Frequency Modulation (TFM).

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# **Tamed Frequency Modulation TFM (CQPSK) in the 802.16.1 Upstream**

*Lars Lindh*

**IEEE 802.16.1 Session #6    Mar. 2000**

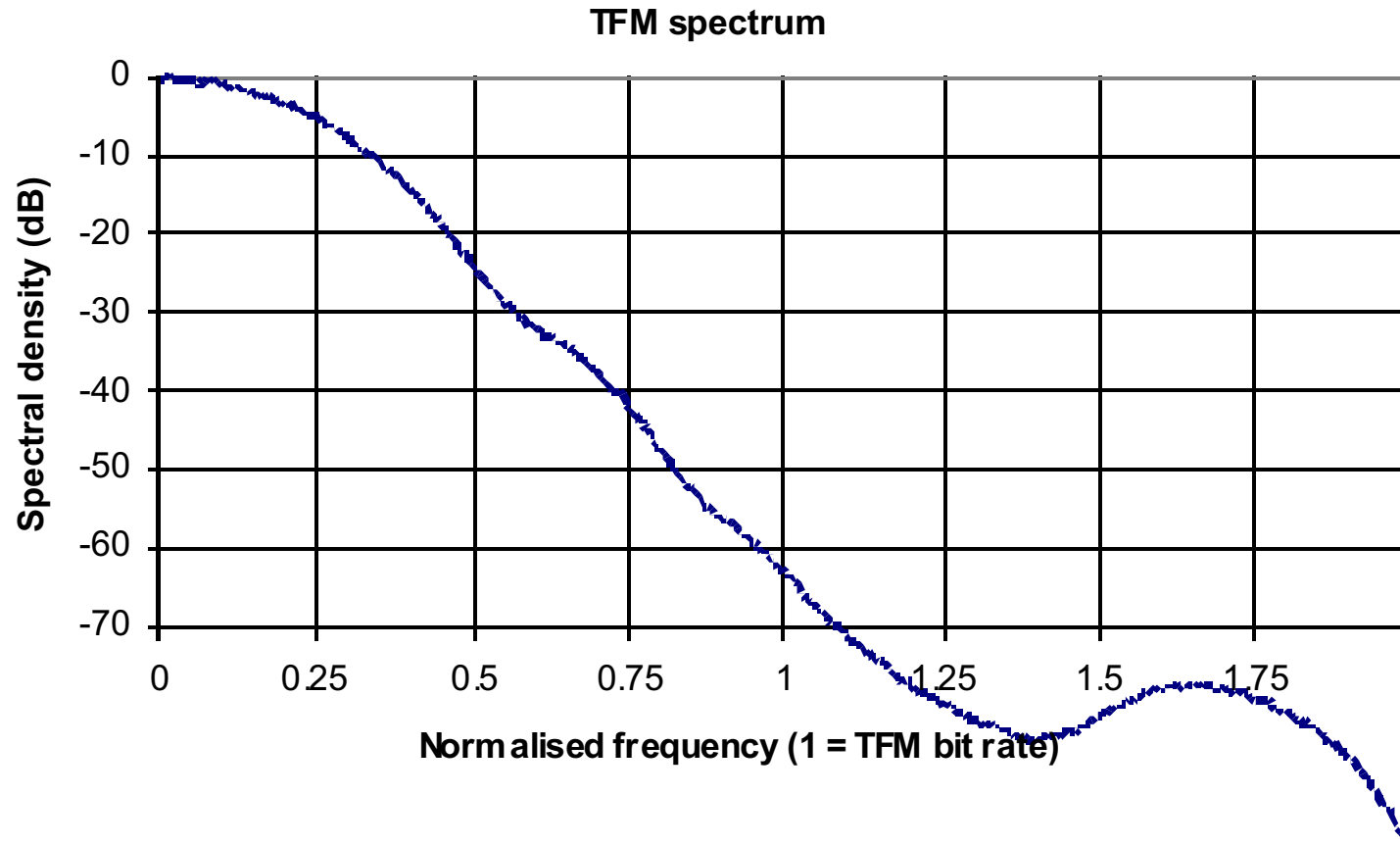
# Issues covered

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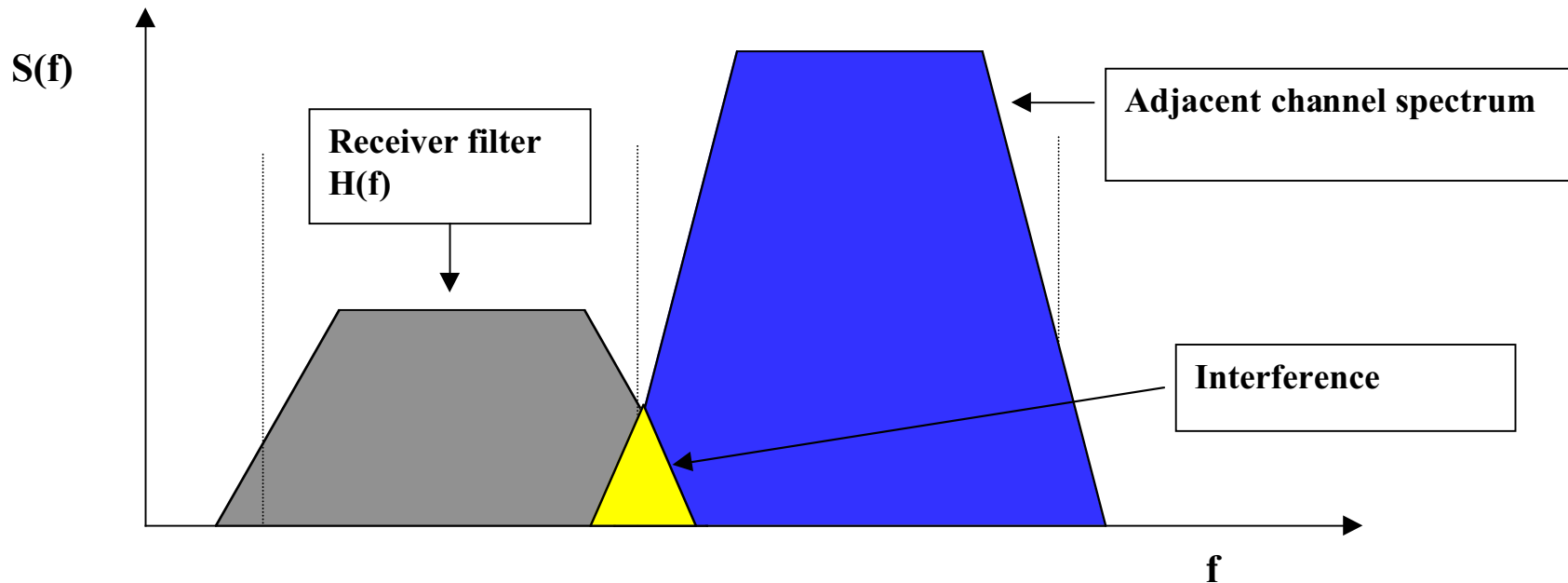
- **Spectral Efficiency**
  - TFM spectrum occupancy
  - Net Filter Discrimination
  - TFM bitrate
- **Bit Error Rate**
  - The Optimal TFM receiver
  - BER curves
- **Power Amplifier structures**
  - The 28 GHz Linear Upconverter
  - The VCO Modulated 28 GHz Transmitter

# TFM spectrum occupancy

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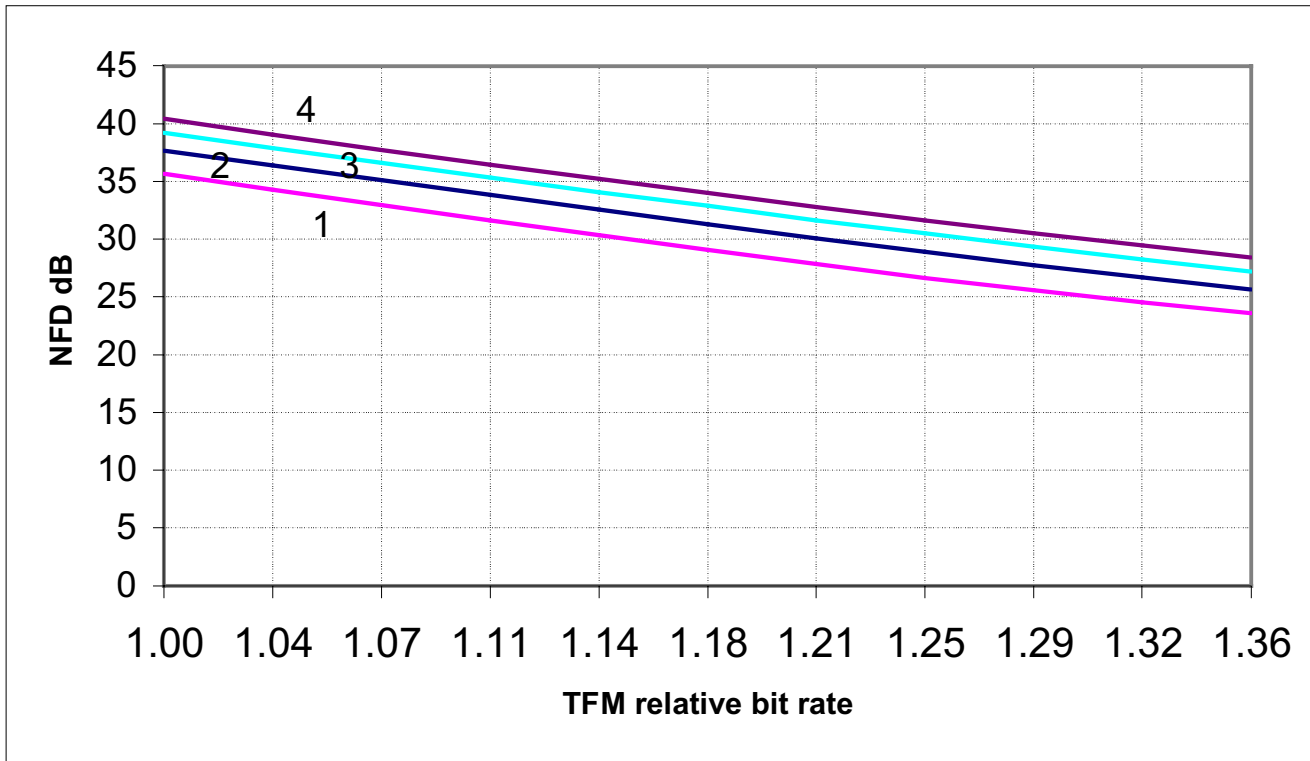
# Net Filter Discrimination NFD



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

Ratio between the power transmitted by the interfering system and the portion that can be measured after the receiver filter in the adjacent channel

# Required and realized NFD



- NFD between TFM and QAM with different values of alphas
- Required NFD assuming equal power and  $BER=10^{-4}$
- -> QAM curves 2,3 and 4 has sufficient NFD for TFM with relative bitrate of 1.33

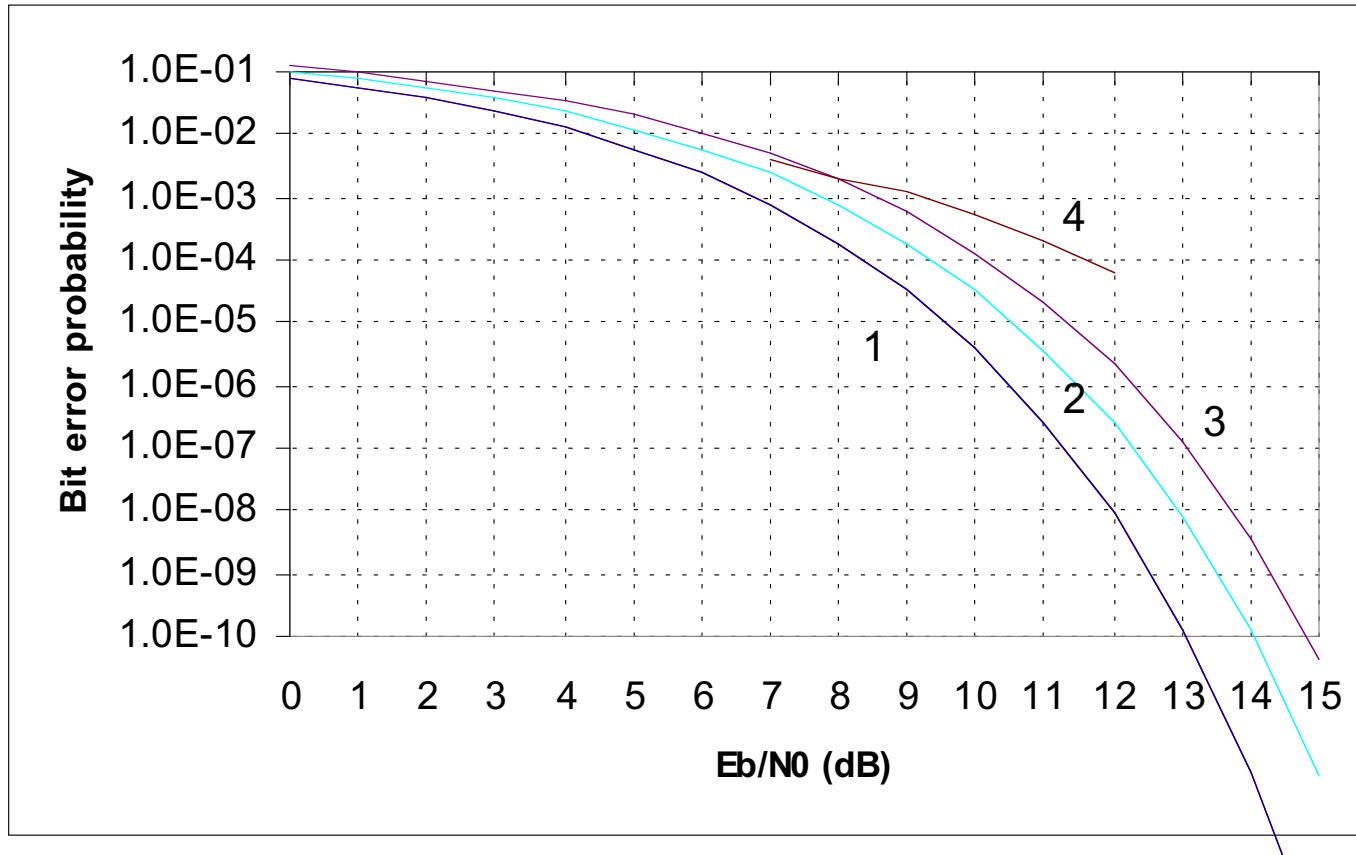
Receiver	Interferer		
	TFM	4QAM	16QAM
TFM	20.7 dB	20.7 dB	20.7 dB
4QAM	19.7 dB	19.7 dB	19.7 dB
16QAM	26.7 dB	26.7 dB	26.7 dB

# The Optimal TFM receiver

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- The optimal TFM receiver selects the most likely signal from all possible signal sequences
  - Squared minimum distance between sequences will determine the performance
    - QPSK has squared minimum distance 2, TFM 1.594
- Optimal receiver is complex but a Viterbi based TFM receiver has an almost equally good performance
- All TFM receivers need an optimal filter
  - Raised Cosine not suitable for TFM
  - Asymptotically Optimum Filter (AOF) good choice
- Also a simple MSK-type receiver has moderate performance when used with an optimal filter

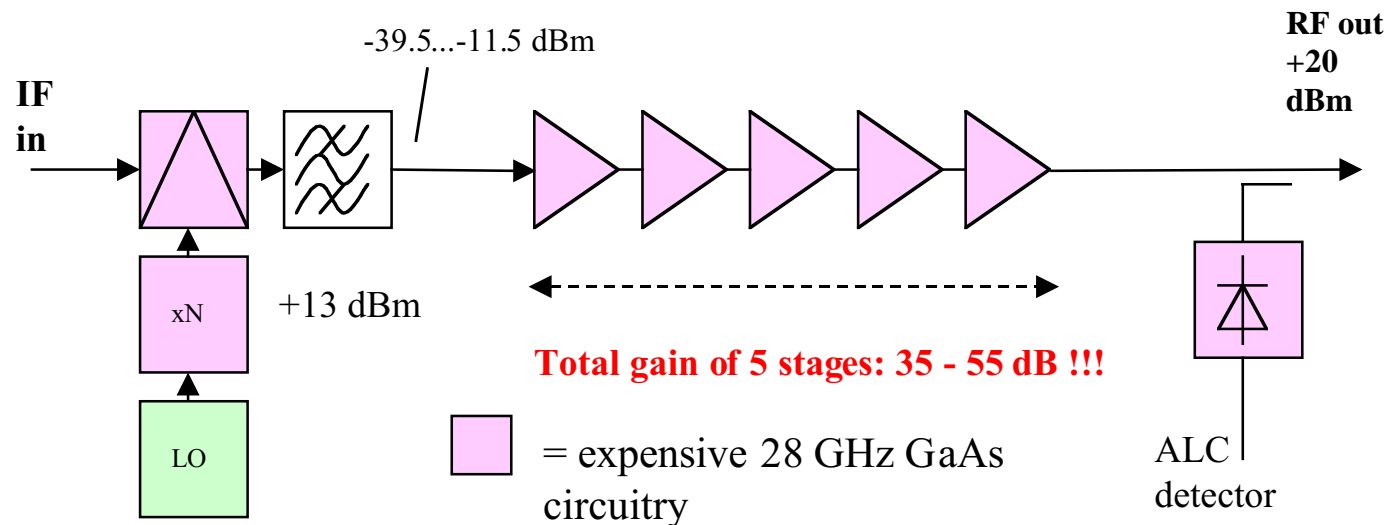
# BER Performance of TFM and QPSK



- 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

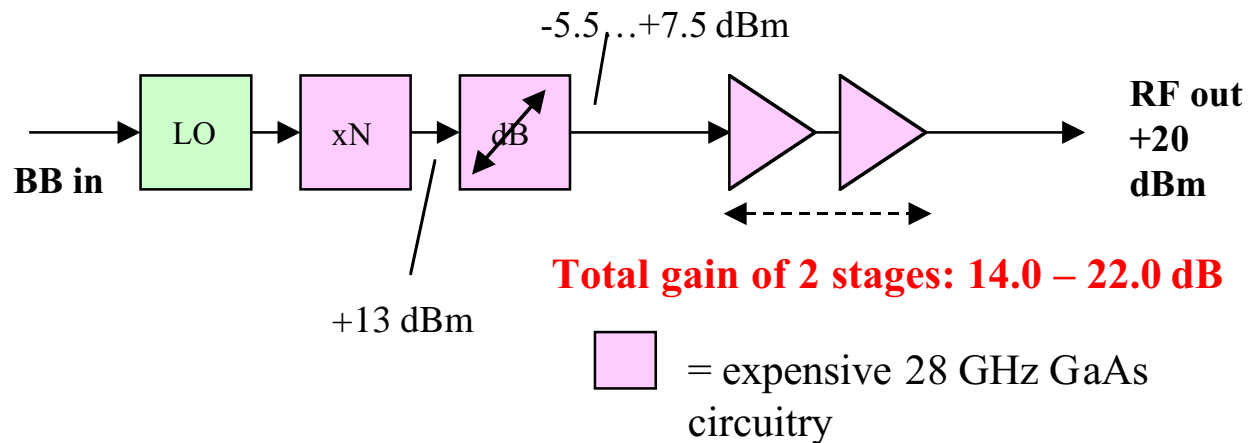


# 28 GHz Linear Upconverter



- 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, instability, 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 amplitude modulation

# VCO modulated 28 GHz transmitter



- 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 saturate. Smaller FETs can be used to produce the output power
- Higher efficiency in power amplifier -> reduced heat sinking and mechanics

# Conclusions

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- **NFD analysis shows that TFM does not interfere with 16-QAM when transmitting in the adjacent channel in a typical scenario where**
  - **BER =  $10^{-4}$**
  - **TFM and QAM received with the same power**
  - **QAM alpha  $\geq 0.2$**
  - **TFM relative bitrate = 1.33**
- **BER analysis shows that there is no more than 1 dB difference in BER curves between QPSK and optimal TFM. Viterbi based TFM receiver with optimal filter is close to optimal TFM. Even MSK-type TFM receiver with optimal filter performs well.**
- **Big savings can be done in transmitters when using TFM. At 28 GHz TFM uses 2 stages where QPSK needs 5. The difference is even larger at higher frequencies**  
**-> reduced cost terminals viable with TFM**