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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).

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

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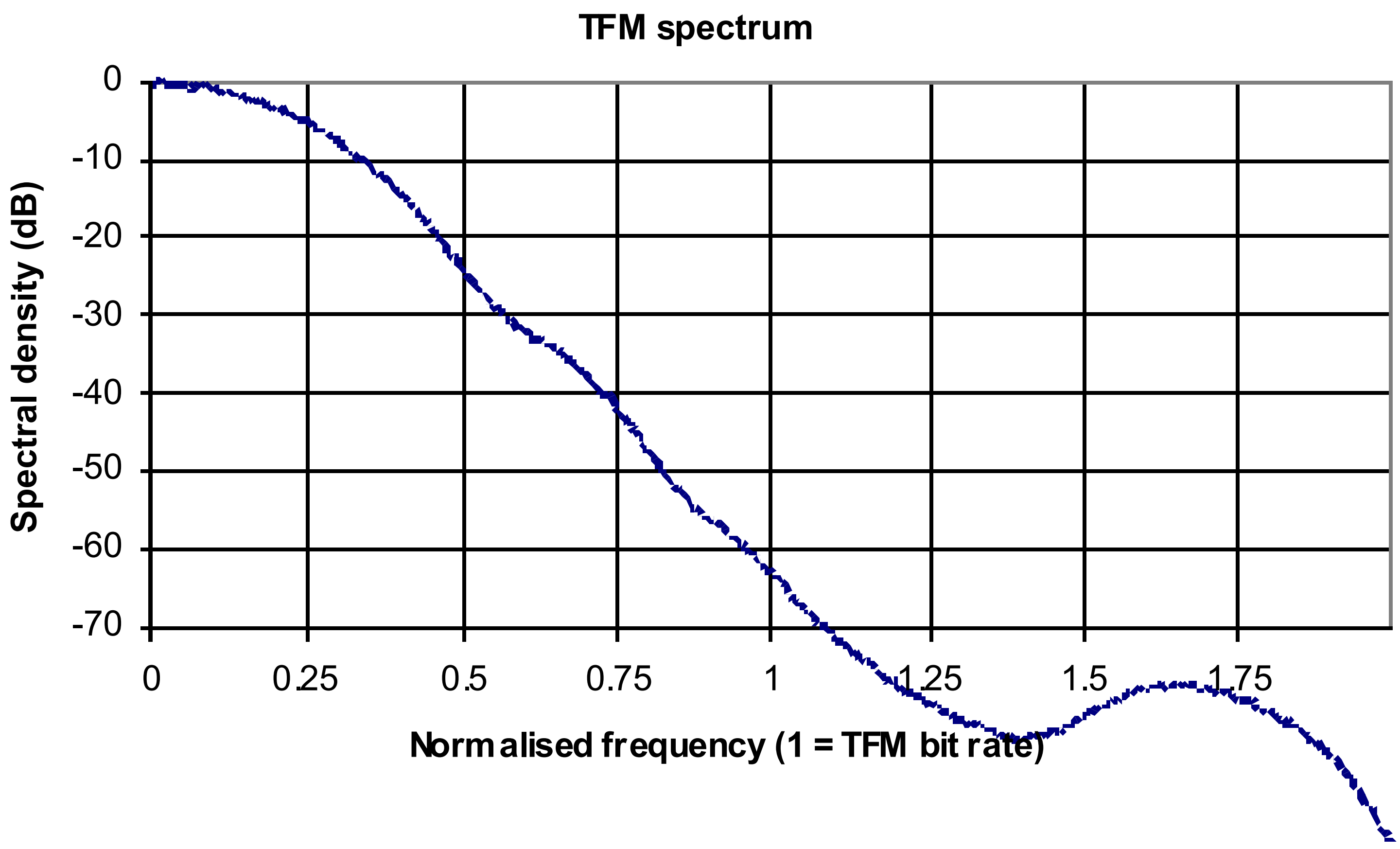
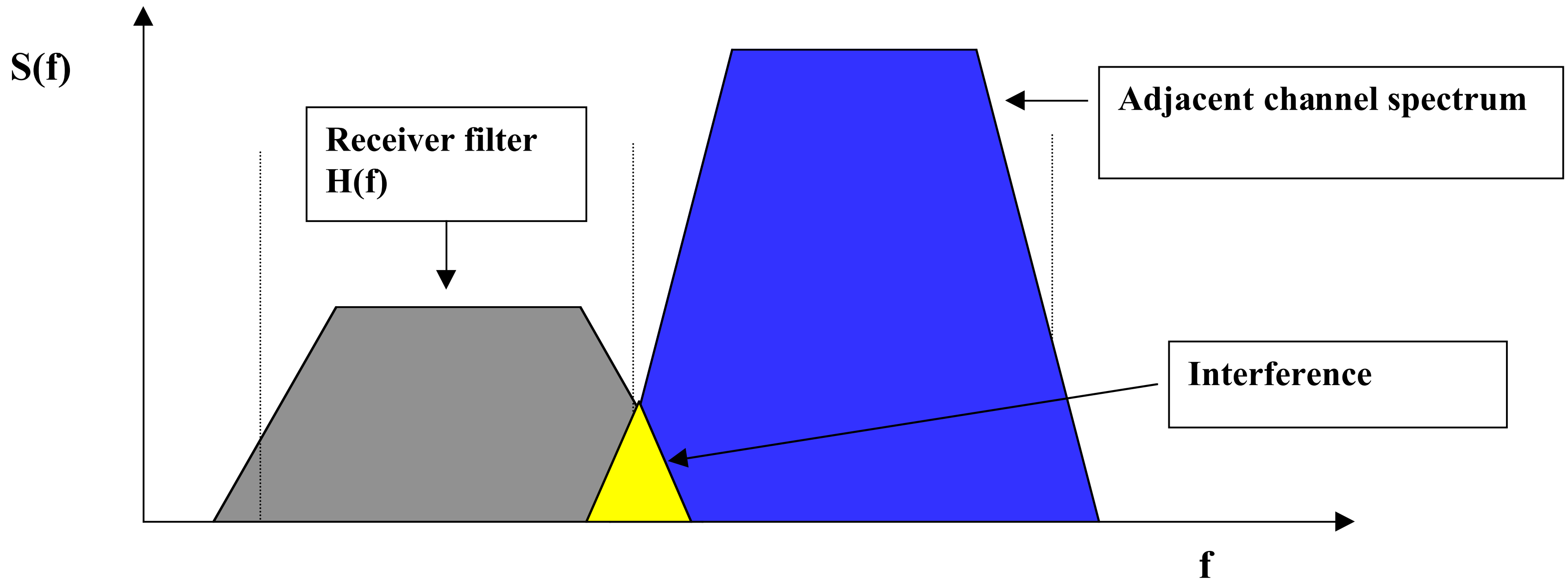
# Issues covered

- 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



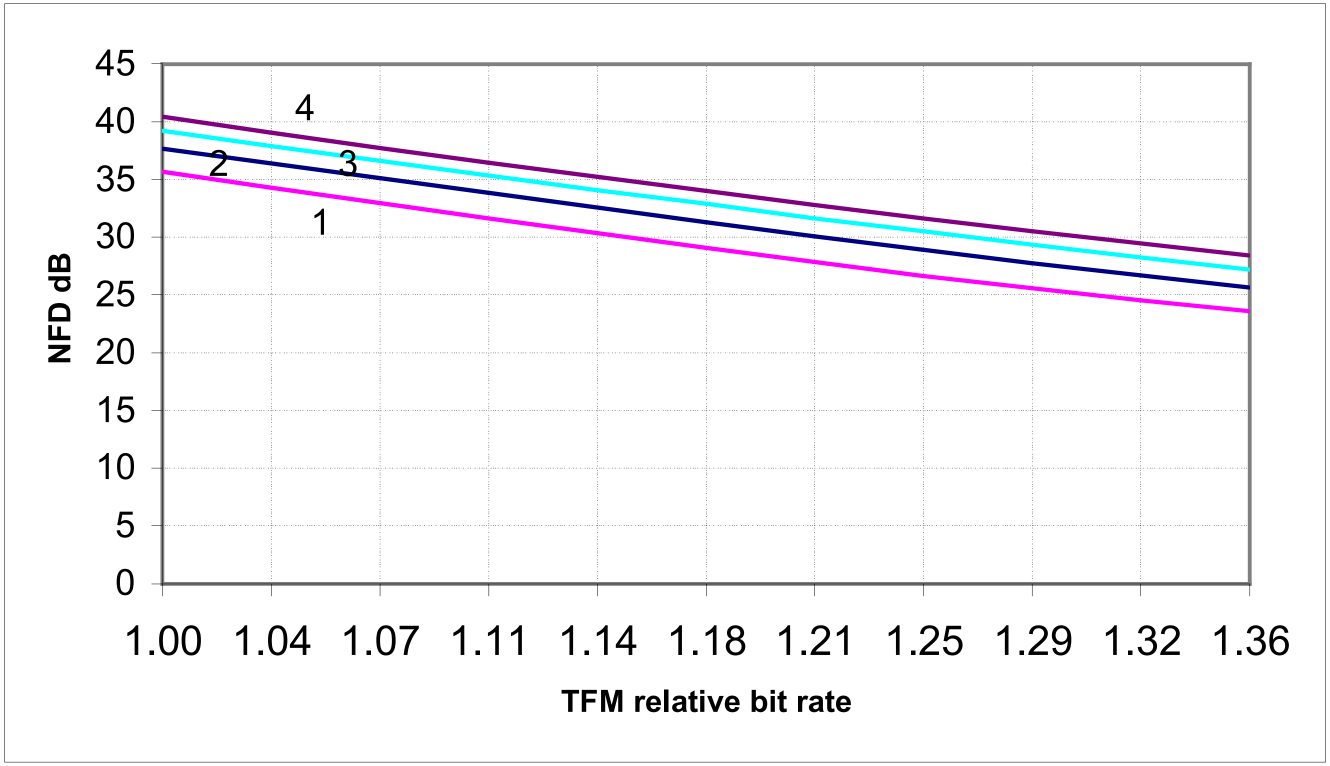
# Net Filter Discrimination NFD




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

**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



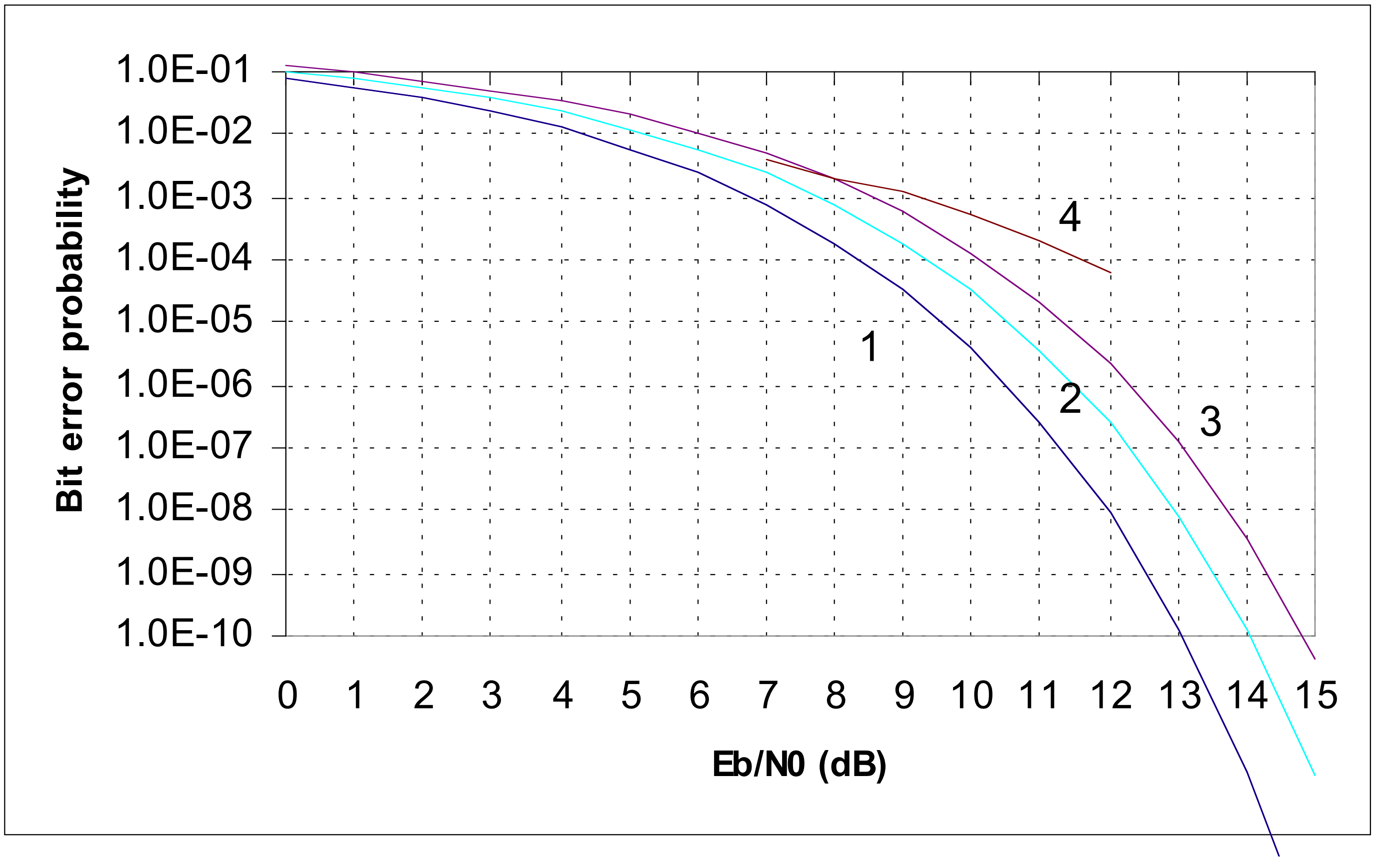

| | Interferer | | |
|---|---|---|---|
| Receiver | **TFM** | **4QAM** | **16QAM** |
| **TFM** | 20.7 dB | 20.7 dB | 20.7 dB |
| **4QAM** | 19.7 dB | 19.7 dB | 19.7 dB |
| **16QAM** | 26.7 dB | 26.7 dB | 26.7 dB |

- 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

# The Optimal TFM receiver

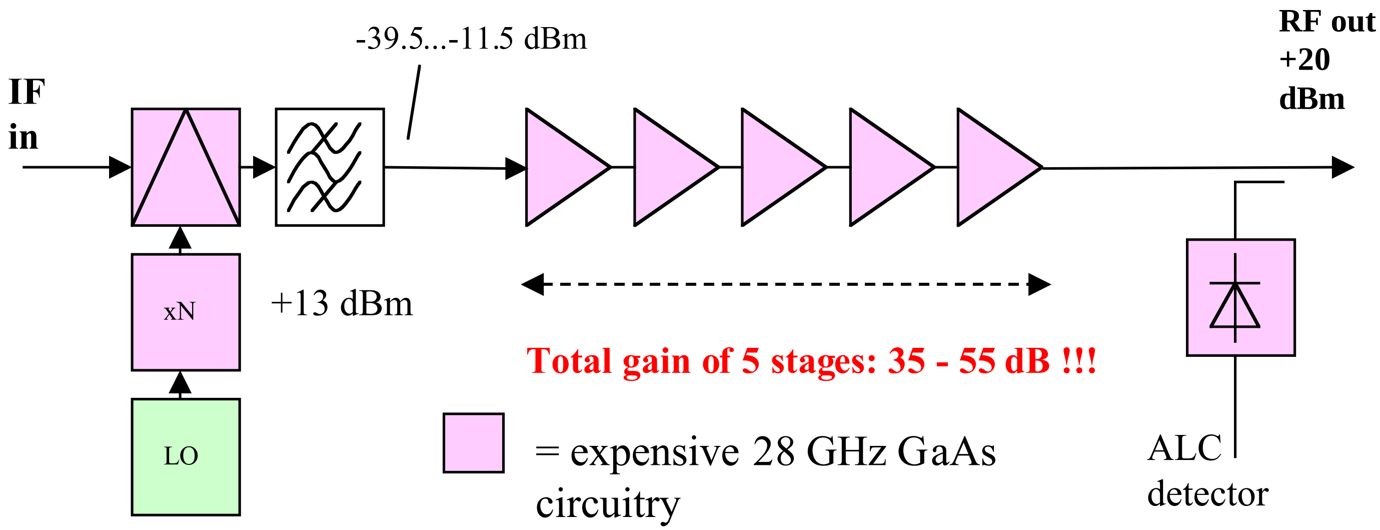
- The optimal TFM receiver selects the most likely signal from all possible signal sequences
  - Squared minimum distance between sequences will determine the performance
    - QPSK has squared minimum distance 2, TFM 1.594
- Optimal receiver is complex but a Viterbi based TFM receiver has an almost equally good performance
- All TFM receivers need an optimal filter
  - Raised Cosine not suitable for TFM
  - Asymtotically 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



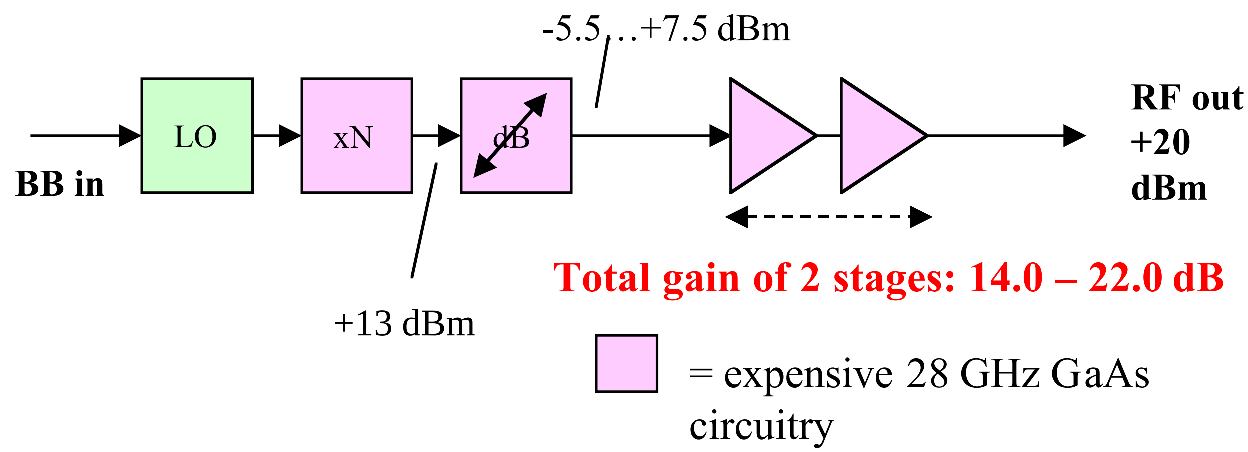

1. QPSK with optimal receiver
2. TFM with optimal receiver
3. TFM with MSK-receiver and AOF-filter
4. TFM with MSK-receiver and RC-filtering

# 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, 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 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 rang 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

- 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 >= 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