Tamed Frequency Modulation (TFM) in the IEEE 802.16.1 uplink

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Purpose:

This document is for a presentation about TFM modulation in the 802.16.1 uplink

Tamed Frequency Modulation (TFM) in the IEEE 802.16.1 uplink

properties, performance and implementation

NOKIA

Introduction

- IEEE 802.16.1 is a broadband wireless access (BWA) standard at the moment optimized for SME use in the U.S market
- In order to be accepted as an international standard the residential and SOHO markets should be addressed as well
- Low cost is a driver for these markets
- Tamed Frequency Modulation (TFM) in the uplink makes low cost terminals possible
- IEEE 802.16.1 is an international standard with a potential for world wide adoption. In order to address the residential and SOHO market sector, especially in Europe, TFM is proposed as an optional modulation scheme for the uplink

TFM basic properties

- TFM is a constant envelope modulation scheme working by modulating the phase while keeping the envelope constant
- TFM allows power amplifier to operate at or near saturation level
- No inter modulation distortion arises in the power amplifier -> no spectrum leakage into the adjacent carrier, lower linearity requirements
- Power amplifier can be 6-7 dB smaller than in a corresponding QPSK modulator
- Good system value
- Ideal for low cost terminal solutions

The TFM signal

- The TFM signal can be written as
  $s(t)=\mathrm{Re}\{\exp(\omega_c t + \phi(t))\}$
  where $\phi(t)$ is given as

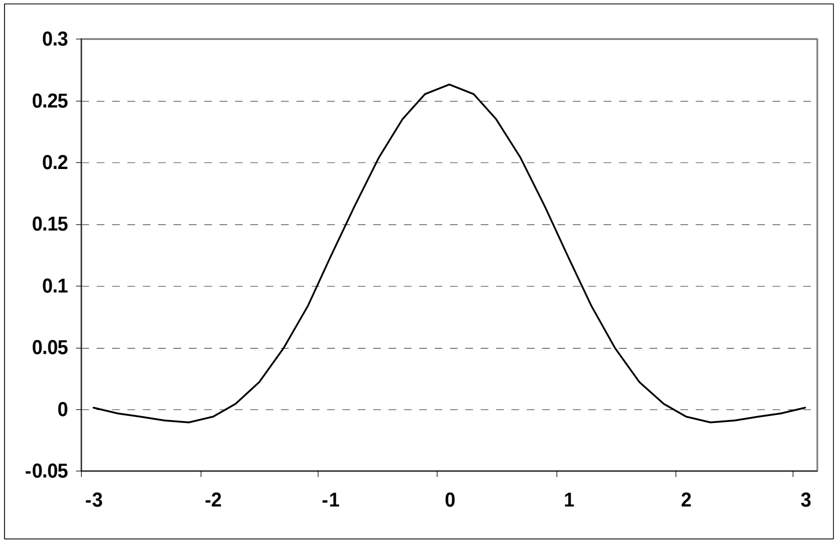
$$\phi(t) = 2\pi h \int_{-\infty}^{t} \left[\sum_{n=-\infty}^{\infty} a_n \cdot g(\tau - nT) \right] d\tau$$

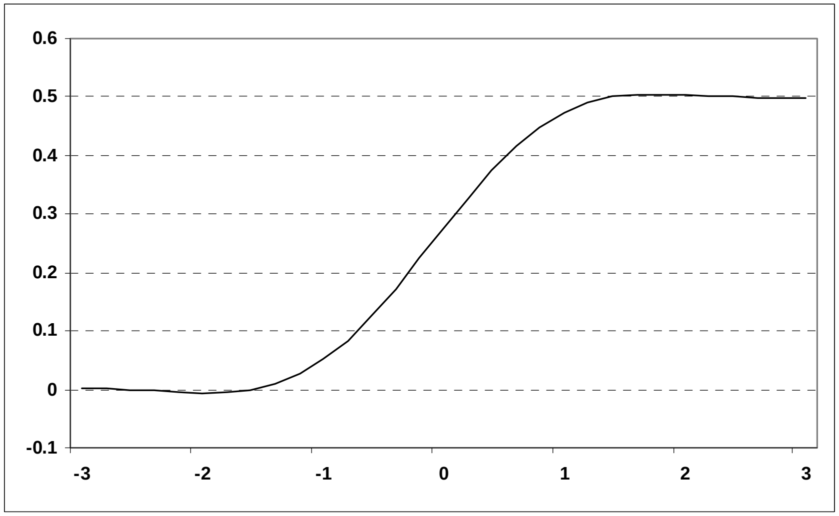
  a_n is the data sequence (+1, -1) and g(t) is the shaping filter and h is the modulation index = 0.5
  g(t) is given as

$$g(t) = \frac{1}{8} g_0(t-T) + \frac{1}{4} g_0(t) + \frac{1}{8} g_0(t+T)$$

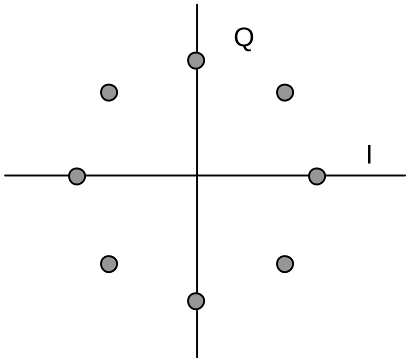
$$g_0(t) \approx \sin\left(\frac{\pi t}{T}\right) \left[\frac{1}{\pi t} - \frac{2 - \frac{2\pi t}{T} \cot\left(\frac{\pi t}{T}\right) - \frac{\pi^2 t^2}{T^2}}{\frac{24\pi t^3}{T^2}} \right]$$

The frequency pulse g(t) and phase response

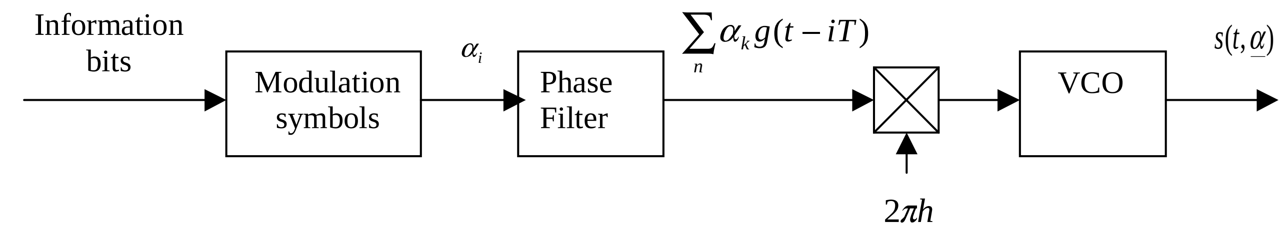




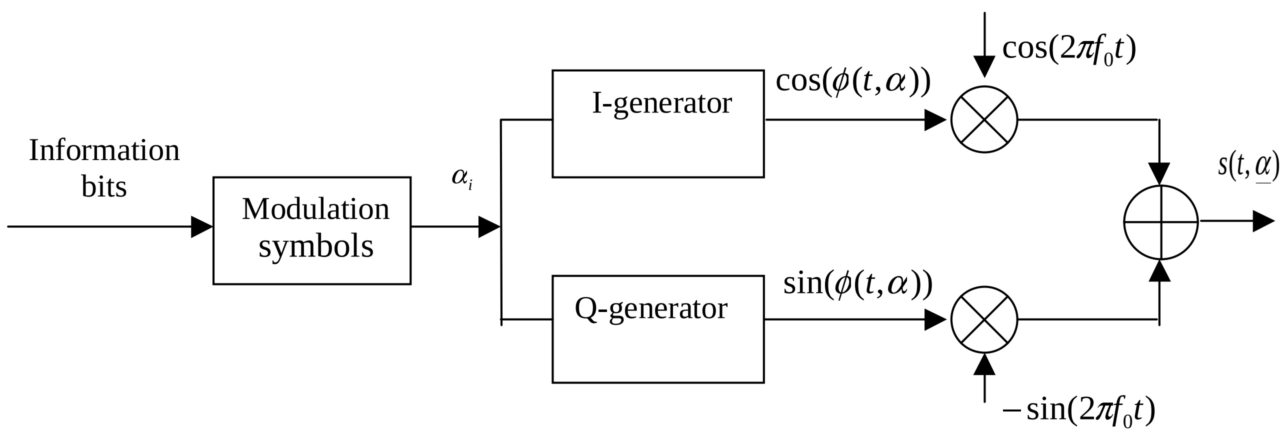
- Frequency pulse g(t) defines the smooth phase transitions between the constellation points
- Possible phase transitions are 0, +/-45 degr and +/-90 degr



TFM modulator types



- VCO based modulator
  - -Low cost
  - -Adjustable modulation index

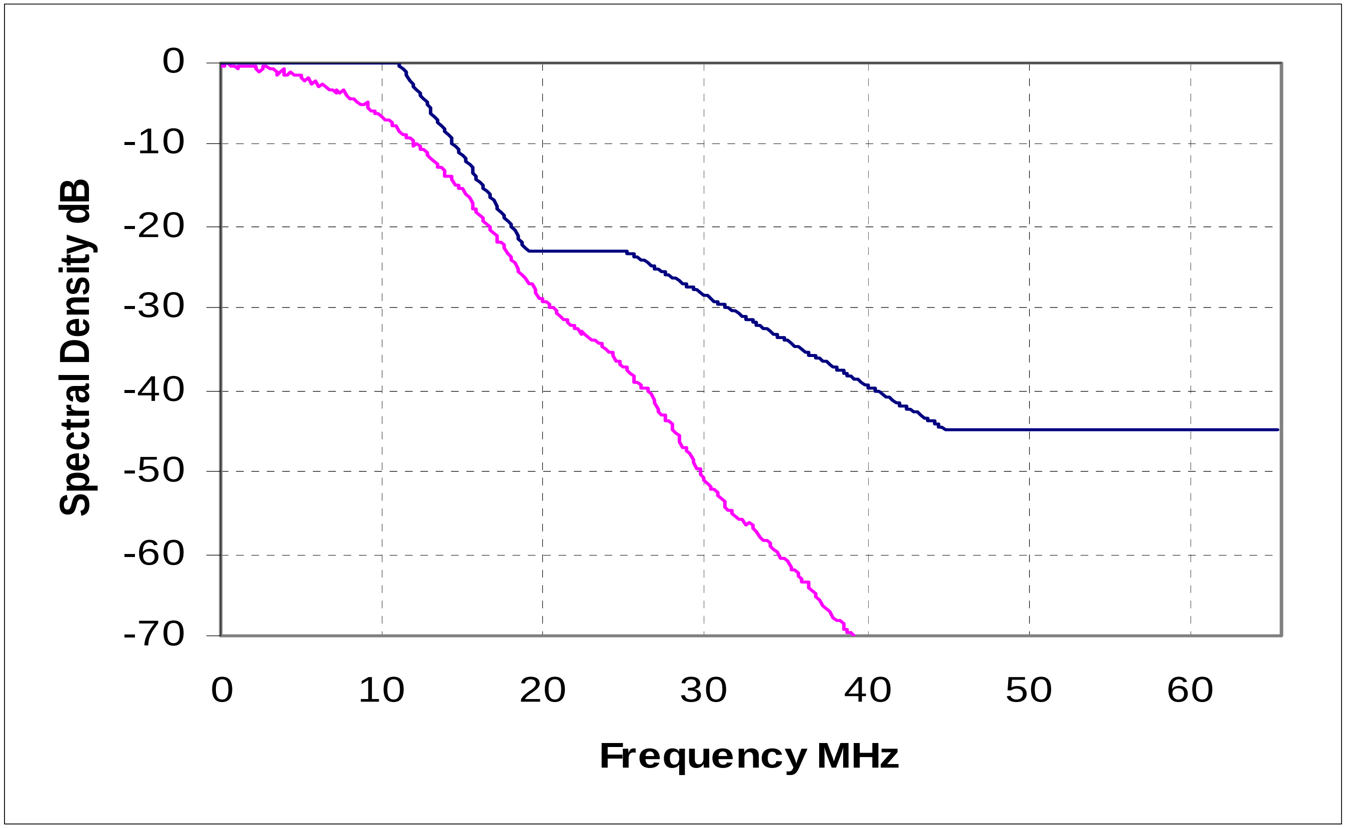


- Quadrature based modulator
  - -Can handle both TFM and QAM

The TFM modulation index

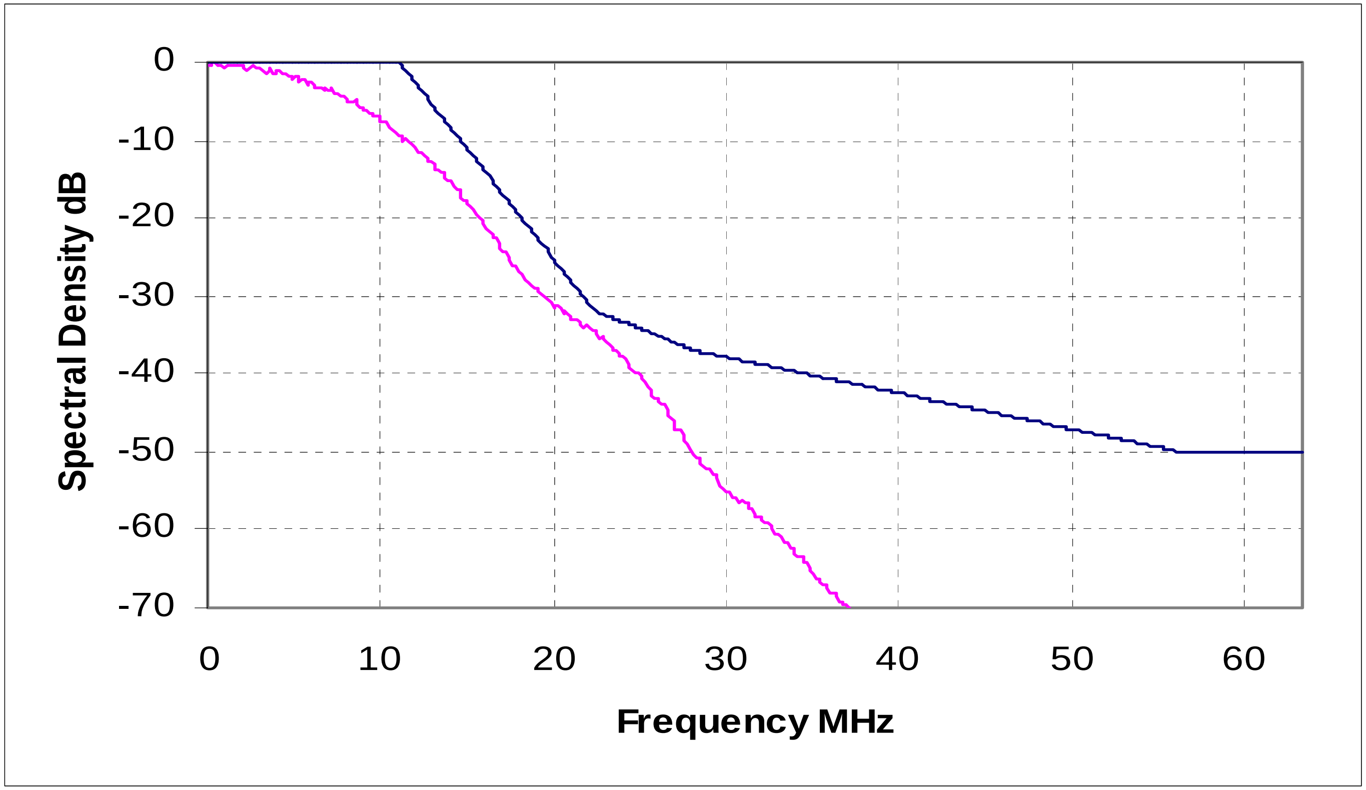
- The modulation index h is part of the gain for the VCO
  - Nominally 0.5
  - Calibrated in the manufacturing stage
- May drift with temperature variations
- Must be measured initially and periodically by the BS receiver
- Mechanism for adjusting the index must be made
  - BS station sends a message indicating the error in the modulation index with 0.0025 unit resolution (4 bits)

The TFM spectrum



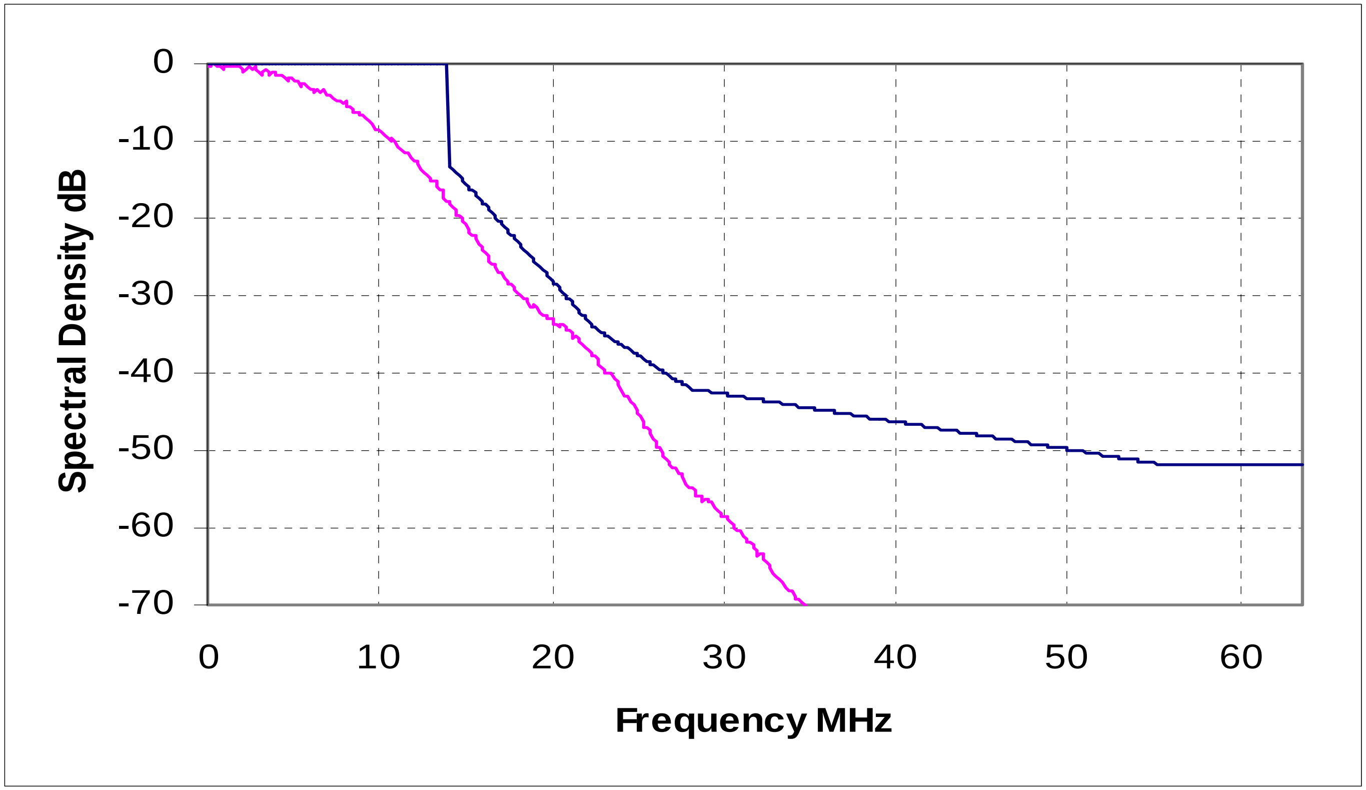
- Grade A bitrate 36 Mb/s
- Example with 28 Mhz channel
- Conforms to ETSI spectrum mask A

The TFM spectrum



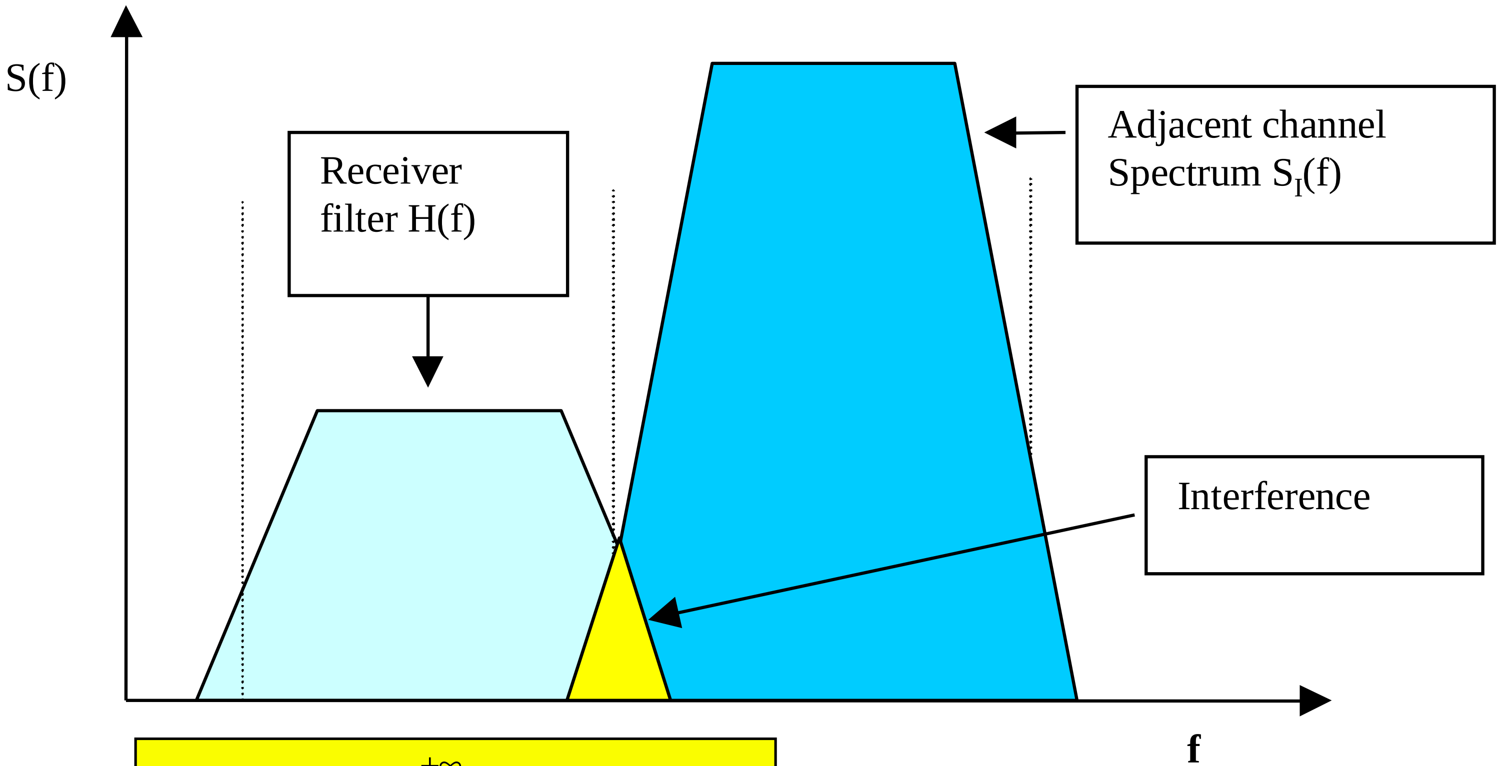
- Grade B bitrate 34 Mb/s
- Example with 28 MHz channel
- Conforms to ETSI spectrum mask B

The TFM spectrum



- Grade C bitrate 32 Mb/s
- Example with 28 MHz channel
- Conforms to ETSI spectrum mask C

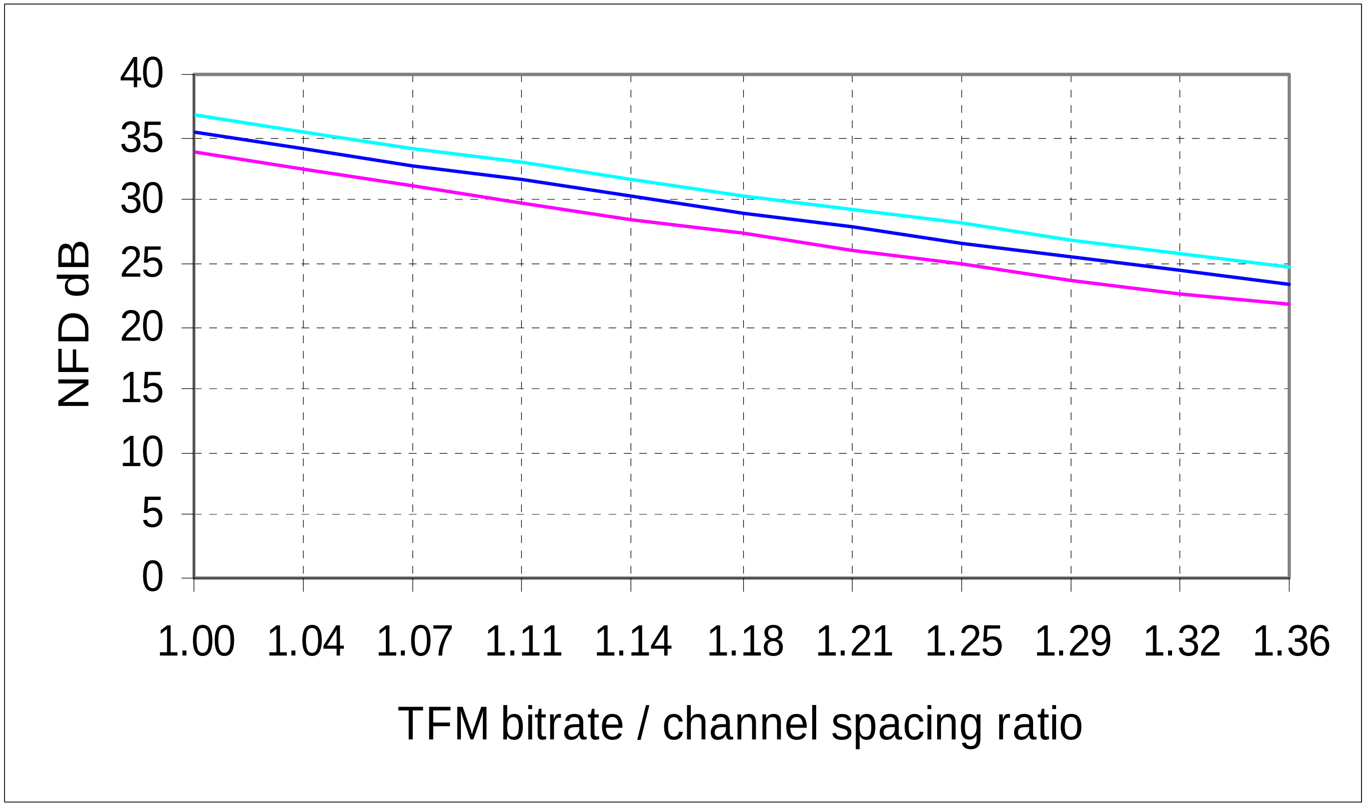
Net Filter Discrimination (NFD)



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

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

Net Filter Discrimination



- NFD between TFM and QAM when TFM is the interferer for different values of alpha (0.15 low, 0.25 mid, 0.35 high curve)
- QAM symbol rate = channel spacing / (1 + alpha)

TFM bit rates

Channel Size (MHz)	Bit rates Mb/s
12.5	16.1
14	18
20	25.6
25	32.2
28	36.0
36	46.2
40	51.2
50	64.4

Channel Size (MHz)	Bit rates Mb/s
12.5	15.2
14	17.0
20	24.2
25	30.4
28	34.0
36	43.6
40	48.4
50	60.8

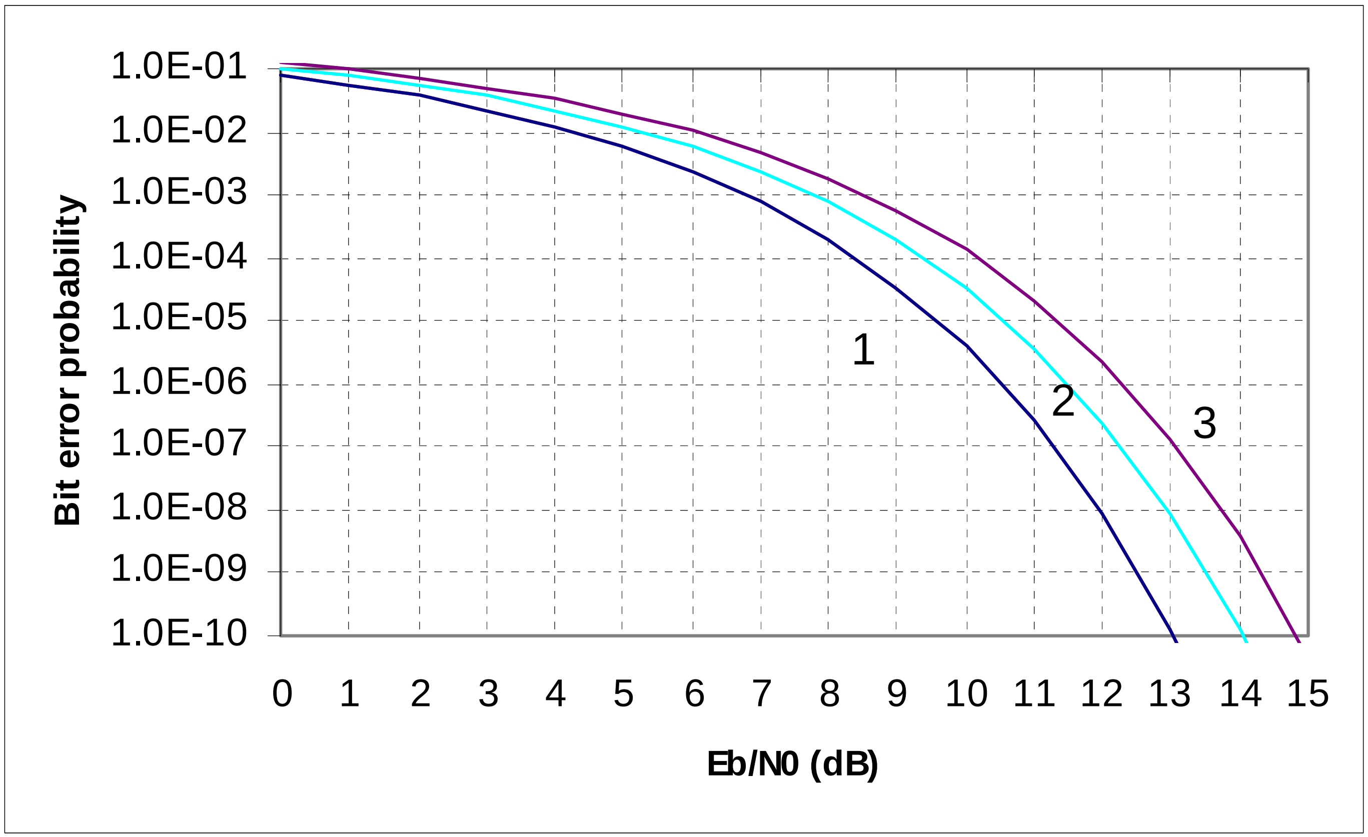
Channel Size (MHz)	Bit rates Mb/s
12.5	14.4
14	16
20	22.8
25	28.8
28	32
36	41.2
40	45.6
50	57.6

- Three different grades of bit rates corresponding to ETSI mask A, B and C
- Gives flexibility, ideal for different cell utilization scenarios

The 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 virtually equal performance (0.1 dB difference)
- 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

Uncoded BER performance for TFM



1 **QPSK with optimal receiver**

2 **TFM with optimal receiver**

3 **TFM with MSK-receiver and AOF-filter**

TFM TX power compared to QPSK

- Minimum PA 1dB compression point 20 dBm
- TFM max Tx power (slightly in saturation) >21 dBm

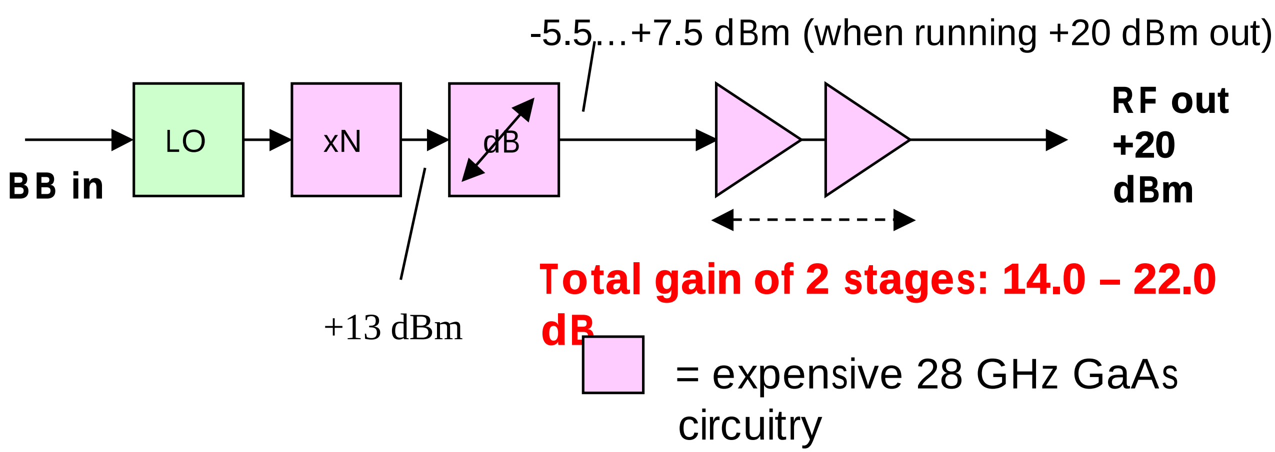
  worst case >21 dBm

- QPSK max power without excessive spectrum spreading:

minimum PA 1 dB compression point	20.0 dBm
min back off	-4.0 dBm
	16.0 dBm
automatic level control tolerance +-1dB	-1.0 dBm
nominal Tx power	15.0 dBm
worst case	14.0 dBm

- Reduced TX PA size affects the following cost items:
  - GaAs area
  - Power consumption and PSU size
  - Heat sinking mechanics

VCO modulated 28 GHz transmitter



mean output power	TFM	QPSK
20 dBm	$137	$277
26 dBm	$179	$574

- **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 and less number of stages can be used to produce the output power**
- **Higher efficiency in power amplifier -> reduced heat sinking mechanics**

TFM in the IEEE 802.16.1 uplink

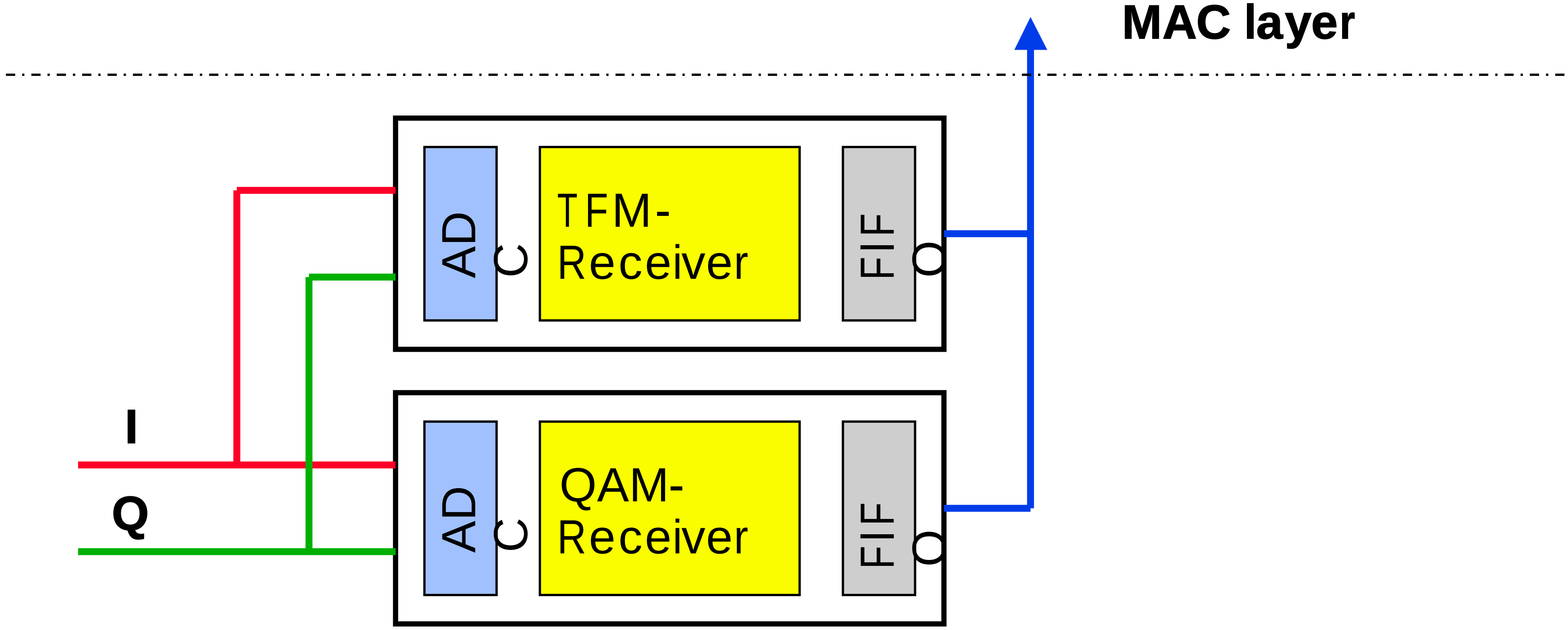
- Proposed as an additional modulation scheme for the uplink, optional for both base station and terminal
- Co-exists in the same channel with QAM modulation for high spectrum utilization: dual mode BS and two kinds of terminals
- Behaves like a QAM terminal in terms of registration, ranging and contention. Transmits in uplink mini-slots granted by the base station.
- Different preambles distinguish TFM from QAM in contention slots
- The number of mini-slots needed to transfer N TFM bits is given by

$$\left\lceil \frac{QAMsymbolrate * N}{TFMbitrate * 4 * sizeof(\min islot)} \right\rceil$$

where where *QAMsymbolrate* and *TFMbitrate* are the rates defined for the channel and sizeof(minislot) is the number of PSs in each mini-slot.

Dual mode base station architecture

- The dual mode base station contains separate and independent receivers for QAM and TFM
- Separate sampling and preamble detection ensures independent operation



Conclusions

- TFM needs 6 dB smaller power amplifier
- TFM needed for low cost terminals
- Flexible use of TFM guarantees easy co-existence with QAM
- Seamlessly adopts to 802.16.1 uplink
- Easy implementation of dual mode base station
- Tamed Frequency Modulation (TFM) in the uplink is proposed as an optional modulation scheme for 802.16.1

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