Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**TFM Modulation for the 802.16.1 Uplink**
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Re:	This document is referred to by a comment, which is issued as a response to the Call for Comments on IEEE 802.16.1-00/01r4 "Air Interface for Fixed Broadband Wireless Access systems".
Abstract	TFM modulation suitable for the 802.16.1 uplink is described.
Purpose	TFM modulation as described in the document is proposed to be included in the standard as an optional modulation scheme for the 802.16.1 uplink.
Notice	
Release	
Patent Policy and Procedures	

TFM modulation for the 802.16.1 uplink

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Introduction

TFM (Tamed Frequency Modulation) is defined as an additional modulation scheme for the uplink. It is optional for both the terminal and the base station and can be used in the same carrier as the QAM modulation schemes. It is distinguished from QAM with the aid of a different preamble. Unlike QAM it only supports Code Type 1 Reed-Solomon over GF(256) as its forward error correction (FEC) scheme.

1.1 Signal definition

The ideal continuous phase modulated (CPM) signal can be presented in the form:

$$s(t,\underline{\alpha}) = \sqrt{2E/T}\cos(2\pi f_0 t + \phi(t,\underline{\alpha}))$$

where E is the average symbol energy, T is the symbol period, f_0 is the carrier frequency, $\phi(t,\underline{\alpha})$ is the phase function containing the modulation, and $\underline{\alpha}$ is the modulation symbol sequence to be transmitted. The modulation symbols are related to the information bits in the following manner:

Table 1. Bits to symbol mapping

Information bits	α
0	-1
1	1

The phase function is defined by the expression

$$\phi(t,\underline{\alpha}) = 2\pi h \sum_n \alpha_n q(t-nT)$$
$$= 2\pi h \int_{-\infty}^{t} \sum_n \alpha_n g(\tau - nT)\,d\tau$$

where h is the modulation index=0.5, α_i is the modulation symbol to be transmitted, q(t) is the phase pulse, and g(t) is the frequency pulse. The relation between q(t) and g(t) is defined by the expression

$$q(t) = \int_{-\infty}^{t} g(\tau)\,d\tau .$$

Furthermore the frequency pulse is normalized in such a way that the phase pulse in the infinity is ½ i.e. $q(\infty) = 0.5$.

For TFM the frequency pulse is defined by the expression

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

where

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

In figure 1 the frequency pulse and the phase response plots is shown.

In figure 2 the constellation figure of the TFM signal is presented.

When generating the TFM signal with a VCO the control voltage applied to the VCO should be

$2\pi h \sum_n \alpha_n g(t - nT)$ as shown in Figure 3.

The TFM signal can be also expressed in the form:

$$\begin{aligned} s(t,\underline{\alpha}) &= \sqrt{2E/T}\cos(2\pi f_0 t + \phi(t,\underline{\alpha})) \\ &= \sqrt{2E/T}\left\{I(t)\cos(2\pi f_0 t) - Q(t)\sin(2\pi f_0 t)\right\} \end{aligned}$$

where $I(t) = \cos(\phi(t,\underline{\alpha}))$ and $Q(t) = \sin(\phi(t,\underline{\alpha}))$ are the modulated baseband signals. In figure 4 the transmitter block diagram of the quadrature modulator is presented.

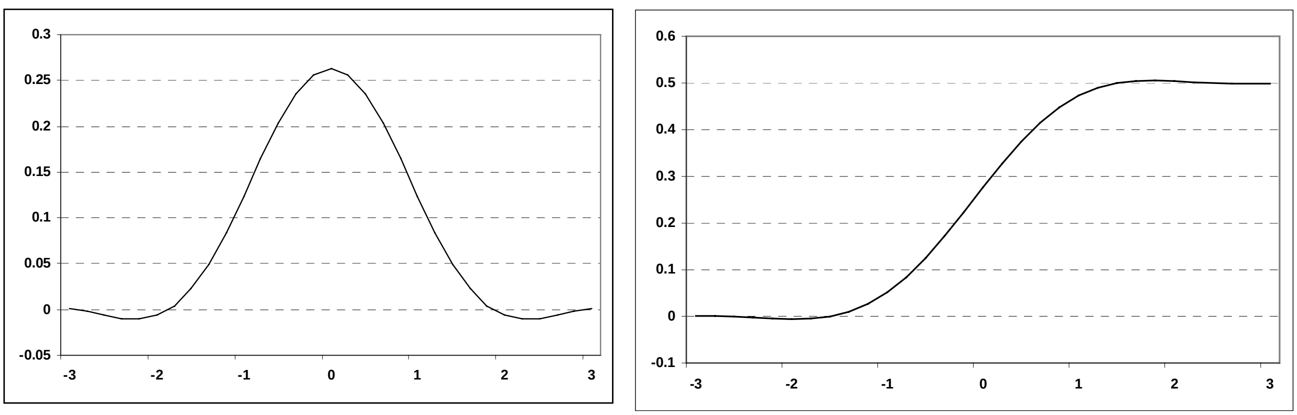

Figure 1. TFM frequency pulse g(t) and phase response function q(t)

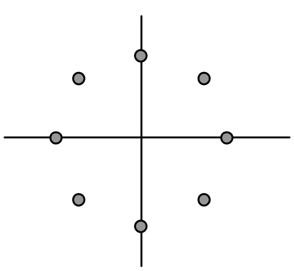

Figure 2. TFM constellation points

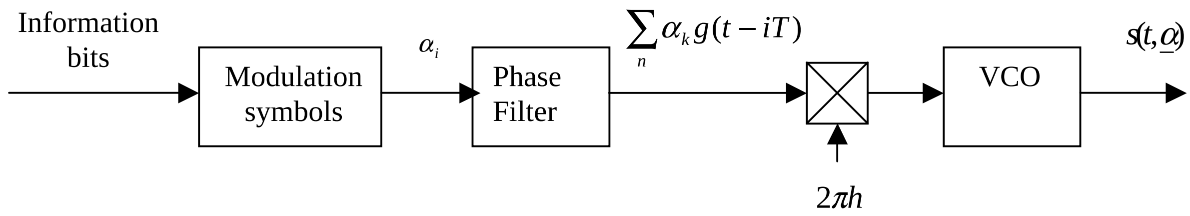

Figure 3. VCO based TFM modulator

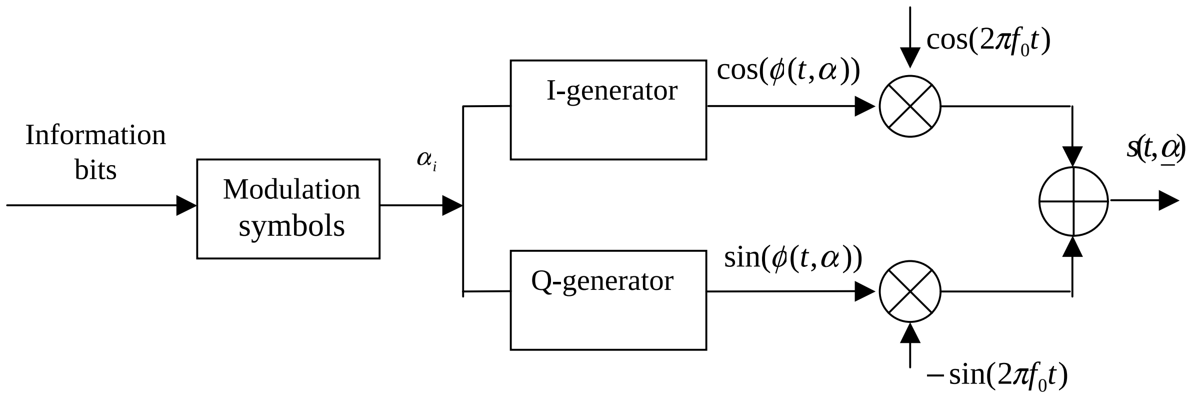

Figure 4. Quadrature based TFM modulator

1.2 Modulation index

Nominally the modulation index for TFM is 0.5, but when the transmitter is implemented using a VCO, the modulation index is dependent on the VCO characteristics. The VCO is calibrated to have a corresponding modulation index of 0.5, but it can drift due to the temperature variations. The base station receiver should be able to measure the modulation index of the incoming TFM signal with an accuracy of 0.0025 and support an initial and a periodic adjustment procedure.

The following procedure is needed when a new terminal logs into the network:

1. Before the log on the terminal adjusts the modulation index to its lowest value which must be in the range of 0.470 – 0.500.
2. When the base station that supports TFM is receiving the TFM signal, it measures the modulation index and commands the terminal, in units of 0.0025, to increase the modulation index until it is 0.5.

1.3 Bitrates and channel bandwidths

The following tables recommend TFM bitrates and channel sizes that that should be implemented in order to allow for interoperable equipment. Three different grades of bit rates, corresponding to different spectrum masks, for each channel bandwidth are recommended.

Table 1. Bit rates corresponding to grade A

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

Table2. Bit rates corresponding to grade B

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

Table 3. Bit rates corresponding to grade C

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

1.4 Relationship between TFM bitrate, PHY slots and mini-slots

The uplink bandwidth allocation MAP (UL-MAP) uses time units of mini-slots. The size of the mini-slot is defined as a number of PHY slots (PS) and is carried in the Uplink Channel Descriptor (UCD) for each uplink channel.

One PS is defined as four QAM modulation symbols. The number of PHY slots needed to transmit N TFM bits can then by calculated by the formula

$$\left\lceil \frac{QAMsymbolrate * N}{TFMbitrate * 4} \right\rceil$$

and number of mini-slots needed is correspondingly

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

where *QAMsymbolrate* and *TFMbitrate* are the rates defined for the channel.

To ensure compatibility with QAM, all timing references in the UL-MAP, given by the MAC layer are in mini-slots.

1.5 TFM preamble

The preamble shall be set by the base station upon an integer number of repetitions of the following length 32 bit sequence. The preamble sequence is a m-sequence with good auto correlation properties.

Symbol	Preamble bits
1	0
2	0

3	0
4	0
5	1
6	0
7	0
8	1
9	0
10	1
11	1
12	0
13	0
14	1
15	1
16	1
17	1
18	1
19	0
20	0
21	0
22	1
23	1
24	0
25	1
26	1
27	1
28	0
29	1
30	0
31	1
32	0

References

F. de Jager and C.B Decker. "Tamed frequency modulation, a novel method to achieve spectrum economy in digital transmissions" IEEE Trans on Comm., vol COM-26, no 5, pp.534-542, May 1978

Carl-Erik Sundberg. "Continuous phase modulation" IEEE Communications Magazine – Vol 24, No. 4, April 1986