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Technical Specification

Digital Video Broadcasting (DVB); Structure and modulation of optional transmitter signatures (T2-TX-SIG) for use with the DVB-T2 second generation digital terrestrial television broadcasting system

Reference

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Foreword

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NOTE: The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

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The Digital Video Broadcasting Project (DVB) is an industry-led consortium of broadcasters, manufacturers, network operators, software developers, regulatory bodies, content owners and others committed to designing global standards for the delivery of digital television and data services. DVB fosters market driven solutions that meet the needs and economic circumstances of broadcast industry stakeholders and consumers. DVB standards cover all aspects of digital television from transmission through interfacing, conditional access and interactivity for digital video, audio and data. The consortium came together in 1993 to provide global standardisation, interoperability and future proof specifications.

1 Scope

The present document describes an optional extension to the DVB-T2 second-generation transmission system for digital terrestrial television broadcasting, as specified in [1]. This extension takes the form of the addition of transmitter-signature information, and is primarily intended for use in single-frequency networks (SFNs). The extension is made in ways which are fully compatible with the original specification by exploiting some of its explicit provisions for future expansion.

The primary purpose of the addition of transmitter-signature information described herein is to assist network operators with the setting-up, maintenance, monitoring and fault-finding of their networks, by making it possible to identify the individual contributions of different transmitters within a single-frequency network. However, once it is present the transmitter-signature information could also be used for other purposes, e.g. applications requiring location information.

The present document specifies the details of the additional signals, and must be read in conjunction with the DVB-T2 specification [1] for full understanding. In order to accommodate different purposes, and different scales of networks, various options are provided; network operators can select from them to suit their requirements.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

[1] ETSI EN 302 755: "Digital Video Broadcasting (DVB); Frame Structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)".

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] FAN P. (2004): "Spreading sequence design and theoretical limits for quasisynchronous CDMA systems". EURASIP Journal on Wireless Communications and Networking2004:1, 19-31.

NOTE: Available from: http://www.hindawi.com/getarticle.aspx?doi=10.1155/s1687147204405015.

[i.2] ZENG, X., HU, L., and LIU, Q, (2005): "New sequence sets with zero-correlation zone".

NOTE: Available from: http://arxiv.org/abs/cs/0508115.

[i.3] The MathWorks, Inc.: "MATLAB®".

NOTE: Available at: http://www.mathworks.com/.

[i.4] Wolfram Inc.: "Mathematica®".

NOTE: Available at: http://www.wolfram.com.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

auxiliary cell: cell in an *auxiliary stream*

auxiliary stream: sequence of cells carrying data of as yet undefined modulation and coding, which may be used for future extensions or as required by broadcasters or network operators

B cell: *auxiliary cell* in a transmitter-signature *auxiliary stream* in which energy is radiated in order to keep the mean power of each OFDM symbol at a particular value

cyclic prefix: prefix attached to a waveform segment, comprising a copy of part of the waveform segment, such that the whole has cyclic properties

NOTE: The guard interval in an OFDM system commonly takes the form of a cyclic prefix. In the context of the present document, cyclic prefixes are added in the construction of *signature periods* in *signature FEF parts*.

discrete sequence: sequence of numbers

FEF part: part of the super-frame between two T2-frames which contains FEFs

NOTE: A FEF part always starts with a P1 symbol. The remaining contents of the FEF part should be ignored by a DVB-T2 receiver.

generalised orthogonality: property of a set of *discrete sequences* whereby they are mutually orthogonal, both directly, *and* when they are mutually cyclically shifted, provided the cyclic shift is limited to a range known as the *zero correlation zone*

L1-post signalling: signalling carried in the P2 symbol of T2-frames (see [1]) conveying more detailed L1 information about the T2 system and the PLPs

perfect sequence: discrete sequence which has a cyclic autocorrelation function which is zero for all (cyclic) offsets except zero

signature FEF part: FEF part which is used to carry a *transmitter signature* of the type defined in clause 6, comprising a P1 symbol, an optional *other-use period* and two *signature periods*

signature period: section of a *signature FEF part* comprising a *signature waveform* and its *cyclic prefix*

signature waveform: band-limited waveform constructed from one of the GO sequences $s_{h,i}$, according to clause 6

T cell: *auxiliary cell* in a transmitter-signature *auxiliary stream* in which energy is radiated by a particular transmitter in order to signal its presence

transmitter signature: component added to a radiated signal in order to enable identification of the source transmitter

NOTE: The present document defines two types of transmitter signature for use with DVB-T2 signals.

Z cell: *auxiliary cell* in a transmitter-signature *auxiliary stream* in which no energy is radiated by a particular transmitter, since the same cell is used as a *T cell* by a different transmitter

zero correlation zone: range of possible offsets over which a GO sequence has desirable correlation properties, as described in clause 6.5.1

3.2 Symbols

For the purposes of the present document, the following symbols apply.

3.2.1 Symbols relating to auxiliary-stream signature method

$b_{BS,j}$	bit value in DVB-T2 BB scrambling sequence having index j
j	integer index of positions in BB scrambling sequence ($b_{BS,j}$ above)
K	total number of cells in the transmitter-signature auxiliary stream
L	number of T2 frames per TX-SIG frame, within which the cycle of cell positions in the auxiliary stream repeats
M	number of transmitters which can be signalled
N	number of cells in the auxiliary stream per transmitter per frame
P	integer in range 0 to 1023 inclusive to which K and M are related
Q	integer in range 0 to 15 inclusive to which N is related
$x_{m,l,p}$	complex cell modulation value for cell index p of OFDM symbol l of T2-frame m

3.2.2 Symbols relating to FEF-based signature method

$c_{l,k'}$	the complex modulation value for 'carrier' k' in signature period l
c_q	value of element of Frank sequence having index q
d	parameter of Zeng's section-III.C method [i.2]
	the duration of the signature cyclic prefix, $\Delta = 14\,546T$
f_c	the centre frequency of the emitted RF signal
h	integer index of sequence, in range 0 to 7
j	$\sqrt{-1}$
K_H	the index value 27 264
$p_1(t)$	the P1 waveform as defined in clause 9.8.2.4 of [1]
	the waveform emitted during the other-use period, if present
$r_{ij}[n]$	cyclic cross-correlation between discrete sequences i and j for an offset of n samples (becomes auto-correlation when $i = j$)
$\mathbf{S}$	the final set of GO sequences $\mathbf{S} = \{\mathbf{s}_0, \mathbf{s}_1, \cdots \mathbf{s}_7\}$, each sequence $\mathbf{s}_h$having elements $s_{h,i}$
T	elementary time period for the bandwidth in use (as in [1])
T_{FEF}	duration of FEF part
T_{OU}	duration of other-use period
T_S	the total duration of one signature period, $T_S = T_U + \Delta = 80\,082T$
T_U	the duration of one signature waveform, $T_U = 65536T$
$V_{h,k}$	value of discrete spectrum of sequence $\mathbf{s}_h$ for frequency coefficient k (where k ranges from 0 to 65 535)
$V'_{h,k'}$	notation for discrete spectrum (see $V_{h,k}$ above) in which k' ranges from $-32\,768$ to $+32\,767$
$W_{k'}$	value of windowing function for frequency coefficient k', where k' ranges from $-32\,768$ to $+32\,767$
$\lfloor x \rfloor$	round towards minus infinity: the most positive integer less than or equal to x
$X_{h,k'}$	value of *windowed* discrete spectrum of sequence $\mathbf{s}_h$ for frequency coefficient k', where k' ranges from $-32\,768$ to $+32\,767$
Z_0	parameter describing length of ZCZ

The symbols i, j, k, l, m, n, q are also used to stand for integer indices and constants in various clauses and equations. Intermediate results in sequence derivations follow a notation directly analogous to that shown above for $\mathbf{S}$.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACF	Auto-Correlation Function
DFT	Discrete Fourier Transform
DVB-T2	second-generation Terrestrial Digital Video Broadcasting

NOTE: As specified in EN 302 755 [1].

FEF	Future Extension Frame

NOTE: As specified in EN 302 755 [1].

FFT	Fast Fourier Transform
GO	Generalised Orthogonal
L1	Layer 1
MISO	Multiple Input, Single Output

NOTE: Meaning multiple transmitting antennas but one receiving antenna.

OFDM	Orthogonal Frequency-Division Multiplex
PAPR	Peak-to-Average Power Ratio
PLP	Physical Layer Pipe
SFN	Single-Frequency Network
SISO	Single Input Single Output

NOTE: Meaning one transmitting and one receiving antenna.

SP	Scattered Pilot
XCF	cross-Correlation Function
ZCZ	Zero-Correlation Zone

4 General description

4.1 Context

EN 302 755 [1] describes the coding and modulation for the second-generation digital terrestrial television broadcasting system known as DVB-T2. It provides the means whereby digital content can be broadcast to viewers and other consumers of content. It offers many options for network operators, including the ability to support single frequency networks (SFNs).

SFNs using OFDM, as DVB-T2 does, have the fundamental feature that the same waveform is emitted by all the constituent transmitters at essentially the same time (see note below). By doing so, it appears to the receiver that a single transmission has been received, albeit subject to 'multipath' - in this case, the reception of multiple versions of the same signal from multiple transmitters, in contrast to the more conventional reception of multiple echoes of the signal from a single transmitter.

NOTE: Network operators may introduce deliberate offsets in the times at which the transmitters in an SFN emit the same signal in order to tailor the areas of best coverage.

A consequence of this is that it is not easy to distinguish and identify the contributions made by the various transmitters in such an SFN. Of course, this is not needed for the primary purpose of physically delivering content to receivers.

However, network operators do have a need to trace or measure the individual transmitter contributions, as part of:

- first bringing a new SFN onto air
- adding an additional transmitter to an existing SFN
- checking the coverage afforded by a network, including assessing the contributions provided by each transmitter

- troubleshooting a network that was working, but where reception problems have been reported, in order to distinguish a cause, e.g.:
  - a transmitter is no longer correctly synchronised in time or frequency with its fellows
  - abnormal propagation causing a distant transmitter to be received at sufficient strength to become a self-interferer in the network
- monitoring a network in service in order to spot, and subsequently fix, problems (like those just listed above) before they become serious enough to cause reception difficulties.

The measurement requirements vary according to the network-operator's application and so the present document offers two different methods. The network operator is free to choose to use none, either one method alone or indeed both methods simultaneously according to need, and may change this choice from time to time to suit requirements. For example, certain checks may only be relevant for a short period after bringing a transmitter on air.

4.2 General principles

Clearly, to include a signature unique to a transmitter implies at least a partial departure from the general SFN principle of radiating identical signals from every transmitter - some part of the signal must be different. However, a cardinal principle remains, that the addition of transmitter signatures must not disturb the normal operation of consumers' receivers. Two general techniques are possible, and both are included as the options defined in the present document:

1) The defined parts of the DVB-T2 waveform comprise OFDM symbols, within which each OFDM carrier is modulated with a different complex number. In DVB-T2, this entity (one carrier within one symbol) is referred to as a cell, and this notation convention is also used in the present document. So, in DVB-T2 the modulation applied to cells may be a constellation point (data cell), defined pilot information (various types of pilot cell) or a value simply inserted in order to tailor the properties of the total signal (reserved-tone cell). In the case of this last, it is not intended that the receiver will take any account of the contents of the cell. It is only inserted at the transmitter to control the properties of the total waveform and there is no reason to assume that it will contain the same complex value for different transmitters in an SFN.

   This principle can be extended to transmitter signatures: certain cells are designated to be used for this purpose, in such a way that consumer receivers following the existing provisions of EN 302 755 [1] will ignore them.

   This method is defined in clause 5. It makes use of the cells in **auxiliary streams** defined in clause 8.3.7 of EN 302 755 [1], which includes the explicit statement "The cell values for auxiliary streams need not be the same for all transmitters in a single frequency network".

   The method is suitable for the simple and relatively quick determination of which transmitters are providing significant contributions to the received power at a location, and their approximate relative power contributions.

2) The DVB-T2 specification [1] includes in its clause 8.4 the concept of **future extension frames**, in which parts (FEF parts) of the entire waveform are left undefined for future use. Nevertheless, EN 302 755 [1] defines signalling means so that the presence, location and duration of FEFs will be known to existing receivers, which are required to ignore them.

   Clause 6 describes a method which uses FEFs to add transmitter signatures.

   The method is able to perform measurements of the timing of individual transmitters and the effective channel impulse response from each transmitter to the receiver, including the relative power of the contributions. It is also suited to frequency measurement of individual transmitters.

   EN 302 755 [1] establishes that there may be none, one or more FEF parts in a DVB-T2 superframe, but if FEF parts are present in a superframe they shall all be of the same length. In consequence, any given superframe in DVB-T2 may contain no FEFs, **or** a FEF or FEFs used by the method of clause 6 to function as a transmitter signature, **and/or** a FEF or FEFs used for some other as-yet undefined purpose; all these FEF parts are of equal length.

Both methods share the common concept of introducing a signature in such a way that receivers following the existing DVB-T2 specification [1] will not be disturbed by the presence of the signature. The 'auxiliary-stream' and 'FEF' methods are complementary and may if desired be used in combination.

5 Transmitter signature using auxiliary streams

5.1 General description

This signature method uses one auxiliary stream in the DVB-T2 signal to carry transmitter identification information. There may also be other auxiliary streams, for other purposes, before or after (or both) the actual auxiliary stream used as a transmitter signature. In line with the DVB-T2 specification there may also be dummy cells before and/or after the transmitter-signature auxiliary stream in the T2 frame.

The DVB-T2 L1 signalling indicates which auxiliary stream is used as a transmitter signature as well as the exact location of the stream. The L1 signalling also signals some other transmitter-signature-related information, as described in the L1 signalling section below.

Let $M = 3(P+1), P = 0, \cdots 1, 2, 3, \ldots 1\,023$ be the number of transmitters to be signalled. In each T2 frame there is one unique pattern of auxiliary cells for each transmitter and these M patterns are orthogonal across all transmitters, i.e. they do not interfere at all, since when a particular cell is used for one transmitter all other transmitters are silent in that cell.

NOTE: M may take the values 3, 6, 9, ... , 3 072. When the actual number of transmitters fall between these values the value of M needs to be higher than the actual number of transmitters. Some allowed patterns of auxiliary cells will then not be used by any transmitter.

When the number of auxiliary cells in the stream so allows there may be more than one auxiliary cell per T2 frame to signal a certain transmitter. The actual number of cells per transmitter and frame is denoted by N. N may take one of the sixteen values: 2^Q, $Q \in \{0, 1, 2, \ldots, 15\}$.

In each T2 frame there are $M\,N$ auxiliary cells available to signal the unique transmitter patterns of all M transmitters and each particular transmitter will signal its identity with N unique cells, called *T cells* having non-zero power and all other transmitters with $(M-1)\,N$ cells, called *Z cells*, with zero power. In order to ensure that the total power of the OFDM symbol remains constant the effect of the Z cells having zero power is compensated for by appropriately adjusting (in most cases boosting) the power of additional cells called *B cells*. Before frequency interleaving, the first cell, the last cell and every 4^{th} cell in-between shall be such a B cell in the actual auxiliary stream. The total number of cells, K, in the auxiliary stream must therefore satisfy $K = 1 + 4\,(P+1)\,N$.

In order to increase frequency diversity the whole structure of the $M\,N$ auxiliary cells (before insertion of the B cells) defined above is cyclically shifted by N cells from one T2 frame to the next so that the first auxiliary cell of TX-SIG frame 1 (which is a T or Z cell) therefore appears as auxiliary cell $N+1$ in TX-SIG frame 2, as auxiliary cell $2\,N+1$ in TX-SIG frame 3 etc. After L T2 frames the original sequence is restarted. The effect of this cyclic shift is that auxiliary-stream cells of M adjacent different T2 frames will be frequency interleaved in a totally different way.

The L T2 frames forming a complete cycle is called a **TX-SIG frame**. The TX-SIG frame does not have to be synchronised with the T2 superframe, but could be independent of this. This means that the TX-SIG frame may start at any T2 frame within a T2 superframe and the length L, in T2 frames, may be different from the number of T2 frames in a T2 superframe. This enables the choice of superframe length and TX-SIG frame length to be independently optimised. The L1 signalling includes a dynamic TX-SIG frame index. The values of M, N and L as well as the TX-SIG frame index are signalled by L1 signalling, see clause 5.4. Clause 5.2 specifies the formation of the transmitter-signature auxiliary stream, while clause 5.3 sets out additional steps that are needed if MISO is in use.

5.2 How the auxiliary streams are formed

We first define the order of the $M\ N$ cells *before* insertion of B cells.

The M transmitters to be signalled are denoted tx_id_1, tx_id_2, …tx_id_M. In the first T2 frame of the TX-SIG frame the N cells signalling tx_id_1 come first followed by the N cells of tx_id_2 etc. until tx_id_M. For each new T2 frame the $M\ N$ cells are cyclically shifted by N cells, as described above. After L T2 frames this total sequence is restarted again from the beginning, marking a new TX-SIG frame.

NOTE 1: The sequence repeats naturally after M frames, so it may be natural to choose L to be an integer multiple of M. However, this is not mandatory.

EXAMPLE: With $M = 3$, $N = 4$ and $L = 5$ there are five T2 frames in a TX-SIG frame, three transmitters are signalled in each T2 frame with four T cells each. The TX-SIG frame will then have the pattern of auxiliary cells (with B for 'boosted' cell, T for 'non-silent TX' and Z for 'silent TX') as depicted in Figures 1 and 2.

TX1

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell i	T	Z	Z	T	Z
cell i+1	T	Z	Z	T	Z
etc	T	Z	Z	T	Z
	T	Z	Z	T	Z
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z

TX2

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell i	Z	Z	T	Z	Z
cell i+1	Z	Z	T	Z	Z
etc	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	T	Z	Z	T

TX3

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell i	Z	T	Z	Z	T
cell i+1	Z	T	Z	Z	T
etc	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z

Figure 1: Pattern of auxiliary cells before insertion of B cells

TX1

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell j	B	B	B	B	B
cell j+1	T	Z	Z	T	Z
etc	T	Z	Z	T	Z
	T	Z	Z	T	Z
	B	B	B	B	B
	T	Z	Z	T	Z
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	B	B	B	B	B
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	Z	T	Z	Z
	B	B	B	B	B
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	B	B	B	B	B

TX2

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell j	B	B	B	B	B
cell j+1	Z	Z	T	Z	Z
etc	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	B	B	B	B	B
	Z	Z	T	Z	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	B	B	B	B	B
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	Z	T	Z	Z	T
	B	B	B	B	B
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	Z	T	Z	Z	T
	B	B	B	B	B

TX3

	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
cell j	B	B	B	B	B
cell j+1	Z	T	Z	Z	T
etc	Z	T	Z	Z	T
	Z	T	Z	Z	T
	B	B	B	B	B
	Z	T	Z	Z	T
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	B	B	B	B	B
	Z	Z	T	Z	Z
	Z	Z	T	Z	Z
	T	Z	Z	T	Z
	B	B	B	B	B
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	T	Z	Z	T	Z
	B	B	B	B	B

Figure 2: Pattern of auxiliary cells after insertion of B cells

After insertion of B cells the sequence of auxiliary cells is mapped to the cell positions determined by the L1 signalling and which may vary from T2 frame to T2 frame. The power of the T cells is boosted by the power ratio 4/3. The power of the B cells is adjusted in such a way that the total expected power of each OFDM symbol containing TX-SIG auxiliary cells is the same as the other symbols in the T2 frame. This will require a boosting of at most 6 dB, since in the worst case only one quarter of the auxiliary cells has non-zero power. This is defined in detail below.

NOTE 2: This maximum B-cell boosting is lower than the maximum allowed pilot boosting (7,4 dB) in DVB-T2.

NOTE 3: At the other extreme, if the TX-SIG auxiliary stream happens to be split between OFDM symbols so that one symbol contains only the short cell sequence BTTT then the power of the single B cell is set to zero to maintain the average power at unity. In general the necessary power of B cells lies in the range 0 to 4 units.

Finally, frequency interleaving is performed symbol by symbol according to the DVB-T2 specification. This frequency interleaving will ensure that the positions of all (non-pilot) cells of the symbol, including auxiliary cells, are pseudo-randomly distributed over the symbol. Thanks to the cyclic N-cell shift of the auxiliary-cell pattern from one T2 frame to the next this pseudo-random distribution will be different between M adjacent T2 frames of the same TX-SIG frame, which will maximise frequency diversity.

The amplitude and phase of the auxiliary-stream cells of a complete TX-SIG frame are specified in the following way:

- The cell values are generated by taking the first $K\ L$ values of the BB scrambling sequence defined in clause 5.2.4 of [1]. The sequence is reset at the beginning of each new T2-SIG frame.

- The resulting bits $b_{BS,j}$, $0 \le j \le KL-1$, are then mapped to cell values $x_{m,l,p}$ according to the following rule, where the bits $b_{BS,j}$ are mapped to cells $x_{m,l,p}$ in order of increasing cell address, starting in the first T2-frame of the TX-SIG frame, from the first address following the previous (non-transmitter-signature) auxiliary stream, if any, or the last PLP otherwise:
  - For auxiliary-stream cell positions which are to contain T or B cells the cell values $x_{m,l,p}$ shall satisfy:

$$\mathrm{Re}\{x_{m,l,p}\} = 2A\left(\frac{1}{2} - b_{BS,j}\right)$$

$$\mathrm{Im}\{x_{m,l,p}\} = 0,$$

    where the value of A for T cells shall be $\sqrt{\frac{4}{3}}$, while the value for B cells is defined below.
  - In all other cell positions of the auxiliary stream, i.e. in the Z cell positions, the value of $x_{m,l,p}$ shall be zero.
- The auxiliary-stream cell values $x_{m,l,p}$ (including T, B and Z cells) shall, in each OFDM symbol, have the same expected mean power as the data cells of the data PLPs, i.e. $E\left(x_{m,l,p}\, x_{m,l,p}^{*}\right) = 1$. The value of A for B cells shall be adjusted so that this condition is fulfilled.

5.3 Special considerations for MISO

Clause 5.2 fully describes the necessary operations for all SISO modes. However, special considerations apply when MISO is used, as noted in the following quote from clause 8.3.7 of EN 302 755 [1]: "The cell values for auxiliary streams need not be the same for all transmitters in a single frequency network. However, if MISO is used as described in clause 9.1, care shall be taken to ensure that the auxiliary streams do not interfere with the correct decoding of the data PLPs".

To use transmitter-signature auxiliary streams together with MISO the following additional steps are needed:

- The T2 frame shall be so arranged that all the cells comprising the transmitter-signature auxiliary stream are contained within one or more OFDM symbols which do not contain any cells conveying PLP data. As described by clause 8.3.8 of EN 302 755 [1], dummy cells shall be inserted into the cells which are not used for L1 signalling, bias balancing cells, PLPs or auxiliary streams.
- The resulting OFDM symbol or symbols containing the transmitter-signature auxiliary-stream cells shall not have the MISO processing specified in clause 9.1 and Figure 46 of EN 302 755 [1] applied to them. Specifically, for those symbols *l* containing the transmitter-signature auxiliary-stream cells then (with the notation of clause 9.1 of EN 302 755 [1]) $e_{m,l,p} = a_{m,l,p}$ for all payload cells. However, the pilot cells shall nevertheless be transmitted as specified for the MISO case in clause 9.2.8 of EN 302 755 [1].

5.4 L1 signalling for TX-SIG auxiliary streams

5.4.1 Configurable L1-post signalling

In accordance with clause 7.2.3.1 of EN 302 755 [1], the use of a transmitter-signature auxiliary stream shall be signalled by including an entry in the auxiliary-stream loop of the DVB-T2 configurable L1-post signalling whose AUX_STREAM_TYPE is set to '0000'. The corresponding 28-bit AUX_PRIVATE_CONF field shall be used in the following way:

P	10 bits
Q	4 bits
R	8 bits

STATIC_AUX_STREAM_FLAG 1 bit

RESERVED 5 bits

P: This 10-bit field indicates indirectly, via the formula $M = 3(P+1)$, the total number of transmitter signatures M that can be signalled with the current configuration. M may therefore take one of the following values: 3, 6, 9, ..., 3 066, 3 069, 3 072.

Q: This 4-bit field signals the number of cells N that are used per transmitter, within the auxiliary stream of a T2-frame. The mapping between Q and N is $N = 2^Q$, and is given in Table 1.

Table 1

Q	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	1	2	4	8	16	32	64	128	256	512	1 024	2 048	4 096	8 192	16 384	32 768

R: This 8-bit field indicates indirectly, via the formula $L = R+1$, the number of T2 frames L per TX_SIG frame. L may therefore take values in the range 1 to 256.

STATIC_AUX_STREAM_FLAG: This 1-bit field indicates whether the value of the AUX_STREAM_START field of the dynamic L1-post signalling is static or not. The value '1' indicates that this field is static and '0' indicates that this is not the case, i.e. dynamic.

RESERVED: This 6-bit field is reserved for future use.

5.4.2 Dynamic L1-post signalling

When the AUX_STREAM_TYPE of the DVB-T2 configurable L1-post signalling is '0000' the 48-bit AUX_PRIVATE_DYN field of the DVB-T2 Dynamic L1-post signalling shall be used in the following way:

TX_SIG_FRAME_INDEX 8 bits

AUX_STREAM_START 22 bits

RESERVED 18 bits

TX_SIG_FRAME_INDEX: This 8-bit field is the index of the current T2-frame within the TX-SIG frame. The index of the first T2-frame of the TX-SIG frame shall be '0'.

AUX_STREAM_START: This 22-bit field indicates the start position of the associated auxiliary stream within the current T2-frame. The addressing shall be identical to that used for PLPs in DVB-T2.

NOTE: The length of the auxiliary stream can be calculated from the configurable L1-post parameters P and Q.

RESERVED: This 18-bit field is reserved for future use.

6 Transmitter signature using FEFs

6.1 General description

In this signature method, the transmitter signature is sent in a FEF part. Typically this FEF part would only be sent once per DVB-T2 superframe, and thus sufficiently infrequently to reduce capacity losses to a minimum. However, it may be sent more frequently if a network operator so chooses. Every transmitter in the network sends its own particular signature simultaneously in the same FEF, so that a suitable monitoring receiver can check the complete network performance at least once per superframe.

The signature FEF part contains four sections:

- a **P1 symbol**, as both defined and mandated in clause 8.4 of [1] as a necessary component of any FEF part;

- an **other-use period**;
- a first **signature period**, comprising a **signature waveform** together with a cyclic prefix of it; and
- a second signature period, comprising a signature waveform together with a cyclic prefix of it.

This structure is illustrated in figure 3.

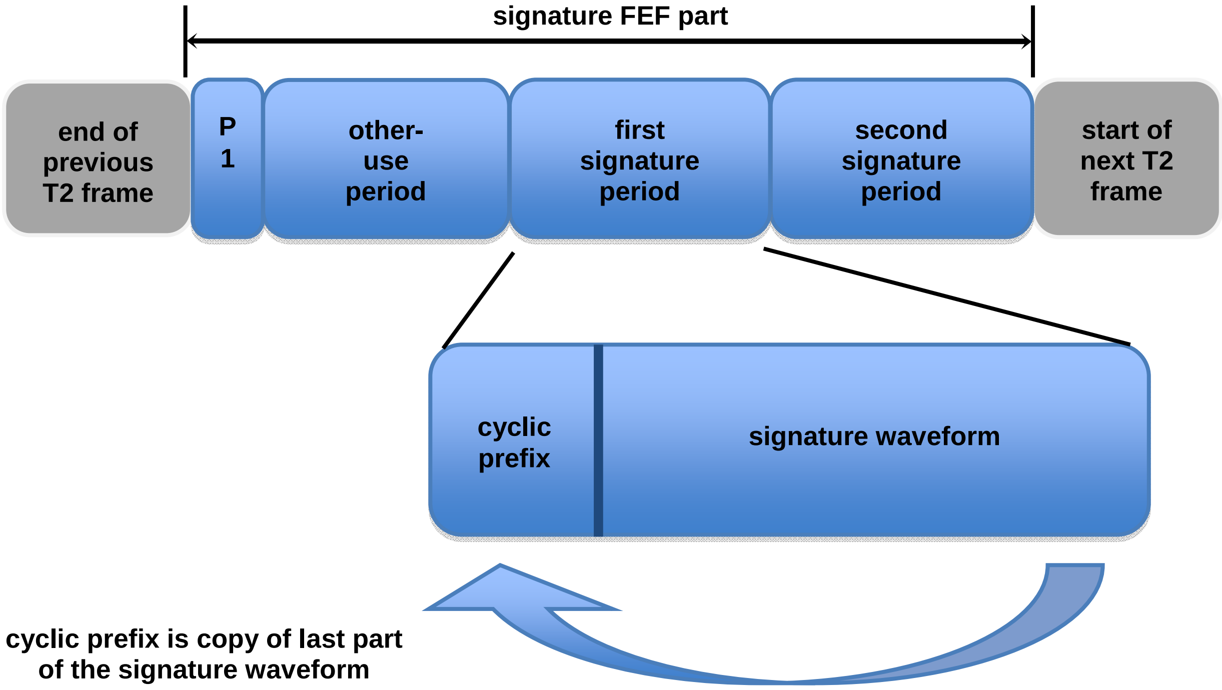

Figure 3: The structure of the signature FEF part (not to scale)

The signature waveforms in the third and fourth sections are chosen from a defined set of eight. It follows that they can be chosen in 64 different combinations, so that up to 64 transmitters can be unambiguously distinguished in a network.

The set of eight waveforms has been designed to have special correlation properties, and the duration of the cyclic prefix is matched to them. A suitable measurement receiver can determine:

- the effective channel impulse response from each transmitter that provides an essential minimum signal strength;
- the relative timing of reception of the signals from the various transmitters, and if a suitable network time reference is available, the absolute timing of reception of these signals relative to that reference, all with a resolution of the order of 1 µs for an 8 MHz system;
- the relative frequency of reception of the signals from the various transmitters, and if a suitable frequency reference is available, the absolute frequency of reception of these signals.

By using correlation techniques between the first signature waveform period, as received, and the eight different waveforms that might have been transmitted, the receiver can determine the composite impulse responses for each group of transmitters that share the same first signature waveform. This is then repeated for the received second signature waveform period. The impulse-response components belonging to the path from a particular transmitter to the monitoring receiver will appear equally in one correlation result for the first waveform period, and in one correlation result for the second waveform period. The results in which this happens will correspond to the particular combination of waveforms that the operator allocates to the particular transmitter. Frequency offsets can be measured by comparing the arguments of the complex-valued correlation peaks obtained for a particular path in the first and second waveform period.

The 'other-use' period (the second section) gives the network operator the opportunity to adjust the total length of the signature FEF part. Its length can be set to zero if it is not required.

6.2 The P1 symbol in the signature FEF part

The signature FEF part shall start with a P1 symbol, as defined in clause 9.8 of [1]. The duration of the P1 symbol is therefore 2 048 *T*, where *T* is the "elementary time period for the bandwidth in use", as defined in [1].

The content of the P1 signalling data (S1 and S2 fields) of this signature-FEF P1 symbol shall be as specified in clause 7.2.1 of [1], and, in particular, Table 19 (b) therein.

NOTE: At the time of writing the present document, this would require the use of the 'Undefined FEF part', signalled by S1=010, S2=000X.

6.3 The other-use period

The P1 symbol of the signature FEF shall be immediately followed by the **other-use period**. The function of this period is to permit the network operator to adjust the total length of the signature FEF part to suit other constraints, or to permit the transmission of an as yet undefined waveform for some future use.

EXAMPLE 1: The network operator wishes to use FEF parts for some other future use in addition to the provision of the transmitter signature. All FEF parts in a superframe must be the same length [1], so the length of the signature FEF part must equal that of these other FEF parts. Making the length of the signature FEF part adjustable therefore permits greater freedom in the future design of those other FEF parts.

The length of the other-use period can be zero; indeed this would be the expected condition where only the transmitter signature is needed, without any other future-uses, since it minimises capacity loss. When the length of the other-use period is greater than zero, the *content* of this period is left unspecified by the present document.

EXAMPLE 2: The network operator is using FEF parts for another use, and (as in Example 1 above) to facilitate this has chosen to extend the signature FEF. Rather than have the resulting other-use period as padding, the operator chooses to send the value zero during this period so as to serve as a 'noise-measuring gap'.

EXAMPLE 3: The network operator wishes to send the FEF-based signature but also requires a small amount of capacity for some currently unspecified use. The additional capacity required is too small to warrant sending dedicated FEF parts, which would have to be at least as long as the minimum-length signature FEF part. The operator therefore extends the signature FEF part slightly, and uses the other-use period to provide the capacity for the new use.

The length of the other-use period, T_{OU}, is not signalled directly, but may be deduced since the total length of the FEF part, T_{FEF}, is signalled as FEF_LENGTH according to clauses 7.2.3.1, 8.2 and 8.4 of [1], and the total length of the other sections of the signature FEF part is fixed, see next clause.

6.4 The first and second signature periods

The other-use period of the signature FEF part shall be immediately followed by the first and second signature periods, which are identical in form. Each comprises a signature waveform, preceded by a cyclic prefix.

Each signature waveform shall have a length of $2^{16}\,T = 65\,536\,T$.

The signature waveform shall be preceded by a cyclic prefix, which shall comprise a copy of the last portion of the signature waveform. This last portion, and hence its copy used as the cyclic prefix, shall be of length $14\,546\,T$.

The length of each of the first and second signature periods is thus $(14\,546 + 65\,536)T = 80\,082\,T$, and the resulting total length of the signature FEF part, excluding the other-use period (if present), is $(2\,048 + 2 \times 80\,082)T = 162\,212\,T$. It follows that the total length of the signature FEF part is $T_{FEF} = 162\,212\,T + T_{OU}$.

Each signature waveform shall be chosen from a set of eight possible waveforms, which in turn are band-limited versions of a set of eight possible sequences. The sequences, their band-limiting and eventual emission are defined in clauses 6.5 to 6.7.

6.5 The set of eight discrete sequences

6.5.1 General

The signature waveforms shall be derived from a set of eight **discrete sequences**, which are chosen to have **generalised orthogonality** (GO) properties, see [i.1].

Generalised orthogonality means that each sequence is orthogonal to the other sequences in the set, not only directly, but also when the sequences are cyclically shifted with respect to each other, provided the cyclic shift does not exceed a number of positions called the **zero correlation zone** (ZCZ) of the sequence set.

This property can also be expressed in terms of the cyclic autocorrelation and cyclic crosscorrelation functions of the sequences, with the size of the ZCZ quantified by the parameter Z_0:

$$\begin{aligned} \text{cyclic ACF, } & r_{ii}[0] = A \\ & r_{ii}[n] = 0, \quad 1 \le |n| \le Z_0 \\ \text{cyclic XCF, } & r_{ij}[n] = 0, \quad -Z_0 \le n \le Z_0, \forall i \ne j \end{aligned}$$

where, for the sequences used, $Z_0 = 7\,273$ and A is a positive constant that depends on the normalisation that is applied.

NOTE 1: Since the zero-correlation zone is two-sided, the cyclic prefix length is therefore chosen to be $2Z_0$.

The set shall be constructed according to the following steps, which are based on the methods of Zeng [i.2]:

- take a single, length-1 024 **perfect sequence**, formed as a 32-phase Frank sequence;
- taking this sequence, together with the set of eight length-8 Hadamard sequences, use the method of Section III.C of [i.2], with parameter $d = 1$, to make an intermediate set of eight length-8 192 GO sequences;
- taking this set of GO sequences, and the set of eight length-8 Hadamard sequences, use Procedure 1 of [i.2] to make the wanted set of eight length-65 536 GO sequences.

These steps are elaborated in detail in the following clauses. Fragments of the calculated sequences are given in clause A.1 by way of example, while example software code to generate the sequences is shown in clause A.2.

NOTE 2: It is not envisaged that a modulator would necessarily perform these operations in real time, or indeed at all, since it would be easier to replay a stored version of the waveform itself. The mathematical steps are outlined here since the sequences themselves are too long to tabulate explicitly in the present document.

6.5.2 The initial perfect sequence

The initial perfect sequence shall be the following sequence of complex numbers:

$$\text{Frank}_{1024} = \left\{ e^{j2\pi \left\lfloor \frac{q}{32} \right\rfloor (q \bmod 32) / 32} \right\}, q = 0, 1, \cdots 1\,023$$

where $\lfloor x \rfloor$ represents the floor of x, the greatest integer whose value does not exceed x, and $j = \sqrt{-1}$. This sequence is of length 1 024 elements. The elements are all of the form $e^{j2\pi n/32}$, where n is an integer, so that they are of unit amplitude and lie on the unit circle, taking one of 32 discrete phases.

NOTE: A perfect sequence has a cyclic autocorrelation function which is zero for all (cyclic) offsets except zero.

6.5.3 The Hadamard sequences

The Hadamard sequences shall be the rows of the following Hadamard matrix:

$$\text{Hadamard}_8 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

6.5.4 The intermediate set of GO sequences

The intermediate set of eight length-8 192 sequences shall be constructed as follows. (This follows the general method of Section III.C (2) of [i.2], with parameter $d = 1$, which itself incorporates the same author's Procedure 1 as its last stage.)

Let c_q, where $q = 0,1,\cdots 1\,023$, denote the values of the perfect sequence Frank_{1024} defined in clause 6.5.2 and let $m = 1\,024$ denote its length.

Form the set $\mathbf{A} = \{\mathbf{a}_0, \mathbf{a}_1, \cdots \mathbf{a}_{n-1}\}$ of *n* length-*m* sequences $\mathbf{a}_i = \{a_{i,0}, a_{i,1} \cdots a_{i,m-1}\}$ whose elements $a_{i,j}$ shall be:

$$a_{i,j} = c_{\left(j(n+d) + i + d\left\lfloor \frac{i+1}{n} \right\rfloor \right) \bmod m}$$

where we set $d = 1$, $n = 8$ (matching the size of the Hadamard matrix), $\lfloor x \rfloor$ represents the floor of *x*, and $m = 1\,024$, as already noted.

Consider $\mathbf{A}$ as an $n \times m$ matrix (having the *n* sequences $\mathbf{a}_i$ as its rows), and take its transpose $\mathbf{A}^T$, so that the sequences now form its columns.

Form the length-8192 sequence $\mathbf{u} = \{u_0, u_1, \cdots u_{mn-1}\}$ by reading $\mathbf{A}^T$ row by row, left to right and from top to bottom.

Now consider the 8×8 Hadamard matrix Hadamard_8 as an ordered set $\mathbf{B} = \{\mathbf{b}_0, \mathbf{b}_1, \cdots \mathbf{b}_{n-1}\}$ of sequences $\mathbf{b}_i = \{b_{i,0}, b_{i,1} \cdots b_{i,n-1}\}$, (the sequences being the rows of the matrix).

Form the intermediate set $\mathbf{S}' = \{\mathbf{s}'_0, \mathbf{s}'_1, \cdots \mathbf{s}'_{n-1}\}$ of eight length-8192 GO sequences $\mathbf{s}'_h = \{s'_{h,0}, s'_{h,1}, \cdots s'_{h,mn-1}\}$ whose elements shall be given by:

$$s'_{h,i} = u_i \, b_{h,\, i \bmod n}$$

NOTE: The ZCZ of these sequences is less than stated in III.C (2) of [i.2] because the accompanying condition "$n > m - 1$" is not satisfied in the present case.

6.5.5 The final set of GO sequences

The final set of eight GO discrete sequences is formed by re-applying the Procedure 1 of [i.2] to the intermediate set $\mathbf{S}'$ defined in clause 6.5.4.

Consider the intermediate set $\mathbf{S}'$ as an $n \times m$ matrix (having the *n* sequences $\mathbf{s}'_i$ as its rows), and take its transpose $\mathbf{S}'^T$, so that the sequences now form its columns. Note that as a result of the last step in clause 6.4.4, we now have $m = 8\,192$ while $n = 8$ remains unchanged.

Form a (new) length-65 536 sequence $\mathbf{u} = \{u_0, u_1, \cdots u_{mn-1}\}$ by reading $\mathbf{S}'^T$ row by row, left to right and from top to bottom.

As before, consider the 8×8 Hadamard matrix $\mathrm{Hadamard}_8$ as the ordered set $\mathbf{B} = \{\mathbf{b}_0, \mathbf{b}_1, \cdots \mathbf{b}_{n-1}\}$ of sequences $\mathbf{b}_i = \{b_{i,0}, b_{i,1} \cdots b_{i,n-1}\}$, (the sequences being the rows of the matrix).

Form the final set $\mathbf{S} = \{\mathbf{s}_0, \mathbf{s}_1, \cdots \mathbf{s}_{n-1}\}$ of eight length-65 536 GO sequences $\mathbf{s}_h = \{s_{h,0}, s_{h,1}, \cdots s_{h,mn-1}\}$ whose elements shall be given by:

$$s_{h,i} = u_i \, b_{h,\, i \bmod n}$$

These are the eight discrete sequences which shall be used to construct the transmitter signature waveforms, once they have been band-limited in accordance with clause 6.6. They have a zero-correlation zone (see clause 6.4.1) of $Z_0 = 7\,273$.

NOTE: Since all the operations performed on the original perfect sequence (see clause 6.5.2) only comprise re-ordering and multiplication by ±1, the elements of the final sequences are also of unit amplitude, each taking one of 32 possible phases.

6.6 The band-limited waveforms

6.6.1 General

The discrete sequences defined in clause 6.6 cannot be emitted as they stand, as they would occupy too great a bandwidth. The bandwidth needs to be constrained to match that of the DVB-T2 signal into which the waveforms will be inserted. This shall be done in the following defined manner, in order that the correlation properties remain satisfactory for the intended purpose, while the peak-to-mean power ratio (PAPR) of the emitted waveform does not become excessive.

The bandlimiting is defined in terms of the use of processing based on Discrete Fourier Transforms (DFTs). Each of discrete sequences defined in clause 6.5 can be considered to exist in the time domain. By taking the DFT, the discrete spectrum is obtained. Multiplying this by a suitable window has the effect of restricting this spectrum so that it does not fall outside that occupied by the main part of the DVB-T2 signal specified in [1]. Then taking the inverse DFT produces a time-domain waveform suitable for emission after appropriate normalisation and addition of the cyclic prefix.

The discrete sequences defined in clause 6.5 are of length 65 536 elements. Using the common notation in which 'K' stands for $2^{10} = 1\,024$ we can conveniently write '64K' to stand for 65 536. Applying the DFT to the length-64K discrete sequences therefore involves the use of a 64K DFT and produces a discrete spectrum having 64K values.

NOTE: The DFT may be implemented as the more efficient Fast Fourier Transform (FFT) equivalent. However, it may not be necessary in practice to perform these calculations in real time, since it may be preferred to store and replay the final time-domain waveform in precomputed form.

6.6.2 The 64K DFT

The discrete spectrum $V_{h,k}$ of each sequence $\mathbf{s}_h$ defined in clause 6.5 shall be calculated as follows:

$$V_{h,k} = \sum_{i=0}^{N-1} s_{h,i}\, e^{-j2\pi ik/N} \qquad k = 0,1,\cdots(N-1)$$

where $N = 65536$. The values $V_{h,k}$ denote the spectral components of the sequence with index *h* where each *k* corresponds to a baseband frequency $k\, f_U = k/T_U$. For $k \geq N/2$ it makes more sense to consider the corresponding *negative* baseband frequency $k'\, f_U = (k-N)/T_U$ where $k' = (k-N)$, whence we may write instead:

$$V'_{h,k'} = \begin{cases} V_{h,k'} & k' \geq 0, \\ V_{h,(k'+N)} & k' < 0. \end{cases}$$

in which k' takes the range $-\frac{N}{2} \leq k' < \frac{N}{2}$.

6.6.3 The filtering window and its application

The discrete spectrum of each sequence shall be both truncated and shaped by the use of the following window:

$$W_{k'} = \begin{cases} 0.42 + 0.5\cos\pi\left(\frac{k'}{K_H}\right) + 0.08\cos 2\pi\left(\frac{k'}{K_H}\right) & -K_H \leq k' \leq K_H, \\ 0 & \text{otherwise} \end{cases}$$

where $K_H = 27\,264$.

The windowed spectrum of each sequence shall be calculated as:

$$X_{h,k'} = W_{k'} V'_{h,k'}.$$

This discrete spectrum can be considered as analogous to the complex 'carrier' amplitudes of a 64K OFDM system, where the carriers have index k' relative to a central carrier whose frequency is the centre frequency of the DVB-T2 signal.

6.7 Modulation - the emitted waveform

This clause defines the emitted waveform in a manner closely analogous to clause 9.5 of the DVB-T2 specification [1]. Clause 9.5 of [1] defines the emitted T2 signal "when neither FEFs nor PAPR reduction are used". It starts with an arbitrary origin for time *t* at the start of a particular T2 frame, and counts out T2 frames and the symbols within them into the indefinite future, while maintaining phase continuity of the centre-frequency term $e^{j2\pi f_c t}$ that accounts for the signal being modulated onto a centre carrier frequency f_c for emission.

This format of equation cannot readily be extended to include FEFs, since the past mix of T2 frames and different-length FEFs cannot easily be accounted for.

In the following, the signature FEF is therefore for simplicity defined assuming a time origin at its start. It is therefore necessary to note that an arbitrary phase φ must be included in the centre-frequency term to ensure phase continuity of this centre-frequency term between the previous T2 symbol and the FEF. Similarly another arbitrary phase will need to be added to subsequent T2 frames to ensure phase continuity between the FEF and the following T2 symbol.

NOTE 1: In reality there should be no difficulty. The signal waveform is in practice assembled at complex baseband, as the appropriate concatenation of T2 frames interspersed with the occasional signature FEF. This entire baseband waveform is then multiplied by the continuous centre-frequency term $e^{j2\pi f_c t}$ in order to shift the whole signal to the emission frequency.

The emitted signal, during the signature FEF, shall be:

$$s(t) = \mathrm{Re}\left\{ e^{j(2\pi f_c t + \varphi)} \left(p_1(t) + p_{OU}(t) + \frac{1}{\sqrt{1+2K_H}} \sum_{l=0}^{1} \sum_{k'=-K_H}^{K_H} c_{l,k'} \, \psi_{l,k'}(t) \right) \right\}$$

where

$$\psi_{l,k'}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_U}(t - \Delta - T_{P1} - T_{OU} - lT_S)} & T_{P1} + T_{OU} + l\,T_S \le t \le T_{P1} + T_{OU} + (l+1)T_S \\ 0 & \text{otherwise} \end{cases}$$

and the other symbols have the following specific meanings within this clause:

k' denotes the 'carrier' index relative to the centre frequency;

K_H the index value 27 264;

l denotes the index of the signature period, 0 for the first signature period, 1 for the second;

T_S is the total duration of one signature period, $T_S = T_U + \Delta = 80\,082T$;

T_U is the duration of one signature waveform, $T_U = 65536T$;

Δ is the duration of the signature cyclic prefix, $\Delta = 14\,546T$;

f_c is the centre frequency of the emitted RF signal;

T_{OU} is the duration of the other-use period;

T_{P1} is the duration of the P1 symbol, $T_{P1} = 2\,048T$;

$p_1(t)$ is the P1 waveform as defined in clause 9.8.2.4 of [1];

$p_{OU}(t)$ is the waveform emitted during the other-use period (if any) $T_{P1} \le t < T_{P1} + T_{OU}$;

T is the "elementary time period for the bandwidth in use", as defined in Table 65 of clause 9.5 of [1];

φ is the phase term needed to ensure phase continuity in the carrier term, as discussed above;

and where in particular:

$c_{l,k'}$ is the complex modulation value for 'carrier' k' in signature period l and shall be as follows:

$$c_{l,k'} = \frac{25\sqrt{1+2K_H}}{1024\sqrt{648\,798}} X_{h_l,k'}$$

where h_l is the index of the sequence that is chosen to be sent as the signature in signature period *l*.

NOTE 2: The factor $\frac{1}{\sqrt{1+2K_H}}$ in the equation for the emitted signal $s(t)$ ensures that $s(t)$ has unit power, given that the expected value $E\left\{c_{l,k'}\, c_{l,k'}^{\;*}\right\} = 1$ is in turn imposed by the use of the scaling factor $\frac{25\sqrt{1+2K_H}}{1024\sqrt{648\,798}}$ in the equation for $c_{l,k'}$. This latter factor takes into account the effects of the Blackman window. Clearly in a practical application these two factors may well be rolled into one, thereby avoiding the $\frac{1}{\sqrt{1+2K_H}}$ term.

Annex A (informative): Examples of the construction of the sequences and waveforms of the signature-FEF

A.1 Example values of the sequence construction

A.1.1 The Frank perfect sequence

The Frank sequence defined in clause 6.5.2 has 1 024 elements making it clumsy to tabulate in its entirety.

The first 32 elements of the sequence are simply +1.

The next 16 elements are: $\left\{1, e^{\frac{j\pi}{16}}, e^{\frac{j\pi}{8}}, e^{\frac{3j\pi}{16}}, e^{\frac{j\pi}{4}}, e^{\frac{5j\pi}{16}}, e^{\frac{3j\pi}{8}}, e^{\frac{7j\pi}{16}}, j, e^{\frac{9j\pi}{16}}, e^{\frac{5j\pi}{8}}, e^{\frac{11j\pi}{16}}, e^{\frac{3j\pi}{4}}, e^{\frac{13j\pi}{16}}, e^{\frac{7j\pi}{8}}, e^{\frac{15j\pi}{16}}\right\}$.

The **last** 16 elements are: $\left\{-1, e^{\frac{15j\pi}{16}}, e^{\frac{7j\pi}{8}}, e^{\frac{13j\pi}{16}}, e^{\frac{3j\pi}{4}}, e^{\frac{11j\pi}{16}}, e^{\frac{5j\pi}{8}}, e^{\frac{9j\pi}{16}}, j, e^{\frac{7j\pi}{16}}, e^{\frac{3j\pi}{8}}, e^{\frac{5j\pi}{16}}, e^{\frac{j\pi}{4}}, e^{\frac{3j\pi}{16}}, e^{\frac{j\pi}{8}}, e^{\frac{j\pi}{16}}\right\}$.

A.1.2 The set of discrete sequences

There are eight, length-65 536 complex-valued sequences. It is clearly impractical to list them in their entirety. Tables A.1 and A.2 list a few small extracts. For clarity of reading, instead of tabulating the complex sequence values (which all take the form $e^{jq\pi/16}, \quad q = -15, -14, \cdots 15, 16$) we tabulate the integer values $q = \frac{16}{\pi}\text{Arg(sequence\_value)}$.

Table A.1: The first 32 entries in each of the discrete sequences s_h

	$\frac{16}{\pi}\mathrm{Arg}\left(s_{h,i}\right)$							
i	$h=0$	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$	$h=6$	$h=7$
0	0	0	0	0	0	0	0	0
1	0	16	0	16	0	16	0	16
2	0	0	16	16	0	0	16	16
3	0	16	16	0	0	16	16	0
4	0	0	0	0	16	16	16	16
5	0	16	0	16	16	0	16	0
6	0	0	16	16	16	16	0	0
7	0	16	16	0	16	0	0	16
8	0	0	0	0	0	0	0	0
9	16	0	16	0	16	0	16	0
10	0	0	16	16	0	0	16	16
11	16	0	0	16	16	0	0	16
12	0	0	0	0	16	16	16	16
13	16	0	16	0	0	16	0	16
14	0	0	16	16	16	16	0	0
15	16	0	0	16	0	16	16	0
16	0	0	0	0	0	0	0	0
17	0	16	0	16	0	16	0	16
18	16	16	0	0	16	16	0	0
19	16	0	0	16	16	0	0	16
20	0	0	0	0	16	16	16	16
21	0	16	0	16	16	0	16	0
22	16	16	0	0	0	0	16	16
23	16	0	0	16	0	16	16	0
24	0	0	0	0	0	0	0	0
25	16	0	16	0	16	0	16	0
26	16	16	0	0	16	16	0	0
27	0	16	16	0	0	16	16	0
28	0	0	0	0	16	16	16	16
29	16	0	16	0	0	16	0	16
30	16	16	0	0	0	0	16	16
31	0	16	16	0	16	0	0	16

Table A.2: The last 32 entries in each of the discrete sequences s_h

	$\frac{16}{\pi}\mathrm{Arg}(s_{h,i})$							
i	$h=0$	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$	$h=6$	$h=7$
65 504	5	5	5	5	5	5	5	5
65 505	5	–11	5	–11	5	–11	5	–11
65 506	5	5	–11	–11	5	5	–11	–11
65 507	5	–11	–11	5	5	–11	–11	5
65 508	–11	–11	–11	–11	5	5	5	5
65 509	–11	5	–11	5	5	–11	5	–11
65 510	–11	–11	5	5	5	5	–11	–11
65 511	–11	5	5	–11	5	–11	–11	5
65 512	4	4	4	4	4	4	4	4
65 513	–12	4	–12	4	–12	4	–12	4
65 514	4	4	–12	–12	4	4	–12	–12
65 515	–12	4	4	–12	–12	4	4	–12
65 516	–12	–12	–12	–12	4	4	4	4
65 517	4	–12	4	–12	–12	4	–12	4
65 518	–12	–12	4	4	4	4	–12	–12
65 519	4	–12	–12	4	–12	4	4	–12
65 520	3	3	3	3	3	3	3	3
65 521	3	–13	3	–13	3	–13	3	–13
65 522	–13	–13	3	3	–13	–13	3	3
65 523	–13	3	3	–13	–13	3	3	–13
65 524	–13	–13	–13	–13	3	3	3	3
65 525	–13	3	–13	3	3	–13	3	–13
65 526	3	3	–13	–13	–13	–13	3	3
65 527	3	–13	–13	3	–13	3	3	–13
65 528	1	1	1	1	1	1	1	1
65 529	–15	1	–15	1	–15	1	–15	1
65 530	–15	–15	1	1	–15	–15	1	1
65 531	1	–15	–15	1	1	–15	–15	1
65 532	–15	–15	–15	–15	1	1	1	1
65 533	1	–15	1	–15	–15	1	–15	1
65 534	1	1	–15	–15	–15	–15	1	1
65 535	–15	1	1	–15	1	–15	–15	1

A.2 Example code for sequence generation and filtering

A.2.1 Code written in Mathematica

Mathematica [i.4] is produced by Wolfram Inc., http://www.wolfram.com. The code examples are presented here in their most basic ASCII-text-compatible form (they have more-readable 2D-formatting and special characters in the original).

A.2.1.1 Preliminary definitions

To make a Frank sequence having `phase_N` phases:

```
FrankSequence[phaseN_Integer]:= Module[{Sx = phaseN^2},
  Table[E^((I 2 Pi Floor[x/phaseN] Mod[x, phaseN])/□phaseN),
  {x, 0, Sx - 1}]]
```

To make the set of eight length-8 Hadamard sequences (8×8 Hadamard matrix):

```
H2 = {{1, 1}, {1, -1}}; H8 = KroneckerProduct[H2, H2, H2];
```

To perform Zeng's Procedure 1 [i.1]:

```
ZengProcedure1[Aset_, Bset_]:=
  Module[{m, n, useq, errflag},
    useq = Flatten[Transpose[Aset]];
    n = Length[Aset]; m = Length[Aset[[1]]];
    errflag = If[n != Length[Bset] || n != Length[Bset[[1]]], True, False];
    If[errflag, Print["ERROR:unmatched A, B dimensions"]; Abort[]];
    Table[useq[[i + 1]] Bset[[1 + h, 1 + Mod[i, n]]],
      {h, 0, n - 1}, {i, 0, m n - 1}]
  ]
```

To perform Zeng's Method III.C [i.1]:

```
ZengMethodIIIC[Cset_,Bset_,d_Integer]:=
  Module[{l,m,n,Asets,Ssets},
    l = Length[Cset];m = Length[Cset[[1]]];n = Length[Bset];
    Asets = Table[
          Cset[[1 + k,1 + Mod[j (n + d) + i + d Floor[(i + 1)/n], m]]],
          {k, 0, l - 1},{i, 0, n - 1},{j, 0, m - 1}];
    Ssets=Map[ZengProcedure1[#, Bset]&, Asets];
    Flatten[Ssets,1]]
```

NOTE: Lists, together with deeper nested structures, in *Mathematica* are accessed using indices which start from 1, so that the index for a list of length *n* runs from 1 to *n*, as compared with the equations where the index would run from 0 to $n-1$. Thus for example `Cset[[1]]` in the above denotes the first sequence $\mathbf{c}_0$ in set $\mathbf{C}=\{\mathbf{c}_0,\mathbf{c}_1,\cdots\mathbf{c}_{l-1}\}$.

A.2.1.2 Use definitions to make the set of sequences

Perform Zeng's method III.C [i.1] and Procedure 1 in succession:

```
set64KfromFrank1024 =
  ZengProcedure1[ZengMethodIIIC[{FrankSequence[32]}, H8, 1], H8];
```

The result is a list of eight elements, each of which is a length-65 536 sequence. In effect it is a 8×65536 matrix whose rows are the sequences.

A.2.1.3 Band-limiting to make set of waveforms

Define 'equivalent number of carriers' for a hypothetical OFDM system based on a 64K (i.e. 65 536) DFT to occupy the same bandwidth as the 'normal' version of 8K DVB-T2 [1] (which has 6817 carriers):

```
n64kActiveCarriers = 6816 (65536/8192) + 1;
```

Design a Blackman window whose length matches this 'equivalent number of carriers':

```
windowbasis64K =
  Table[0.42 + Cos[(2 Pi i)/(n64kActiveCarriers - 1) - Pi]/2
    + 0.08 Cos[2 ((2 Pi i)/(n64kActiveCarriers - 1) - Pi)],
  {i, 0, n64kActiveCarriers - 1}];
```

Pad it out with zeros to match a 64K DFT, and perform cyclic rotation so the peak aligns with the zero-frequency ('DC') carrier position in the *Mathematica* DFT notation:

```
windowPadded64K =
  RotateLeft[windowbasis64K~Join~ConstantArray[0, 11007], 27264];
```

Apply the band-limiting to all the sequence sets in one operation:

```
waveforms64KfromFrank1024=
  (65536*25/(1024 Sqrt[648798]))Map[InverseFourier[
  zwindowPadded64K Fourier[#]]&,zset64KfromFrank1024];
```

NOTE 1: If this code is to provide values of the frequency coefficients for use in the equation of clause 6.7 it is necessary to set the defaults for `Fourier` to ensure that its operation matches the DFT definition of clause 6.6.2 by setting `FourierParameters -> {1, -1}`. (It is not necessary when `Fourier` and `InverseFourier` are used jointly as above, as any self-consistent DFT-notation definition will give the same result).

NOTE 2: The additional factor 65536 in the last code statement above is there to correct for a built-in factor of (1/65536) in the *Mathematica* `InverseFourier` operation, assuming that `FourierParameters` is set as in note 1. When this is the case, the final waveforms are normalised to have an RMS value of unity.

A.2.2 Code written in MATLAB

MATLAB [i.3] is produced by The Mathworks, Inc. http://www.mathworks.com/.

```
m=1024; n=8; d=1;
cpSamples = 14546;

% Make the Frank sequence
q=0:m-1;
c=exp(j*2*pi*floor(q/32).*mod(q,32)/32);

% Make the Hadamard sequence
b = hadamard(n);

% Make the intermediate GO sequences
   % Make matrix A
ii=repmat((0:n-1)', 1, m); % ii is row number (the i in expression for a_i,j)
jj=repmat(0:m-1, n, 1); % jj is column number
A = c(mod(jj*(n+d)+ii+d*floor((ii+1)/n), m) + 1); % Add 1 for matlab indexing
   % Read column-wise (equiv to transpose and read row-wise in definition)
u = A(:);
   % Form S'
sdash = repmat(u.', n, 1) .* repmat(b,1,m);

% Make final set of GO sequences
   % Read column-wise. (uu is the new u of clause 6.4.5)
uu = sdash(:);

   % Form S
s = repmat(uu.', n, 1) .* repmat(b,1,m*n);

% 64K DFT
N = m*n*n;
V = fft(s.'); % transpose and DFT each column (i.e. each sequence)

Vdash = fftshift(V,1);
kdash = (-N/2:N/2-1)';

% Filtering window
   % Generate window
Kh = 27264;
W = 0.42+0.5*cos(pi * kdash/Kh) + 0.08*cos(2*pi*kdash/Kh);
W(abs(kdash)>Kh) = 0;
   % Apply window
X = repmat(W, 1, n) .* Vdash;

% convert to time domain
coeffScale = 25*sqrt(1+2*Kh)/(1024*sqrt(648798));
overallScale = 1/sqrt(1+2*Kh);
x = N * overallScale * ifft(fftshift(coeffScale*X,1));

% add cyclic prefix
x = [x(end-cpSamples+1:end,:); x];
```

Annex B (informative): Using the signature-FEF for measurements

B.1 Introduction

The scope of the present document is to specify the signal transmitted. Nevertheless, a broad indication of how the transmitter signature can be exploited is helpful to provide some understanding. This annex therefore describes ways in which the signature-FEF of clause 6 could be used in a measurement receiver to assist in monitoring a single-frequency transmission network (SFN). It is far from exhaustive.

In an SFN, all transmitters radiate essentially identical signals (the exceptions being the signatures, if any, and certain others, such as the use of some cells for PAPR reduction following the method of clause 9.3 of [1]). The signals are radiated at nominally identical times and frequencies, but perturbed by instrumental errors plus any deliberate offsets introduced by the choice of the network operator. The received signal at some location will appear to be identical to a transmission from a virtual single transmitter which has passed through a composite channel which comprises the superposition of the channel impulse responses from each of the individual real transmitters. The relative timing of the path components will depend on the relative locations of the transmitters with respect to the receiver, plus any offsets deliberately or accidentally introduced. Each path component will also potentially have an individual frequency error or offset.

The guard interval built in to the T2 system for all data symbols in the T2 frame means that reliable reception remains possible as long as the total range of apparent path delays, the 'channel extent', does not exceed the guard-interval duration (assuming the receiver achieves suitable time synchronisation). When paths are present having a wider channel extent, then some degradation is inevitable unless the most spread-out path components are of very small amplitude.

A conventional T2 receiver makes use of channel-response measurements made using the Scattered Pilots (SPs). The channel impulse response can be estimated from these by applying an inverse DFT. The accuracy of this impulse-response estimation starts to deteriorate once the channel extent exceeds the guard-interval duration; and becomes dramatically in error once the channel extent is sufficiently greater still so that the Nyquist limit is violated. Note that the various guard-interval and pilot-pattern options in T2 are linked so that in general the guard interval amounts to either 75 % or 89 % of the Nyquist limit.

A measurement receiver based on conventional techniques for T2 reception is thus limited in the channel extent it can measure reliably; furthermore, while indicating the received path components, and their delays, corresponding to every transmitter in an SFN, it cannot unambiguously indicate which is which. These two limitations are the key reasons for the existence of the FEF-based transmitter signature.

Within limits, the conventional approach can also give information concerning the frequency error/offset of individual transmitters, since the argument of the corresponding complex-valued impulse-response peak will rotate over time. The rate of rotation gives the frequency error. Only small errors can be resolved unambiguously (and without performance degradation); however, this is not usually an issue for monitoring a network with a static receiver, since the permitted transmitter frequency errors are anyway rather small.

B.2 Nature of the FEF-based transmitter signature

As explained in clause 6, this is effectively defined in the time domain. More precisely, a set of discrete sequences (which can be thought of as existing in the time domain) is defined, then the necessary band-limiting process is defined so that the sequence becomes a waveform which can be transmitted within the confined bandwidth of a broadcast spectrum allocation. For simplicity, this band-limiting is defined (and performed in practice) by transformation into the frequency domain, where the spectrum is limited and shaped. In this way, the signature acquires, in effect, a frequency-domain definition. In many ways this makes the transmission and subsequent handling of the signature in the measurement receiver have many parallels with OFDM; similar processing approaches may be used.

NOTE: Frequent reference will be made to the use of a DFT or its inverse. Usually, any practical implementation of the DFT will use one of the FFT algorithms.

B.3 Measuring the channel impulse response

B.3.1 Basics

B.3.1.1 Conventional OFDM pilot-based measurements (e.g. DVB-T2)

The received signal is the convolution of the transmitted signal with the channel impulse response. The receiver observes a section of this signal, the FFT window, of length equal to the so-called 'useful' symbol duration $T_U = N_{FFT}\,T$. Provided the channel extent does not exceed the guard-interval duration (and the receiver is correctly synchronised), the waveform within this period is the *circular* convolution of the transmitted 'useful' symbol with the channel impulse response. It follows that upon transformation into the frequency domain, the frequency coefficients are the product of the transmitted complex carrier values and samples of the channel frequency response at the corresponding carrier frequencies.

In the case of scattered-pilot cells, the carrier values transmitted are known. So by *dividing* by these known values (they are only ± a real constant) we get the sampled values of the channel frequency response for every SP position. By inverse DFT from these we then get the estimated channel impulse response. Note that the bandwidth over which we measure the channel is abruptly restricted to the bandwidth occupied by the carriers we actually transmit. The bandwidth restriction slightly spreads out the peaks of the estimated impulse-response (corresponds to Heisenberg's principle); the abrupt nature of the restriction causes 'ringing', with appreciable sidelobes. The true impulse response has in effect been convolved with a Sinc function.

Because the measurement is sub-sampled in frequency (we cannot have SPs on every carrier in the same symbol, there'd be no data capacity!) there is a Nyquist limit which sets an absolute maximum to the channel extent that can be measured without ambiguity ('aliasing'). The Nyquist limit is maximised by performing temporal interpolation between measurements in different symbols so that we have channel measurements available for every pilot-bearing carrier.

B.3.1.2 Using the signature waveform with a single transmitter

Suppose that a signature FEF is transmitted by a single transmitter, and we wish to use the signature to determine the channel impulse response from that transmitter to a measurement receiver.

Consider first the behaviour of a single one of the two signature periods in the signature FEF. It is constructed in a way which is somewhat similar to a symbol in a guard-interval OFDM system such as found in the main DVB-T2 frames. It comprises the signature waveform (analogous to the 'useful symbol' of OFDM) and a cyclic prefix, which is constructed in the same way as an OFDM guard interval, in this case by taking the last part of the signature waveform.

The cyclic prefix has exactly the same purpose as the OFDM guard interval: it turns normal convolution of the transmitted signal with the channel impulse response into a *cyclic* one. Note that the length of the signature cyclic prefix is appreciably longer than any of the options of the main T2 signal. This means that appreciably greater channel extents can be measured without ambiguity or error than is the case for the methods used by 'conventional' receivers, as just described in clause B.3.1.1. Of course, if the total channel extent exceeds the cyclic prefix, then the measurement will degrade. The maximum channel extent allowed is thus $2\,Z_0\,T = 14546\,T$, or about 1,59 ms for an '8 MHz' system.

At the receiver, an appropriately timed segment of received waveform is taken, equal in length to the signature waveform $T_U = 65536T$. The 64K DFT is used to transform this into frequency-domain coefficients from which we could deduce the channel frequency response, given that we know the transmitted frequency-domain coefficients $X_{h,k'}$ of clause 6.6.3. There are some subtle differences from the method we described in clause B.3.1.1:

- the transmitted frequency-domain coefficients $X_{h,k'}$ are not simply ± real constant, like the SP amplitudes. Because of the windowing, some are deliberately small in value. Division would not therefore be a good idea; it would lead to noise amplification. So instead of *dividing* by $X_{h,k'}$, we *multiply* the received frequency-domain coefficients by the *complex-conjugate* values $X^{*}_{h,k'}$. The results are now the sampled values of the frequency response of the channel, but weighted in amplitude by the square of the Blackman window. When these are transformed back by IDFT, the result is the channel impulse response convolved with the ACF of the signature waveform. This ACF has a broader main lobe than the Sinc function of the conventional SP-based method, but ringing and sidelobes (within the ample ZCZ) are negligible, so there is less possibility of confusing sidelobe peaks with true weaker channel components.

It may be noted that this method is equivalent to a *matched-filter* implementation of a time-domain correlator, but with the convenience of an FFT implementation. It should also be noted that the 'conventional' SP-based approach described in B.3.1.1 also falls into this category but for the very different waveform (the SP ensemble) used there. Indeed, although for convenience of understanding the use of *division* was described for the SP-based method, the very same operation could also have been described as conjugate multiplication (barring an overall scaling) since the pilot amplitudes are ± a real constant.

- The ACF properties of the signature waveforms are maintained for cyclic offsets in the range from $-Z_0 T$ to $+Z_0 T$. If we are to exploit this fully, we need to arrange that the first possible path appears to have the maximum negative cyclic delay, while placing the DFT window so that all paths within the maximum channel extent maintain their cyclic behaviour. To do this, the received waveform segment gathered in the DFT window should be cyclically shifted by $-Z_0 T$ before taking the DFT, ensuring that a path in the middle of the acceptable range then appears to have zero cyclic delay. (This is very similar to normal OFDM processing, where a similar shift (or equivalent process) of one-half the guard interval is performed. In that case it is done so that paths appear to lie within a range of delays from minus to plus one-half of the guard interval; this simplifies frequency interpolation so that real tap weights can be used.)

B.3.2 Using the signature waveforms in a small SFN

Suppose we have a small SFN, with no more than eight transmitters. In this case the mapping of signature waveforms (of which there are eight) to the first and second signature periods for each transmitter can take a form which makes both explanation and processing simple. Suppose we follow the simple rule that transmitter 1 sends waveform 1 in both the signature periods, transmitter 2 uses waveform 2 in both periods and so on.

To measure the path from one of the transmitters, we follow the procedure just described in clause B.3.1.2, taking care to multiply the received frequency-domain coefficients by the complex conjugate values $X^*_{h,k'}$ corresponding to the signature waveform chosen for that transmitter. Provided any paths from the other transmitters lie within the acceptable channel extent, then the XCF properties of the signature waveforms ensure that measurements of one transmitter are not affected by the simultaneous presence of the signatures of the others which use different members of the waveform set.

So, using the signal received in the first signature period, a measurement receiver can simultaneously obtain the channel impulse response for each transmitter independently. This can be repeated using the second signature period. Assuming the channel itself has not changed, the same result should be obtained, except for:

- any effects of noise
- the presence of frequency offset and Doppler shift on any received path component. This will cause the corresponding impulse-response peak to have rotated on the Argand plane by the angle $2\pi\Delta f\ 80082T$ radians, where Δf is the combined frequency offset and Doppler shift of that path component.

A convenient form of processing is simply to multiply the impulse response calculated from the first period by the conjugate of that calculated from the second. The magnitude of this is then the *power* impulse response, while the argument of any peak gives the frequency error of the corresponding path.

The signature thus enables the measurement of time and frequency of each transmitter - relative to the reference available to the receiver. If this is the reference used by the operator to establish the network, absolute measurements are possible. If not (e.g. the receiver has simply locked to the total received signal) then the relative timing between transmitters can be determined. Furthermore, any transmitter having a rogue frequency error will stand out as different from the others.

B.3.3 Using the signature waveforms in a larger SFN

Let us suppose the number of transmitters in the SFN is more than eight but not greater than 64. In this case it will be possible to assign each transmitter its own unique combination of signature waveforms, given that in most cases different waveforms would be assigned for the first and second signature periods.

Suppose for simplicity we performed essentially the same processing as in clause B.3.2, but for each transmitter now using the appropriate allocated waveform for the calculations from the first and second periods.

The calculation from the first period will contain a composite impulse response, encompassing the paths from all the transmitters sharing the same waveform for the first signature period. The calculation from the second period will encompass the paths from all the transmitters sharing the same waveform for this second period. However, because we have assigned a unique combination to each transmitter, the only path components appearing in both measurements belong to the transmitter we want to measure.

Suppose for a moment we assume noise is negligibly small, and that no path components from different transmitters have exactly the same delay. The result when we do the conjugate multiplication will then be exactly as obtained in clause B.3.2. Wherever an unwanted path component belonging to some other transmitter appears in the first measurement, it will not appear in the second and *vice versa*, so that unwanted paths get multiplied by zero.

In fact, when noise is not negligible, unwanted paths get multiplied by a small noise value, and are not therefore fully cancelled. So noise will set a limit to the smallest paths that can be reliably distinguished from crosstalk with this method.

What of the other assumption? Suppose the paths from two transmitters have identical delay; the peak in the response calculated in whichever of the two periods has them sharing a waveform will therefore be a vector sum of the two. The corresponding peak in the other period will be the correct value for the transmitter of interest. When we take the conjugate product, the resulting peak will be the wrong size as a measurement of the wanted transmitter. However, this erroneous result could be detected and flagged by noting that the amplitude of the peak in the first and second period is significantly different (i.e. more than attributable to noise). In such situations resolution of the uncertainty is possible by:

- using a directional antenna pointed towards the wanted transmitter (presuming the geography of the problem is not particularly pathological)
- using a more complicated method of processing

Finally we consider a network having more than 64 independent transmitters in an SFN. In this case signature combinations will have to be re-used, so that measurement of a particular signature combination will yield the composite response of two or more transmitters allocated the same code. In this case the operator will have to make some use of knowledge of geography, careful allocation of the combinations, directional antennas at the monitoring site and possibly combining results from more than one monitoring site (which might be necessary with this scale of network anyway) to resolve ambiguities.

Not all transmitters will be independently fed and allocated a unique signature. Sometimes repeaters will be used that receive a signal from another main 'parent' transmitter, then filter, amplify and retransmit it. Except in very fortunate situations where great isolation can be achieved between the repeater's receiving and transmitting antennas, some form of echo-cancelling processing will also be needed unless the output power is very small. Such *on-channel repeaters*, sometimes called *active deflectors*, will clearly transmit the same transmitter signature as their parent transmitter. So their contribution will form part of the measured impulse response of their parent transmitter. It can be distinguished by virtue of geography plus the known delay that their processing introduces.

History

Document history		
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