Single Frequency Networks (SFN) in Digital Terrestrial Broadcasting

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Abstract. *The paper deals with principles and properties of single frequency networks of digital television and radio transmitters. Basic definitions and contextual relationships (guard interval, area of SFN, influence of used modulation parameters etc.) are explained.*

Keywords

Digital television, single frequency network (SFN), standard DVB-T, transmitter, terrestrial broadcast, guard interval, multipath reception, SFN area.

1. Introduction

The transmission channel (path) for the terrestrial TV broadcasting is commonly and rightfully considered as the worst quality channel. Terrestrial transmission channel is a subject to many influences - additive noise and other disturbing signals (namely in the municipal and industrial agglomerations), signal echoes – so-called **multipath reception.** There are mainly the many echoes which mostly influence the quality of received signals. This effect leads to location- and frequency -selective fading. After a reflection from natural and other objects, one or more variously delayed signals (echoes) come to the receiving antenna. These time delayed signals cause severe degradation of a received television signal and corresponding image particularly in the analogue television, where additional images appear shifted in the scan direction – so-called “ghosts”. In digital terrestrial television broadcasting, the effects of multipath reception were largely suppressed by choosing of sophisticated modulation methods. One of many advantages of the emerging terrestrial digital video broadcast standards **DVB-T** (Digital Video Broadcasting – Terrestrial defined in ETS 300744), **DVB-H** (Handheld), but also next services - e.g. digital audio broadcasting **DAB** (Digital Audio Broadcasting) or **DRM** (Digital Radio Mondial) is, apart from **mobile reception** support, the suppression of multipath reception impacts. In the all mentioned standards, digital modulation method (**C**)**OFDM** (Coded Orthogonal Frequency Division Multiplex) is used. The first symbol C in the abbreviation means, that the data stream is protected by the error correcting encoding **FEC** (Forward Error Correction) to detect and correct errors that occur during the transmission. For symbol protection, a block Reed-Solomon code is used, and for bit protection, a convolutional code with different code rates is employed. Modulation (C)OFDM is characterized by high robustness against inter-symbol interference (**ISI**), which would threaten the received signal and increase their error rates due to the multipath reception.

Digital broadcasting in the above mentioned standards can be performed in so-called **single frequency network SFN** (Single Frequency Network)**.** Reception of more delayed signals from several transmitters working in the single frequency network can be utilized even for improvement of the power efficiency of transmitters.

Note:
The application of (C)OFDM modulation is an effective, most frequently used, but only possible tool to eliminate the impacts of multipath reception. A different approach is for instance **multi-sensor reception** with the angularly oriented system of reception antennas and consequent complex signal processing including filtering, sampling, base-band conversion followed by location and separation of different signal sources (so-called **Array Processing**). A more detailed overview is beyond the scope of this paper and can be found in [4], for instance.

2. Principle of the SFN

The signal coverage of a certain area can be provided by a number of transmitters, transmitting the multiplex of digital television or radio signals in the identical frequency channel. Their partial signal contributions in the reception point not only do not interfere, under certain circumstances then even improve the reception. It is thus obvious that single frequency networks of digital transmitters may considerably improve the utilization of frequency bands and channels as well as energy balance of digital transmitters. Digital transmitters in SFN might be considerably lesser power for the signal coverage of the given area sufficient for quality reception. Methods of SFN cannot be used with the terrestrial analogue television broadcasting, where in fact all the present-day world’s television standards use amplitude vestigial sideband modulation and operate in multi-frequency networks MFN (Multi Frequency Network).

Single frequency networks can be built only in a limited area, not over a whole country – even as small as the Czech Republic. Wherewith the SFN size is affected actually? Let us assume that in the analyzed SFN area:

- a number of transmitters DVB-T operate,
- all transmitters operate at the same frequency,
- these transmitters operate with the **same** and **exact time synchronous** digital data multiplex,
- the level of received signals anywhere in the SFN area reaches leastwise the **threshold limit value** (the level, which DVB-T receiver needs to able to demodulate and decode the signal properly).

2.1 Time Synchronization of Transmitters in SFN

In a single frequency network all the individual transmitters must be exactly time synchronized. Every transmitter must broadcast absolutely identical OFDM symbol at the same time. The DVB-T modulation is structured in **frames,** one frame being composed of 68 OFDM symbols. Four frames make up one so-called **super-frame** and two super-frames make up so-called **mega-frame** (in the mode 2k four super-frames). With regard to different time duration of the symbol OFDM, which depends on the parameters of used modulation and encoding (mode i.e. number of carriers, code rate, guard interval etc.), the time duration of single frame can be different, too.

Time synchronization of the all transmitted packets in the transport stream of the final data multiplex is ensured by the time signal **1 pps** (pulse per second), which is acquired from the GPS system. This signal controls time synchronous insertion of the special packet **MIP** (Mega-frame Initialization Packet) into the transport stream at the beginning of every mega-frame. Transport stream MPEG-2, generated for example in the playout center (TV studio), can be carried to the individual transmitters by the diverse distribution networks (via satellite, microwave line, optical fibre, ATM networks) with different time delays. Therefore the time synchronization by the GPS signal is performed again in each of transmitters. A result of this operation is the state, whereat every DVB-T transmitter broadcasts identical OFDM symbols at exactly the same time.

2.2 Principle of the OFDM Modulation

The basic parameter that defines the size of the SFN area is the g**uard interval** T_G. To understand this term, we will to need at least basic explanation to fundamentals of OFDM modulation method. Its great robustness against inter-symbol interference as an effect of multipath reception (an impact of time delayed signals – echoes) consists in largely extending the very short bit time interval T_b in the serial original data stream. The symbol time extension is done by first mapping the original data stream $S_b(t)$ into n parallel data (symbol) streams S_0 to S_{n-1} .The parallel streams are then modulated using a discrete digital method (e.g. m-QAM or QPSK) onto a number of n **simultaneously transmitted orthogonal** sub-carrier signals - see Fig. 1, where the power spectra of only 4 sub-carrier waves are illustrated. Orthogonality of this system is ensured by keeping the maxima (minima) spacing of the respective sub-carrier waves and integer multiple of the inverted symbol time value.

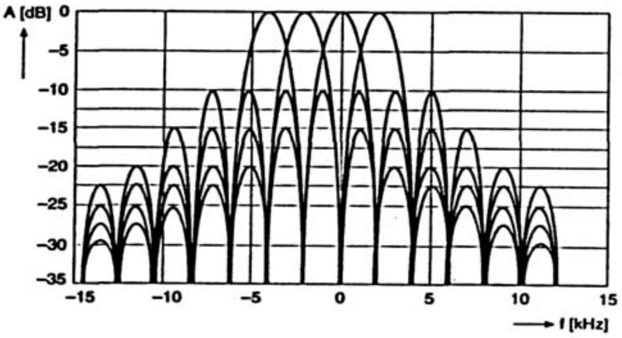

Fig. 1. Power spectrum of an orthogonal system for the simplified case of 4 sub-carriers.

For the most commonly used (but not the only one possible) modulation 64-QAM, the number of states is in binary representation m = 6 ($2^m = 2^6 = 64$). One of the options to quite simply produce OFDM signal of the desired orthogonal spectral structure is to use **IDFT** (Inverse Discrete Fourier Transform) – see Fig. 2.

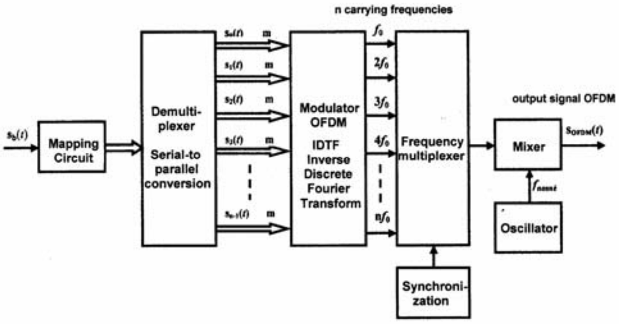

Fig. 2. Block diagram of OFDM modulator realized by the IDFT.

2.3 SFN Gain

Power contributions from the individual transmitters working in the single frequency network add. Therefore the single frequency network shows so-called SFN gain. This gain can be simply formulated as follows – two DVB-T transmitters with the broadcast power P_v ensure in the same conditions (the same directivity and antenna gain) better signal coverage (greater values of the field intensity) in the receiver position than a single transmitter with the double broadcast power $2P_v$. Quantitative expression of the SFN gain, which depends on the receiver position and on many other factors, is beyond the scope of this paper.

3. Assessment of the SFN Area

Let us specify the problem a bit. TV channel of 8 MHz frequency band allows in a specific setup of **8k** mode COFDM modulation with sub-carrier m-state quadrature amplitude modulation 64-QAM (considering particular parameters of this modulation mentioned below) to reach a bit rate R_b of data stream $S_b(t)$ $R_b \approx 22$ Mbit/s. In this case, the time interval of one bit is $T_b = 1/R_b \approx 45$ ns. The number n of orthogonal sub-carrier waves in DVB-T standard is $n = 2048$ (for **2k** mode), $n = 8192$ (for **8k** mode), eventually for DVB-H also $n = 3408$ (for **4k** mode). For the actual transmission of the information data, not all the sub-carriers are used – in 2k mode, the number of active sub-carriers is $n = 1075$ and in 8k mode, there are $n = 6817$ active sub-carriers. The remaining sub-carrier waves are used as pilot signals, and some of them carry information about the parameters of the modulation used. The frequency gap Δf between them must conform to the bandwidth B_k of the assigned frequency channel (for video broadcasting 8, 7, 6 MHz) and represents, in fact, the symbol rate R_s of OFDM modulation.

For 8 MHz bandwidth channels, used in frequency rasters of terrestrial as well as cable distribution in the Czech Republic (the exact value is 7.61 MHz), the spacing of sub-carrier frequencies Δf, which also represents the symbol rate R_s, can be written as

$$\Delta f = R_s = B_k / n = 7.61 \cdot 10^6 / 6817 = 1.116 \text{ kHz} . \quad (1)$$

The corresponding time extended symbol T_s is then

$$T_s = (R_s)^{-1} = (1.116 \cdot 10^3)^{-1} = 896 \text{ µs}. \quad (2)$$

This time is then further extended by the so-called **guard interval** T_G, which is often defined as a part (k_T) of symbol time, i.e.

$$k_T = T_G / T_s = 1/4, 1/8, 1/16, 1/32. \quad (3)$$

In the guard interval T_G, no useful information is transmitted. It is used to eliminate reception of delayed signals and thus influences the possible choice of transmitter distances in the single frequency network. For instance, in 8k mode transmitted in a channel of 8 MHz bandwidth, the longest guard interval of

$$T_G = k_T \cdot T_s = 1/4 \cdot T_s = 896/4 \text{ µs} = 224 \text{ µs}$$

can be achieved. The time properties within the OFDM signal conforming to different mode / bandwidth settings for the longest time interval with $k_T = 1/4$, calculated based on the considerations above, are listed in Tab. 1.

Channel bandwidth [MHz]	**Mode 2k (k_T =1/4)**			**Mode 8k (k_T = 1/4)**		
	T_s [µs]	T_G [µs]	$T_s + T_G$ [µs]	T_s [µs]	T_G [µs]	$T_s + T_G$ [µs]
8	**224**	**56**	**280**	**896**	**224**	**1120**
7	**256**	**64**	**320**	**1024**	**256**	**1280**
6	**298**	**75**	**373**	**1197**	**296**	**1493**

Tab. 1. Time properties within the COFDM signal in 6, 7, 8 MHz channels for modes 2k and 8k and k_T = ¼.

In this table, the total lengths of extended symbols $T_N = T_s + T_G$ can be observed. Based on these values, we can express the bit rate R_b of the input bit stream that the OFDM encoder can process in the respective modes. For example, if a usual internal modulation of the orthogonal sub-carrier waves 64-QAM is used, where one modulation symbol holds $m = 6$ bits of the input serial stream, we can write for a 8 MHz bandwidth channel in 8k mode and the guard interval with factor $k_T = 1/4$ (see Tab. 1)

$$R_b = (T_s + T_G)^{-1} \cdot n \cdot m = (1120.10^{-6})^{-1} \cdot 6817.6 \cong 36 \text{ Mbit/s}. \quad (4)$$

This value expresses the maximum bit rate that can be processed and allows even suitably compressed (MPEG-4, MPEG-4 AVC) digital television signals in high definition HDTV to be broadcast in the future. The truly usable bit rate R_{bn} (Net Data Rate) is **lower**, as the protective data stream of the inner and outer error protection codes FEC1 and FEC2 is added to the usable information data stream. The FEC1 and FEC2 represent a redundant, yet purposeful extension of the data stream. As the outer block (symbol) error protection code FEC1, DVB-T uses the Reed-Solomon code RS 204,188, which adds 16 parity bytes to the 188 bytes transport packets and allows a correction of up to 8 erroneous bytes. The inner code FEC2, a bit-based protective code, is a convolutional code with variable code rates KR = 1/2, 2/3, 3/4, 5/6 and 7/8. As a result, the usable bit rate R_{bn} is lowered to the value

$$R_{bn} = 188/204 \cdot KR \cdot R_b. \quad (5)$$

In the extreme case of the highest quality protection (KR = 1/2), the usable bit rate R_{bn} goes down to 46 % of the original value R_b and, according to equation (4), to the value

$$R_{bn} = 0{,}46 \cdot 36 \cdot 106 \cong 26{,}5 \text{ Mbit/s}.$$

For the very often used code rate KR = 2/3, the decrease is circa 61.4 %, and thus R_{bn} = 22.3 Mbit/s. This bit rate can hold a data multiplex of roughly 4 to 5 compressed program stream (MPEG-2) of television programs having a standard PAL quality, several stereo sound radio programs and other services – e.g. TELETEXT, MHP1 (Multimedia Home Platform with local interactivity), etc. The component program streams do not usually have constant bit rates assigned. **Statistical multiplexing** is used instead, where the instantaneous bit rate is assigned as higher for the programs with richer information content (dynamically demanding video sequences containing high spatial frequencies of luminance as well as chrominance distribution – sport transmission, for instance) at the expense of reducing bit rates of other streams.

It is also obvious in Tab. 1 that the longest guard interval can be obtained at channel bandwidth 8 MHz (used in television norm CCIR D/K) in 8k mode – T_G = 224 µs**.** The theoretically largest diameter of the region with a working single frequency network and accordingly the maximum possible distance between the transmitters working in this network, provided the signals anywhere in the monitored area reach the over-threshold level, can be described by a formula expressing the distance of an air propagated electromagnetic wave delayed by T_G (in this particular case)

$$l_{max} \le c \cdot T_G = 3 \cdot 10^8 \cdot 224 \cdot 10^{-6} \cong 67 \text{ km}. \qquad (6)$$

In 2k mode, this distance would be four times shorter due to four times shorter guard interval (see Tab. 1). However, it is worth noting, that the **2k** mode **is more suitable for mobile reception** as the sub-carrier spacing is four times wider and consequently the signal is much more robust to Doppler shift (the receiver can move faster, yet ensuring error-free reception).

4. Conclusions

The above presented simplified calculations are a result of pure theoretical thoughts, as the trajectory of some signals reflected from different obstacles having over-threshold level at the receiver input might reach over the calculated l_{max} value. On the other hand, these distant transmitter signals do not necessarily have to reach over-threshold level at the receiver site. The actual size of a SFN transmitter covered area could then theoretically be even larger than the thoughts infer. If we look apart from troubles associated with, at least in a time limited period of coexistence of the emerging DVB-T broadcasting with the original analogue broadcasting and the consequential possible interference caused by analogue signals transmitted at near frequency channels, the fundamental issue of examining the mutual interference between DVB-T (DVB-H) single frequency network transmitters lies in defining the area, where the delayed signals of the same network reach over-threshold levels and where they don't. It remains unanswered, whether or not the effort to enlarge the areas of the particular SFNs is desirable, as the frequency channels are likely to be left over in the future. Examining the size of an area, where the SFN will work safely, requires not only the detailed knowledge of positions and decisive parameters of all the transmitters operating in the same network (position, radiated power, transmitting antenna radiation patterns), but even the ground topography and reception conditions in the particular area. In 2006 the new frequency plan for the digital television and radio broadcasting on the European Regional Radio Communication Conference RRC 2006 was validated. Frequency quotas assigned by this plan to the dominant regions of European states represent terminal conditions only. In the state frontier areas, this extends to the positions and parameters of the neighboring abroad transmitters, even though their frequencies should be different according to international frequency plan agreements.

Defining the size of an area covered by SFN broadcasting (or more precisely, defining its boundaries) is thus not simple at all, as it depends on a number of elements. Calculations of areas, where single frequency networks can be applied, are not applicable without sophisticated simulation program tools. At their inputs, a huge amount of data must be available – e.g. the longitudes and latitudes of all the considered transmitters in the simulated network, their powers, radiation patterns, terrain profile of the analyzed area around all the transmitters and, last but not least, the relative timing (synchronization) of the particular transmitters, operating in the single frequency network, etc. One example of such sophisticated software for this purpose is a product of the **CRC Data Company**. The structure of the product can be assessed on the demos available at the company webpage http://www.crcdata.cz - see Fig. 3. It displays a demonstration of some output configurations of the SFN design program. It is evident that even the results obtained this way are not absolutely reliable, and before building an economically demanding single frequency transmitter network for DVB-T terrestrial broadcasting, a number of challenging and extensive verifying measurements must be performed.

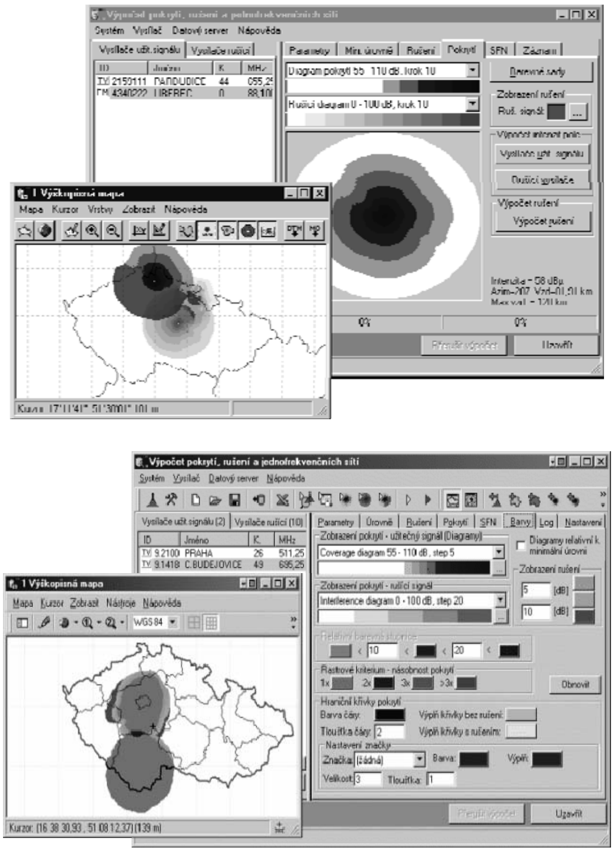

Fig. 3. A demonstration of some program output configurations.

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Svačina, J. at all "Electronics and Communication Technologies as an Adventure and Challenge for the Young Generation".

References

[1] FISCHER,W. *Digital television.* Berlin: Springer Verlag, 2004. ISBN 3-540-01155-2.

[2] O′LEARY, S. *Digital Terrestrial Broadcasting.* London: Artech House, 2000. ISBN 1-58053-063X.

[3] LEGIŇ, M. Televizní technika – Digitální vysílání DVB -T. (Television Technology – Digital Broadcasting DVB -T). Prague: BEN, 2006. ISBN 80-7300-204-3. (in Czech)

[4] BUREL, G., MAGNIEZ, P. Transmitters separation for Single Frequency Networks. In *Proceedings of IEEE Conference - SPAWC.* Anapolis (USA), 1999.

[5] DOEVEN, J. Planning of Single Frequency Network. In *Presentation on Workshop on Digital Broadcasting EBU IT*. Sofia, 2004.

[6] DOUG, L. Single Frequency Network for DTV presentation (part 1). http://www.tvtechnology.com.

[7] ŘÍČNÝ, V. Co je to jednofrekvenční síť digitálních vysílačù a jaký je její rozsah ? (What is SFN and what is its area ?). In Internet magazine STEREOMAG, 2005. http://www.stereomag.cz (in Czech).

[8] Design program of SFN: http://www.crcdata.cz.

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