The Limitation of Primary Signals Entering DVB-T On-Channel-Repeater Working in SFN Network

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Abstract. *This paper considers an issue of signal coverage in uncovered places using a broadcasting device called a Gap Filler. The main focus is placed on the analysis of potential negative effects while signals from two and more primary transmitters simultaneously enter to the Gap Filler. In particular, in the measurements the impact of reception cross delayed signals received by the Gap Filler from two adjacent primary transmitters operating in the Single Frequency Network was analysed. The influence of different receive signal levels from two adjacent primary transmitters was also examined. In the conclusion, based on the experiments, the limiting factors useful for individual transmitters in the Single Frequency Network were determined. The analysis and finding the limit parameters can help broadcasters in further setting and debugging of the Gap Filler network. Finally, the described laboratory experiment was also verified under the real SFN network condition in border region Vsetinsko to verify the laboratory findings.*

Keywords

DVB-T, Gap Filler, MER, on-channel-repeater, SFN, signal delay.

1. Introduction

The procedure of switching from analogue to Digital Video Broadcasting-Terrestrial (DVB-T) in the Czech Republic was completed in 2011. In the first phase, the basic network of primary high-power transmitters was build. The primary transmitters are located on high places and cover wide areas. Since the primary network was launched, the secondary network of transmitters has been built in the areas with insufficient reception quality from the primary network. For correct reception of such a DVB-T signal, a significantly lower signal level is sufficient comparing to the reception of analogue broadcasting.

Nevertheless, the landscape shape or improperly planned signal coverage can still cause gaps in the signal coverage, and, therefore, some areas are still uncovered by the signal from the primary network. To improve the coverage of this type of areas, the broadcasting device called a Gap Filler (GF) is used [1], [2]. Unfortunately, the amount of broadcasting channels in the fourth and fifth TV bands, in which the digital GFs operate, is extremely limited by frequency planning. Moreover, in case of the boundary areas between the neighbouring countries, the used frequencies must be internationally coordinated.

In such areas, the most effective solution is to use the GFs operating on the same frequency in the Single Frequency Network (SFN). The GF working in this mode is called on-channel-repeater. Nevertheless the general topic of SFN network is in the technical papers well described, there are several unsorted issues that appeared after practical experiences in configuration of the secondary GFs network in specific areas. On some GFs was identified a primary signal issue while signals from more than one primary transmitter can be reachable on the GF input (see Fig. 1). In that case, some special conditions beyond the standard necessary conditions of the SFN have to be observed [3]. This article describes and determines those extra condition.

2. Extension of Primary SFN Network Using Gap Filler

The basic requirements for the SFN are time synchronisation, frequency synchronisation and transmitting exactly the same bit stream. Figure 2 shows a block diagram of the basic SFN network configuration [4]. Input MPEG-2 stream is brought to re-multiplexer, which includes an SFN adapter. The SFN adapter forms input MPEG-2 transport stream packets into a *Mega-frame*. It also inserts a *Mega-frame Initialisation Packet* (MIP). The MIP contains a pointer that points to the beginning of the next *Mega-frame*. The SFN adapter is synchronised by the signals of 10 MHz and 1 pps from a Global Positioning System (GPS) receiver as well as all transmitters in the SFN network. This mechanism ensures that every *Mega-frame* is initiated in all SFN transmitters at the same moment.

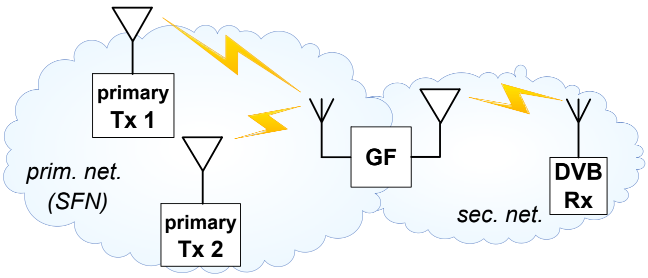

Fig. 1: Broadcasting network with the GF and two source signals from two primary transmitters working in the SFN.

Between the SFN adapter and the individual transmitters is placed a distribution network. At its entry a *TX Network adapter* is plagged after the SFN adapter, which converts the MPEG-2 transport stream into a format suitable for broadcast via the distribution network. On the other end of the distribution network is an *RX Network adapter*, the function of which is its reverse to the Tx adapter. The total time delay of the transport signal in the distribution network must be less than 1 s. This configuration ensures the achievement of the three basic conditions for the correct operation of the SFN network. An important parameter in the SFN network is also a Guard Interval (GI). The GI is inserted into the beginning of each transmitted Orthogonal Frequency Division Multiplexing (OFDM) symbol, see Fig. 3.

The GI specifies the time in which multipath propagation delayed signals from all transmitters in the SFN network must arrive at the input of the DVB-receiver. The length of the GI is specified as the ratio of the duration of the useful OFDM symbol. In the case of the setting of the SFN networks used in the Czech Republic, all multiplexes operate with the duration of the OFDM useful symbol equal to 896 µs. In Tab. 1 are listed the GI lengths and resulting maximum transmitters across the distance in the SFN network.

Tab. 1: Length of the GI for 8 MHz channel and mode 8k.

OFDM symbol [µs]	GI [-]	GI [µs]	Maximum distance [km]
896	1/4	224	67, 2
896	1/8	112	33, 6
896	1/16	56	16, 8
896	1/32	28	8, 4

The maximum transmitters distance is calculated by the formula:

$$d_{max} = c \cdot t_{gi}, \quad (1)$$

where d_{max} is maximum distance of SFN transmitters, c is speed of the light and t_{gi} is duration of GI.

The transmitters in the first and the second multiplex in the Czech Republic use GI 1/4. Referring to the Tab. 1, the maximum distance of the transmitters operating in the SFN network at those multiplexes is maximally 67, 2 km. The third multiplex has GI 1/8 and the maximum distance for transmitters is only 33, 6 km. These distances are very important for planning of the position of the digital GFs. It is necessary to meet the conditions for the SFN network to operate the GF on the same frequency as the primary network. To ensure identical frequency, the GF must be supplied with a GPS receiver for accurate frequency control. It is also essential to use the source signal from the same primary transmitter. This ensures that the GFs will broadcast exactly the same data content as well as correct timing broadcast of the *Mega frames*. This could be a problem on some GFs as there are reachable signals from more than one primary transmitter. The GF commonly supports two basic operating modes:

- If the GFs are set in the mode *signal retransmitters*, a DVB-receiver can be farther from the primary transmitter than the setting of the GI across the network allows. It is given due to the low radiated power (e.r.p) of the local GFs. It is obvious that the distance between the *retransmitter* and the DVB-receiver will be in units of kilometers. The re-broadcasting signal of each *re-transmitter* will be time-shifted by the time that corresponds to the distance between the *retransmitters* and the primary transmitter. This distance will be significantly lower than the maximum distance of 67, 2 km.
- The different situation would be if the GFs were set in the *on-channel-repeater* mode. In case the signal from the primary transmitter in the service area is reachable, the distance from the primary transmitter to the *on-channel-repeaters* will have to be shorter than the maximum distance allowed for the GI (see Tab. 1). The reduced distance corresponds to the internal signal delay of the signal processing inside the *on-channel-repeater*. The common time delay inside the *on-channel-repeater* is 10 µs, which approximately corresponds to a 3 km distance. Consequently, the primary transmitter should not be more than about 64, 2 km away from the GF in mode of the *on-channel-repeater*. If the primary signal is not reachable in the serviced area, there will be no distance limit for the *on-channel-repeaters* [2], [5].

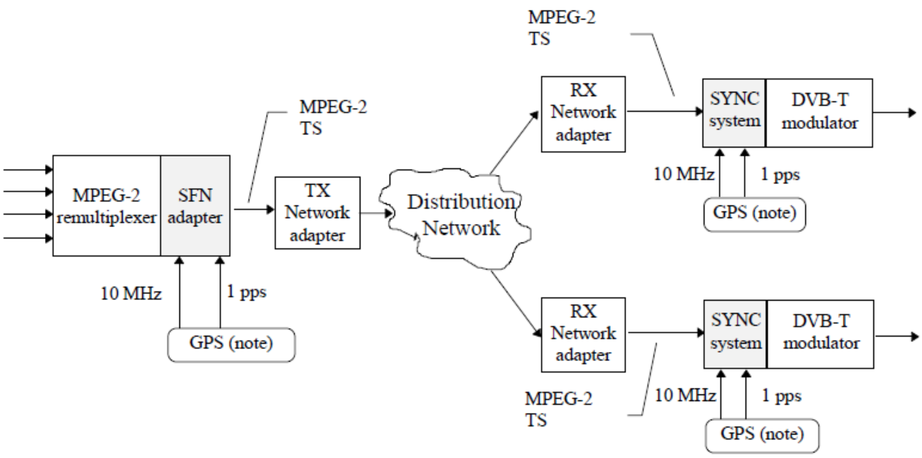

Fig. 2: SFN network block diagram [4].

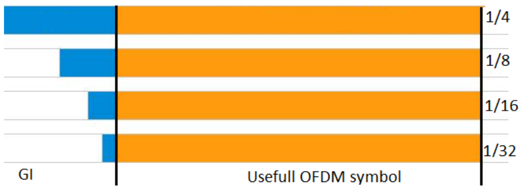

Fig. 3: Structure of the OFDM symbol.

3. Two Primary Transmitters Serving One Gap Filler

3.1. The Experiment Settings

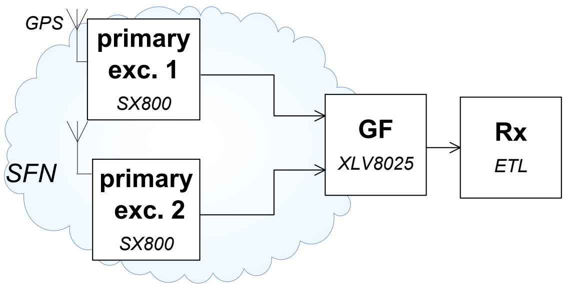

Fig. 4: The schema of the experiment.

The laboratory measurements were made to find the limiting factors while the GF was working in the SFN network using the signals either from one or more primary transmitters. An experiment with two exciter generators R&S©SX800 [6] simulating function of two primary transmitters was run in order to obtain some information about the behaviour of the GF working on the SFN network. R&S©XLx8000 UHF/VHF [5] was used as GF. The broadcasting mode of both exciters was set to follow the real setting of the first multiplex used in the Czech Republic. The desired result was to obtain the parameters of the GF output signal using DVB analyser R&S©ETL (see Fig. 4), [8]. The main evaluation factor to analyse is the Modulation Error Ratio (MER), which objectively reports the quality of the received signal [9], [10].

The signals from two exciter generators DVB-T working in the SFN network were brought at the input port of the GF (see Fig. 4). The signals from both exciters were measured separately and also while working simultaneously. There were made following experiments:

- Experiment 1: Determination of GF input sensitivity of two cross-delayed primary SFN signals incoming to the GF input. The signal time shift of 0, 10, 20 and 30 µs between the exciters was investigated. The time shifts were simulated by setting an internal static delay on one of the exciters as shown in Fig. 5. It was monitored the GF ability to be synchronised with the SFN network and consequently the quality of the GF output signal.
- Experiment 2: The next experiment was carried out for each time shift from the first experiment while the receiving level on the GF input port differed by 0, 1, 2, 3, 6 and 10 dB (by experiments was confirmed, that this level range is appropriate). There was also monitored the same parameters as in the first test.

Figure 6 shows the parameters of the first and the second exciters.

3.2. Determining the Primary Signal Limitations

As the main indicator of the reception quality was considered the Modulation Error Ratio (MER) [9]. With each measured value the frequency spectrum, constellation diagrams and the echo diagrams were also saved

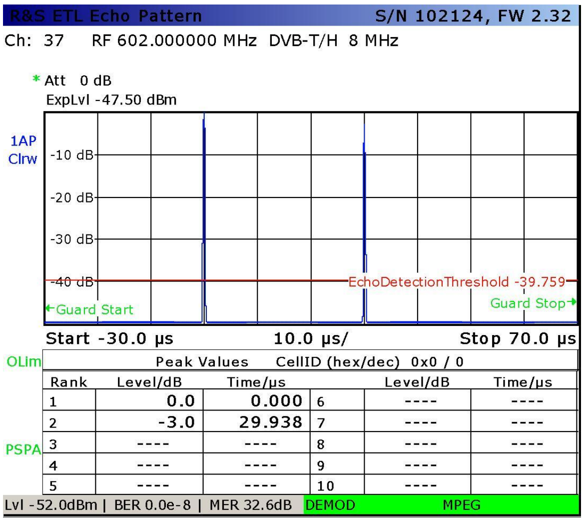

Fig. 5: The time-shift of two primary exciters.

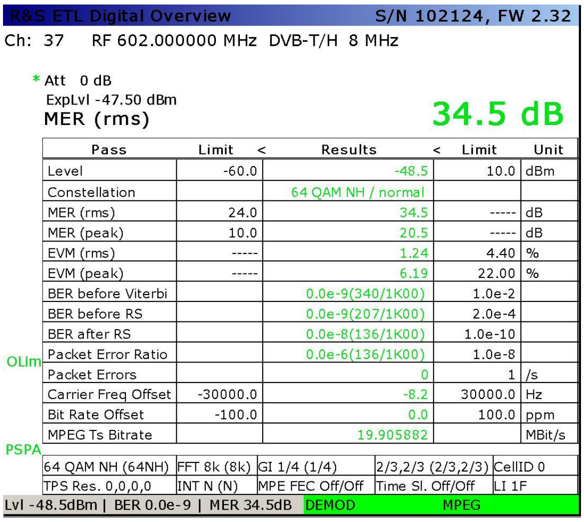

Fig. 6: The exciter parameters.

for the further analysis. Table 2 contains the main resulted measured values of root mean square ($\mathrm{MER_{rms}}$) and peak values ($\mathrm{MER_{peaks}}$).

The measured data are for the distinctive analysis presented in the graphs (Fig. 8 and Fig. 10). Figure 7 shows the apparently correct MER chart across all carriers (6 817 in mode 8k). The summary view of the measured values is shown in the Fig. 8. If the received signal level from both exciters were equal, then the measured $\mathrm{MER_{rms}}$ would be about 27 dB. As the threshold value for the operating mode of multiplexes 1 and 2 is 24 dB, it would seem that this value might be sufficient for reliable reception.

However, the $\mathrm{MER_{rms}}$ is not too considerable for correct determination of the signal quality. The MER_{peak} value shows significantly greater objectivity. Figure 9 displays a MER detail of 400 carriers where deep falls of the MER close to the permitted limit of 10 dB are

Tab. 2: Measured MER values for the time-shifted signals.

Time Shift [µs]	**Signal level difference** [dB]	$\mathrm{MER_{rms}}$ [dB]	$\mathrm{MER_{peaks}}$ [dB]
0	0	33, 4	19, 4
0	1	32, 6	18, 5
0	2	32, 6	17, 2
0	3	32, 6	16, 5
0	6	32, 6	19, 2
0	10	34, 2	22, 1
10	0	27, 4	3, 7
10	1	28, 0	8, 0
10	2	30, 0	13, 0
10	3	32, 0	15, 6
10	6	33, 0	18, 6
10	10	33, 3	21, 0
20	0	27, 2	3, 7
20	1	30, 0	5, 0
20	2	31, 0	12, 2
20	3	32, 0	16, 1
20	6	33, 0	18, 7
20	10	33, 4	19, 4
30	0	27, 5	3, 7
30	1	30, 1	10, 5
30	2	31, 1	13, 5
30	3	32, 6	16, 5
30	6	33, 9	20, 2
30	10	34, 2	21, 0

shown. This type of signal makes the reception condition for the GF unstable.

The results of performed experiments:

- The hight values of MER in the bottom lines at the each time-shift (Tab. 2) indicate, that the cross-time delay of differ-level primary signals is not significantly critical for the correct GF operation ant the GF output signal quality. This is caused due to the basic GF ability to work in SFN network. If the cross-time delay of two level-differ primary signals does not exceed the SFN GI, than GF works correctly.
- The critical situation occurs if the received primary signal levels are equal (or close to equal). This situation can be seen in the low values of MER in the first lines at the each time-shift (Tab. 2). In this case the GF cyclically try to synchronise with both primary signals that, however, can be cross-time shifted.

The performed measurements proved that as soon as the received signal level difference of the two primary signals is above 1 dB, the $\mathrm{MER_{peaks}}$ increases to 10, 5 dB (see Fig. 10). When the difference reaches at least 3 dB, the signal quality is comparable to the reception from a single primary transmitter. When the difference increases to 6 or even more dB, the signal parameters are already identical with the parameters received by a single primary transmitter. In that case, the mechanism of the SFN works perfectly.

Consequently, for correct GF operation the significant difference in the levels of the signals from both primary transmitters working in the SFN is considerable. The results of the second experiment shows a different behaviour of the input of GF compare to a common DVB-T receiver that synchronises to the first incoming signal regardless of received signal level.

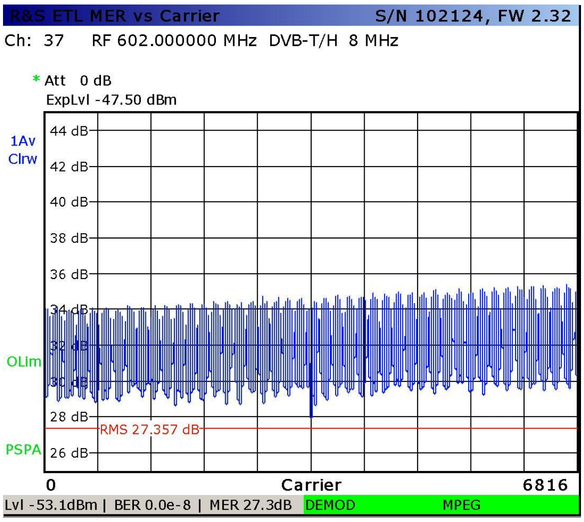

Fig. 7: MER chart at the equal level of two primary signals with the time shift of 30 µs (6 817 sub-carriers).

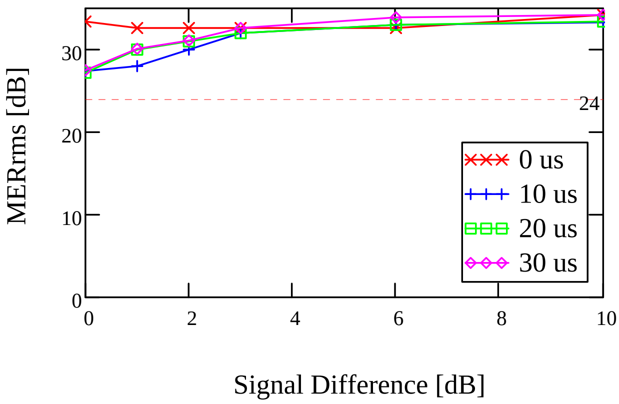

Fig. 8: MER_{rms} for 0, 10, 20 and 30 µs delayed signals.

4. Conclusion

This article introduces an experiment with two primary transmitters working in the SFN network serving one Gap Filler. The limitations responding to the level of the primary received signals being received by the Gap Filler have been introduced.

The differ primary signal time delay (which must not overrange GI) does not influence the correct function of GF. Despite the variable time shift of the received primary signals, the equal value of the received level from

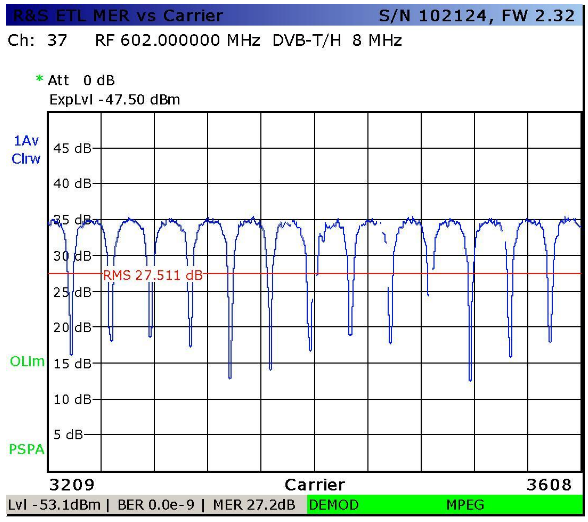

Fig. 9: Detailed MER chart at the equal level of two primary signals with the time shift of 30 µs (zoom to 400 sub-carriers).

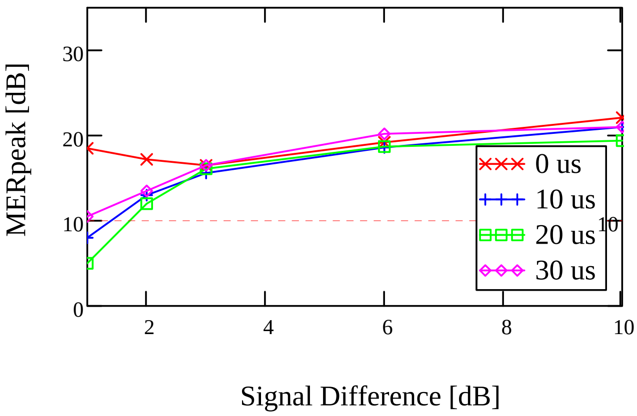

Fig. 10: MER_{rms} for 0, 10, 20 and 30 µs delayed signals.

different primary transmitters has appeared to be the critical problem. The results of the second experiment shows a different behaviour of the input of GF compare to a common DVB-T receiver that synchronises to the first incoming signal regardless of received signal level.

The described issue was dealt with company Ceske Radiokomunikace a.s. as the part of the building process of the secondary network on the border region Vsetinsko (namely GFs: Vsetin, Huslenky, Novy Hrozenkov and Velke Karlovice). The issue with two primary SFN signals feeding one GF appeared to be for the correct function of GF critical.

Based on the performed tests and analysis, it can be concluded that if the conditions for the SFN network are observed, several GFs can operate in neighbouring locations on the same broadcasting channels. To ensure the correct signal reception and the GF function it is recommended to avoid the GF input antenna to receive the primary signals with the identical signal level. It is recommended do keep at least a 3 dB level distance. The situation described in this text is mainly an issue for designers of secondary GF networks.

In their further work, the research team are going to focus on the same issues regarding the new generation of the GFs working in the DVB-T2 SFN networks.

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