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Single Frequency Networks for FM Radio

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ABSTRACT

Single Frequency Networks (SFN) and Near Single Frequency Networks (NSFN) are usually not considered suitable for FM radio. Some countries are now re-planning their FM bands for the use of (N)SFN, in order to make space for more stations. Even though some stations use it, like a station covering a highway, re-planning the FM-band with the use of SFN for a whole country, is a different thing. The first country to do this was the Netherlands, and the first experiences with it, are not as good as expected. The requirements for synchronization of FM transmitters used for (N)SFN are explained, and SFN networks are tested from real transmitter sites. The result is a proposed correction for the Dutch norm.

1. INTRODUCTION

The International Telecommunication Union (ITU) recommendations 1546 [1] and 412 [2] has been used for a long time as guidance for coordination of FM radio frequencies and planning norms for protection against interference. ITU 1546, and before that ITU 370 [3], describes the propagation of RF signals over different terrain types. ITU 412 describes the required field strength for good reception of FM radio, and the max. field strength of interfering stations compared to the wanted station.

In some countries, the ITU recommendations have been viewed as a bit too conservative, i.e. it was possible to have stations spaced closer, meaning the protection norm set out in ITU 412 could be lowered. This was the case for the Netherlands in the beginning of this decade, and now the same thing is happening in Denmark. Governments want to make space for more radio stations, and this is done by a re-planning of the FM frequencies. When the FM band is re-planned, all existing FM frequencies (except those from neighbouring countries), are considered non-existing, and the FM band is then filled as efficiently as possible. In the Netherlands, this process was called *Zerobase*. When planning the new Dutch FM band, space for as many stations as possible was made using:

- Removal of double-coverage. For any given area, it should (ideally) not be possible to receive the same program on more than one frequency.

- A lower definition of "good reception". Acceptance of lower field strengths and higher levels of interference than defined in ITU 412.
- Single Frequency Networks (SFN) and Near Single Frequency Networks (NSFN[1]) where possible.

A Single Frequency Network is a network of synchronized transmitters, transmitting the same program on the same frequency, and where their coverage areas overlap each other, so that a listener (ideally) is able to listen to the same station on the same frequency, driving from one transmitter to the other.

A Near Single Frequency Network is also synchronized transmitters, transmitting the same program, and spaced closer in distance and frequency than they could have been, if they were transmitting different programs. The idea is, that noise from an interfering transmitter will be masked by the audio from the wanted transmitter, because the noise caused by the interfering transmitter will be proportional to the audio level of the wanted transmitter.

The re-planning in the Netherlands was carried out by the two network operators *Broadcast Partners* and *Nozema*, and the re-planned FM networks were put in operation in 2003. The first years of experience showed that several stations didn't get the expected coverage, and there were problems with some NSFN transmitter clusters.

Since it has been decided by the Danish government to make a re-planning like the Dutch one, it was worth investigating some of the aspects of the re-planning, to avoid the same problems.

In the following sections, the relevant planning norms for planning FM radio will be explained, together with the importance of synchronization in (N)SFN[2] applications. SFN has been tested on real transmitter sites, and based on these tests, a possible implementation of SFN in a re-planned FM-band is proposed.

This paper is based on a Masters Thesis report, from the Technical University of Denmark, 2005.

[1] In other literature, NSFN may be written as NSF.

[2] Throughout this text, (N)SFN will be used to indicate both SFN and NSFN, where no distinction is needed. SFN is used when the frequency distance is 0 kHz. NSFN is used when the frequency difference is 100 kHz.

2. PLANNING NORMS

As stated earlier, the Dutch re-planning was done accepting a lower requirement for field strengths and higher levels of interference than stated in the ITU 412 norm. The Dutch values are stated in the Dutch Zerobase report [4]. The values are based on research done by *the Netherlands Organisation for Applied Scientific Research TNO*, and named TNO-II. These required field strength values are compared with ITU 412 in table 1. Table 2 shows the ITU 412 and the TNO-II values for interference protection.

When calculating the field strength using ITU 1546, the result is given as a value in dBμV/m for 50% time and 50% of the locations, meaning that the field strength will be at least this value for 50% time and location. These 50% time values are used both for the wanted transmitter and the interfering transmitter(s). A field strength from a transmitter obtained using the 50% time value is used for calculation of the *steady interference*. Other percentages for the

	ITU 412 (10m)	TNO-II (10m)	TNO-II (1.5m)
Rural	54	50	37
Urban	66	60	47
Large cities	70	-	-

Table 1: Minimum field strengths in dBμV/m for good FM radio reception, assuming the reception antenna is in the stated height above the ground.

	ITU 412 (Stereo)	TNO-II	TNO-II (N)SFN
0 kHz	45	40	2..25
100 kHz	33	30	5
200 kHz	7	-2	-5
300 kHz	-7	-15	
400 kHz	-20	-25	

Table 2: Protection ratios in dB. Example: If a (wanted) station on 100.0 MHz has a field strength of 60 dBμV/m in some reception area, an interfering station on 100.1 MHz must not have a field strength higher than 27 dBμV/m according to ITU or 30 dBμV/m according to the Dutch norm, unless the unwanted transmitter is a part of the same NSFN, where a field strength up to 55 dBμV/m is allowed.

time can be chosen to calculate *tropospheric interference*, that is interference when special weather conditions occur. In this case, the time percentage is often chosen to be 1%. This kind of interference is only relevant over long distances (100 km or more). In the following, the distances between (N)SFN transmitters are much shorter, so the tropospheric interference is not considered. The locations percentage is always 50%, and this should be taken into account when deciding on the values in table 1 and 2.

ITU 1546 contains a formula for deriving other location percentages than the 50%. A few other percentages are summarized in table 3.

In normal frequency planning using ITU 412, other location percentages are not very relevant, but they may become relevant when lowering the protection norms and in (N)SFN situations. The 5 dB protection of transmitters in NSFN, where the distance in frequency is 100 kHz, seems very small. In fact it will be shown later that the sound becomes significantly impaired when the difference in field strength levels become less than 4 dB. So a 5 dB protection seems to be just on the limit. According to ITU 1546, the location standard deviation is 8.3 dB for analogue broadcasting, meaning that the 4 dB limit will be exceeded very often, with a limit at 5 dB.

3. SYNCHRONIZATION OF FM SIGNALS

In order for (N)SFN to work, the signals from the transmitters must be synchronised. Three types of synchronization is relevant. Each of them are explained below.

q %	$Q_i(q/100)$	E corr. (dB)
1 / 99	+ / − 2.327	+ / − 19.3
5 / 95	+ / − 1.645	+ / − 13.6
10 / 90	+ / − 1.282	+ / − 10.6
25 / 75	+ / − 0.674	+ / − 5.6

Table 3: Correction of the calculated field strength as a function of the wanted location percentage. The values are derived from the inverse cumulative normal distribution, shown in the centre column. Example: For an interfering transmitter, it is relevant to find a lower value, e.g. 5%. The 5% value is found by adding 13.6 dB to the 50% value.

3.1. Audio

Synchronization of the audio is known from all setups – (N)SFN or not – where more than one transmitter broadcasts the same signal. The basic requirement is that a listener will not notice when the RDS causes the receiver to switch to another frequency. Small differences in delay are accepted, as long as they remain within a few ms.

3.2. MPX

The MPX signal is the composite signal in an FM transmitter, before it is FM modulated onto a carrier. This signal is also present in the receiver after frequency-demodulation. It consists of a mono signal (L+R), an AM (DSB-SC)-modulated stereo difference signal (L−R), a 19 kHz pilot tone (for correct demodulation of the L−R signal in the receiver), RDS, and maybe some other data signals. If a receiver receives a signal from an (N)SFN network, it is important to keep the MPX delay low, that is: The MPX signals from the two transmitters should arrive at the receiver at the same time. The synchronization requirement is much stronger here. Delays of a few μs can severely disturb the reception, of course depending also on the difference in field strength between the transmitters.

These delays are caused by the fact that electromagnetic waves only travel at a speed of $3 \cdot 10^8$ m/s, so if two transmitters are exactly synchronized, but the receiver is 300 m closer to one of them, the delay difference will be 1 μs. ITU 412 [2] has summarized the relation between audio impairment (according to ITU's *5-scale impairment grade*), delay difference, and field strength difference, for an SFN network, shown in table 4.

3.3. Carrier

For SFN, the last relevant signal to synchronize is the carrier. When two transmitters are transmitting on the same frequency, interference will occur. The goal of synchronizing carriers is to make sure that this interference will only vary as a function of the position, but not as a function of time. Very small differences in carrier frequency (e.g. a few tens of Hz) will cause the receiver antenna input voltage to oscillate with the same frequency, disturbing the detection of the signal.

The interference as a function of the position is relevant for mobile receivers. In theory, it is possible to

Delay Δ (Distance)	Impairment Grade 3	Impairment Grade 4
2 μs (0.6 km)	4 dB	6 dB
5 μs (1.5 km)	10 dB	12 dB
10 μs (3 km)	14 dB	16 dB

Table 4: Minimum field strength difference in SFN networks, as a function of the delay and the wanted impairment grade. Example: If we want the audio impairment to be 4 and have a delay difference of 5 μs, then the difference in field strength, between our two transmitters, must be at least 12 dB.

synchronize two transmitters, so that their carriers will be exactly in phase on a straight line between the transmitters. As soon as the receiver moves away from this straight line, the interference will change from positive to negative and back, each time the difference in distance changes by one wavelength. Assuming a wavelength of 3 m (100 MHz), and a receiver in a car driving 30 m/s (108 km/h), this will happen 10 times pr. sec. No matter how much effort is put into synchronization of the carriers and the MPX signal, this problem will always occur.

4. LAB TESTS

The first tests were carried out in a lab with two transmitters, a combiner network and a measurement receiver. The goal was to find the minimum difference in signal strength of the two RF signals, where audio quality would be preserved. Since the signals were transmitted into a cable network, there would be no unknown reflections or other disturbances. The values obtained would then not be statistical values, but absolute values that can be reproduced.

4.1. Equipment and Measurement Procedure

The transmitters used are a Telefunken T3270 (100W transmitter) and a T3271 (250W transmitter). For this test, the RF outputs were connected to dummy loads, and the cable network, combining the two signals, was connected to the RF monitoring outputs of the transmitters. Both transmitters were fed with the same MPX signal (so this was always completely synchronized). There was no carrier synchronization. The receiver was a Profline SFDx. This receiver is normally used for re-broadcasting on slave transmitter sites and can display various parameters about the received signal.

By adjusting the transmitted power, it was possible to simulate the situation where two transmitters are causing interference with different distances in signal strength (for NSF and NSFN) and frequency (for NSFN).

4.2. SFN Tests

The two transmitters transmit on the same frequency, and their RF levels are varied. The results show that when playing pop music, the problems caused by the second transmitter were no longer audible, when the difference in signal strength was greater than 1 dB. In SFN, the usual division of transmitters into *wanted* and *interfering* gets more unclear, since both transmitters are wanted. The "interfering" transmitter will just be the transmitter with the lowest RF signal at a given location. When measuring on the noise alone (playing silence), the noise was no longer measurable (lower than -60 dBFS on the Profline tuner) when the signal strength difference was greater than 4 dB. The test was repeated using a consumer tuner, and showed a bit worse result for small differences in RF level.

4.3. NSFN Tests

This test was done using the same setup, only this time, the frequencies were 100 kHz apart. The disturbance from the interfering transmitter was not audible if its RF level was 4 dB lower than the wanted transmitter, when playing pop music. When playing silence, the noise from the interfering transmitter could be measured until its RF level was 14 dB lower than the wanted transmitter. Using a consumer tuner, the noise from the interfering transmitter was audible all the time, and significant when the RF level distance was smaller than 4 dB.

4.4. Conclusions

Unlike SFN, the results of NSFN will be much more dependent of the filters in the receivers. The conclusion so far is that SFN behaves equally or better than NSFN, where it may have been expected that NSFN would behave better than SFN. When this is the case, it is more frequency efficient to use SFN or to use 200 kHz frequency spacing if possible. For this reason, NSFN with 100 kHz spacing will not be tested further on.

5. FIELD TESTS

The results obtained in the previous section, are obtained in the nicest imaginable environment. In a real landscape, SFN is expected to behave much worse, because of the location distribution. To find out how much worse, SFN tests have been carried out on real transmitter sites in Denmark.

5.1. Transmitter Sites and Landscape

The transmitter sites used, are low-power sites up to 1 kW ERP on masts up to 80 m high. The measurements were done in two areas in Denmark. As most people know, Denmark is quite flat, so altitude differences of 50 m is hilly terrain after Danish standards. The first set of measurements was done in an area west of *Roskilde*, which is quite hilly. The second measurement set was done in an area around the small town *Grindsted* in the south-west of *Jutland*. This area is more flat. Both areas are farm land, with some small forests and villages.

In the area near Roskilde, a network of two transmitters was used, and in the area near Grindsted, networks of two and three transmitters were used.

5.2. Measurement Setup

In order to achieve a synchronized MPX signal, all transmitter sites used in the SFN test, had to be slave transmitters of the same main transmitter. So a setup would have to include min. two slave transmitters and a main transmitter. A slave transmitter setup is shown in fig. 1. The main transmitter was transmitting on a different frequency, and this transmitter never became a part of the SFN networks. Its role was only to provide the slave transmitters with the same signal. The distance from the main transmitter to the slave transmitters was known, and thus the MPX delay. The carriers were not synchronized.

Fig. 2 shows the setup. From the main transmitter to the receiver, there is two signal paths (in reality there is a lot more, because of reflections in the paths to the receiver). One has the length $A + B$, the other $D + C$. Since the signals travel at the speed of light, c, the time needed for the signal to travel from the main transmitter to the receiver via slave transmitter 1 is $(A + B)/\mathrm{c}$ and $(D + C)/\mathrm{c}$ via slave transmitter 2. The interesting figure here is

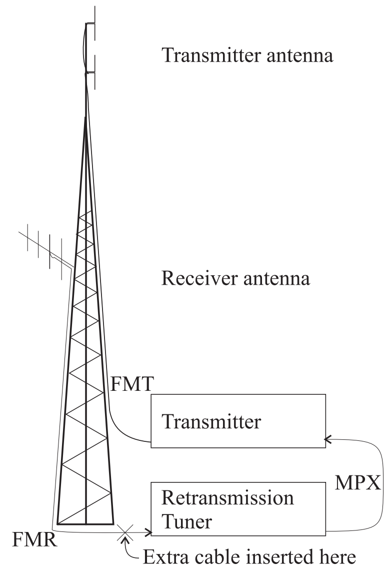

Fig. 1: Components of a slave transmitter site. The signals are written next to the cable. FMR is the received FM signal, FMT is the transmitted.

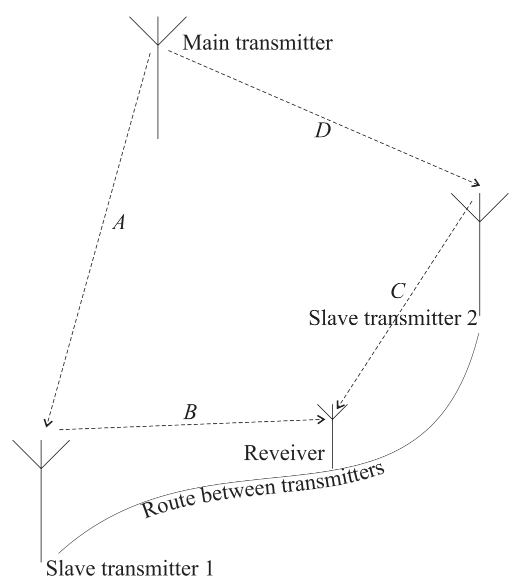

Fig. 2: Diagram showing the signal path from the main transmitter, via the slave transmitters to the receiver.

the difference in delay:

$$T_D = \frac{|(A+B) - (D+C)|}{\mathrm{c}}$$

This delay can then be used with table 4. In a normal situation, there would not be a main transmitter feeding two slaves like this, so A and D would be 0. The slave transmitters would get their signal via satellite, cables or microwave link, and some device should then synchronize the MPX accurately, that is in order of 1 μs.

The receiver was an Audemat FM-MC4 located in a car with a roof "whip" type antenna. The receiver would measure the RF signal strength and the MPX deviation, and was monitored by a PC along with the current position of the car, from a GPS receiver. The audio from the receiver could also be recorded on the PC, enabling playback of both the audio and all the other parameters recorded, in real time.

The route travelled would be from one transmitter to the other (the same route all the time), each time after changing something with the transmitters. So it was possible to turn on and off the transmitters and adjust their power, and compare the different situations by location. The recorded locations were used to calculate T_D.

In the area near Grindsted, insertion of extra MPX delay tested. In a certain transmitter configuration, T_D turned out to be approx. 5 μs along 800 m of the route. It was possible to insert an extra delay of 3.75 μs using 1 km antenna cable and a CATV amplifier. This delay was inserted before the input of the receiver at the slave transmitter site, as shown on fig. 1. This way, T_D became less than 2 μs, which is the lowest value in table 4.

5.3. Evaluation of Audio Quality

The audio quality was evaluated using the normal 5-grade audio impairment scale. To do this, it is usually required to have a panel of expert listeners, listening to the original and the impaired audio and giving grades to the impaired audio. Since these measurements produced days of audio, this approach was not realistic.

Instead the audio quality was evaluated directly as a function of the frequency deviation. Under normal circumstances, the frequency deviation (MPX level) must not exceed 75 kHz. Levels higher than this, indicate reception problems, and can be heard as hisses and scratches. The scale was set interactively, using the Goldenear program from Audemat, where a playback of the recorded audio and the measured values of the frequency deviation, was used to decide which level of frequency deviation corresponded to a certain grade of impairment. When this scale was fixed, it was applied to all measurements. This means that all measurements have been evaluated exactly the same way.

5.4. Results

5.4.1. Audio quality vs. field strength difference

For a given combination of transmitter powers, there is a measurement with only the first transmitter on, and another measurement with the only the second transmitter on. These two measurements are used to determine the RF field strength difference at each position. Both transmitters are then turned on, and for each value of RF field strength difference, the audio quality is plotted, as in fig. 3. One dB value is an average over many observations. For each field strength difference value, the mean value and standard deviation is shown. This result is for the transmitters near Roskilde, which showed out as one of the nicer results.

The figure clearly shows that for values below approx. 16-18 dB, audio quality deteriorates almost proportionally with the field strength difference, because of the disturbance from the other transmitter. This could also be caused by other things. The area where the field strength from the two transmitters is equal will in most cases be where we have the lowest field strengths on the route, because we are half-way between the transmitters.

To make sure that the deteriorated audio is caused by SFN and not just a weak signal, a reference audio quality is put together from the two single transmitter measurements. For each position, the audio quality of the most powerful transmitter is used. This corresponds to the behaviour of a mobile receiver with RDS. The RDS will select the most powerful transmitter, without the listeners interaction. This new reference audio quality is then compared with the SFN measurement, as shown in fig. 4. A big negative value here indicates that SFN causes deterioration in audio quality.

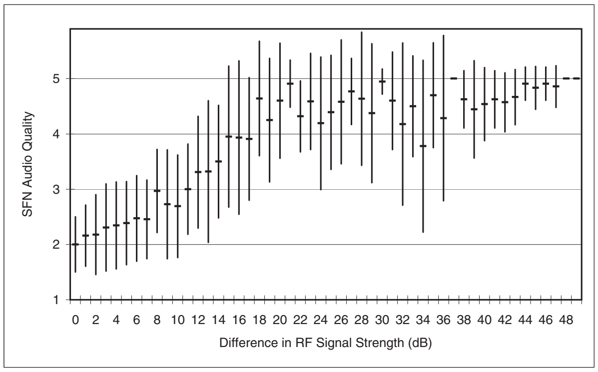

Fig. 3: SFN audio quality as a function of the RF field strength difference from the two transmitters

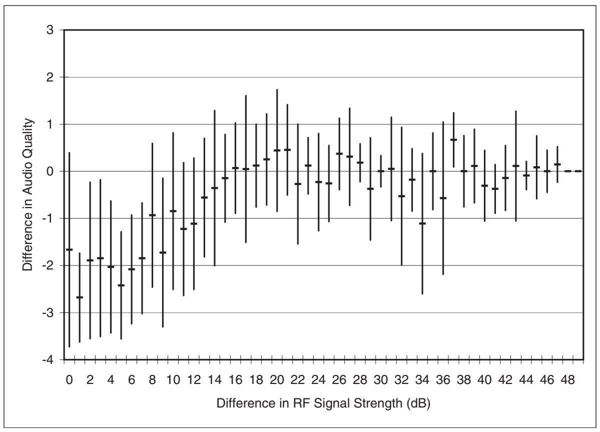

Fig. 4: SFN audio quality impairment a function of the RF field strength difference from the two transmitters

The same test was repeated near Grindsted in Jutland, where the results were not that nice. The clear relation shown in fig. 3 and 4 was no longer very clear. One reason for this is that there was no longer a very clear connection between field strength and audio quality. Reflections etc. cause the audio to have problems in some areas (and some ranges of signal strengths) while reception gets better at lower signal strength levels.

In order to see the relation between the field strength difference and the audio quality of the different transmitter combinations, the results are plotted differently. Fig. 5 shows the audio quality. The dotted lines are the transmitters measured independently and the solid line is the SFN network. The field strength difference now has both negative and positive values, since it is simply defined as the field strength from the first transmitter, subtracted from the second transmitter (in dB). Now the field strength difference is related closer to the position.

It is seen that the Olgod audio quality curve becomes good for difference values above 20 dB, which is as far from it as possible. This is unusual and probably caused by a slow elevation in the terrain, when moving towards the Sdr. Omme transmitter.

It is also seen that the SFN curve follows the Olgod curve in the range between 0 and 20 dB, even when the Sdr. Omme curve has better audio quality in this range. For negative differences, the SFN curve follows the Sdr. Omme curve, even when the Olgod curve has better audio quality. This leads to what is probably the most remarkable result in this investigation:

When the difference in field strength from two transmitters is smaller than approx. 25 dB (regardless of which transmitter is the strongest), the audio quality of an SFN network made with these transmitters, will have the same audio quality as the transmitter with the lowest audio quality (or a bit worse).

This is not depending on which transmitter is the most powerful, which is surprising. One should expect that the audio quality of an SFN network would follow the audio quality of its strongest transmit-

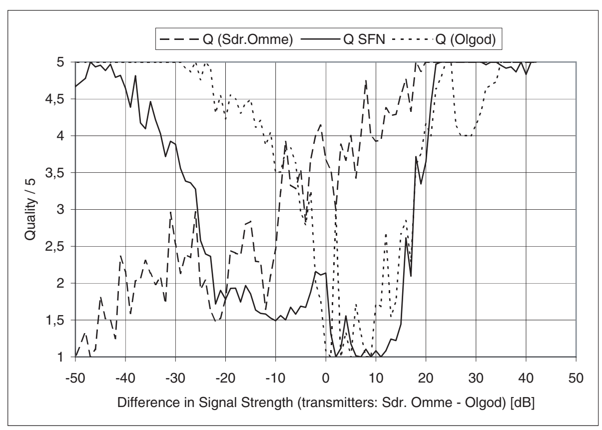

Fig. 5: Audio quality as function of RF signal strength difference. "Sdr. Omme" and "Olgod" are the names of the transmitters.

ter, maybe with some exceptions when the RF signal from two transmitters are almost equal.

This can also be seen in fig. 6. Again, the SFN curves follows the single transmitter curve with the lowest audio quality, when the difference is (numerically) smaller than 25 dB. The transmitters in fig. 5 and 6 are the same, but the measurement route is not. Where the route in fig. 5 was between the transmitters, the route shown in fig. 6 is going away from both transmitters, towards a third transmitter (not on air in the current measurements).

In regions where the RF signal from two SFN transmitters is almost equal, none of them will probably have a very good audio quality. So we can expect SFN networks to have problems when the difference in signal strength is less than 25 dB.

5.4.2. Delay changes

Insertion of an extra delay of 3.75 μs before one of the transmitters, gave a small improvement of the audio quality. The improvement was only noticeable after a lot of averaging. On the road listening to the radio, it was not possible to tell the difference. The SFN network with extra delay is shown in fig. 6 as the grey line and can be compared with the black line. It is seen that the most significant change is around 0 dB, where the audio quality is improved by approx. 0.5. Geographically, this corresponds to where the delay difference was in the order of 1-2 μs.

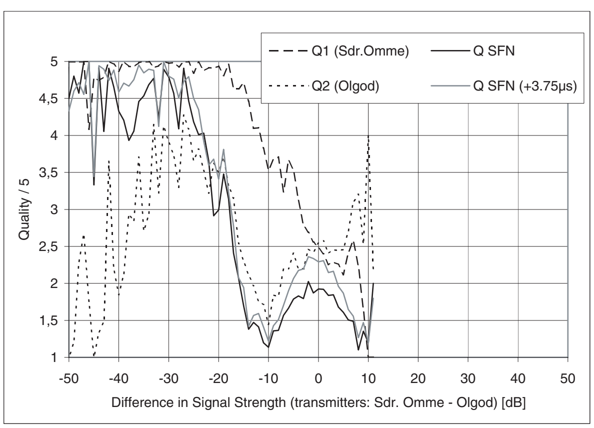

Fig. 6: Same transmitters as in fig. 5, but a different measurement route. Extra delay in the MPX signal inserted to minimize the delay difference.

6. DISCUSSION

6.1. SFN Lab test vs. field test

In the lab, a signal strength difference greater than 1 dB gave a good result. In the field, this difference should be 25 dB or greater. In the field, one signal is really a collection of many signals because of reflections, and one of them happens to be stronger than the others. This stronger signal is then detected. In an SFN situation, the disturbing signals is not only one signal from the interfering transmitter, but many signals from the interfering transmitter and many reflected signals from the wanted transmitter. This explains (a part of) the difference between the field and lab results.

In the field tests, the 25 dB was read from curves that showed the averaged field strengths over many measuring points. It was observed that there were rapid signal strength variations of 5-10 dB, when driving at normal speed (80 km/h). This rapid variation is most likely created by the location distribution. So while the location distribution is averaged out when calculating the field strength difference, it is still there in the audio quality. So the 25 dB field strength difference is including the location distribution.

When comparing this result with the lab test, the variation in field strength, caused by the location, should be added to the field strength difference from the lab test. The lab test showed that noise due to a disturbing SFN transmitter was no longer audible when the protection became greater than 1 dB. So the 1 dB is the value that must "never" be exceeded.

If this is related to the usual frequency planning, the calculated values here will be 50% location. To make sure that the 1 dB is "never" exceeded, this percentage must be much smaller, e.g. 1%. Using the 90% location probability for the wanted transmitter and 10% location probability for the unwanted, the probability that the 1 dB will be exceeded will be 1%. This is based on the assumption that the two location probabilities are uncorrelated. Since this probability is based on the receivers local environment, and the signal paths from the transmitters are different, this is generally the case. Local variations in the landscape could cause a positive correlation, which will not be a problem, since this will make both signals stronger or weaker at the same place.

Using the 90% and 10% values from table 3, the wanted signal must be assumed to be 10.6 dB lower, and the unwanted signal 10.6 dB higher, compared to the results obtained from the 50% time and location values from the ITU 1546 propagation model. To calculate values that can be used with the normal 50% locations, these values are all added, giving a protection ratio of 22.2 dB. This value is close to the value found in the field tests.

6.2. A Simple Network of 4 SFN's

In ITU 412, the protection ratio is 45 dB, when the transmitters have the same frequency, so something can be gained from the use of SFN. To overcome the problem when the field strength difference is smaller than 25 dB, one could imagine a setup like the one shown in fig. 7. This is 4 SFN's, all carrying the same program, where the receivers will use RDS to switch to the best SFN. In each cell, there is a transmitter. It's frequency is written in the cell as F1..F4. So all F1's are one SFN, F2's are an other SFN and so on. This example is thought as small transmitters with the antennas placed on cell-phone masts, and the transmitter power around 500 W ERP with an effective antenna height of 40 m. Calculations were done with ITU 1546 as propagation model, implemented in MATLAB [5].

If all cells are completely symmetrical, w.r.t. the transmitter position inside the cell, transmitter powers etc., the 25 dB interference protection on all the borders can not be fulfilled with only 4 frequencies. If this symmetry is broken somehow (and in most cases it will be), then it should be possible to have at least one undisturbed frequency (where the interference protection is 25 dB or better) anywhere in the area. The critical areas are along the cell borders, where the SFN's on each side of the border will be equally disturbed.

Symmetry could be broken using a transmitter-antenna with a *front-to-back ratio* of 6 dB (and orienting different antennas in different directions), placement of the transmitter a few km away from the centre of a cell, variations in transmitter power from cell to cell, etc. What to choose in a given situation, will depend on the location of existing masts and other local properties.

In some situations, it may be necessary to use more than 4 frequencies, and in regions where the landscape produces natural RF boundaries (like valleys and hills), the number of frequencies needed may be lower than 4.

6.3. Measurement Results Compared with Dutch Norm

The Dutch norm for SFN states that the protection should be 2..25 dB, without any further explanation. Since the calculated figure is the median of the location distribution, the measurements suggest that the SFN protection should not be lower than 25 dB.

6.4. Experimental conditions

The major limitation on the field tests was the availability of transmitter sites, where the smallest setup for doing a test was three transmitters. It was important that the tests were done on real transmitter sites in a real environment. The availability is of course limited by the fact that the sites are owned by a radio station, and most stations will not accept to lend out their sites, for such experiments. It would have been nice also to test SFN in a city, but there were no transmitter sites available.

It was not possible to synchronize the carrier of the transmitters. This had required special equipment that was not present at the sites. It would have been nice to test, if the result where the SFN audio quality follows that of the poorest single transmitter, could be improved with synchronized carriers.

The MPX synchronization was achieved in a very simple but effective way. Since the MPX was never demodulated underway, the only changes that could happen to it was a level change. In a real SFN situation, synchronized local MPX generation with a 1 μs precision is a challenge. A workaround could be to use MPX microwave links, which basically does the same thing as our main transmitter and retransmission tuner, only the frequency is around 2.3 GHz.

6.5. Receiver and RDS Test

The Audemat receiver used is better than average receivers. The quality of the receiver is mostly noticeable w.r.t. frequency selectivity (good filters) and the ability to detect weak signals. None of these properties are very important when the coverage area from an SFN transmitter is limited by other SFN transmitters. So there is no reason to believe that the SFN results will be much different for lower quality receivers.

An other property that may have very big influence on the receiver performance in an SFN environment

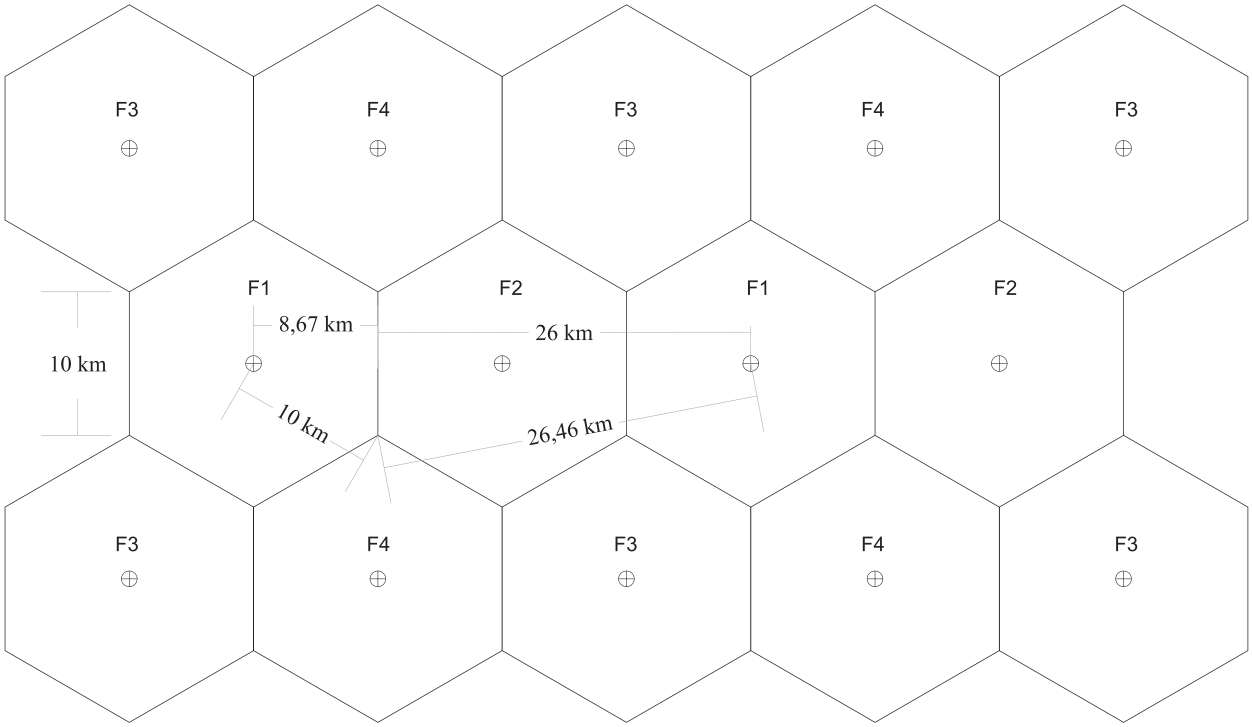

Fig. 7: Simple model of an aera covered by 4 SFN networks.

is the RDS implementation. In section 6.2 it was assumed that a mobile receiver could find the alternative SFN's using RDS. One of the main functions of RDS today is to find alternative frequencies (AF) for the same program, so in theory it should work.

When a receiver finds an AF, the search for a new frequency is initiated by something. This could be detection problems (low carrier quality, stereo detection problems etc.) or simply low signal strength.

The behaviour of the AF function in an SFN environment may be different from what it is under normal conditions. To make sure that the AF function actually finds the most undisturbed SFN, this function must be tested in an environment with several SFN networks. This should be tested on a variety of car radios, since the implementation of the RDS function varies.

7. CONCLUSION

The lab tests show that the norm used in the Netherlands for NSFN (100 kHz frequency distance) is a bit too optimistic. The value itself is o.k., if it is guaranteed that it is never exceeded, but most other frequency planning is based on median values (50% time and 50% location probability for a field strength higher than the calculated value). The same can be said for the SFN value (0 kHz frequency distance). The field tests here show that a protection of 25 dB for transmitters in the same SFN should be used.

With such a big protection ratio for transmitters in the same SFN, it is clear that an area can not be covered just by one SFN network. There must be other transmitters on other frequencies to fill the gaps. These other transmitters could then be an other SFN, and the transmitters from the first SFN could then serve as gap fillers for the second SFN. This way, it is possible to benefit from SFN, where the protection ratio is lowered by 20 dB, compared to the normal ITU protection, while the problems with SFN networks are solved using massive double coverage from other SFN networks. Local properties of the landscape will determine how many SFN networks (frequencies) are needed in a certain area.

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