FM RECEIVER STUDY

This study was performed by Nozema on behalf of the Swiss Federal Office of Communications.

FINAL REPORT

Lopikerkapel, May 2004
Version 1.1

Abbreviations

AF STIR	Audio Frequency Signal-To-Interference Ratio
IPC	Industrial Personal Computer
MAD	Mean Absolute Deviation
MOS	Mean Opion Score
OBU	Output Balancing Unit
PWC	PairWise Comparison
WTISR	(Radio-Frequency) Wanted To Interfering Signal Ratio

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Management summary

The goal of this study is twofold. First, the technical characteristics of a representative group of present day FM receivers should be assessed. Second, the protection ratios for the network configurations conventional, same programme and HF-synchro should be determined using a reference receiver.

From a set of thirty present day FM receivers, consisting of ten car radio, ten portables and ten handhelds, the radio-frequency protection ratio curve according to Recommendation ITU-R BS.641 was used to characterize a receiver. Initial tested showed that some of the car radios and most of the portables and handhelds were not able to meet the minimal required audio-frequency signal-to-interference ratio of 56 dB. To be able to objectively compare the receivers it is important that all receivers use the same minimal audio-frequency signal-to-interference ratio as starting point for the determination of the radio-frequency protection ratio curve. Therefore, the minimal audio-frequency signal-to-interference-ratio was lowered to 46 dB. In the ZeroBase study the original value of 56 dB for the audio-frequency signal-to-interference was used because the number of receivers that were not able to reach this value was less. However, it is more likely that this is due to the composition of the two representative groups than that is due to a deterioration of the quality of car radios and portables.

With the adjusted value for the audio-frequency signal-to-interference ratio the protection curves of two third of receivers were determined. The receivers that were still not able to meet the revised audio-frequency signal-to-interference ratio or that could not produce an stereo audio signal, were discarded. Based on the measured protection ratios the Sanyo DC-DA1000 was selected as reference receiver.

The reference receiver was used to record an extensive set of sound samples for the network configurations: conventional, same programme and HF-synchro. The quality of the recorded sound samples was assessed by a representative panel. This assessment resulted in protections ratio curves for the network configurations conventional, same programme and HF-synchro.

In general the results of these subjective tests are in fair agreement with the Recommendation ITU-R BS.412-9. For planning of conventional network it is advised to use the radio-frequency protection ratio values of this recommendation. The Zero-Base study resulted in a 3 to 8 dB reduction for the protection ratios for conventional networks. These results, however, could not be confirmed by this study. It should be noted that the starting points for the ZeroBase study differ from this study.

For frequency planning of transmitters carrying the same programme it is advised to use the protection ratios based on a grade of ‘3,5’ in case of steady interference. In case of tropospheric interference it is advised to use the protection ratios based on a grade of ‘3,0’. Both the protection ratios for steady and tropospheric interference show a considerable improvement compared to the ITU values for the conventional network configuration. The use of these protection ratios may lead to a higher frequency efficiency in case coverage areas are interference limited. The values for same programme and steady interference do not differ much from the Zero-Base values for MPX synchronisation, except for 100 kHz frequency

difference. It should be noted that the Zero-Base value is optimistic. The Zero-Base study gave no directions for tropospheric interference.

Because the results for synchronized networks are not significantly better than those of same programme and former are more complicated to operate than the latter it is advised to use same programme in stead of HF-synchro between transmitters carrying the same programme. Compared to the Zero-Base study the protection ratios for synchronized transmitters are higher for frequency difference of 0 and 100 kHz. The reason for this could be the different synchronisation used.

The results of the high signal performance test clearly indicate that third order inter-modulation products significantly deteriorate the performance of the tested portables and handhelds. Experience in The Netherlands has shown that interference from third order inter-modulation products may occur around FM transmission sites where many frequencies are used. There the reception of signals from either a station with much lower power than the others, or from other more distant sites could lead to problems. In these situations frequencies should be chosen such that no third order inter-modulation products occur in the pass-band of the receiver tuned to the low level signal. If this is not possible either the power of the low power transmission should be increased or a gap-filler should be installed to achieve the required protection ratio.

Results of the RDS tests showed that the switching behaviour due to difference in radio-frequency levels depended on the frequency difference. When the frequency difference is small, all tested car radios switched over when the radio-frequency level of current frequency drops just below the radio-frequency level of the alternative frequency. When the frequency difference is large about half of receivers switches over after a small drop in radio-frequency level while the other half of the receivers only switched over after a significant drop in radio-frequency level. There is no significant difference in switching behaviour due to multipath between the tested car radios.

Summary

Introduction

The 'Expertengruppe UKW 2001', formed by the Swiss federal office of communications, has recommended to optimize FM-networks because FM will remain the main modulation technique for radio for the coming fifteen to twenty years. FM networks could be optimized by revising the protection ratios used for frequency planning. The goal of this study is twofold. First, the technical characteristics of a representative group of present day FM receivers should be assessed. Second, the protection ratios for the network configurations conventional, same programme and HF-synchro should be determined using a reference receiver.

Approach

From a set of thirty present day FM receivers, consisting of ten car radio, ten portables and ten handhelds, the technical characteristics were determined as follows. First, the characteristics of the individual receivers were measured according to Recommendation ITU-R BS.641. Based on these measurements a good, a reference and a bad receiver was selected from the total group of receivers. Next, the protection ratios for frequency planning for three different network configurations based on subjective assessment of sound samples recorded with the good, the reference and the bad receiver were determined. Finally, the high signal performance and the RDS switching behaviour of a select group of receivers was investigated. This summary will present the results and the conclusions for each of these steps.

Results and conclusions

For this study the radio-frequency protection ratio curve according to Recommendation ITU BS.641 was used to determine the characteristics of the individual receivers. To be able to objectively compare the receivers it is important that all receivers use the same minimal audio-frequency signal-to-interference ratio as starting point for the determination of the radio-frequency protection ratio curve. Therefore, the maximum attainable audio-frequency signal-to-interference ratio per receiver was determined first. During this test the audio distortion per receiver was also measured. The audio distortion also gives an indication of the quality of the receiver. The results of this test are given in tables below.

#	Car radios	afstir max [dB]	af distortion [%]
1	Kenwood KDC-3024A	-52,5	0,60
2	Panasonic CQ-RDP162N	-57,5	1,00
3	Panasonic CQ-RDP003N	-56,6	0,42
4	Becker Mexico Pro CD 4627	-51,0	0,03
5	Blaupunkt Woodstock DAB 52	-57,0	0,17
6	Supertech AR-921 CD	-55,3	5,70
7	Jvc KD-SX997R	-52,0	1,90
8	Jvc KS-FX480REX	52,0	1,50
9	Sony CDX-M850MP	-55,6	1,50
10	Vdo Dayton CD 2200	-47,0	0,10

Table S.1: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for car radios.

#	Portables	afstir max [dB]	af distortion [%]
1	Sanyo DTA-300M	-47,5	0,35
2	Grundig Luna RP 9200 PLL	-45,5	1,00
3	Grundig Ocean Boy 350	-51,5	1,40
4	Panasonic RX-EX1	-44,0	1,30
5	Philips AZ3012	-54,0	2,80
6	Sanyo DC-DA1000	-52,0	0,30
7	Sony CFD-S550L/SC	-47,0	0,45
8	Sony ICF-C743L	-49,7	0,50
9	Thomson AM1180	-45,5	1,40
10	Thomson RR 600CD	-49,0	1,25

Table S.2: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for portables.

#	Handhelds	afstir max [dB]	af distortion [%]
1	Sony ICF-M33RDS	-47,0	0,80
2	Grundig City Boy 52	-43,0	3,70
3	Digitalway FD100	-46,0	0,80
4	Nokia 8310	-40,0	0,70
5	Philips AZT9500	-46,5	4,80
6	Samsung YP-90S	-44,0	4,20
7	Sony ICF-C1200	-47,0	0,20
8	United DM2595-2	-47,0	6,43
9	Aiwa HS-RM539	-47,4	0,17
10	Sony WM-FX491	-45,6	0,14

Table S.3: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for handhelds.

The results showed that some of the car radios and most of the portables and handhelds were not able to meet the minimal audio-frequency signal-to-interference ratio of 56 dB. With a audio-frequency signal-to-interference ratio of 46 dB it was possible to measure two third of the receivers. The results are presented the figures below.

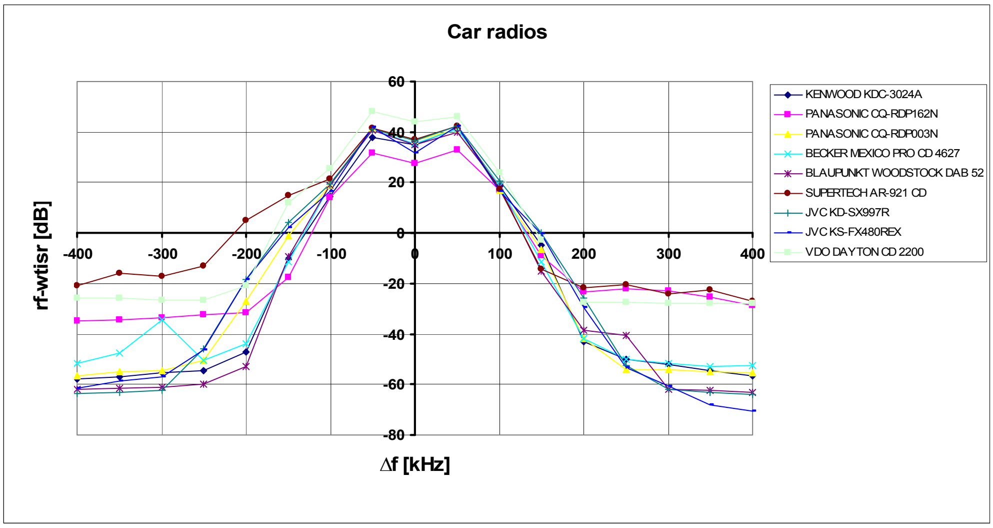

Figure S.1: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for car radios recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

For the category car radios only one receiver was discarded. The reason for this was that this receiver automatically switched over to mono at a low radio-frequency signal levels.

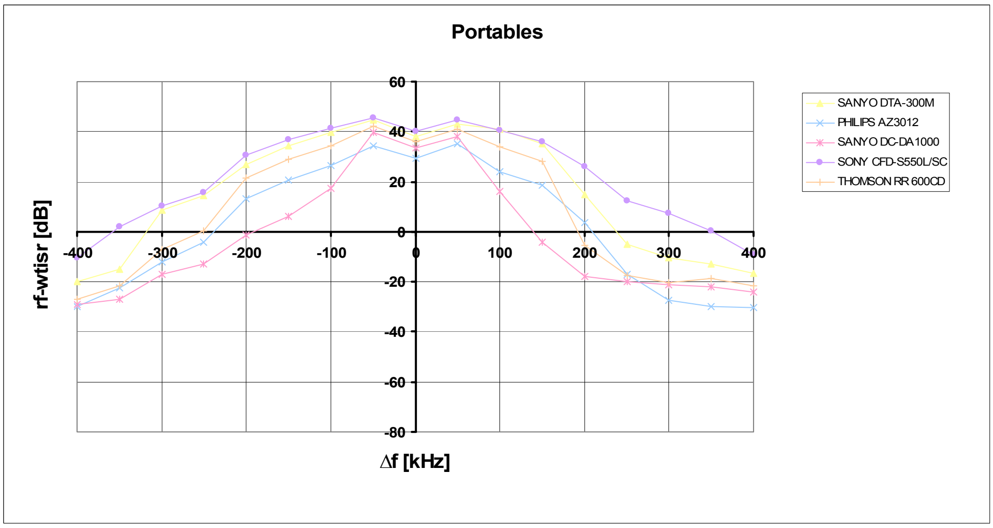

Figure S.2: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for portables recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

For the category portables five receivers were discarded. Three of the receivers could only produce a mono audio signal, the other two were not able to reach the minimal required audio-frequency signal-to-interference ratio of 46 dB.

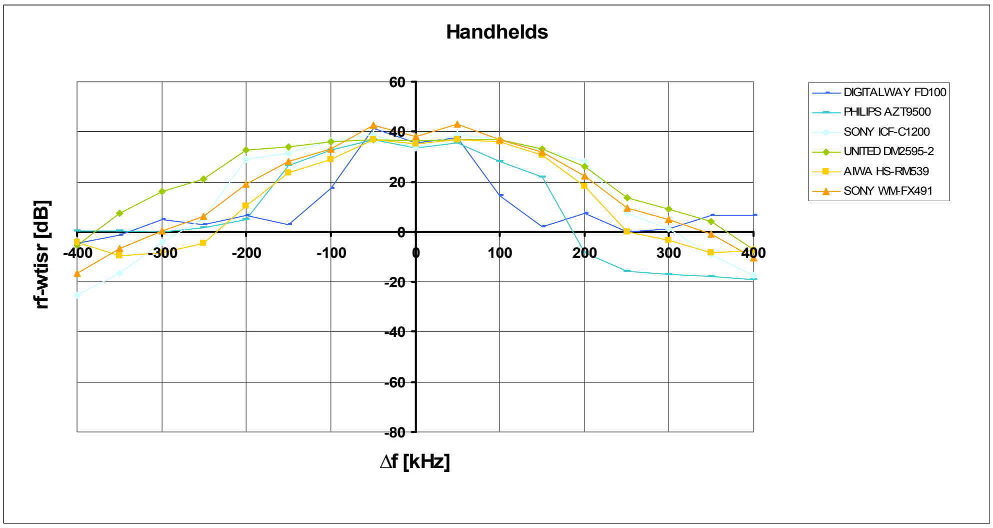

Figure S.3: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for handhelds recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

Four of the ten handhelds were left out because they couldn't not produce a stereo signal.

At the start of the automated measurement of the protection ratio curve, the sensitivity of each receiver was determined for audio-frequency signal-to-interference ratios of 20 and 46 dB. The values for the sensitivity depended on the way the signal was fed to the receiver. For this study three different feeds were used: a direct feed, an indirect feed using an alligator clip and an indirect feed using a wire. The first one is used for receivers equipped with an antenna connector, the second one is used for receivers with a fixed antenna and the third one was used for receivers that had a wire antenna. The results of the sensitivity measurement, together with the type of feed are given in the tables below.

#	Car radios	Tof	Sensitivity [dBµV] SNR (af)= 20 dB	Sensitivity [dBµV] SNR (af) =46 dB
1	Kenwood KDC-3024A	D	-0,9	35,3
2	Panasonic CQ-RDP162N	D	4,5	41,4
3	Panasonic CQ-RDP003N	D	1,2	38,3
4	Becker Mexico Pro CD 4627	D	1,9	37,1
5	Blaupunkt Woodstock DAB 52	D	-0,9	36,2
6	Supertech AR-921 CD	D	16,7	43,3
7	Jvc KD-SX997R	D	-0,9	35,8
8	Jvc KS-FX480REX	D	-1,6	37,3
9	Sony CDX-M850MP	D	-	-
10	Vdo Dayton CD 2200	D	4,1	57,9

Table S.4: Overview of the type of feed (tof) and sensitivity for car radios. The letter D in the column type of feed stands for Direct feed.

#	Portables	Tof	Sensitivity [dBµV] SNR (af)= 20 dB	Sensitivity [dBµV] SNR (af) =46 dB
1	Sanyo DTA-300M	I-C	26,9	55,3
2	Grundig Luna RP 9200 PLL	I-C	-	-
3	Grundig Ocean Boy 350	I-C	-	-
4	Panasonic RX-EX1	I-C	-	-
5	Philips AZ3012	I-C	21,4	47,9
6	Sanyo DC-DA1000	I-C	19,3	51,3
7	Sony CFD-S550L/SC	I-C	18,9	48,3
8	Sony ICF-C743L	I-C	-	-
9	Thomson AM1180	I-C	-	-
10	Thomson RR 600CD	I-C	23,9	52,3

Table S.5: Overview of the type of feed (tof) and the sensitivity for portables. The letters I-C in the column type of feed stand for Indirect feed using an alligator Clip.

#	Handhelds	Tof	Sensitivity [dBµV] SNR (af)= 20 dB	Sensitivity [dBµV] SNR (af)= 46 dB
1	Sony ICF-M33RDS	I-C	-	-
2	Grundig City Boy 52	I-C	-	-
3	Digitalway FD100	I-W	29,4	62,8
4	Nokia 8310	I-W	-	-
5	Philips AZT9500	I-W	20,6	54,7
6	Samsung YP-90S	I-W	-	-
7	Sony ICF-C1200	I-C	18,7	57,9
8	United DM2595-2	I-W	25,4	57,8
9	Aiwa HS-RM539	I-W	27,0	57,9
10	Sony WM-FX491	I-W	35,4	66,3

Table S.6: Overview of the type of feed (tof) and the sensitivity for handhelds. The letters I-W in the column type of feed stand for Indirect feed using a Wire.

Since the sensitivity measurement is part of the automated protection ratio measurement, the sensitivity was only measured for stereo receivers that were able to reach an audio-frequency signal-to-interference ratio of 46 dB.

It should be noted that in case of an indirect feed the measured value is not equal to the signal level at the input of the receiver. For both types of indirect feeds correction factors were determined to account for the loss due to the indirect feed. With the correction factor it is possible to convert the measured value to a signal level at the input of the receiver. The correction factors for the indirect feed using an alligator clip and the indirect feed using a wire are respectively 11,40 and 6,20 dB. Using the correction factors the average sensitivity for car radios, portables and handheld are respectively 40,2, 39,6 and 52,5 dBµV. It should be noted that the correction factors are based on only one measurement and can possibly deviate significantly from the average value.

Based on these measurements and average receiver was selected. The decision was mainly based on the radio-frequency protection ratio curves. From all radio-frequency protection ratio curves, depicted in Figure S.4, an average and a median radio-frequency protection ratio curve was calculated.

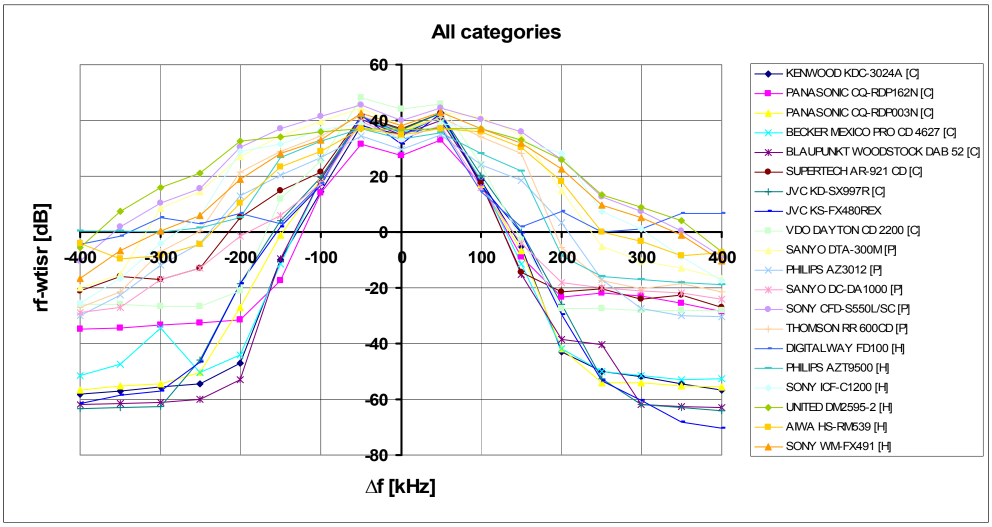

Figure S.4: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for twenty receivers recorded according to ITU Recommendation BS.641. The category to which the receivers belong is indicated between brackets. The letters C, P and H are used for respectively the category car radios, portables and handhelds. An enlarged version of this graph can be found in Appendix A.

The Sanyo DC-DA1000 was chosen as reference receiver since it had the lowest mean absolute deviation from the mean and median radio-frequency protection ratio curve.

Based on their protection ratio curves it was decided that the Blaupunkt Woodstock DAB52 represents a good receiver and the Sony WM-FX491 represents a bad one. The radio-frequency protection ratio curves of the good, the reference and the bad receiver as well as the Zero-Base reference receiver are shown in the Figure S.5.

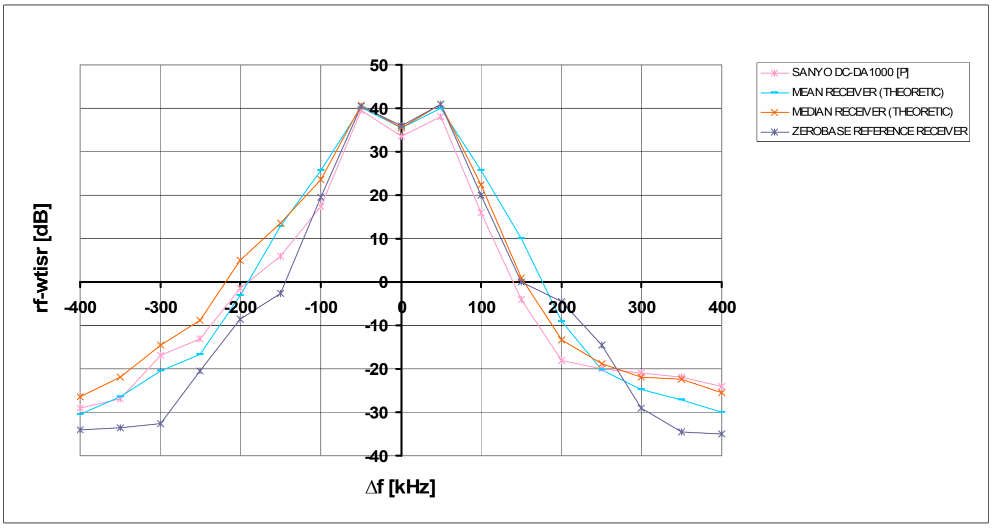

Figure S.5: Comparison between the Zero-Base reference receiver, the Sanyo DC-DA1000, the mean and the median receiver of this study. Both the mean and median receivers are theoretic receivers. An enlarged version of this graph can be found in Appendix A.

The reference receiver was used to record an extensive set of sound samples for the network configurations: conventional, same programme and hf-synchro. In a conventional network the wanted transmitter carries a different programme than the unwanted transmitter. In both a same programme and a hf-synchro network the wanted and unwanted transmitter belong to the same programme chain and will therefore transmit the same programme. The main difference between the same programme and the hf-synchro network configuration is the frequency tolerance of the transmitter. For a hf-synchro network this tolerance is lower.

This extensive set of sound samples covered a predetermined range of different receiving conditions such as frequency differences, delays and signal-to-noise ratios for wanted signals speech and classical music. To limit the total number of receiving conditions a limited set of sound samples per network configuration were recorded with the good and the bad receiver.

The recorded sound samples were used in subjective tests. The goal of these tests was to assess the quality of the recorded sound samples using pairwise comparison and the mean opion score. From these results the protections ratio curves for the network configurations conventional, same programme and HF-synchro were determined. The protection ratio curve based on a grade of 3,5 for speech samples recorded with the reference receiver is presented in the figure below.

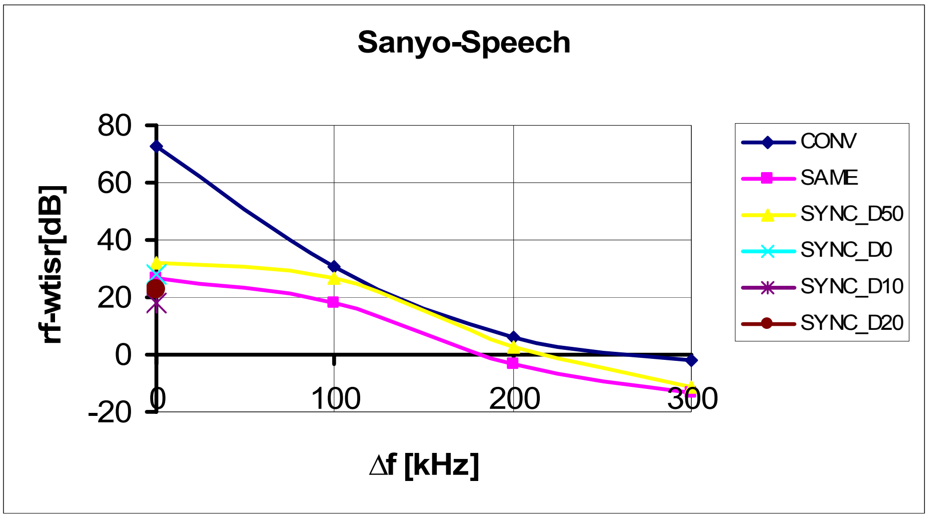

Figure S.6: The protection ratio as function of the frequency distance based on a grade of '3,5' for speech recorded with the Sanyo receiver.

Recommendation ITU-R BS.412.9 makes a distinction between radio-frequency protection ratios for steady and troposheric interference. According to Recommendations ITU-R BS.562.2 and ITU-R BS.412-9 tropospheric interference corresponds to grade '3' on a scale of '1' to '5'. However, it is unclear on what grade the steady state interference is based. What is clear is that the grade is higher than '3' and that it corresponds to an audio signal-to-noise of 50 dB. The subjective test showed very few results for grade '4'. Furthermore this grade would likely result in unrealistic high values. Therefore grade '3,5' was chosen as basis for steady interference.

Based on a grade of '3' for troposheric interference and '3,5' for steady interference the results of the subjective tests for the convention network configuration, with the exception of the 0 kHz case, are in fair agreement with the ITU values. Therefore, it is advised to use the radio-frequency protection ratio values of Recommendation ITU-R BS.412-9 for frequency planning in case of conventional networks. The 3 to 8 dB reduction, compared to the ITU values for conventional networks, found by the Zero-Base study could not be confirmed by this study.

The results of the subjective tests for the network configuration same programme show a considerable improvement compared to the ITU values for the conventional network configuration. This is in line with Recommendation ITU-R BS.412-9. For frequency planning of transmitters carrying the same programme it is advised to use the protection ratios based on a grade of '3,5' in case of steady interference. In case of tropospheric interference it is advised to use the protection ratios based a grade of '3,0'. The values for same programme and steady interference do not differ much from the Zero-Base values for MPX synchronisation, except for 100 kHz frequency difference. It should be noted that the Zero-Base value is optimistic. The Zero-Base study gave no directives for tropospheric interference.

The results of the subjective tests for the HF-synchro network configuration also show a considerable improvement compared to the ITU values for the conventional network configuration. Again this is in line with Recommendation ITU-R BS.412-9. Although it was expected that the results for synchronized transmission with a delay of 50 μs would be similar to those of same programme the protection ratio in the synchronized case turned out to be higher. Also an increase in protection ratio with delay times was expected. The results show, in particular for the 0 µs case, a relatively high value. Compared to the Zero-Base study the protection ratios for synchronized transmitters are higher for frequency difference of 0 and 100 kHz. The reason for this could be the different synchronisation used.

Since a synchronized network is more complicated to operate an the results are not significantly better than those of same programme it is advised to use same programme in stead of HF-synchro between transmitters carrying the same programme.

The results of the high signal performance test clearly indicate that third order inter-modulation products significantly deteriorate the performance of the tested portables and handhelds. Figure S.7 shows the high signal performance for two portables (the Sanyo DC-DA1000 and the Sony CFD S550L) and two handhelds (the Philips AZT9500 and the Sony WM-FX491).

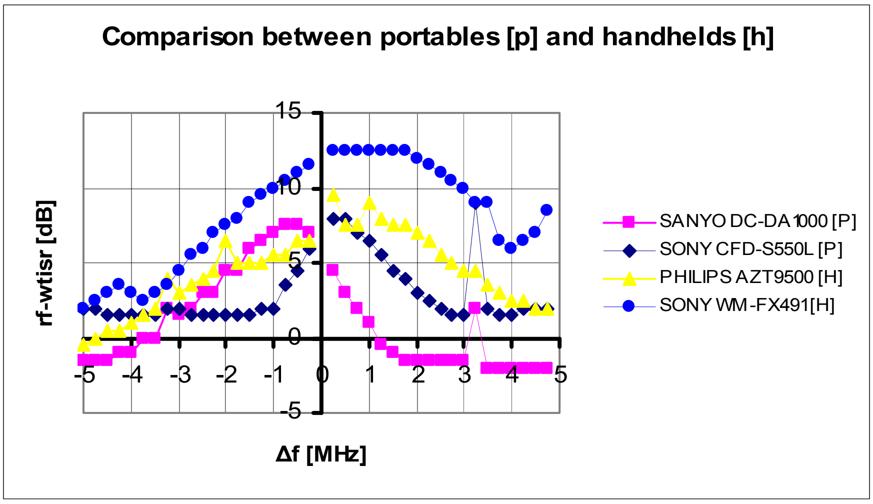

Figure S.7: Comparison between the high signal performance of two portables (the Sanyo DC-DA1000 and the Sony CFD S550L) and two handhelds (the Philips AZT9500 and the Sony WM-FX491). The radio-frequency level of the wanted transmitter was set to 87dBµV.

Expected was that the graph would be symmetric with respect to Δf. This, however, is not the case. Possible explanation for this would be that the characteristics of receiver's amplifier are frequency dependent. The results for the Sanyo DC-DA1000 for Δf>0 are in fair agreement with an investigation performed in the Federal Republic of Germany of domestic and car FM radio receivers on their tendency to inter modulate in the presence of strong RF signals. For Δf>0 all tested receivers are significantly worse than the Sanyo DC-DA1000.

Experience in The Netherlands has shown that interference from third order inter-modulation products may occur around FM transmission sites where many frequencies are used. There the reception of signals from either a station with much lower power than the others, or from other more distant sites could lead to problems. In these situations frequencies should be chosen such that no third order inter-modulation products occur in the pass-band of the receiver tuned to the low level signal. If this is not possible either the power of the low power transmission should be increased or a gap-filler should be installed to achieve the required protection ratio.

Two aspects of the RDS switching behaviour were studied. The first aspect is the switching behaviour due to differences in radio-frequency levels. The second aspect is the switching behaviour due to multipath. The results indicate that the switching behaviour due to difference in radio-frequency levels depends on the frequency difference. When the frequency difference is small, all tested car radios switched over when the radio-frequency level of current frequency drops just below the radio-frequency level of the alternative frequency. When the frequency difference is large about half of receivers switches over after a small drop in radio-frequency level while the other half of the receivers only switched over after a significant drop in radio-frequency level. The results focussed on the RDS switching behaviour due to multipath indicate that there is no significant difference in the multipath behaviour of the tested car receivers.

1 Introduction

This report describes the results of the FM receiver study according to the request for tender from SRG/SSR/idée Suisse from 25 June 2002 and the conclusions reached at the meeting between representatives of the Swiss Companies and Nozema on 26 May 2003 in Lopik. During this meeting the measurements described in original proposal were downsized to reduce the costs.

2 Measuring protection ratio curves

The first step in this receiver study is to determine the radio-frequency protection ratio curves of thirty receiver. This should be done according to Recommendation ITU-R BS.641. Based upon the radio-frequency protection ratio curves a reference receiver will be selected. The following paragraphs describe the selection procedure.

2.1 Receiver selection

Thirty receivers were used in this study: ten car radios, ten portables and ten handhelds. The client provided a list with the make and type of the radio. Per category a high and a low end type, based on price, was selected. Tables 2.1 to 2.3 give an overview of the selected receivers. Also the Zero-Base reference receiver, the NAD 1600, was included in the tests.

2.2 Method

Recommendation ITU-R BS.641 is used to the determine the radio-frequency protection ratio curves of the receivers. This recommendation indicates that the audio-frequency signal-to-interference ratio should be at least 56 dB. Initial tests with only a few receivers indicated that the 56 dB audio-frequency signal-to-interference ratio could not always be reached.

To be able to objectively compare receivers it is important that all receivers use the same minimal audio-frequency signal-to-interference ratio as starting point for the determination of the radio-frequency protection ratio curve. Receivers which are not able to reach the minimal can not be taken into account . Therefore, it was decided to determine the maximum attainable audio-frequency signal-to-interference ratio per receiver first. During this test the audio distortion per receiver is also measured. The audio distortion also gives an indication of the quality of the receiver. The results of this test are given in tables below.

#	Car radios	afstir max [dB]	af distortion [%]
1	Kenwood KDC-3024A	-52,5	0,60
2	Panasonic CQ-RDP162N	-57,5	1,00
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6	Supertech AR-921 CD	-55,3	5,70
7	Jvc KD-SX997R	-52,0	1,90
8	Jvc KS-FX480REX	52,0	1,50
9	Sony CDX-M850MP	-55,6	1,50
10	Vdo Dayton CD 2200	-47,0	0,10

Table 2.1: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for car radios.

#	Portables	afstir max [dB]	af distortion [%]
1	Sanyo DTA-300M	-47,5	0,35
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3	Grundig Ocean Boy 350	-51,5	1,40
4	Panasonic RX-EX1	-44,0	1,30
5	Philips AZ3012	-54,0	2,80
6	Sanyo DC-DA1000	-52,0	0,30
7	Sony CFD-S550L/SC	-47,0	0,45
8	Sony ICF-C743L	-49,7	0,50
9	Thomson AM1180	-45,5	1,40
10	Thomson RR 600CD	-49,0	1,25

Table 2.2: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for portables.

#	Handhelds	afstir max [dB]	af distortion [%]
1	Sony ICF-M33RDS	-47,0	0,80
2	Grundig City Boy 52	-43,0	3,70
3	Digitalway FD100	-46,0	0,80
4	Nokia 8310	-40,0	0,70
5	Philips AZT9500	-46,5	4,80
6	Samsung YP-90S	-44,0	4,20
7	Sony ICF-C1200	-47,0	0,20
8	United DM2595-2	-47,0	6,43
9	Aiwa HS-RM539	-47,4	0,17
10	Sony WM-FX491	-45,6	0,14

Table 2.3: Overview of the maximum audio-frequency signal-to-interference ratio (afstir) and the audio-frequency distortion for handhelds.

The results of this test show that only three of thirty receiver are able to reach the minimal audio-frequency signal-to-interference ratio of 56 dB.

Since it is important to use the same the start value for the audio-frequency signal-to-interference ratio for all receiver it was decided to lower this start value from 56 dB to 46 dB. The start value is now lower than the original stop value for the audio-frequency signal-to-interference ratio. Therefore the stop value was lowered to 40 dB. With this adaptation it was possible to measure the protection ratio of twenty fore of the thirty receivers.

In the ZeroBase study the original value of 56 dB for the audio-frequency signal-to-interference was used because the number of receivers that were not able to reach this value was less. However, it is more likely that this is due to the composition of the two representative groups than that is due to a deterioration of the quality of car radios and portables.

During the measurement of the protection ratio, the sensitivity is also measured.

2.3 Measurement arrangement

The protection ratios have been measured in accordance with Recommendation ITU-R BS.641. Figure 2.1 shows a diagram of the measuring arrangement. This arrangement is a practical realisation of the schematic measuring arrangement from Recommendation ITU-R BS.461.

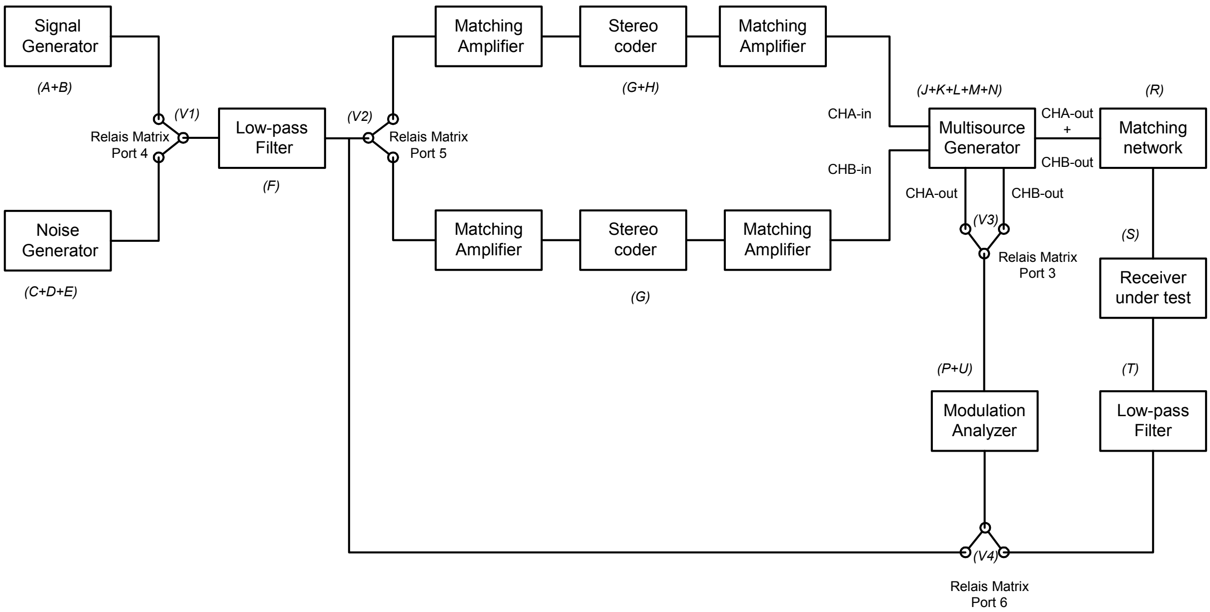


Figure 2.1: Practical measuring arrangement. Each apparatus in this arrangement has been given a reference – an letter printed in italics and placed between brackets - to the function blocks used in schematic diagram of Recommendation ITU-R BS.461.

The stereo coder in the lower branch of Figure 2.1 is set up in such a way that only the pre-emphasis network is used. This is realised by setting the operation mode of the stereo coder to mono and by switching the four dip switch on the circuit board to the off position. The matching amplifiers in the upper and lower branch are used to go from unbalanced (*output of the signal and noise generator*) to balanced (*input of the stereo coder*) and back from balanced (*output of the stereo coder*) to unbalanced (*input of the multi-source generator*). Details of the equipment used in the measuring arrangement depicted in figure 2.1 are listed in the table below.

Equipment	Id	#
Rohde & Schwarz, Noise Generator SUF 2 282.8819.03	N6274	1
Rohde & Schwarz, Generator APN04	N6201	1
IFR, Multisource Generator 2026A	N6427	1
C.N. Rood b.v. Electronics, Stereo coder SC2000	03E154, 03E154	2
Rhode & Schwarz, Modulation Analyzer FMAS 0856.6001.52	N6377	1
C.N. Rood b.v. Electronics, Low Pass Filter 0-15kHz	N6297, N6298	2
C.N. Rood b.v. Electronics, Matching Ampilfier Type SP-3	N6301, N6302	2
Nozema n.v., Matching Network	-	1
Rohde & Schwarz, RF Relais Matrix PSU 290.8014.02	N6242	1

Table 2.4: Equipment used for measuring the protection ratio according to Recommendation ITU-R BS.641.

The measuring method described in Recommendation ITU-R BS.461 has been fully automated. The procedure for determining a radio-frequency protection ratio curve be can be split up in the following three steps:

1 – Setting up the wanted transmitter (Determination of the reference level).

Source A of the multi-source generator, which represents the wanted transmitter, is frequency modulated with a 500 Hz sinusoidal tone. The output level of the tone generator is adjusted to obtain a frequency deviation of ±75kHz, including the pilot tone in stereophonic operation. The QUASI-PEAK reading of the modulation analyzer, with the weighting network switched off (i.e. CCIR UNWEIGHTED) indicates the reference level. This reference level corresponds to 0 dB.

2 - *Setting up the unwanted transmitter.*

Source B of the multi-source generator, which represents the unwanted transmitter, is modulated with a 500 Hz sinusoidal tone obtained from tone generator. The output level of the tone generator is adjusted to obtain a deviation of ±32 kHz. The audio-frequency level at the input of the unwanted transmitter before pre-emphasis is measured by means of the modulation analyzer (noise meter U). The noise-weighting network is switched off (i.e. CCIR UNWEIGHTED). Next a noise signal obtained from the noise generator replaces the sinusoidal tone and its output level is adjusted to obtain the same QUASI-PEAK reading as before at the noise meter.

3 - *Measuring the radio-frequency protection ratio curve.*

The following procedure is repeated for channel spacings ranging from 0 to 400 kHz, in steps of 50 kHz, between the wanted and unwanted transmitter:

The output level of the unwanted transmitter is adjusted to obtain an audio-frequency signal-to-interference ratio of 40 dB at the audio-frequency output of the receiver. In this case, the weighting network of the modulation analyzer must be switched in (i.e. CCIR WEIGHTED) and the QUASI-PEAK detector must be selected . The ratio between the radio-frequency levels of the wanted and unwanted transmitters is the required radio-frequency wanted-to-interfering signal ratio.

2.4 Results

2.4.1 Radio-frequency protection ratio curves

Most receivers were not able to meet the required start value of 56dB for the audio-frequency signal-to-interference ratio dictated by Recommendation ITU-R BS.461. Therefore, this start value has been lowered to 46 dB. Since this start value is lower than the original stop value for the audio-frequency signal-to-interference ratio this value was lowered to 40 dB. With this adaptation it was possible to measure the radio-frequency protection ratio curve of twenty receivers. The results are presented per category and are depicted in Figures 2.2 to 2.4. The frequency difference is defined as the frequency of the unwanted transmitter minus the frequency of the wanted transmitter.

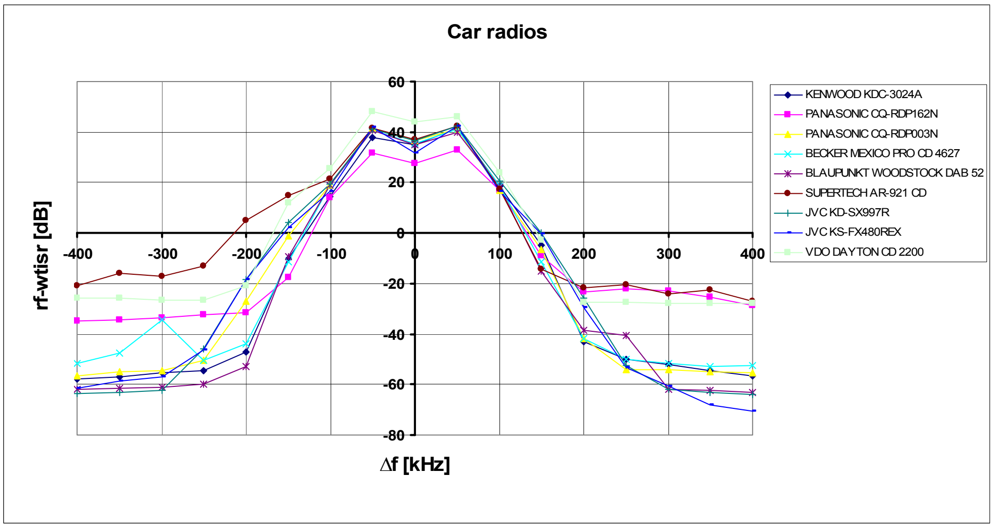


Figure 2.2: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for car radios recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

For the category car radios only one receiver was discarded. The reason for this was that this receiver automatically switched over to mono at low radio-frequency signal levels.

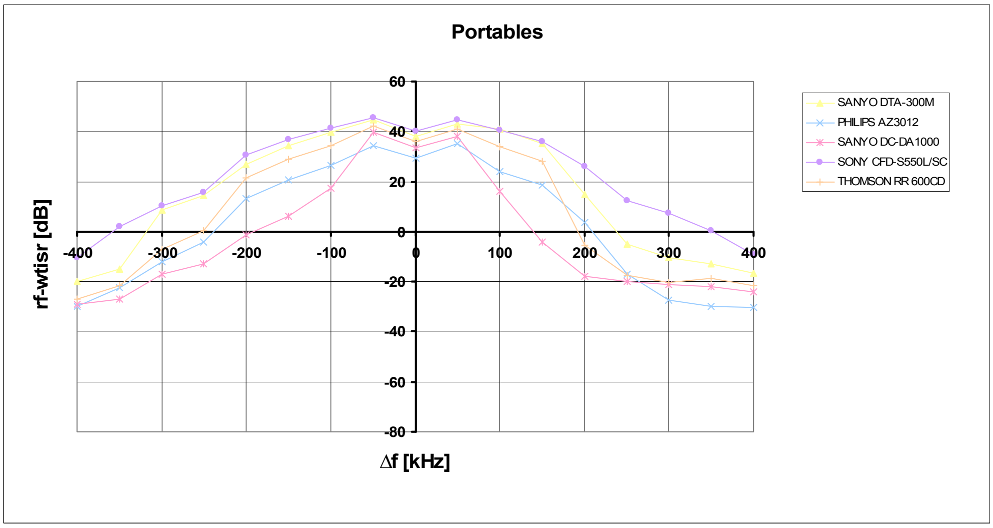


Figure 2.3: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for portables recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

For the category portables five receivers were discarded. Three of the receivers could only produce a mono audio signal, the other two were not able to reach the minimal required audio-frequency signal-to-interference ratio of 46 dB.

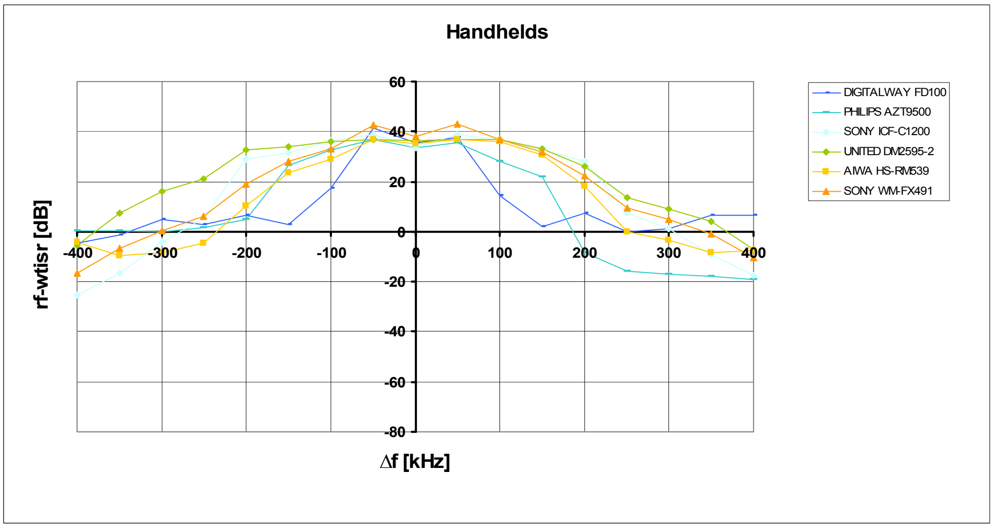


Figure 2.4: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for handhelds recorded according to ITU Recommendation BS.641. An enlarged version of this graph can be found in Appendix A.

Four of the ten handhelds were left out because they couldn't not produce a stereo signal.

To ease the comparison between the different categories Figure 2.5 shows all protection ratio curves in one graph.

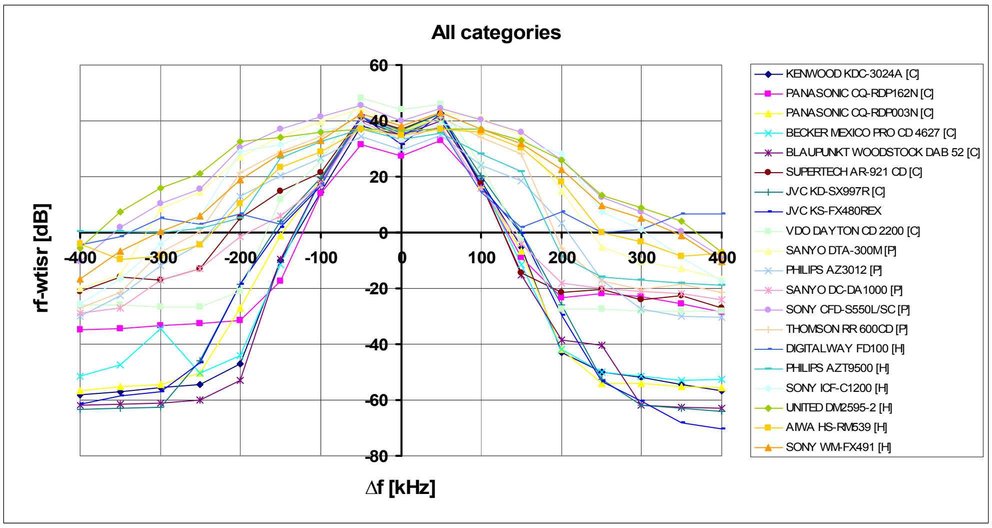


Figure 2.5: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for twenty receivers recorded according to ITU Recommendation BS.641. The category to which the receivers belong is indicated between brackets. The letters C, P and H are used for respectively the category car radios, portables and handhelds. An enlarged version of this graph can be found in Appendix A.

Details of the measurements can be found in Appendix A. About half of the receiver did not have an antenna input. This meant the signal from the multi-source generator had to be transmitted via the fixed or wire antenna of the receiver under test. Disadvantage of this method is that the input level at the input of the receiver is not known. This, however, is not necessary for the determination of the radio-frequency protection ratio if it is assumed that ratio between the output level of the transmitter and the input level of the receiver is the same for both the wanted signal and the unwanted signal.

2.4.2 Sensitivity

At the start of the automated measurement of the protection ratio curve, the sensitivity of each receiver was determined for audio-frequency signal-to-interference ratios of 20 and 46 dB.

Not all receivers can be compared based on sensitivity since sensitivity depends on the way the signal is fed to the receiver. For this study three different feeds are used. The first one is a direct feed. This type of feed can be used for receivers that are equipped with an RF-input connector. All receivers from the category car radios have such a feed. Advantage of this type of feed is that the signal level at the input of the receiver is equal to the signal level at the output of the transmitter.

The second type of feed uses a alligator clip to transmit the signal onto the fixed antenna. For the third type of feed the receive antenna, a wire, is wrapped around the transmit antenna. In both cases it is not possible to determine the exact input level. This means that only the sensitivity of receivers that use the same type of feed can be compared.

The results of this test together with the type of feed, are given in the Table 2.5 to2.7.

Note: *The sensitivity measurement is part of the automated protection ratio measurement. Therefore, the sensitivity was only measured for stereo receivers that were able to reach an audio-frequency signal-to-interference ratio of 46 dB.*

#	Car radios	Tof	Sensitivity [dBµV] SNR (af)= 20 dB	Sensitivity [dBµV] SNR (af) =46 dB
1	Kenwood KDC-3024A	D	-0,9	35,3
2	Panasonic CQ-RDP162N	D	4,5	41,4
3	Panasonic CQ-RDP003N	D	1,2	38,3
4	Becker Mexico Pro CD 4627	D	1,9	37,1
5	Blaupunkt Woodstock DAB 52	D	-0,9	36,2
6	Supertech AR-921 CD	D	16,7	43,3
7	Jvc KD-SX997R	D	-0,9	35,8
8	Jvc KS-FX480REX	D	-1,6	37,3
9	Sony CDX-M850MP	D	-	-
10	Vdo Dayton CD 2200	D	4,1	57,9

Table 2.5: Overview of the type of feed (tof) and sensitivity for car radios. The letter D in the column type of feed stands for Direct feed.

#	Portables	Tof	Sensitivity [dBμV] SNR (af)= 20 dB	Sensitivity [dBμV] SNR (af) =46 dB
1	Sanyo DTA-300M	I-C	26,9	55,3
2	Grundig Luna RP 9200 PLL	I-C	-	-
3	Grundig Ocean Boy 350	I-C	-	-
4	Panasonic RX-EX1	I-C	-	-
5	Philips AZ3012	I-C	21,4	47,9
6	Sanyo DC-DA1000	I-C	19,3	51,3
7	Sony CFD-S550L/SC	I-C	18,9	48,3
8	Sony ICF-C743L	I-C	-	-
9	Thomson AM1180	I-C	-	-
10	Thomson RR 600CD	I-C	23,9	52,3

Table 2.6: Overview of the type of feed (tof) and the sensitivity for portables. The letters I-C in the column type of feed stand for Indirect feed using an alligator Clip.

#	Handhelds	Tof	Sensitivity [dBμV] SNR (af)= 20 dB	Sensitivity [dBμV] SNR (af)= 46 dB
1	Sony ICF-M33RDS	I-C	-	-
2	Grundig City Boy 52	I-C	-	-
3	Digitalway FD100	I-W	29,4	62,8
4	Nokia 8310	I-W	-	-
5	Philips AZT9500	I-W	20,6	54,7
6	Samsung YP-90S	I-W	-	-
7	Sony ICF-C1200	I-C	18,7	57,9
8	United DM2595-2	I-W	25,4	57,8
9	Aiwa HS-RM539	I-W	27,0	57,9
10	Sony WM-FX491	I-W	35,4	66,3

Table 2.7: Overview of the type of feed (tof) and the sensitivity for handhelds. The letters I-W in the column type of feed stand for Indirect feed using a Wire.

To get an indication of the actual input level of the receivers that use an indirect feed, two of such receivers were modified. The fixed antenna of the Sanyo DC-DA1000 and the wire antenna of the Sony WM-FX491 were replaced by a BNC connector. The table below lists the sensitivity before and after the modification.

	Sanyo DC-DA1000	Sony WM-FX491
Sensitivity before modification [dBμV]	19,30	35,40
Type of feed	*Indirect via alligator clip*	*Indirect via wire*
Sensitivity after modification [dBμV]	7,90	29,20
Type of feed	*Direct via BNC connector*	*Direct via BNC connector*

Table 2.8: Indication of actual sensitivity for receivers which are fed indirectly.

Table 2.8 indicates that the loss due to the indirect coupling is 11,40 dB in case the signal is transmitted to the fixed antenna via an alligator clip and 6,20 dB in case the transmitted by wrapping the wire antenna of the receiver around the wire antenna of the transmitter.

Based on these correction factors the average sensitivity to obtain an audio-frequency signal-to-interference ratio for car radios, portables and heldhelds are respectively 40,2, 39,6 and 52,5 dBµV. It should be noted that the correction factors are based on a single measurement and can possibly deviate significantly from the average value.

2.5 Selection of the reference receiver

The radio-frequency wanted-to-interfering signal ratios are used to select a reference receiver. This is done in two steps. The first step is to determine and average and mean radio-frequency protection ratio curve. The second step is to select the receiver which radio-frequency protection ratio curves is closest to the mean and median radio-frequency protection ratio curve.

Before the mean and median radio-frequency protection ratio can be determined, the following question needs to be answered:

How many receivers from each category are used for determining the average protection ratio curve?

With the adjusted minimal value for the audio-frequency signal-to-noise ratio it is possible to determine the protection ratio curves for nine car radios, five portables receivers and six walkmans. In principle the are two options for the determination of the mean and median audio-frequency protection ratio curves. In the first option the mean and median curve will be based on an equal number of receivers per category. The category with the lowest number of receivers determines the total number of receivers. Consequently, in the other two categories receivers have to be dropped. The problem then is which receiver is, and which receiver is not, taken into account.

In the second option the mean and median will be based on all receivers. Although this means that the three categories are not equally represented it was decided to determine the mean and median protection ratio curve based on all receivers. This decision is (primarily) based on the fact that the difference between the portable and the walkman category is arbitrary. A division into two categories is more logical since the car radios perform significantly better than the remaining receivers. In that perspective the two categories are more or less equally represented: nine car receivers and eleven other receivers.

Based on the mean and median protection ratio curve a reference receiver will be selected. This receiver is used to record the sound samples which will be used in the subjective tests. The selection of the average receiver is based on the mean absolute deviation (MAD) from the mean and the median. These mean absolute deviations are calculated for channel spacings ranging from –400 kHz to 400 kHz in 50 kHz steps. The results are listed in Table 2.9.

Reciever	Mad mean	Mad median
Kenwood KDC-3024A	22,3	23,8
Panasonic CQ-RDP162N	10,8	11,9
Panasonic CQ-RDP003N	20,3	21,7
Becker Mexico Pro CD 4627	19,4	20,8
Blaupunkt Woodstock DAB 52	24,6	26,2
Supertech AR-921 CD	5,9	3,5
Jvc KD-SX997R	20,4	21,8
Jvc KS-FX480REX	21,4	22,8
Vdo Dayton CD 2200	6,4	7,5
Sanyo DTA-300M	16,4	14,8
Philips AZ3012	5,8	6,1
Sanyo DC-DA1000	4,6	3,6
Sony CFD-S550L/SC	22,9	21,3
Thomson RR 600CD	8,6	7,0
Digitalway FD100	16,4	13,4
Philips AZT9500	10,7	9,3
Sony ICF-C1200	16,1	14,7
United DM2595-2	23,4	22,0
Aiwa HS-RM539	14,3	12,8
Sony WM-FX491	17,7	16,0

Table 2.9: Mean average deviation (mad) from the mean and the median.

The Sanyo DC-DA1000 has the lowest mean average deviation from the mean and the second lowest mean average deviation from the median. Therefore, this receiver is selected as reference receiver.

In comparison with the ITU Recommendation BS.641 this study uses a different start and stop value for the audio-frequency signal-to-noise ratio. Due to these different values it is not possible to compare the protection ratio curve of the Sanyo DC-DA1000 with the curve from ITU Recommendation BS.412-9. It is however possible to compare the Sanyo DC-DA1000 with the Zero-Base reference receiver, the NAD1600.

To make this comparison possible the radio-frequency protection ratio curve of the Zero-Base reference receiver was recorded with the same start and stop values as were used for receiver listed in Table 2.1 to 2.3. Figure 2.6 depicts the protection ratio curves of the Sanyo DC-DA1000 together with the protection ratio curve of the Zero-Base reference receiver, the average and median protection ratio curve from this study.

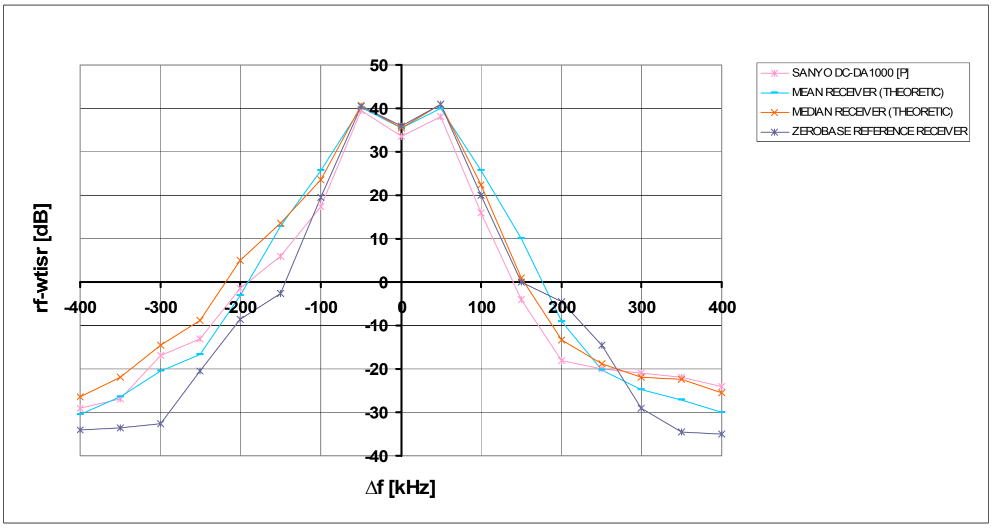


Figure 2.6: Comparison between the Zero-Base reference receiver, the Sanyo DC-DA1000, the mean and the median receiver of this study.

2.6 Selection of the good and the bad receiver

Besides the reference receiver, a good and bad receiver will be used for recording sound samples. It is preferred that the good, average and bad receiver each belong to a different category. Therefore, the good and the bad receiver will be selected from a category other than portables. Since car radios are better receivers than walkmans the good receiver will be selected from the category car radios. Consequently, the bad receiver will be selected from the category walkmans.

The fact that the good receiver doesn’t have to be the best receiver makes the selection of a good receiver somewhat arbitrary. The same holds for the selection of the bad receiver.

Considering the shape and position of the protection ratio curves with regard to the reference radio-frequency protection ratio curve three receivers were considered as good receivers and three as bad receivers. Candidates for the title good receiver are: The Jvc KD-SX997R, the Jvc KS-FX480REX and the Blaupunkt Woodstock DAB52. Candidates for the title bad receiver are: the United DM2595-2, the Sony ICF-C1200 and the Sony WM-FX491.
In mutual agreement the Blaupunkt Woodstock DAB52 car radio was selected as good receiver and the Sony WM-FX491 was selected as bad receiver. The protection ratio curves of the good and bad receiver are depicted in Figure 2.7.

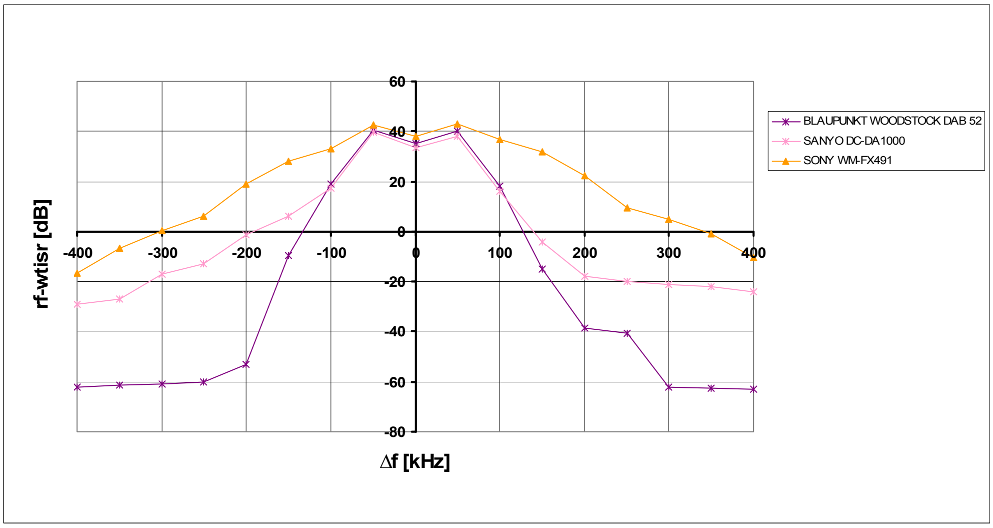


Figure 2.7: The protection ratio curves of the good, the reference and the bad receiver.

3 Recording of the sound samples

For the subjective tests sound sample via a simulated radio link between the transmitters and receiver are recorded. The simulated radio link makes it possible to do this for different conditions. For this study the frequency difference and the delay between the wanted and interfering transmitter as well as the ratio between radio-frequency level of the wanted and interfering transmitter are varied. The sound samples are recorded for three different network configurations. Per network configuration three different receivers are used: the good, the reference and the bad receiver. Details of the recordings are explained in the next paragraphs.

3.1 Test setup

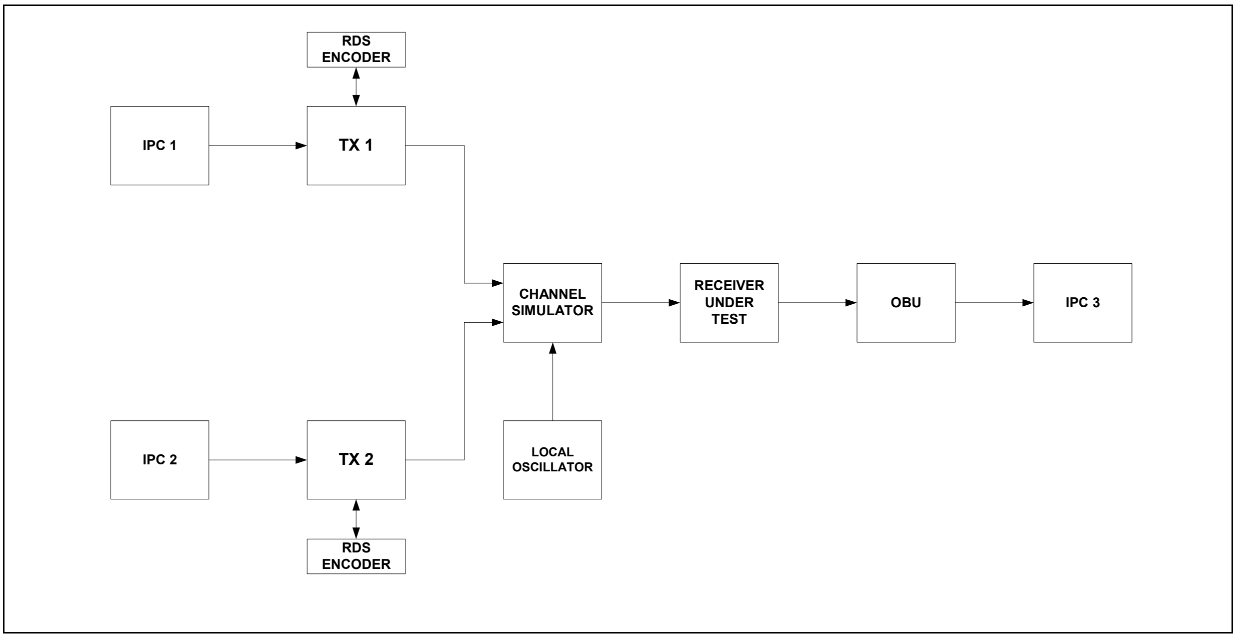
Figure 3.1 shows the diagrams of the measurement arrangements which are used for the recording of the sound samples. The modulating signals originate from industrial personal computers (IPCs) 1 and 2. The audio output of the receiver under test is fed to IPC 3. This IPC is used for recording the sound samples All IPCs are equipped with a professional sound card. An output balancing unit (OBU) is placed between the audio output of the receiver and the input of the IPC to go from unbalanced to balanced audio.

For the network configurations conventional and same programme two analogue exciters, with integrated stereo encoders, were used. In case of the network configuration same programme the exciters are locked to an external frequency reference, in case of the conventional network configuration they are not. The network configuration HF-synchro uses two digital exciters which are also locked to an external frequency source. The RDS and stereo encoders are integrated in the digital exciter.

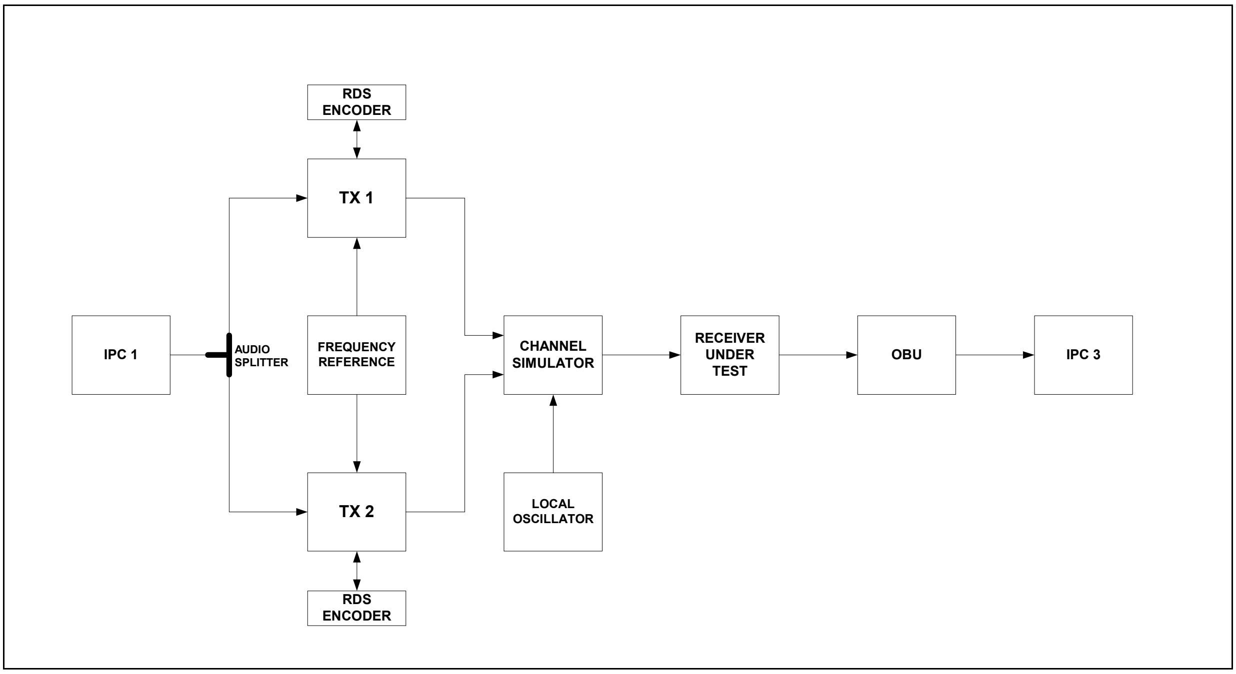
Table 3.1 gives the details of the equipment that is used.

Equipment	Nc	Id	#
Musicam Encoders	CN, SP, SN	Musicam1,2 and 3	3
Elettronika MIRA 30S	CN, SP	0202,0206	1
BE Fxi60	SN	8011895-001, 002	2
Azted Audemat RDS encoder	CN, SP	0202	2
Agilent Frequency counter (Frequency reference)	SP, SN		1
MP2700 Multipath Fading Emulator	CN, SP, SN	-	1
Rhode& Signal Generator (Local Oscillator)	CN, SP, SN		2
Nozema n.v. AES/EBU Audio splitter	SN	-	2
Output Balacing Unit EA811	CN, SP, SN	-	1
Nozema n.v. Analogue Audio splitter	CN, SP	-	1
Aztec Audemat FM-MC3.2	CN, SP, SN	-	1

Table 3.1: Equipment used for the recording of the sound samples. The column network configuration (nc) indicates for which network operation mode the equipment was used.



(A)



(B)

Figure 3.1: Measuring arrangement for the recording of sound samples. (A) measuring arrangement for the conventional network configuration. (B): measuring arrangement for the network configurations same programme and synchro.

The frequency of the wanted transmitter is set to 100 MHz, the frequency of the interfering transmitter is equal to the frequency of the wanted transmitter plus the frequency difference. The situation where the interfering frequency is higher than the wanted frequency corresponds to the right-hand side of the protection ratio curves. The wanted and interfering transmitter are modulated in accordance with Swiss regulation. The requirement that maximum 10% of the instantaneous frequency deviations must lie in the interval from 75 to 85 kHz turned out to be leading.

3.2 Source sound samples

Source sound samples are the sound samples that are used to frequency modulate the transmitters. Three different types of source sound samples are used. The first type is speech. For this type a fragment from the Dutch radio station *Radio 1* is taken. The second and third type are respectively pop/rock and classical music. For Pop/rock a fragment of *Need you tonight* by *INXS* is taken. For classical music a fragment of *Der Nussbaum* by *Vesselina Kassarova* is used. All fragment are about one minute in length.

3.3 Sound sampled recorded with the reference receiver

The reference receiver is used to record sound samples with speech and classical music as wanted signal. This is done for all three network configurations. The different conditions per network mode - frequency difference, delay and signal to noise ratio - that are used are listed in Table 3.2 to3.4.

	Network configuration: conventional Δf[kHz]			
Delay[μs]	**0**	**100**	**200**	**300**
50	36; 42; 48; 54	12;18;4;30;36;42;48	-12;-6;0;6;12	-30;-24;-18;-12

Table 3.2: Overview of the different conditions used for the recording of sound samples for the conventional network configuration. The cells in this table list the signal to noise ratios in dB that were used for a specific combination of frequency difference and delay.

	Network configuration: same programme Δf[kHz]			
Delay[μs]	**0**	**100**	**200**	**300**
50	9, 15, 21, 27, 33	-6; 0; 6; 12; 18	-15;-9; -3;3;9	-30;-24;-18;-12

Table 3.3: Overview of the different conditions used for the recording of sound samples for the same programme network configuration. The cells in this table list the signal to noise ratios in dB that were used for a specific combination of frequency difference and delay.

	Network configuration: HF-synchro Δf[kHz]			
Delay[μs]	**0**	**100**	**200**	**300**
0	-3; 3; 9; 15	-	-	-
10	-3; 3; 9; 15; 21	-	-	-
20	0; 6; 12; 18; 24	-	-	-
50	0; 6; 12; 18; 24	-6; 0; 6; 12; 18	-15;-9; -3;3;9	-30;-24;-18;-12

Table 3.4: Overview of the different conditions used for the recording of sound samples for the HF-synchro network configuration. The cells in this table list the signal to noise ratios in dB that were used for a specific combination of frequency difference and delay.

For the conventional network configuration pop/rock is always used as interfering signal. For the other two network configurations the wanted and interfering signal are the same.

3.4 Sound samples recorded with the good and the bad receiver

The good and the bad receiver are used to record sound samples with speech as wanted signal for the three different network configurations. Only frequency differences of 0 kHz and 200 kHz, both with a delay of 50 µs, are used. Tables 3.2 to 3.4 list the different signal to noise ratios, in dB, per network configuration that are used.

4 Subjective assessment of the sound samples

4.1 Participants

Fourty participants took part in the quality tests: 20 participants between 18 and 45 year of age (male and female), and 20 participants between 45 and 65 year of age (male and female). All had normal hearing verified by standard audiometric tests. They were paid for their participation.

4.2 Procedure

The quality assessment consisted of two tests:

- the pairwise comparison (PWC), and
- the mean opinion score (MOS).

The participants took part in both tests and always started with the pairwise comparison test. In the PWC test, ten younger and ten older participants were presented with the speech samples, and the other ten younger and ten older participants with the classical music samples. In the MOS test, all 40 participants were presented with the speech and classical music samples. The samples, stored on a PC, were played back through high-quality headsets, the sound was set at a comfortable listening level (speech at 68 dBA, classical music at 66 dBA).

4.2.1 Pairwise comparison

The participants listened to the samples presented in pairs. Their task was to compare the two stimuli in each pair and to indicate what stimulus had a higher sound quality. Thus, participants gave relative judgments. With 4 PWC runs (containing 25 different conditions), each participant judged 246 pairs of samples, as explained earlier. Each pair was presented only once.

During the presentation of a sample pair, the participants could hear the samples by mouse clicking on the buttons labelled ‘fragment 1’ or ‘fragment 2’ on a computer display. They could repeat the samples as often as they wanted. After hearing both samples, the participants made their judgments by mouse clicking on the buttons labelled ‘fragment 1 is better’ or ‘fragment 2 is better’ on the display. After they made their selection, a new pair of samples was presented. For the presentation of the 4 PWC runs, ten different orders were created, resulting in 2 participants (a younger and an older) receiving the same order of runs. The order of the sample pairs within each run was different for each participant (randomized). Prior to the first PWC run, the participants were presented with 10 practice sample pairs, to familiarize them with the experimental procedure and with the sample quality range to be expected in the experiment. In total, the PWC test (4 runs) took approximately 2 hours, including short breaks.

4.2.2 Mean Opinion Score

In this test, the participants rated the quality of the individually presented samples using a five-point scale from ‘bad’ (1) to ‘excellent’ (5) and entered their ratings on a computer display using a keyboard. The presentation of the sample was followed by a warning signal to warn the participants that they should enter their ratings (there was a 2-sec interval between samples). Each sample was presented only once. The participants were tested in groups of 3 or 4, in separate testing booths with individual headphones. For each group of participants, the order of the speech samples (MOS run 1) and of the classical music samples (MOS run 2) was different. About twenty (half) of the participants started with the speech samples and the other participants with the classical music samples. Prior to each MOS run, the participants were presented with eight practice trials to familiarize them with the experimental procedure and with the quality range for both the speech and classical music samples to be expected in the experiment. In total, the MOS test (2 runs) took approximately 25 minutes, including a short break.

4.3 Analysis and results of the pairwise comparison

For each participant, the preference matrix of the samples was determined. Table 4.1 illustrates an artificial comparison between five samples. A cell value of ‘1’ indicates that the column variable is preferred over the row variable, a cell value of ‘0’ indicates that the row variable is preferred. The sum of the column reflects the number of times the column variable is preferred over all row variables.

Sample	Preference				
	A	B	C	D	E
A	-	0	1	0	0
B	1	-	1	1	1
C	0	0	-	0	0
D	1	0	1	-	0
E	1	0	1	1	-
Column total	**3**	**0**	**4**	**2**	**1**

Table 4.1: Quality preference matrix based on an artificial pairwise comparison of five samples.

A cumulative preference matrix of the preference matrices of all participants was calculated for each network configuration, and for speech and classical music separately. In order to determine the rank order of the samples and to normalize the distances between rankings, we constructed a new matrix from the cumulative preference matrix in which the proportion of times a sample was preferred above another is depicted. Then we converted the proportions into Z-scores using the cumulative normal distribution. In order to get an idea of the spread of the Z-scores caused by the individuals participants and to be able to perform statistical analyses on these data, we applied the Quenouille-Tukey-jackknife method. According to this simulation procedure, we calculated the Z-scores 40 times (40 listeners participated in the experiment) by leaving out the data from one participant each time. With the obtained Z-scores it is now possible to rank order the sample conditions within each network configuration.

In order to obtain one rank order that includes the results of the three network configurations, we re-scaled the data. For this purpose we used the Z-scores for the best (ref1) and worst references (ref4) to derive the translation and scaling factors, because these anchor points were included in each of the PWC runs

To detect possible differences in the judgments of the speech samples by younger (younger than 45) and older (between 45 and 65) listeners, we compared the Z-scores of these two groups in a statistical analysis (linear regression Pearson's r). The analysis shows that the Z-scores of the younger and older participants are highly correlated ($0.89 < r < 0.97$ for speech, and $0.84 < r < 0.93$ for classical music, $p<0.05$). This indicates that the two age groups judged the samples in a similar way, and that it is therefore allowed to pool the data of the two groups and consider them as one group.

4.4 Analysis and results of the mean opinion score

In the MOS test the participants rated the quality of the samples on a five-point scale from 'bad' to 'excellent'. For calculation purposes, we converted the judgments to a scale from '1' to '5' where '1' equals 'bad' and '5' equals 'excellent'. Per sample condition, these MOS scores were averaged over the participants.

The MOS scores appear to nicely correspond to the Z-scores. The correlation between the two data sets is very high, correlation coefficient $r = 0.90$ for speech, and $r = 0.96$ for classical music (regression analysis Pearson's r, $p<0.05$). This means that the participants rated the quality of the speech samples in the PWC test in a similar way as they did in the MOS test.

A comparison between the Sanyo, Blaupunkt, and Sony receivers reveals that the quality judgements for Blaupunkt are significant higher than those for Sanyo ($F(2,78)=4.45$, $p<0.02$), and that other differences are not significant.

4.5 Protection ratios

In order to base protection ratios on results of both the MOS and PWC tests, we converted the Z-scores of the PWC test into MOS scores, using the regression line obtained in the regression analysis to project the Z-scores onto the MOS scale. For each test condition, the MOS scores of both datasets were averaged. Figures 4.1, 4.2 and 4.3 present MOS scores as a function of SIR (dB) for speech and the Sanyo receiver, for the conventional, the same program and the HF-synchro networks respectively.

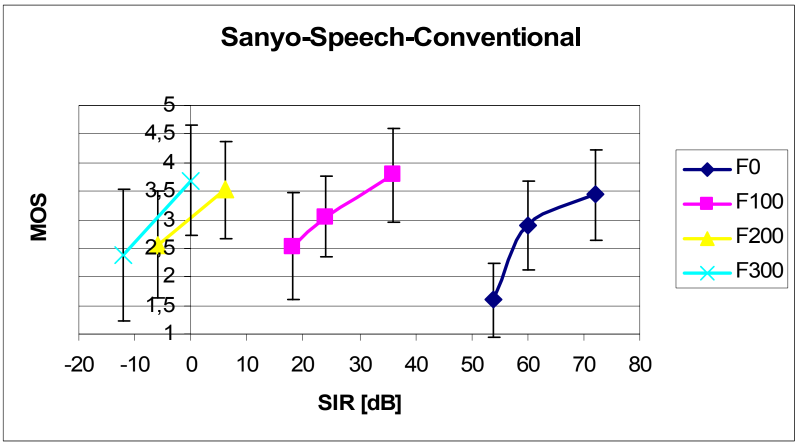


Figure 4.1: Mean opinion score as a function of the signal-to-interference ratio for speech recorded in a conventional network with the Sanyo receiver.

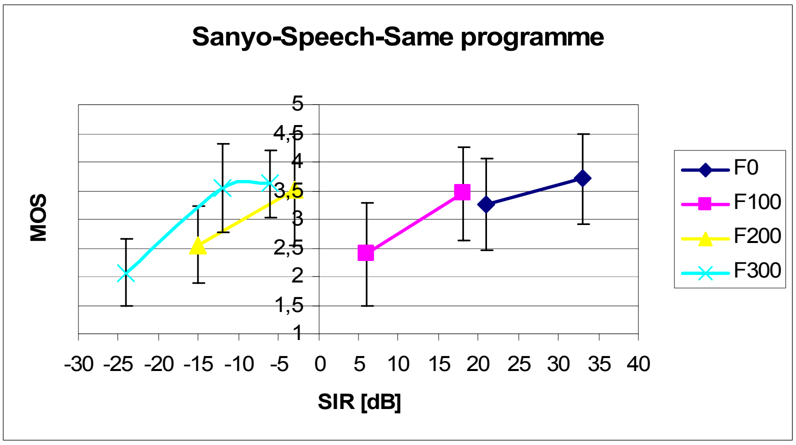


Figure 4.2: Mean opinion score as a function of the signal-to-interference ratio for speech recorded in a same programme network with the Sanyo receiver.

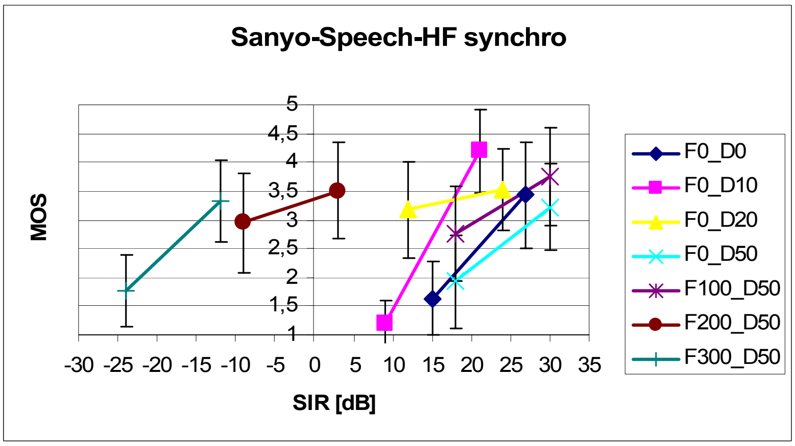


Figure 4.3: Mean opinion score as a function of the signal-to-interference ratio for speech recorded in a HF synchro network with the Sanyo receiver.

Figures 4.4, 4.5 and 4.6 present the results for classical music and the Sanyo receiver, for the conventional, the same program and the HF-synchro networks, respectively.

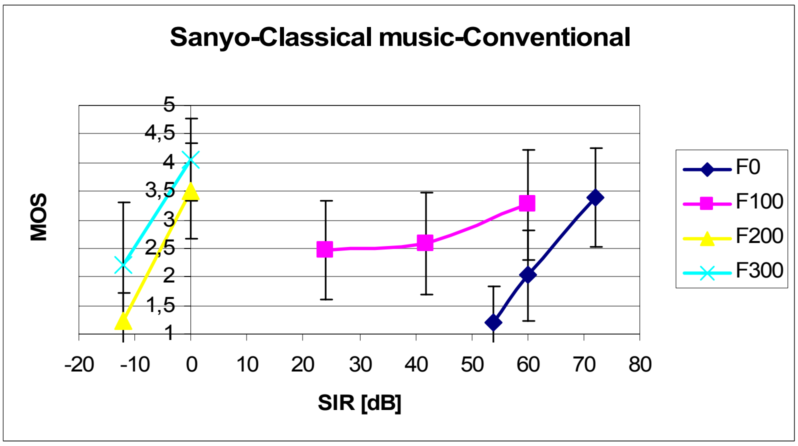


Figure 4.4: Mean opinion score as a function of the signal-to-interference ratio for classical music recorded in a conventional network with the Sanyo receiver.

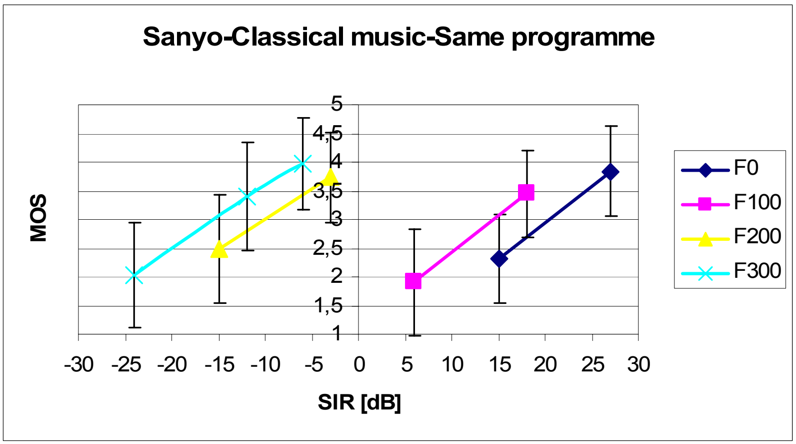


Figure 4.5: Mean opinion score as a function of the signal-to-interference ratio for classical music recorded in a same programme network with the Sanyo receiver.

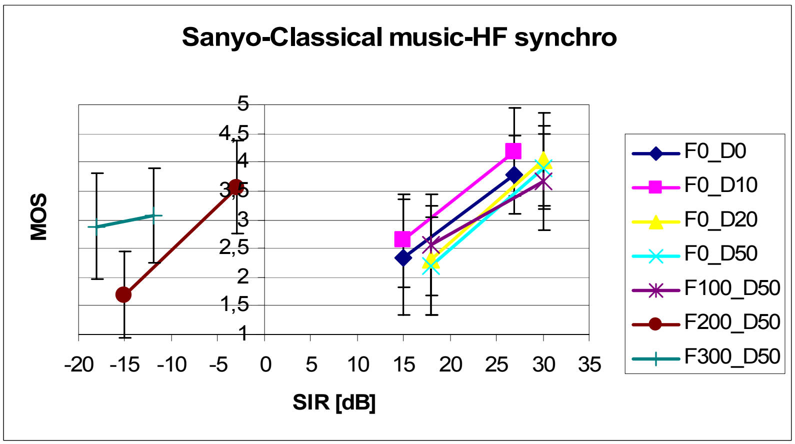


Figure 4.6: Mean opinion score as a function of the signal-to-interference ratio for classical music recorded in a HF synchro network with the Sanyo receiver.

For the Blaupunkt and Sony receivers a MOS test was carried out for speech only. Figures 4.7 and 4.8 show MOS scores as a function of SIR (dB) for Blaupunkt and Sony, respectively.

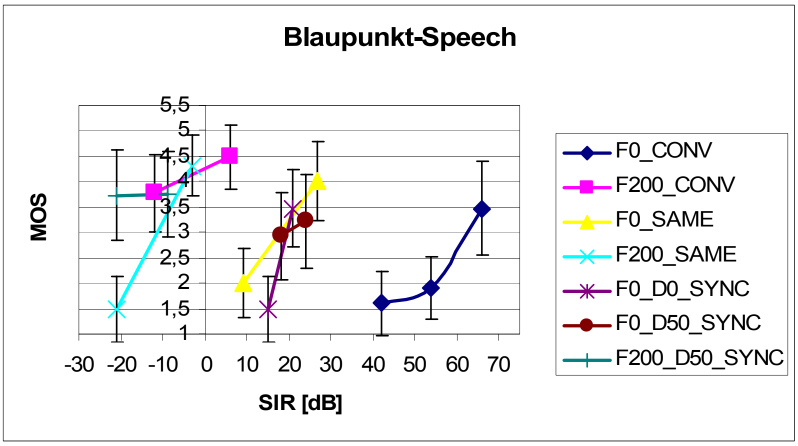


Figure 4.7: Mean opinion score as a function of the signal-to-interference ratio for speech recorded in a conventional, same programme and HF-synchro network with the Blaupunkt receiver.

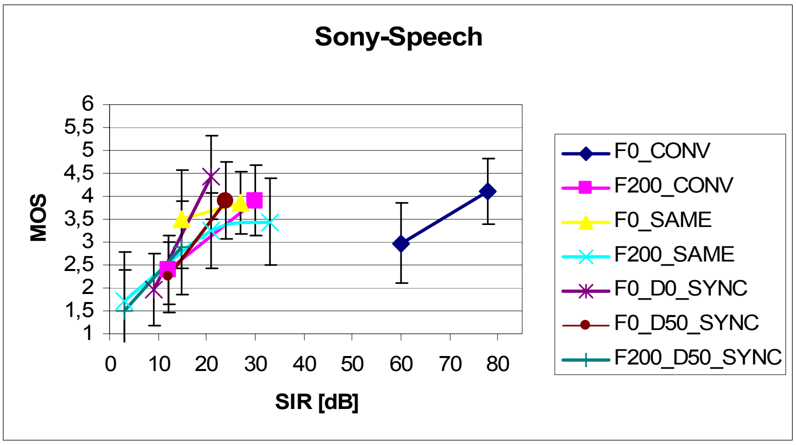


Figure 4.8: Mean opinion score as a function of the signal-to-interference ratio for speech recorded in a conventional, same programme and HF-synchro network with the Sanyo receiver.

If a quality criterion of MOS = 3.5[1] is regarded as acceptable, then the following protection ratios can be obtained.

[1] The criterion of MOS = 3.5 is similar to the criterion applied in the ZeroBase study .

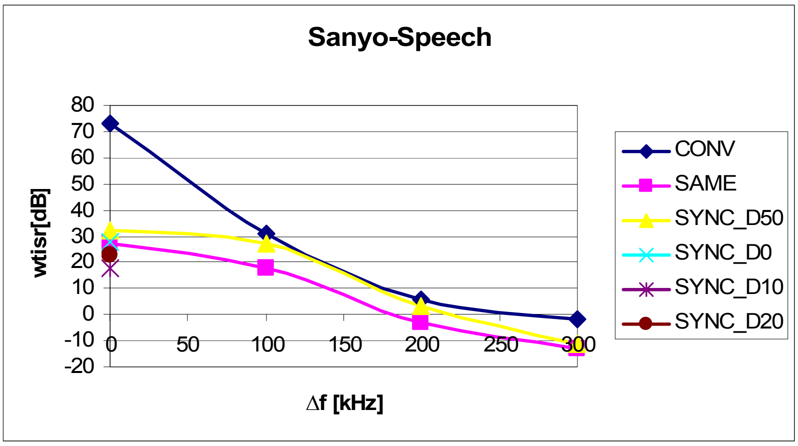


Figure 4.9: The protection ratio as function of the frequency distance based on a mean opion score of 3,5 for speech recorded with the Sanyo receiver.

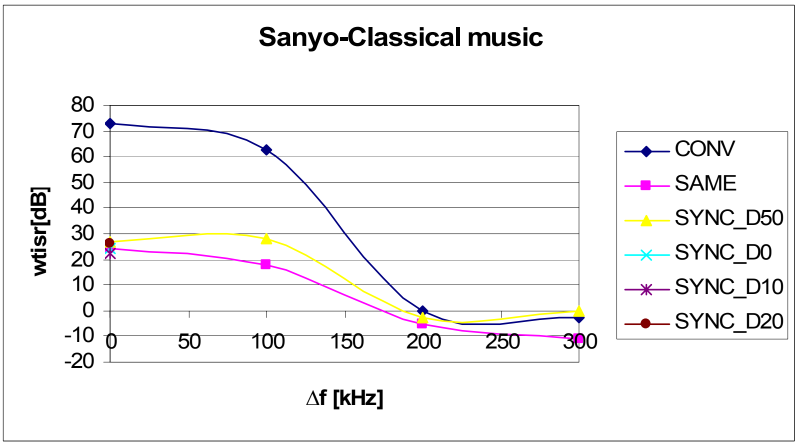


Figure 4.10: The protection ratio as function of the frequency distance based on a mean opion score of 3,5 for classical music recorded with the Sanyo receiver.

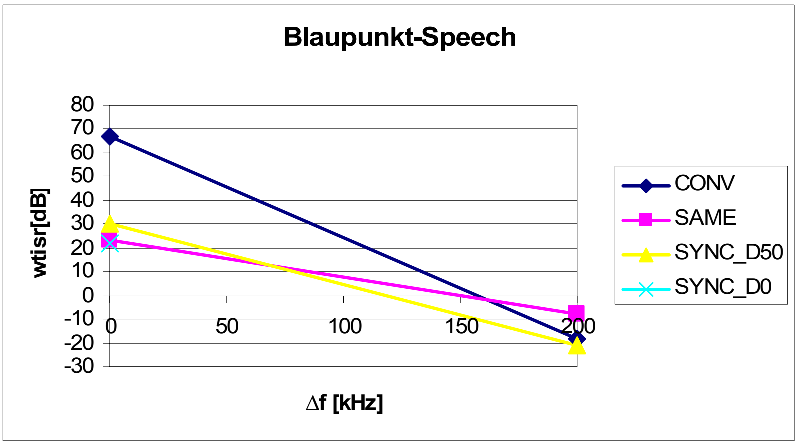


Figure 4.11: The protection ratio as function of the frequency distance based on a mean opion score of 3,5 for speech recorded with the Blaupunkt receiver.

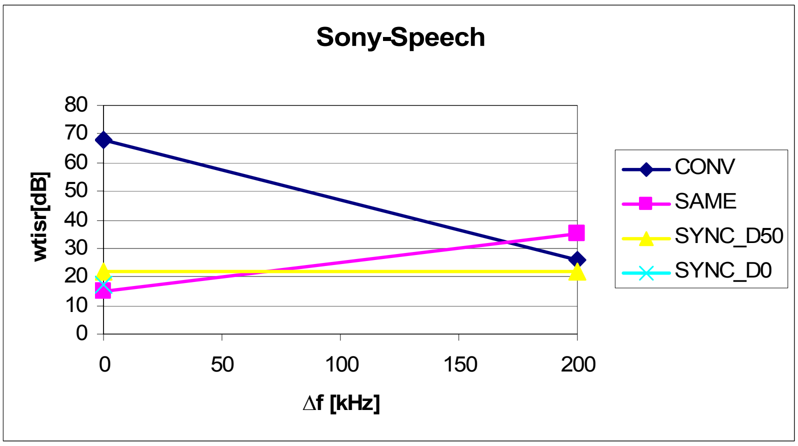


Figure 4.12: The protection ratio as function of the frequency distance based on a mean opion score of 3,5 for speech recorded with the Blaupunkt receiver.

It should be noted that the protection ratios are obtained by means of interpolation and extrapolation and may differ from the values obtained through real experimental measurement.

The protection ratios show some surprising results. First, the network configuration same programme resulted in a lower protection ratio than HF-synchro. The opposite was expected. Second, a higher delay didn't always result in a higher protection ratio for the network configuration HF-synchro. Third, the Sony required a higher protection ratio for Δf=200 kHz than for Δf=0 kHz. This result is in contradiction with the results of the objective measurements. Fourth, the bad receiver required a lower protection ratio for Δf=0 kHz for both the network configuration HF-synchro and same programme than the good receiver.

The consequences of these protection ratios for frequency planning will be discussed in the next chapter.

5 Consequences for frequency planning

5.1 General

5.1.1 ITU

Recommendation ITU-R BS.412-9 indicates that protection ratios for steady interference provide approximately 50 dB signal-to-noise ratio. The protection ratios for tropospheric interference correspond closely to a slightly annoying impairment condition. According to Recommendation ITU-R BS.562-3, table 1, ‘slightly annoying’ relates to grade ‘3’ on the five-grade impairment scale.

It is not clear why the curves for steady and tropospheric interference of Recommendation ITU-R BS.412-9 merge from 200 kHz onwards. Possibly the effect that stations with higher frequency separations may be closer and therefore only steady interference is interest, has been brought in the curves.

Recommendation ITU-R BS.412-9 states that in case of identical programmes an improvement of the protection ratio is expected at least for monophonic signals. In case of the same frequency and modulation, with synchronised signals, the protection ratios for monophonic signals are much lower than the one for different programmes. For stereophonic signals the protection ratios depend on the propagation delay and stereophonic content.

Recommendation ITU-R BS.641 recommends to use an objective method using a sinusoidal tone of 500 Hz as wanted signal and a standard coloured noise signal as interfering source.

5.1.2 This study

In objective tests according to Recommendation ITU-R BS.641, the test conditions for achieving an audio signal-to-noise ratio of approximately 50 dB could not be reached with most receivers. Therefore the audio signal-to-noise ratio for the tests has been lowered to 40 dB. The results should therefore not be compared to the ITU-R protection ratio values for steady interference, which provide approximately 50 dB signal-to-noise ratio. It raises however the question if the quality standard for steady interference is not too high for present day FM reception.

The objective results show a great variety in performance of the tested receivers. A receiver with an average protection ratio curve has been selected as reference receiver. Car radios are in general considered as better than the reference receiver (higher achievable audio signal-to-noise-ratio and better selectivity), and walkman-radios are in general considered as worse receivers. If frequency planning is based on the average receiver, it should be born in mind that a large number of receivers may be subject to more than ‘slightly annoying’ interference, in particular resulting from transmitters with frequency differences of 200 kHz and 300 kHz. On the other hand in particular car radios may still give acceptable reception outside the calculated coverage area.

Three network configurations have been subjectively tested:

- Conventional.

- Same programme.
- Synchronised.

Of these three conditions, conventional corresponds to the ITU conditions. However in the FM receiver study the wanted signal was either speech or classical music, whereas pop/rock has been used as interfering signal. These test conditions are much more critical than using a sinusoidal tone of 500 Hz as wanted signal and a standard coloured noise signal as interfering source as referred to in Recommendation ITU-R BS.412-9.

Seen the remarks in Recommendation ITU-R BS.412-9 and results of investigations in the Netherlands, it is expected, that "same programme" results in considerable lower protection ratios than "conventional". Furthermore "synchronised" with small delay times is expected to give somewhat lower protection ratios than "same programme".

The subjective tests certainly show the first expectation. But the synchronised condition appears not to be better than "same programme". This may be caused by the performance of the digital exciters that were agreed to be used for the tests. Monitoring of the audio quality of the sound samples recorded in this part of the tests showed a poorer sound quality compared to the sound quality in the tests with the analogue exciters.

5.2 Considerations on protection ratios for conventional networks

5.2.1 Comparison

The results from the protection ratio measurements for the "conventional" case and for the selected reference receiver are compared with the ITU values in the tables 7.1 and 7.2.

Δf [kHz]	Protection Ratios [dB]			
	ITU-Steady Interference	ITU-Tropospheric Interference	Sanyo-Speech MOS score 3,5	Sanyo-Speech MOS score 3,0
0	45	37	73	61
100	33	25	31	24
200	7	7	6	0
300	-7	-7	-2	-6

Table 7.1: Comparison between the protection rations from recommendation ITU-R BS.412-9 and those based on the subjective tests for conventional networks.

Δf [kHz]	Protection Ratios [dB]			
	ITU-Steady Interference	ITU-Tropospheric Interference	Sanyo-Objective method (ITU-R BS.641)	Average- Objective method (ITU-R BS.641)
0	45	37	34	34
100	33	25	16	25
200	7	7	-4	-9
300	-7	-7	-22	-25

Table 7.2: Comparison between the protection rations from recommendation ITU-R BS.412-9 and those based on the objective tests for conventional networks.

5.2.2 Conclusions regarding conventional networks

The following conclusions can be drawn:

- The average results of the objective measurements compare well to the ITU-tropospheric values for 0 and 100 kHz.
- The subjective tests using speech as wanted signal and pop/rock as interfering signal show a considerable higher protection ratios than the objective tests.
- ITU tropospheric values are likely to correspond to quality grade 3. It is therefore proposed to use results of the FM receiver test presented for grade 3 as the basis for protection ratios for tropospheric interference.
- ITU steady interference is based on an unspecified grade which is higher than 3 and provides an audio signal-to-noise ratio of about 50 dB. The subjective tests show relative few results for grade 4. Furthermore grade 4 would likely result in unrealistic high values. It is therefore proposed to use grade 3.5 as the basis for protection ratios for steady interference.
- Taking into account the great variety in performance of the tested receivers and the subjective results that are more or less in line with the ITU values (except the 0 kHz case) it is advised to use the protection ratio values of Recommendation ITU-R BS.412-9 for frequency planning in case of conventional networks.

5.3 Considerations on protection ratios for same programme networks

5.3.1 Comparison

The results from the protection ratio measurements for the same programme case and for the selected reference receiver are compared with the ITU values in the Table 5.1.

Δf [kHz]	**Protection Ratios [dB]**			
	ITU-Steady Interference	ITU-Tropospheric Interference	Sanyo-Speech MOS score 3,5	Sanyo-Speech MOS score 3,0
0	45	37	27	19
100	33	25	18	12
200	7	7	-3	-9
300	-7	-7	-13	-17

Table 5.1: Comparison between the protection rations from recommendation ITU-R BS.412-9 and those based on the subjective tests for same programme networks.

5.3.2 Conclusions regarding same programme networks

The following conclusions can be drawn:

- The results of the subjective tests for the network condition same programme show a considerable improvement compared to the ITU values which are for wanted and interfering signals having different programmes, also taking into account that the test conditions (wanted signal speech, unwanted signal pop/rock) are much more unfavourable than the conditions assumed for the ITU results.

- No reliable result could be found for 0 kHz, grade 3. Extrapolation of the results in the table above would lead to about 19 dB.
- For frequency planning of transmitters carrying the same programme it is advised to use the protection ratios based on MOS score3,5 in case of steady interference. Furthermore the considerations of section 5.2.2 should be taken into account.
- For frequency planning of transmitters carrying the same programme it is advised to use the protection ratios based on MOS score3,0 in case of tropospheric interference. Furthermore the considerations of section 5.2.2 should be taken into account.

5.4 Considerations on protection ratios for HF-synchro networks

5.4.1 Comparison

The preliminary results from the protection ratio measurements for the “synchronised” case and for the selected reference receiver are compared with the ITU values in the table 7.4 in case of a frequency difference of 0 kHz. For reference also the values for same programme measured with a delay of 50 µs are indicated between brackets.

Delay [µs]	Protection Ratios [dB]			
	ITU-Steady Interference	ITU-Tropospheric Interference	Sanyo-Speech MOS score 3,5	Sanyo-Speech MOS score 3,0
0	45	37	28	24
10	45	37	18	16
20	45	37	23	-
50	45	37	32 (27)	26 (19)

Table 5.2: Comparison between the protection rations from recommendation ITU-R BS.412-9 and those based on the subjective tests for HF-synchro for Δf=0kHz. The values between brackets represent the values for network configuration same programme under the same conditions.

5.4.2 Conclusions regarding HF-synchro networks

The following conclusions can be drawn:

- The results of the subjective tests for the network condition hf-synchro show a considerable improvement compared to the ITU values which are for wanted and interfering signals having different programmes, also taking into account that the test conditions (wanted signal speech, unwanted signal pop/rock) are much more unfavourable than the conditions assumed for the ITU results.
- Although it was expected that the results for synchronised transmissions with a delay of 50 µs would be similar as those for same programme, the protection ratio in the synchronised case appears to be higher.
- Although an increase in protection ratio with delay time had been expected, the results show in particular for the 0 µs case an relative high value.

- The results for the delays 0, 20 and 50 µs are relatively close to each other, statistical analysis has shown that there is no significant difference.
- As synchronised transmitters are more complicated to operate and the results are not significantly better than same programme it is advised not to use synchronised transmitters for achieving a higher frequency efficiency, but in stead same programme.

5.5 Planning considerations

5.5.1 Usable field strength calculations

For calculating usable field strength, the nuisance fields of relevant interfering transmitters should be calculated. Transmitters carrying the same programme should be identified. This may require a special code in the transmitter database. The nuisance field of these transmitters should be calculated with the reduced protection ratios (see section 7.3). The nuisance field of the other relevant transmitters should be calculated with the protection ratios for conventional networks (see section 7.2). All relevant nuisance fields should be combined using the agreed method (e.g power sum).

5.5.2 Optimised networks

The use of protection ratios for same programme networks may lead to higher frequency efficiency in case coverage areas are interference limited. However flexibility in network operation is reduced. If a transmitter that is part of the network for which the reduced protection ratios are applied, needs to carry another programme, either a regional opt-out or a completely different programme, a new network planning is required; the reduced protection ratios are not applicable any more.

The application of transmitters with frequencies N ± 200 or 300 kHz with the same programme is particularly useful for coverage optimisation in the periphery of a coverage area of a transmitter with frequency N. As there is a negative protection ratio, either the transmitter with frequency N or the one with N ± 200 or 300 kHz (having the same programme) can always be received.

Another application could be made in case of a more or less full replanning. A network carrying the same programme could consist of several transmitters having frequency differences of 0 or 100 kHz. The interference zones between these transmitters should be covered by transmitters on other frequencies. It may also be possible by careful planning to situate the interference zones in areas of low population densities. Also in this case coverage areas can be optimised by transmitters with frequency differences of 200 or 300 kHz as described above.

An example of a network that has been planned on the basis of reduced protection ratios for transmitters carrying the same programme is shown in annex [7.1]. This network shows the combination of cases indicated above. The network consists mainly of two sets of frequencies, around 103.1 MHz and around 97.7 MHz respectively. Although the example shows the way planning could be done, it should be noted that the protection ratios in this example are different than those advised in this report. Furthermore also other criteria and methods in the example are different than those recommended by ITU.

5.5.3 International frequency coordination

Reduced protection ratios for networks carrying the same programme are not contained in GE84 plan and are not recommended by ITU. Also the GE84 transmitter databases do not contain provisions for indicating that transmitters are working in networks carrying the same programme. Calculations done in the framework of GE84 frequency co-ordinations can therefore not take into account the reduced protection ratios. The usable field strength at test points in the coverage area of transmitters with the same programme, in these circumstances may therefore be much higher than calculated for national frequency planning purposes. Consequently more interference may need to be accepted from neighbouring countries, unless specific bi-lateral agreements have been made.

It is advisable to make such bi-lateral agreements before national planning starts in order to take into account possible limitations resulting from interference to neighbouring countries in a proper way.

5.5.4 General observations

The three tested categories of receivers show clearly different results. In general portable receivers have an average performance, car radios show a better audio signal-to-noise ratio and are more selective. Walkman radios are worse in audio performance and selectivity.
It could be considered to create two sets of planning criteria (as is proposed for T-DAB in relation to the RRC). One set for portable reception and one set for mobile reception. Coverage areas could, as far as possible, be optimised for portable reception in urban areas and mobile reception on motorways and major roads. Planning criteria suitable for walkman radios would result in very spectrum demanding frequency plans. The more pragmatic approach is not to plan for reception by walkman radios and leave it to the user if and where to use these kind of receivers. However, if more dense FM networks are planned reception on walkman radios may become more limited than at present.

6 Comparison with zero-base results in The Netherlands

6.1 General

The results from this study show somewhat different results than those from the zero-base FM study in The Netherlands. It should be noted that the starting points for both studies were different. The main differences are given in the table below.

Item	Zero-Base study	This study
Receivers	Tuners, portables and car radios	Portables, car radios, walkman-type radios
Reference receiver	NAD 1600 tuner	Sanyo DC-DA1000 portable
S/N in objective tests	50 dB	40 dB
Frequency deviation	ITU-R SM.1268, annex 1	ITU-R SM.1268, annex 2

Table 6.1: Differences between the starting point for this study and the Zero-Base study.

6.2 Conventional network

The tables below show a comparison between the values used for FM planning in The Netherlands. For this study it was concluded to use the ITU values for conventional networks.

Δf [kHz]	Steady interference		Troposferic interference	
	NL values [dB]	This study [dB]	NL values [dB]	This study [dB]
0	40	45	32	37
100	30	33	22	25
200	-2	7	-2	7
300	-15	-7	-15	-7

Table 6.2: Comparison between this study and the Zero-Base study for the network configuration conventional.

The 3 to 8 dB reduction in protection ratios, compared to ITU, as used in The Netherlands for conventional networks have not been confirmed by this study.

6.3 Same programme network

In the Zero-Base project the MPX synchronisation has been used. Although it is not exactly the same as the network operation a comparison between the two is possible.

Only protection ratios for steady interference were used in the Zero-Base project because it assumed that synchronised transmitters are spaced relatively closely.

Δf [kHz]	Steady interference		Troposferic interference	
	NL values (MPX synchro) [dB]	This study (same programme) [dB]	NL values (MPX synchro) [dB]	This study (same programme) [dB]
0	25	27		20
100	5	18		12
200	-2	-3		-9
300	-15	-13		-17

Table 6.3: Comparison between this study and the Zero-Base study for the network configuration same programme.

The values for same programme and steady interference do not differ that much from the Zero-Base values for MPX synchronisation, except for 100 kHz frequency difference. It should be noted however, that the Zero-Base protection ratio at 100 kHz difference is optimistic.

6.4 Synchronised network

As indicated above the synchronised conditions in the Zero-Base project were different than for this study.

The table below only shows the protection ratios for synchronised transmitters with a delay of 50 μsec. In the Zero-Base study a delay of 50 μsec has not been measured. The table show the interpolated value between 20 and 100 μsec.

Only protection ratios for steady interference are used in the Zero-Base project because it assumed that synchronised transmitters are spaced relatively closely.

Δf [kHz]	Steady interference		Troposferic interference	
	NL values (MPX synchro) [dB]	This study (HF-synchro) [dB]	NL values (MPX synchro) [dB]	This study (HF-synchro) [dB]
0	18	32		28
100	5	28		21
200	-2	3		-9
300	-15	-11		-15

Table 6.4: Comparison between this study and the Zero-Base study for the network configuration HF-synchro.

The results from this study show reasonably high for 0 kHz and 100 kHz. The reason for this could be the different synchronisation used.

7 High signal performance

High signal performance can be defined as the tendency of a receiver to inter-modulate in the presence of strong signals. Recommendation ITU-R BS412 describes a method for determining a receiver's performance in the presence of strong signals. This measurement uses three RF signals: one wanted signal and two interfering signals. The performance is expressed as a protection ratio. Details of the high signal performance test can be found in the next paragraphs.

7.1 Approach

The frequencies of the two interfering signals of equal levels are positioned above or below the frequency of the wanted signal at equal differences of frequencies. The frequency difference is defined as:

$$\Delta f = f_{i2} - f_w = f_{i1} - f_{i2} \quad (1)$$

The interfering signal f_{i2} is unmodulated and the interfering signal f_{i1} is modulated with coloured noise according to Recommendation ITU-R BS.461. The RF protection ratio is measured according to the same recommendation, the only difference being that two interfering signals are used.

The procedure for determining the interference caused by inter-modulation of strong RF be can be split up in the following three steps:

1 – *Setting up the wanted transmitter (Determination of the reference level).*

Source A of the multi-source generator, which represents the wanted transmitter, is frequency modulated with a 500 Hz sinusoidal tone. The output level of the tone generator is adjusted to obtain a frequency deviation of ±75kHz, including the pilot tone in stereophonic operation. The QUASI-PEAK reading of the modulation analyzer, with the weighting network switched off (i.e. CCIR UNWEIGHTED) indicates the reference level. This reference level corresponds to 0 dB.

2 - *Setting up the unwanted transmitters.*

Source B of the multi-source generator, which represents the first unwanted transmitter, is modulated with a 500 Hz sinusoidal tone obtained from tone generator. The output level of source B is adjusted to obtain a deviation of ±32 kHz. The audio-frequency level at the input of the unwanted transmitter before pre-emphasis is measured by means of the modulation analyzer (noise meter U). The noise-weighting network is switched off (i.e. CCIR UNWEIGHTED). Next a noise signal obtained from the noise generator replaces the sinusoidal tone and its output level is adjusted to obtain the same QUASI-PEAK reading as before at the noise meter. Source C of the multi-source generator, which represents the second unwanted transmitters, is unmodulated. The output level of source C is made equal to the output level of source B.

3 - *Measuring the radio-frequency protection ratio curve.*

The following procedure is repeated for frequency differences ranging from 500 kHz to 5 MHz in steps of 500 kHz:

The output levels of the unwanted transmitters are kept equal and are simultaneously adjusted to obtain an audio-frequency signal-to-interference ratio of 40 dB at the audio-frequency output of the receiver. In this case, the weighting network of the modulation analyzer must be switched in (i.e. CCIR WEIGHTED) and the QUASI-PEAK detector must be selected . The ratio between the radio-frequency levels of the wanted and unwanted transmitters is the required radio-frequency wanted-to-interfering signal ratio.

7.2 Results

The high signal performance tests are executed for two receivers from the category portables a handhelds. For the first category the Sanyo DC-DA1000 and the Sony CFD-S550L are tested, for the second category the Philips AZT9500 and the Sony WM-FX491.

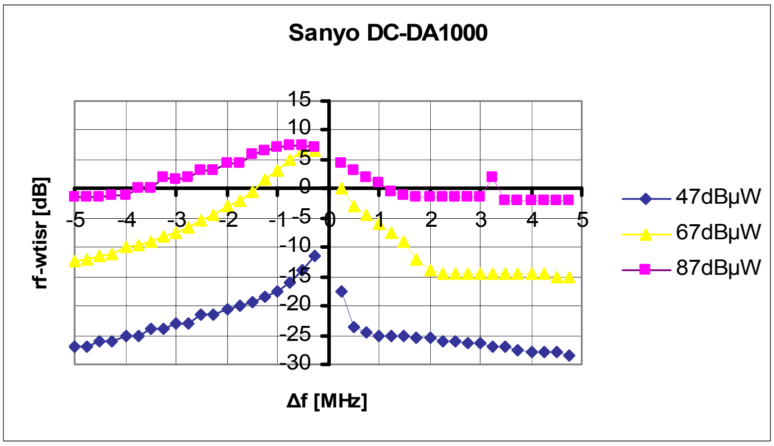


Figure 7.1: Radio-frequency wanted-to-interfering signal ratio as a function of frequency difference for the Sanyo receiver.

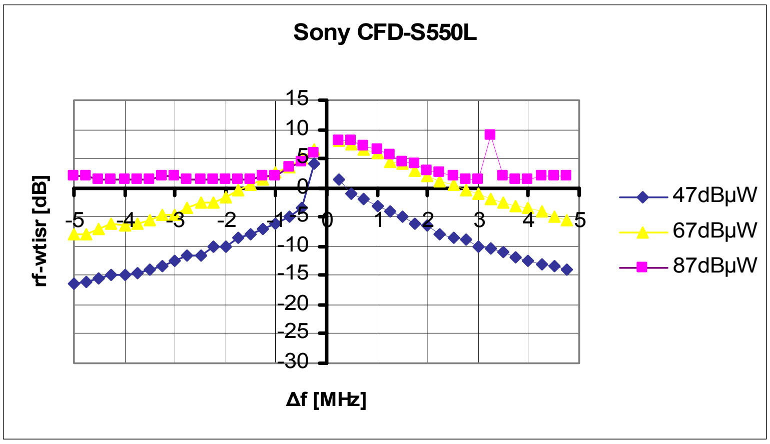


Figure 7.2: Radio-frequency wanted-to-interfering signal ratio as a function of frequency difference for the Sony receiver.

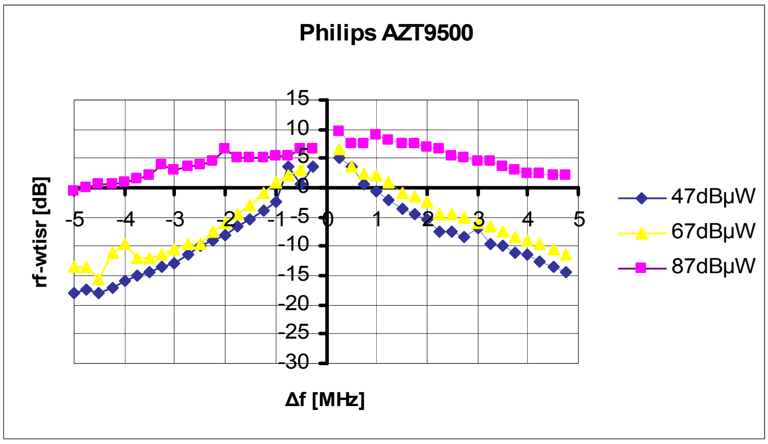


Figure 7.3: Radio-frequency wanted-to-interfering signal ratio as a function of frequency difference for the Philips receiver.

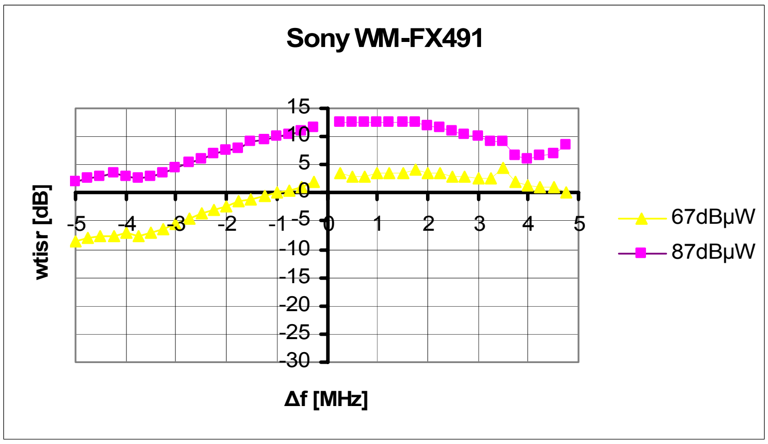


Figure 7.4: Radio-frequency wanted-to-interfering signal ratio as a function of frequency difference for the Philips receiver.

Expected was that the graphs would be symmetric with respect to Δf. This, however, is not confirmed by the results. Possible explanation for this would be that the characteristics of amplifier in the receiver are frequency dependent. The results for the Sanyo DC-DA1000 for Δf>0 are in fair agreement with an investigation performed in the Federal Republic of Germany of domestic and car FM radio receivers on their tendency to inter modulate in the presence of strong RF signals. In most cases the performance of both the Sony CFD-S550L and the Philips AZT9500 is worse than the Sanyo DC-DA1000 but better than the Sony WM-FX491.

In general, the results clearly indicate that inter-modulation products significantly deteriorate the performance of the receiver under test. The frequencies of the second and third order inter-modulation product, expressed in f_w and Δf, can found in Table 7.1.

Order of the IM products	Frequencies of the IM-products
Second	Δf, $2\Delta f$, $2f_w$, $2f_w+\Delta f$, $2f_w+2\Delta f$, $2f_w+3\Delta f$,$2f_w+4\Delta f$
Third	$f_w-2\Delta f$, $f_w-\Delta f$, f_w, $f_w+\Delta f$, $f_w+2\Delta f$, $f_w+3\Delta f$, $f_w+4\Delta f$, $3f_w$, $3f_w+\Delta f$, $3f_w+2\Delta f$, $3f_w+3\Delta f$, $3f_w+4\Delta f$, $3f_w+5\Delta f$, $3f_w+6\Delta f$

Table 7.1: Frequencies of the first, second and third order inter-modulation products for the choice of frequencies in accordance with (1).

From this table it can be seen that the inter-modulation effects are caused by third order inter-modulation products. The effect of these third order inter-modulation products is most noticeable when they are located in the pass-band of the receiver.

Experience in The Netherlands has shown that interference from third order inter-modulation products may take place if reception is near an FM transmission site where many frequencies are used and:

a) at least one with much lower power (for instance a local station) than the others
b) reception of signals from another, more distant, site is required

In these situations frequencies should as far as possible be chosen in such a way that no third order inter-modulation products occur in the pass-band of the receiver tuned to the low level signal. If it is not possible to avoid third order inter-modulation products in case a) the power of the low power transmission may need to be increased in order to achieve the required protection ratio for this situation. In case b) a fill-in transmitter may be required that fulfils the conditions indicated for case a).

An example of case b) in the Netherlands is shown in Appendix C

The results for Sanyo DC-DA1000 are in fair agreement with an investigation performed in the Federal Republic of Germany of domestic and car FM radio receivers on their tendency to inter modulate in the presence of strong RF signals. The performance of both Sony CFD-S550L and Philips AZT9500 is worse than the Sanyo DC-DA1000 but better than the Sony WM-FX491.

8 RDS Switching

This receiver study focuses on two aspects of RDS switching behavior. The first one investigates the RDS switching behavior due to differences in radio frequency levels of two different sources transmitting the same program on different frequencies. The second one investigates the RDS switching behavior due to multipath. The approach followed in both cases will be explained in the next paragraph.

8.1 Approach

8.1.1 RDS switching behavior due to differences in radio frequency levels

This test represents the situation when traveling from the coverage area of one transmitter to the coverage area of another transmitter belonging to the same program chain and thus transmitting the same program on a different frequency. This test investigates the behavior of a receiver under such conditions and can be split up in the following two steps:

1 - Setting up the transmitters.

Sources A and B of the multi source generator are frequency modulated with a 500 Hz sinusoidal tone and RDS. For both sources the frequency deviation due to RDS is set to 2 kHz. The combined output of sources A and B is fed to the receiver under test.

2 - Measuring the radio frequency switching level

The following procedure is repeated for the following combinations of carrier frequencies:

Combination	Source A, f (MHz)	Source B, f (MHz)
1	90,0	105,0
2	90,0	90,1
3	105,0	90,0
4	90,0	89,9

Table 8.1: Frequency combinations for RDS switching behavior due to differences in radio frequency levels.

The carrier frequency of sources A and B are set according to table 8.1. The radio frequency levels of both sources are set to the same level. The receiver under test is tuned to source A. Next the radio frequency level of source A is lowered, in steps of 1 dBµV, until the receiver under test switches to source B. The radio frequency level of source A at the time of the switch over is the required radio frequency switching level.

8.1.2 RDS switching behavior due to multipath

This test represents the situation where the receiver receives a number of reflected signals. Normally a channel simulator is used for multi path testing. Due to the fact that such a device was not available an alternative approach for measuring multi path effects is explained below. This alternative test can be split up into the following two step:

1 - Setting up the transmitters.

Sources A and B of the multi source generator are frequency modulated with a 500 Hz sinusoidal tone and RDS. For both sources the frequency deviation due to RDS is set to 2 kHz. Station C of the multi source generator is frequency modulated with pop music. The outputs of sources A, B and C are combined and fed to the receiver under test.

2 - Measuring the radio frequency switching level

The following procedure is repeated for the following combinations of carrier frequencies:

Combination	Source A, f (MHz)	Source B, f (MHz)
1	90,0	105,0
2	90,0	90,3
3	105,0	90,0
4	90,0	89,7

Table 8.2: Frequency combinations for RDS switching behavior due to multipath.

The carrier frequency of sources A and B are set according to Table 8.2. The carrier frequency of source C is made equal to that of source A. The radio frequency levels of sources A and B are set to the same level. The receiver under test is tuned to source A. The radio frequency level of source C is chosen such that it does not lead to any interference on channel A. Next the radio frequency level of source C is raised, in steps of 1 dBμV, until the receiver under test switches to source B. The radio frequency level of source C at the time of the switch over is the required radio frequency switching level.

8.2 Results

8.2.1 RDS switching behavior due to differences in radio frequency levels

The level of sources A and B is set to 60 dBμV. The radio-frequency level of source A at the time of switch over is given in table 8.3.

Receiver	f, source A (MHz) & f, source B (MHz)			
	90,0&105,0	90,0&90,1	105,0&90,0	90,0&89,9
Blaupunkt Woodstock DAB52	40	56	27	58
Jvc KD-SX997R	18	58	49	58
Vdo Dayton CD2200	12	55	12	60
Sony CDX-M850MP	54	53	45	49
Becker Mexico Pro CD4627	50	58	46	58
Jvc KS-FX480REX	11	57	12	58
Panasonic CQ-RDP003N	33	58	31	57
Panasonic CQ-RDP162N	30	58	30	56

Table 8.3: Results for RDS switching behaviour due to differences in radio-frequency levels. The value in the cell is the radio-frequency level, in dBμV, of source A when the receiver switches from source A to source B.

Based on the results he following conclusions can be drawn:

- When the frequency difference is small, a small reduction of the radio-frequency level makes all receivers switch over.
- When the frequency difference is large (Δf>300 kHz), some receivers accept a low radio-frequency level before switching over while other receivers already switch over after a small reduction of the radio-frequency level.
- The Blaupunkt Woodstock DAB52 and the JVC KD-SX997 show an asymmetric switching behaviour for large frequency differences. The reason for this behaviour is not clear.
- The Sony and the Becker switch over after a small reduction in radio-frequency level for both small and large frequency differences. For the other car radios the switching behaviour depends on the frequency differences.

8.2.2 RDS switching behavior due to multipath

The level of sources A and B is set to 60 dBμV. The radio-frequency level of source C at the time of switch over is given in table 8.4.

Receiver	**f, source A (MHz) & f, source B (MHz)**			
	90,0&105,0	**90,0&90,3**	**105,0&90,0**	**90,0&89,7**
Blaupunkt Woodstock DAB52	46	47	-	47
Jvc KD-SX997R	44	41	-	41
Vdo Dayton CD2200	55	52	53	50
Sony CDX-M850MP	40	40	40	42
Becker Mexico Pro CD4627	49	48	49	47
Jvc KS-FX480REX	78	41	43	41
Panasonic CQ-RDP003N	42	43	41	42
Panasonic CQ-RDP162N	41	43	42	42

Table 8.4: Results for RDS switching behaviour due to multipath. The value in the cell is the radio-frequency level, in dBμV, of source C when the receiver switches from source A to source B.

In general all receivers, except the Jvc KS-FX480REX, show a comparable multipath behaviour.

Appendix A: Detailed results of the protection ratio measurements

RECEIVER	tof	rf-w2isr max [dB]	wt-rfl max [dBµV]	m/s		ut-afl[V]: dev=32kHz	wt-afl[V]: afs2ir=46dB	ut-dev [Hz]	wt-dev [Hz]	wt-rfl [dBµV]: snr=20dB	wt-rfl [dBµV]: snr=20dB corrected	wt-rfl [dBµV] afs2ir=46dB	rfw2isr [dB]: Δf=-400kHz	rfw2isr [dB]: Δf=-350kHz	rfw2isr [dB]: Δf=-300kHz	rfw2isr [dB]: Δf=-250kHz	rfw2isr [dB]: Δf=-200kHz	rfw2isr [dB]: Δf=-150kHz	rfw2isr [dB]: Δf=-100kHz	rfw2isr [dB]: Δf=-50kHz	rfw2isr [dB]: Δf=-0kHz	rfw2isr [dB]: Δf= 50kHz	rfw2isr [dB]: Δf= 100kHz	rfw2isr [dB]: Δf= 150kHz	rfw2isr [dB]: Δf= 200kHz	rfw2isr [dB]: Δf= 250kHz	rfw2isr [dB]: Δf= 300kHz	rfw2isr [dB]: Δf=-350kHz	rfw2isr [dB]: Δf=-400kHz
													-400	-350	-300	-250	-200	-150	-100	-50	0	50	100	150	200	250	300	350	400
CAR RADIOS																													
KENWOOD KDC-3024A	D	-52,5	51	S	V	0.9046	0.9258	32010.14	74724.57	-0.90	-	35.30	-58	-57	-55,5	-54,5	-47	-10	14,5	38	35	41,5	18,5	-5	-43	-50	-52	-54,5	-56,5
PANASONIC CQ-RDP162N	D	-57,5	64	S	V	0.9108	0.9259	32042.29	74956.31	4.50	-	41.40	-35	-34,5	-33,5	-32,5	-31,5	-17,5	14	31,5	27,5	33	17	-9	-23,5	-22	-23	-25,5	-28,5
PANASONIC CQ-RDP003N	D	-56,6	60	S	V	0.9017	0.9258	31993.26	74872.42	1.20	-	38.30	-56,5	-55	-54,5	-50,5	-27	-1	19	41,5	36,5	41	17	-6,5	-42	-54	-54	-55	-55,5
BECKER MEXICO PRO CD 4627	D	-51	60	S	V	0.9041	0.9256	31950.95	74685.72	1.90	-	37.10	-51,5	-47,5	-34,5	-50,5	-44	-11,5	19	40,5	35,5	41	18,5	-11,5	-42	-50	-51,5	-53	-52,5
BLAUPUNKT WOODSTOCK DAB 52	D	-57	62	S	V	0.9131	0.9256	31984.38	74875.18	-0.90	-	36.20	-62	-61,5	-61	-60	-53	-9,5	19	40,5	35	40	18	-15	-38,5	-40,5	-62	-62,5	-63
SUPERTECH AR-921 CD	D	-55,3	59	S	V	0.9077	0.9256	31976.70	74756.56	16.70	-	43.30	-21	-16	-17	-13	5	15	21,5	41,5	37	42,5	17,5	-14,5	-21,5	-20,5	-24	-22,5	-27
JVC KD-SX997R	D	-52	53	S	V	0.9067	0.9256	31974.76	74719.53	-0.90	-	35.80	-63,5	-63	-62,5	-46	-18,5	4	19,5	41	36,5	42,5	20,5	0	-26	-52,5	-62	-63	-64
JVC KS-FX480REX	D	52	55	S	V	0.9100	0.9258	32010.92	74778.81	-1.60	-	37.30	-61,5	-58,5	-57	-46,5	-18,5	2	16,5	42	31,5	42,5	16,5	-0,5	-29,5	-53,5	-60,5	-68	-70,5
SONY CDX-M850MP	D	-55,6	40	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VDO DAYTON CD 2200	D	-47	65	S	V	0.9096	0.9258	31951.32	74631.60	4.10	-	57.90	-26	-26	-26,5	-26,5	-21	12	25,5	48	44	46	24	-3	-27,5	-27,5	-28	-28	-28
PORTABLES																													
SANYO DTA-300M	I-AC	-47,5	63	S	V	0.9207	0.9258	31992.42	74704.33	26.90		55.30	-20	-15	8,5	14,5	27	34,5	39,5	44,5	38	43	41	35	15	-5	-10,5	-13	-16,5
GRUNDIG LUNA RP 9200 PLL	I-AC	-45,5	48	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GRUNDIG OCEAN BOY 350	I-AC	-51,5	53	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PANASONIC RX-EX1	I-AC	-44	58	S	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PHILIPS AZ3012	I-AC	-54	65	S	V	0.9037	0.9254	32015.91	74804.85	21.40		47.90	-30	-22,5	-12	-4	13	20,5	26,5	34,5	29,5	35	24	18,5	3,5	-17	-27,5	-30	-30,5
SANYO DC-DA1000	I-AC	-52	64	S	V	0.9120	0.9254	32005.53	74759.15	19.30		51.30	-29	-27	-17	-13	-1,5	6	17,5	39,5	33,5	38	16	-4	-18	-20	-21	-22	-24
SONY CFD-S550L/SC	I-AC	-47	56	S	V	0.9104	0.9255	31982.09	74703.06	18.90		48.30	-10,5	2	10,5	15,5	30,5	37	41,5	45,5	40	44,5	40,5	36	26	12,5	7,5	0,5	-9
SONY ICF-C743L		-49,7	74	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
THOMSON AM1180	I-AC	-45,5	66	S	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
THOMSON RR 600CD	I-AC	-49	66	S	V	0.9076	0.9254	31968.27	74701.85	23.90		52.30	-27	-21,5	-7	0,5	21,5	29	34,5	42	36	41	34	28	-5,5	-17,5	-20,5	-18,5	-21,5
WALKMANS																													
SONY ICF-M33RDS	I-AC	-47	27	M	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GRUNDIG CITY BOY 52		-43	45	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DIGITALWAY FD100	I-W	-46	83	S	V	0.9238	0.9256	32024.31	74841.69	29.40		62.80	-4,5	-1,5	5	3	6,5	3	17,5	41,5	35,5	37,5	14,5	2	7,5	0	1	6,5	6,5
NOKIA 8310	I-W	-40	43	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PHILIPS AZT9500	I-AC	-46,5	58	S	V	0.9304	0.9258	32051.97	74899.77	20.60		54.70	0,5	0,5	0	1,5	5	26,5	32,5	37	33,5	35,5	28	22	-8,5	-16	-17	-18	-19
SAMSUNG YP-90S	I-W	-44	50	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SONY ICF-C1200	I-AC	-47	65	S	V	0.9182	0.9257	31994.37	74746.54	18.70		57.90	-25,5	-16,5	-4	5,5	29	31,5	36,5	39	33,5	39	37	32,5	28	7,5	1	-9	-17,5
UNITED DM2595-2	I-W	-47	60	S	V	0.9235	0.9256	31991.69	74766.51	25.40		57.80	-5,5	7,5	16	21	32,5	34	36	37	36,5	37	37	33	26	13,5	9	4	-7
AIWA HS-RM539	I-W	-47,4	64	S	V	0.9371	0.9256	31998.95	74754.54	27.00		57.90	-4	-9,5	-8,5	-4,5	10,5	23,5	29	37	35	37	36	30,5	18	0	-3,5	-8,5	-7,5
SONY WM-FX491	I-W	-45,6	76	S	V	0.9228	0.9258	32048.98	74915.90	35.40		65.30	-16,5	-6,5	0,5	6	19	28	33	42,5	38	43	37	32	22,5	9,5	5	-1	-10,5
INTERTRONIC DT-22	I-AC	-40	42	M	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAD 1600						0.9323	0.9256	31978.98	74742.69	8.00	-	33.60	-34	-33,5	-32,5	-20,5	-8,5	-2,5	19,5	40,5	36	41	20	0	-4,5	-14,5	-29	-34,5	-35

Abbreviations

Tof	Type of feed. The following tof were used:1-Direct feed (D), 2-Indirect feed using an alligator clip (I-AC) and 3-Indirect feed using a wire antenna (I-W).
Rf-w2isr max	The maximum radio-frequency wanted-to-interfering signal ratio.
Wt-rfl: rfw2isr max	The radio-frequency level of the wanted transmitter to obtain the maximum radio-frequency wanted-to-interfering signal ratio.
M/s	Mono/stereo.
Ut-afl: dev=32 kHz	The audio frequency level of the unwanted transmitter to obtain a frequency deviation of 32 kHz.
Wt-afl: afs2ir=46 dB	The audio frequency level of the wanted transmitter to obtain a audio-frequency signal-to-interference ratio of 46 dB.
Ut-dev	The frequency deviation of the unwanted transmitter.
Wt-dev	The frequency deviation of the wanted transmitter.
Wt-rfl: SNR=20dB	The radio frequency level of the wanted transmitter to obtain a signal-to-noise ratio of 20 dB.
Wt-rfl: SNR=20dB corrected	The corrected, due to using an indirect feed, radio frequency level of the wanted transmitter to obtain a signal-to-noise ratio of 20 dB.
Wt-rfl: afs2ir=46 dB	The radio frequency level of the wanted transmitter to obtain a audio-frequency signal-to-interference ratio of 46 dB.
Rf-w2isr: df= 400 kHz	The radio-frequency wanted-to-interfering signal ratio for a frequency difference between the wanted and unwanted transmitter of –400 kHz.

Table A.1: Detailed results of the radio-frequency protection ratio measurements.

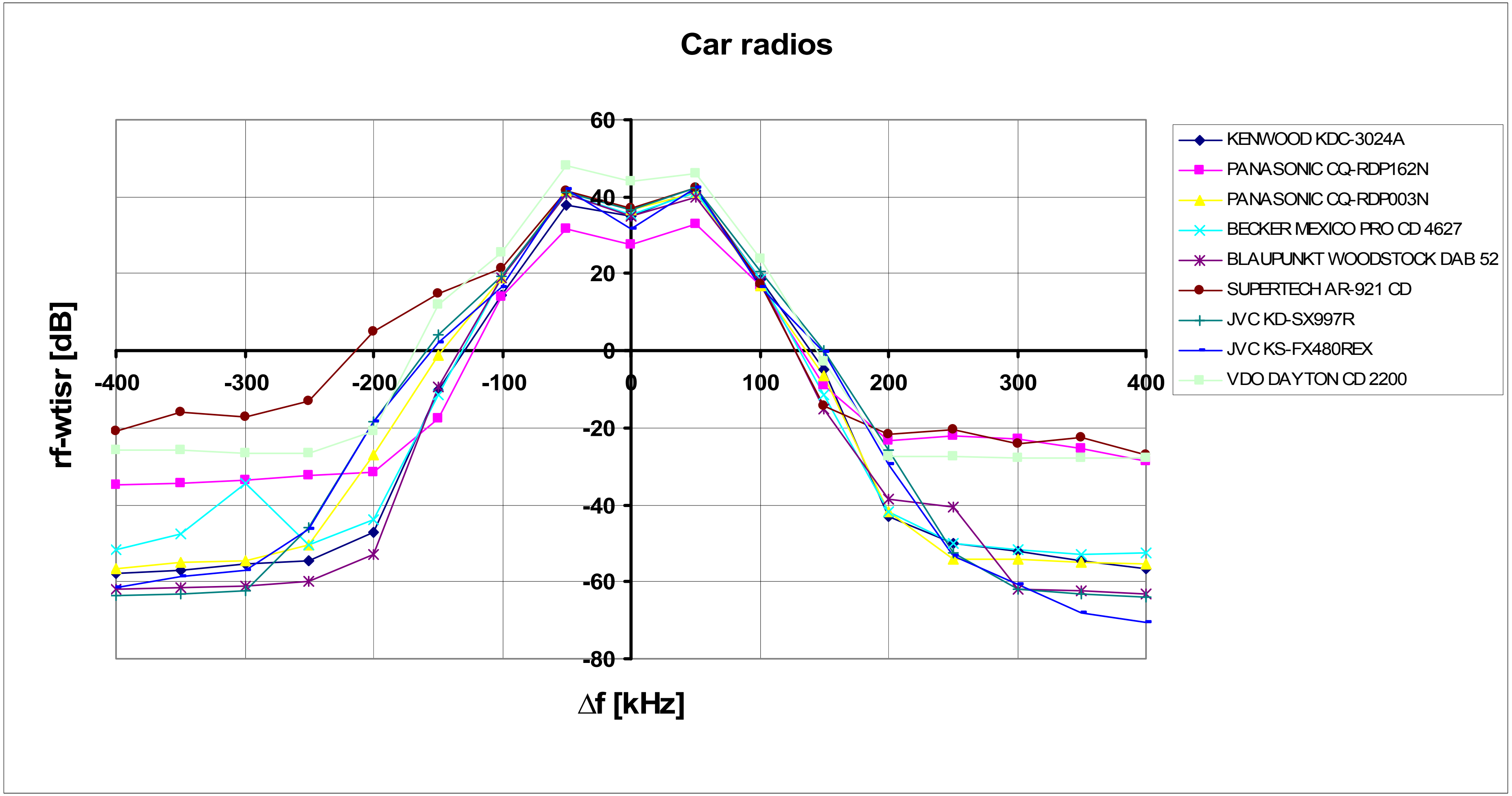


Figure A.1: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for car radios recorded according to ITU Recommendation BS.641.

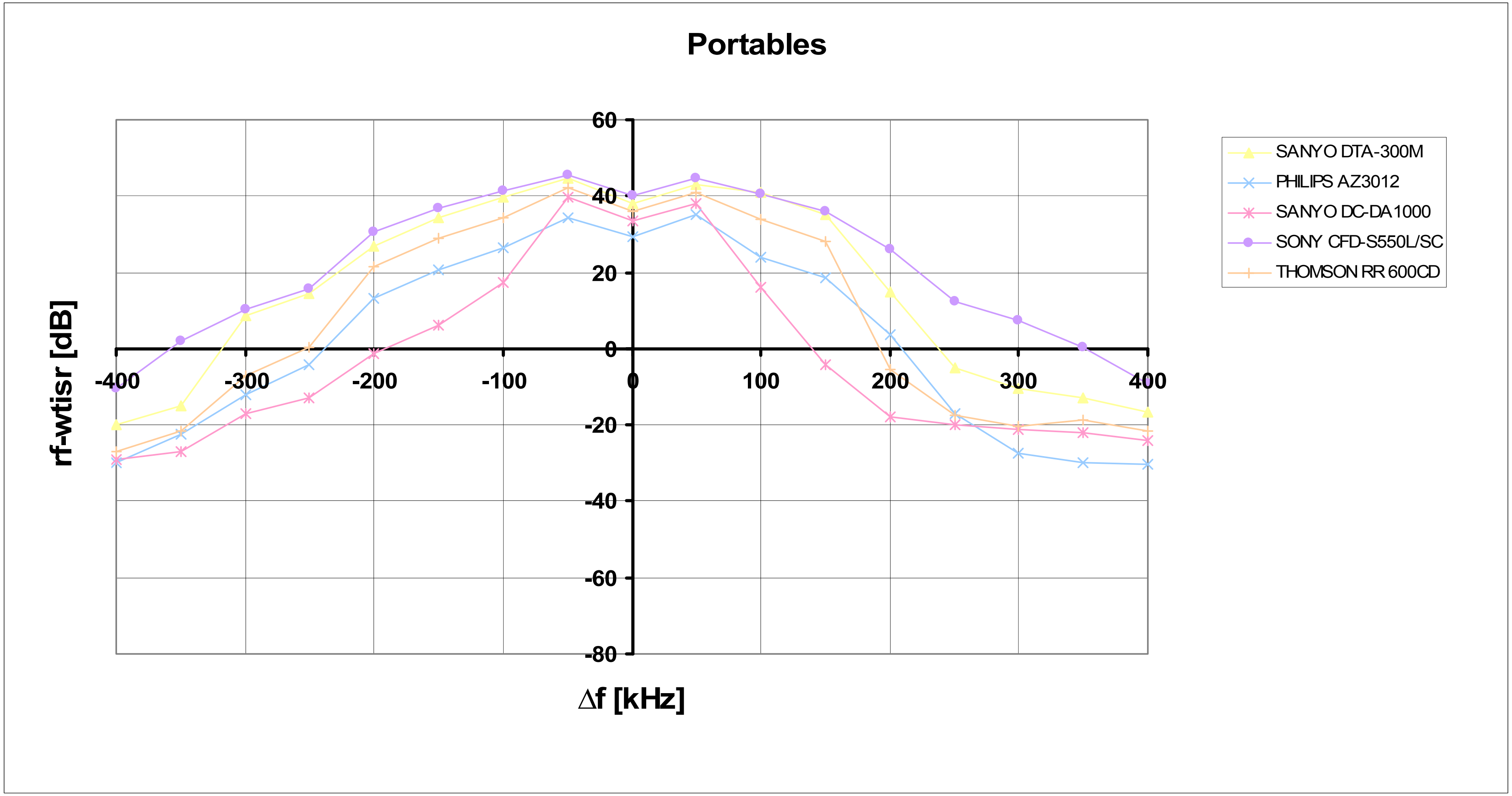


Figure A.2: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for portables recorded according to ITU Recommendation BS.641.

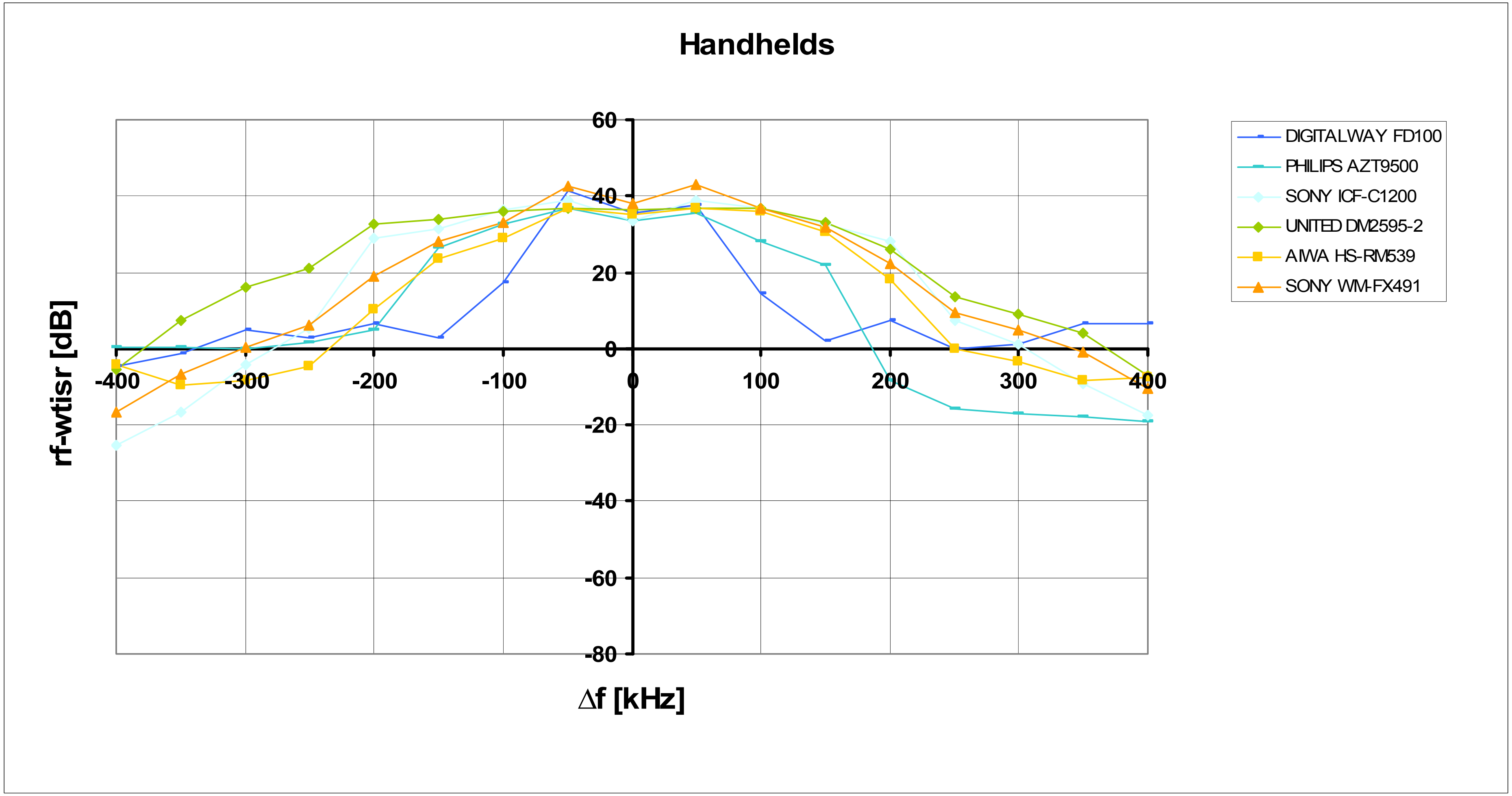


Figure A.3: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for handhelds recorded according to ITU Recommendation BS.641.

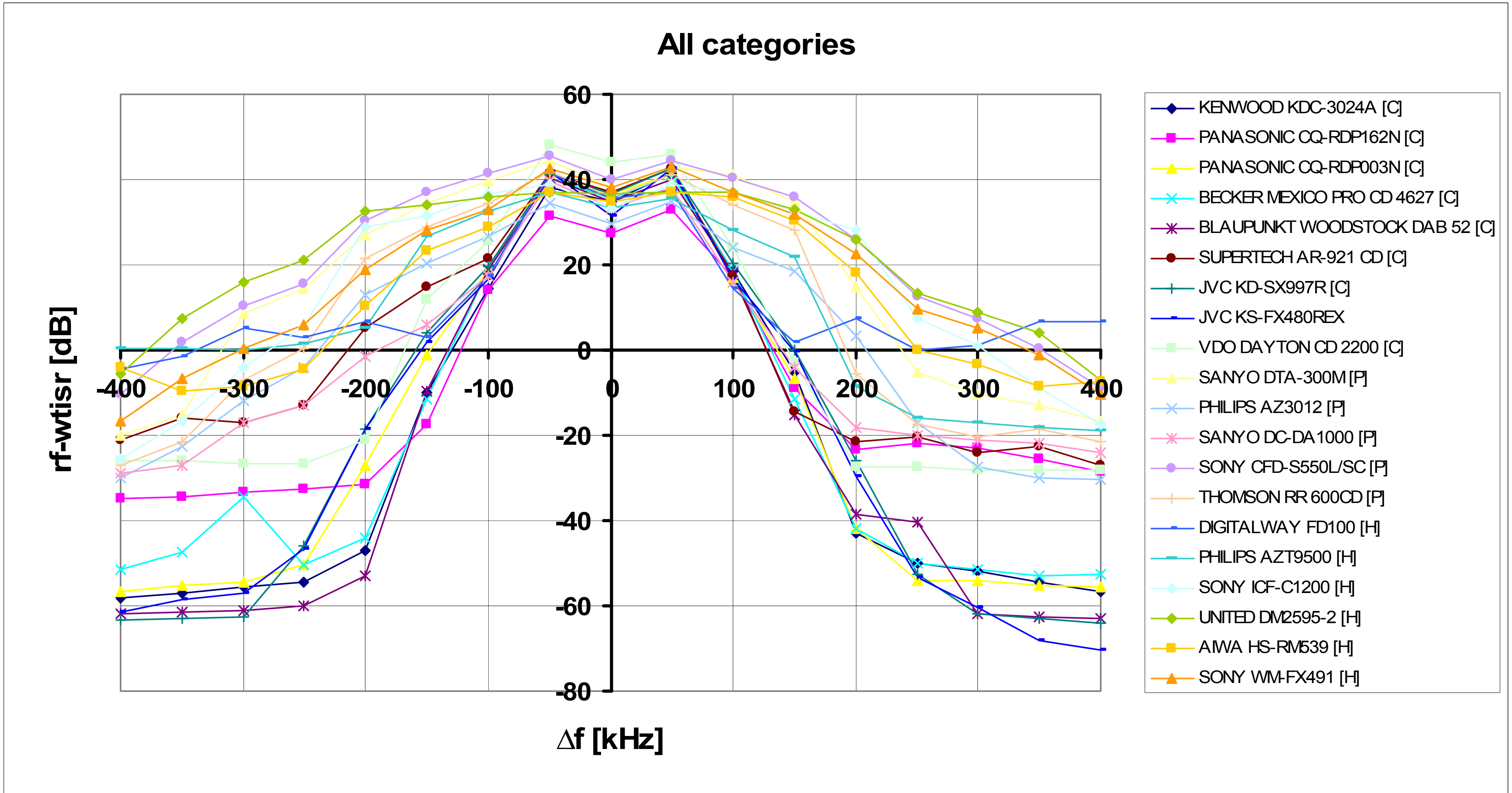


Figure A.4: Radio-frequency wanted-to-interfering signal ratio (rf-wtisr) for twenty receivers recorded according to ITU Recommendation BS.641. The category to which the receivers belong is indicated between brackets. The letters C, P and H are used for respectively the category car radios, portables and handhelds.

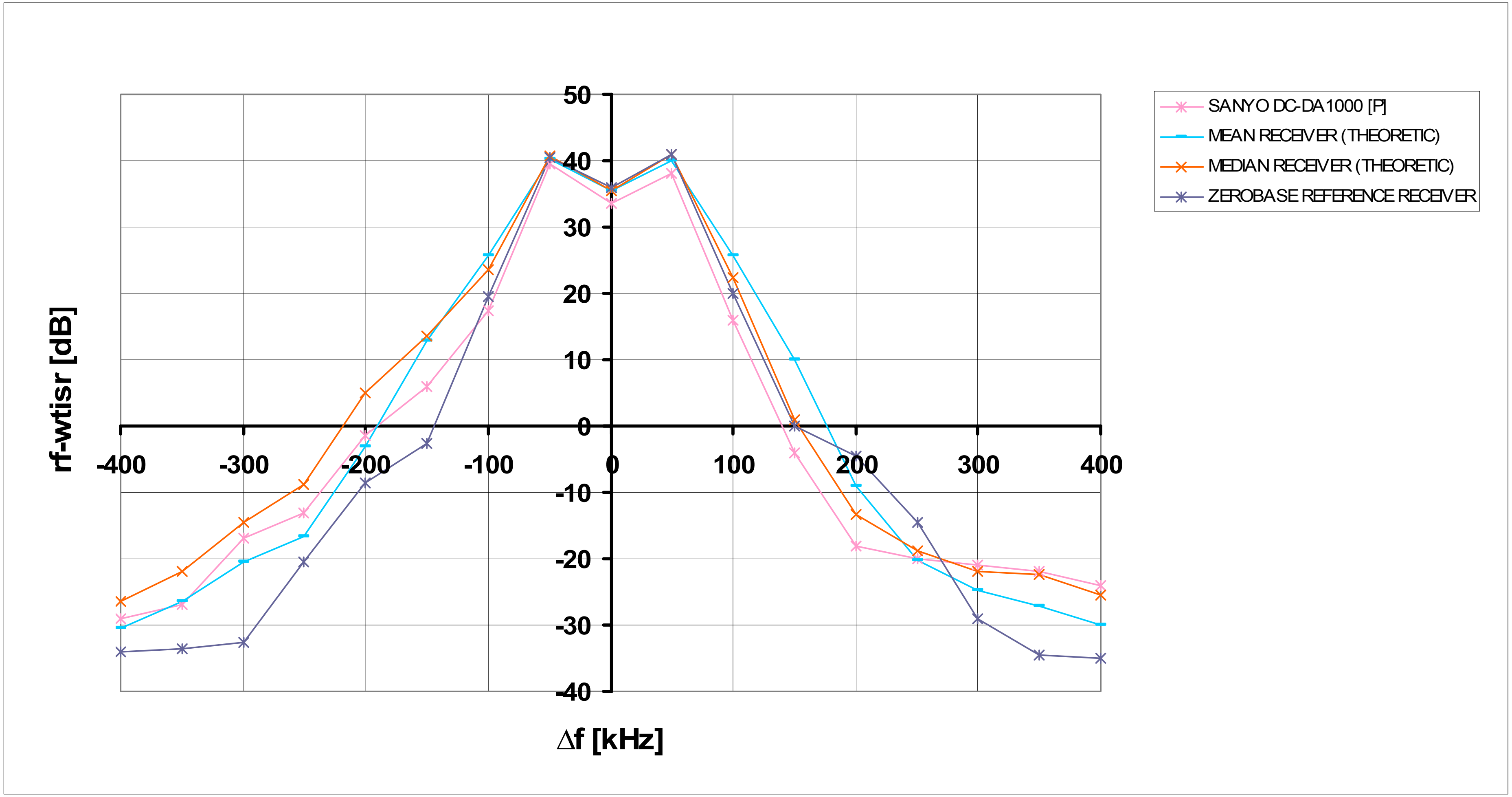


Figure A.5: Comparison between the Zero-Base reference receiver, the Sanyo DC-DA1000, the mean and the median receiver of this study. Both the mean and median receivers are theoretic receivers.

Appendix B: Example of a same programme network

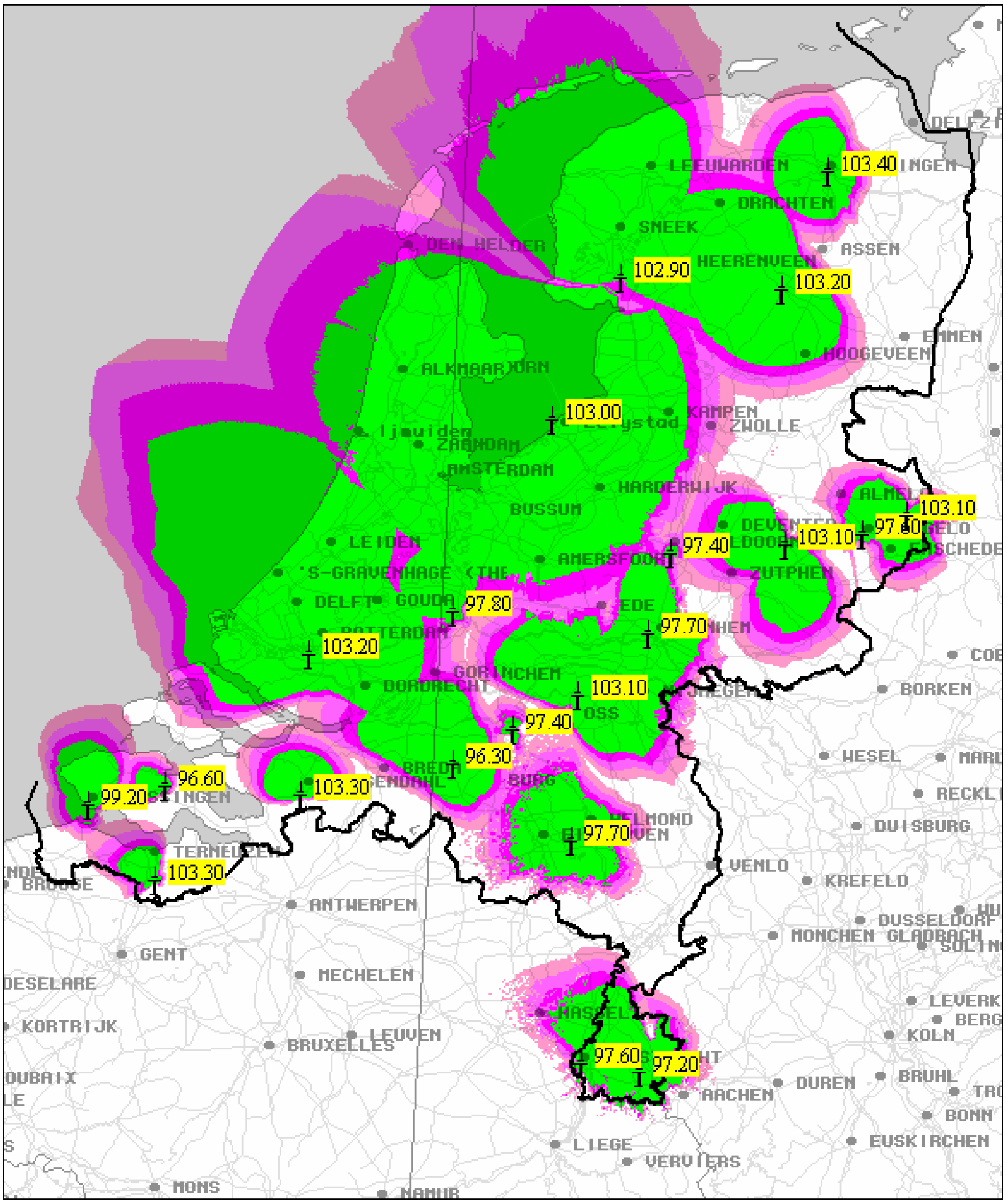


Table B.1: Example of a same programme network in The Netherlands

Appendix C: Reception problems due to inter-modulation

An FM site in Rotterdam transmits the frequencies indicated in the table 1 below.

Station	f (MHz)
Radio TV West	89.3
Business News Radio	91.3
RTV Rijnmond	93.4
Noordzee FM	100.4
Sky Radio	101.5
Radio 538	102.7
Veronica	103.2
RTL FM	104.6

Table C.1: FM transmissions fromRotterdam

The ERP on 102.7 MHz is highest (100 kW) and within about 6.5 km from the transmitter the field strength is 95 dBµV/m or more. FM networks Radio 1, 2 and 3 are not transmitted from the site in Rotterdam, but from Lopik about 45 km away. The field strength of the Lopik transmissions near the site in Rotterdam is about 61 dBµV/m.

Reception of Radio 1, 2 and 3 is interfered by third order inter-modulation products within 6.5 km from the Rotterdam site as indicated in table 2.

Station	Frequency (MHz)	Frequency of 3rd order inter-modulation-products (MHz)
Radio 1	98.9	98.6 98.7 99.0 99.1 99.2
Radio 2	92.6	92.3 92.4 92.5 92.7 92.9
Radio 3	96.8	96.5 97.0 97.1

Table C.2: Frequency of the third order inter-modulation products near Rotterdam.

Frequencies could not be changed and the solution was to install at the Rotterdam site three fill-in transmitters to improve coverage of Radio 1, 2 and 3. It was not possible to find inter-modulation free frequencies for the fill-in transmitters. Consequently the ERP of the fill-in transmissions should be high enough to respect the required protection ratios in case of high signal performance.

Appendix D: Photographs of tested receivers

Car radios

KENWOOD KDC-3024A

PANASONIC CQ-RDP162N

PANASONIC CQ-RDP162N

BECKER MEXICO PRO CD 4627

BLAUPUNKT WOODSTOCK DAB 52

SUPERTECH AR-921 CD

Car radios continued

JVC KD-SX997R

JVC KS-FX480REX

SONY CDX-M850MP

VDO DAYTON CD 2200

Table D. 1: Photographs of the tested car radios.

Portables

SANYO DTA-300M

GRUNDIG LUNA RP 9200 PPL

Portables continued

GRUNDIG OCEAN BOY 350

PANASONIC RX-EX1

PHILIPS AZ3012

SANYO DC-DA1000

SONY CFD-S550L/SC

SONY ICF-C743L

Portables continued

THOMSON AM1180

THOMSON RR 600CD

Table D. 2: Photographs of the tested portables.

Handhelds

SONY ICF-M33RDS

GRUNDIG CITY BOY 52

DIGITALWAY FD100

NOKIA 8310

Handhelds continued

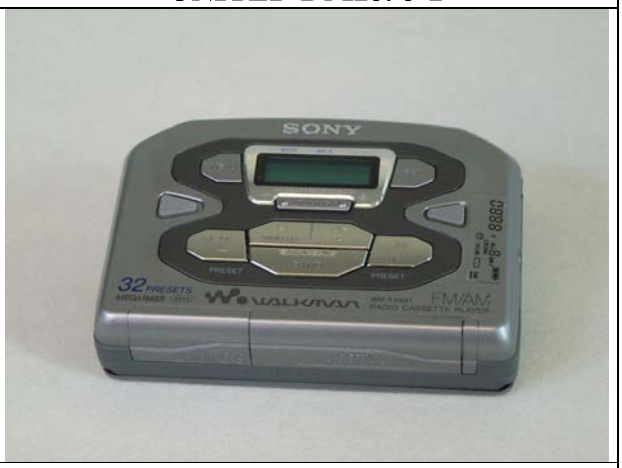
PHILIPS AZT9500

SAMSUNG YP-90S

SONY ICF-C1200

UNITED DM2595-2

AIWA HS-RM539



SONY WM-FX491

Table D. 3: Photographs of the tested handhelds.