RDS - Radio Data System
A Challenge and a Solution

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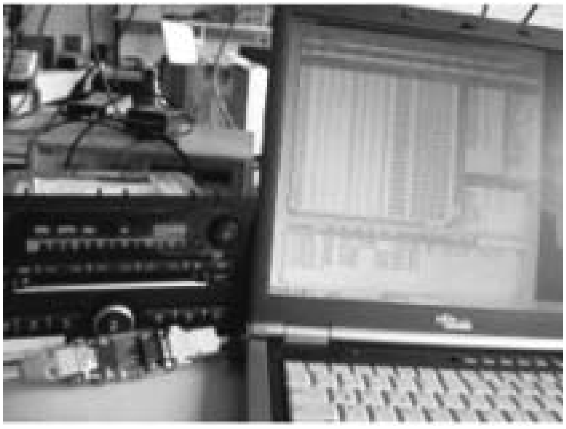


Abstract

The launch of the FM broadcasting system in the middle of the 20th century constituted an enormous improvement compared to AM. Nevertheless it turned out that car radios cannot reach the performance level of stationary receivers. Therefore in Europe the RDS system has been developed. It provides among other features for increased convenience also specific functions to overcome the performance problems of car radios to a large extent.

RDS is the most complex technology to receive analog broadcasting stations. To use this technology to the full extent it requires a lot of know how about the specific reception problems in the field, RDS and reception technology in general. All this leads to a large and very complex software solution.

This paper describes the main reception problems of car radios. The basic features of RDS are explained shortly. The main part of this essay deals with the software and the required tools. It is shown, based on three key issues, how these problems can be solved with high sophisticated software. The tool for monitoring the behaviour in the field, dedicated for detailed analysis and evaluation, is explained in detail. At the end the results of different test drives show the evidence that this new RDS software developed by Technical Center Nuremberg has reached a performance which is state of the art.

1 RDS - Introduction.

The launch of the FM broadcasting system in the middle of the 20th century constituted an enormous technological step forward with regard to reception quality and stability. The most obvious improvements of FM compared to AM are a considerable extension of the audio frequency range up to 15 kHz, a much higher S/N ratio, less distortion and no audio signal fluctuations as it is the case with AM fading

The FM system is very effective for stationary receivers. More or less directional antennas as dipole or Yagi antennas outside the buildings are adjusted to the transmitter's site, so that mainly the signal of the direct path is received, excluding reflected and delayed signals arriving from lateral paths.

During the following decades FM-receivers in cars became more and more popular. But it turned out that mobile receivers cannot reach the quality level and signal stability of stationary receivers. Mobile receivers are normally operated together with omni-directonal antennas as the reception angle of the radio waves can adopt any value within 360) degrees. Therefore car receivers have to cope with all the signals arriving at the receiving antenna, independent of the driving direction and the speed of the vehicle.

This so-called "mobile transmission channel" suffers from multipath propagation and from Doppler shift which is caused by the movement of the receiver itself or by moving reflecting obstacles.

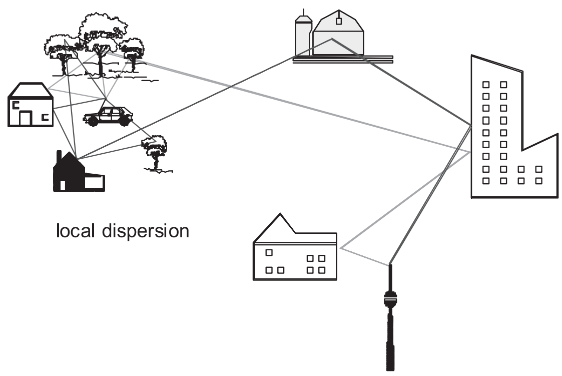


Fig.1 Multipath propagation

The example of Figure 1 shows two main propagation paths where the waves are reflected on discrete obstacles like tall buildings, hills or mountain ridges. As the average length of the two paths is different, the signals will arrive at different time instants in the vicinity of the car. Additionally the signals are exposed to local dispersion due to further reflections in the immediate surrounding of the receiving antenna.

All these influences lead finally to a sum signal at the antenna which is continuously varying in amplitude, phase and frequency. In consequence this fading signal has strong impact onto the quality of the audio signal after demodulation in the receiver:

- **Heavy distortion due to missing parts of the FM signal spectrum**
- **Fluctuating noise occurring each time the signal level falls below the limiting threshold of the receiver**
- **Periodical noise bursts (paling fence effect) in case the fading signal is dominated by two main paths with Doppler shift**

The above described problems of the FM system show that FM is not suited for mobile transmission. The extension to FM stereo even increased these effects

Therefore in Europe the RDS system has been developed which provides among other very useful features means for the realisation of network following. The receiver gets via the RDS data channel detailed information about other frequencies of the same programme or transmitter chain. That enables a receiver to continuously check in the background all alternative frequencies and always select and tune to frequency with the best quality. By implementing very sophisticated RDS strategies and plausibility checks in the receiver's software the drawbacks of the FM system can be overcome in a very large extent.

Since the first RDS specification has been published in 1984 the RDS system experienced continuous improvement and optimisation and was finally issued as European Standard EN 50067 in April 1998. RDS has become a really success story in Europe, so that even in America a subset of RDS has even been implemented as RBDS system.

2 The Radio Data System -RDS-

The Radio Data System, RDS, is intended for application to FM sound broadcasts in the range 87.5MHz to 108.0 MHz which may carry either stereophonic (pilottone system) or monophonic programs. The main objectives of RDS are to enable improved functionality for FM receivers and to make them more user-friendly by using features such as Program Identification, Program Service Name and automatic tuning for portable and car radios, in particular.

The radio can make use of this information by a more or less sophisticated software strategy for an almost non disturbed radio reception over a long driving distance and period of time.

The data bits are transmitted with 1187.5 bits per second (57kHz/48). The bit stream is structured in blocks.

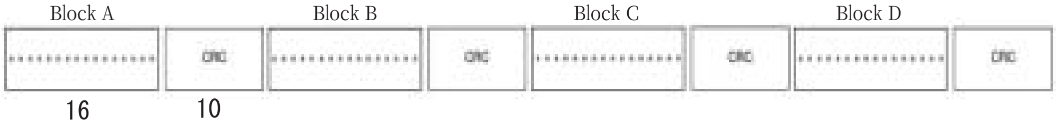


Fig.2 RDS group

A block with 26 bits consists of 16 data bits and 10 check bits (CRC = cyclic redundancy check). This code can correct 2 random errors in a block. An RDS group consists of 4 blocks (ABCD).

Every group contains a block A with the program identification (PI) code, which is a unique identifier of a radio station. This information is repeated 11.4 times per second. The PI code:

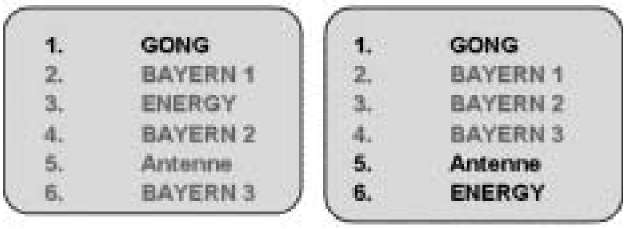
- **uniquely identifies a program and the country in which the program is broadcast**
- **allows selection of a program independent of a frequency**
- **allows automatic frequency changes to frequencies transmitting the same or related programs.**

PI codes must be assigned by national authorities to avoid that different programs share the same PI code.

The PI code delivers also information about programs belonging to the same broadcast chain, for example: Bayern 1, Bayern 2, Bayern 3. Some programs split into programs with regional content for a certain period of time. For example: Bayern 1 split into Bayern Franken, Bayern Bamberg and Bayern Ingolstadt.

The PI code offers the possibility to group the programs of a broadcaster including the regional services. European customers expect the station list sorted by PI code and not only by frequencies or field strength.

Sorted acc. to field strength   Sorted acc. to grouped PI code



In Europe the PI-code is the key for program identification. Selection by frequency is of minor importance.

Block B comprises the program type (PTY code), the indication for traffic program (TP flag) and the RDS group number (group type GT) which indicates the type of data encoded in the blocks C and D. The program type signals the type of music or information which is currently broadcast by the tuned radio station (classical music, music, news ect.).

The bit after the GT is the version bit. It indicates the GT version: A or B (for example 14A or 14B

Example of a block A and block B with the bit pattern of a group type 11A

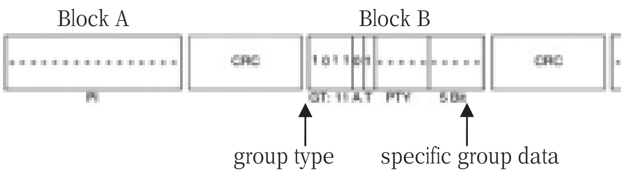


Fig.3 block A+B group 11A

2.1 Description of important group types

In all groups are available:

PI information (block A), PTY (block B), TP (if it is a traffic program and if it supports traffic announcements on related stations, in block B).

Group 0A

Alternative frequency information is transmitted, either as method A (up to 25 frequencies, normally used to transmit the frequency of neighbor transmitters) or method B (more than 25 frequencies, normally every frequency on which the current station is broadcasted).

Program Service Name is sent in group 0A and 0B.

TA, a traffic announcement is send in 0A 0B and 15B (indicates a starting or ongoing traffic announcement). The same groups apply for the MS bit (music/speech).

DI the decoder information is send in 0A 0B and 15B. It can be used to signal if a compressed or not compressed program is broadcasted or if the program is recorded in mono, stereo or with an artificial head

Group 2A, 2B

Radio text information is transmitted here.

Group 14A

Information about a related station which broadcasts traffic announcement, like the frequency, alternative frequencies if it is a network and the PI code of this station.

Group14B

Indicates the start of a traffic announcement at the other station with the traffic program

2.2 How to perform sophisticated network following

This was about the signalling which the broadcaster can add to his program. Let us have a focus on the receiver.

To reduce it to one sentence: The receiver should be able to perform the best reception under any conditions.

The RDS information is one part of this strategy. Another part is determined by the used hardware concept and how the signal processing of the radio is performed.

The radio normally has different detectors for

- Fieldstrength or level detector
- Multipath distortion
- Ultra sonic noise detector (USN) (for detecting neighbour channels)
- Offset detector

Additional detectors

- Pause detector
- Pilot detector

2.2.1 Fieldstrength:

This detector gives an indication of the signal strength of the desired channel at the input of the tuner. The fieldstrength is a good indication for the signal quality, as signal to noise ratio depends on it. Therefore it is a good detector for signal to noise ratio.

To assure that the output represents really the signal strength this detector has to be aligned to compensate the spread in analogue components.

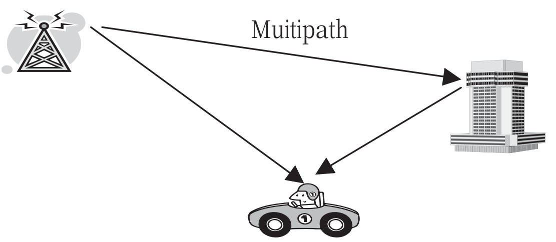


Fig.4 Multipath

2.2.2 Multipath:

The multipath detector measures amplitude fluctuations of the signal. An FM signal is broadcast with a fixed level. Therefore level fluctuations indicate less signal quality. At multipath conditions large level fluctuations can be measured.

The multipath detector does not require any alignment.

2.2.3 USN:

To give an indication about the Ultra Sonic Noise the amplitude of the high frequency content of the MPX signal is measured. This is measured in the bandwidth of approximately 80 kHz up to 150 kHz.

Offset:

With this detector the misalignment between the modulation and demodulation frequency can be measured. As the misalignment is expected to be small, a large offset indicates disturbance (for example adjacent channel breakthrough).

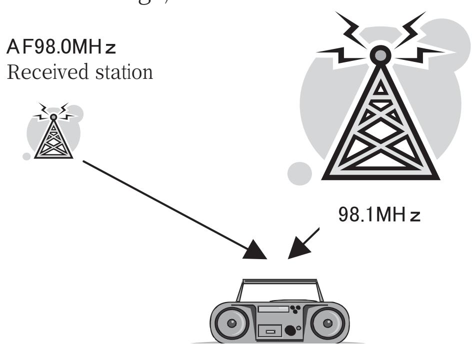


Fig.5 AF check with offset

Radio switches to 98.0MHz for a short AF check (<10 ms). 98.1MHz is detected but offset is detected too therefore no NF took place

2.3 Conclusion

If one or more detectors are triggered, the radio can react with different kinds of strategies to suppress distortion.

One of these strategies is to switch very fast to a frequency where the same program is broadcasted, preferably with no audible distortion. Therefore mainly the PI code is used to determine if the original station is the same as the newly tuned station. This is the reason why the PI code is send at the maximum repetition rate to enable the radio to detect very fast if it has performed a correct network follow.

Sometimes it could be that it took a while to decode the PI code. During this time the radio has two possibilities. The first is to stay muted until the PI code is verified or to enable audio with the risk to be on a different radio program and hear different audio content.

If the reception of the preferred station overall is not so good (no alternatives, low fieldstrength), the radio can activate its concealment strategies. These are:

- Mono stereo blend switch the signal between stereo and mono in dependence of distortions. This can be activated by multipath distortion or low fieldstrength.
- High cut is a reduction of higher audio frequencies. The most annoying audio distortions are in the higher frequency band, so a low pass filter is activated which reduces the higher frequencies. The cut off frequency and the suppression rate can be set by parameters, which are evaluated during test drives.
- Soft mute is a total reduction in the volume of the audio signal. Soft mute mostly is active at low fieldstrength. At low fieldstrength the audio signal is reduced, the noise level is increasing and this is disturbing. When this happens the soft mute reduces the audio level to make this distortion not so annoying. The start and the slope of the soft mute is set by parameters and evaluated during test drives.
- Bandwidth control becomes active when the IF filter is not able to suppress adjacent channel breakthrough. In this case an overlap exists between the wanted channel and the adjacent channels. This is often the case in regions with a channel grid of 100 kHz. The selectivity (the bandwidth) of the IF filter need to be adaptive in this case. In this way the bandwidth of the channel filter is reduced if necessary. The bandwidth reduction results in a suppression of the adjacent channel, while keeping the distortion of the wanted signal to a minimum.

2.4 Traffic program and enhanced other networks (TP and EON)

Besides the network following the second major advantage of the RDS system is the traffic announcement feature. Therefore two bits exist to signal a station with traffic announcements and if the announcement is active or not.

The feature EON normally is related to a complete network chain (e.g. SWR1, SWR2, SWR3 and SWR4). One station is transmitting the announcements (here it is SWR3) and the other programs switch to it when an announcement starts. The customer must not listen to the traffic station he can also listen to his preferred program (e.g. classic music) and will not miss any announcement on the other station.

The information for the change to the traffic station is sent in the 14A groups, including the PI code of the traffic program and all alternative frequencies of it. When an announcement takes place the radio knows it has to switch to the other program. The best frequency is selected out of the AF list. When the announcement is finished, the radio goes back to the original program.

- **The indication for the program is called TP (traffic program).**
- **The indication for the announcement is called TA (traffic announcement).**

3 RDS - The Software

RDS is the most difficult technology to receive analog FM stations. There are different ways to use this technology.

The easiest way is to decode the program station name and display it. In this case the software is very small and simple but it does not use all the possibilities of RDS and gives the customer only a little benefit.

The next stage is the implementation of all RDS features according the standard. And make some additional improvements by optimising thresholds during test drives. Now the software becomes larger and a little bit more complex. This is the way manufacturer use, who does not deliver radios to the European car industry.

The best solution is to implement the standard. In addition several quality parameters are defined. These are used in specific developed algorithm. All this enables the software to switch fast to the best alternative frequency in critical reception areas.This way requires a lot of know how and knowledge of problems in the field. This is the only possibility to develop RDS software which will be accepted by the European car manufacturers. To achieve this kind of performance the RDS software becomes very big and complex. To explain what kind of improvements are possible three examples of main features of RDS are chosen.

3.1 NF-Following

Target of network following is to tune automatically to the frequency with the best quality without any notable mutes, miss change and sound effects.

The old RDS software controls continuously the field strength, multipath and noise of the alternative frequencies. In the background the AFs are maintained according field strength, history of the PI code and the neighbourhood relation to the actual frequency. Up to 100 alternatives frequencies are stored even if the field strength is below the threshold. The software switches to an AF, if the field strength, multipath or noises of the tuned frequency reach a certain threshold. The AF with the best field strength is selected.

This implementation has some weakness.

- It can occur that the selected AF has a lot of multipath and/or noise. Therefore the sound is worse than current frequency.
- It can also happen that it switches to an AF but not on the exact right frequency but 100 kHz beside. In this case the sound quality is also not good.
- If the actual frequency has very low field strength high cut and stereo blend are activated.
- If the alternative frequency has strong field strength than a change is audible because high cut and stereo blend are switched off immediately.
- The main problem occurs in weak signal areas. The software starts every few seconds an AF search to find a better AF which leads to a mute. So there is alternating noisy sound and mute which is very annoying.

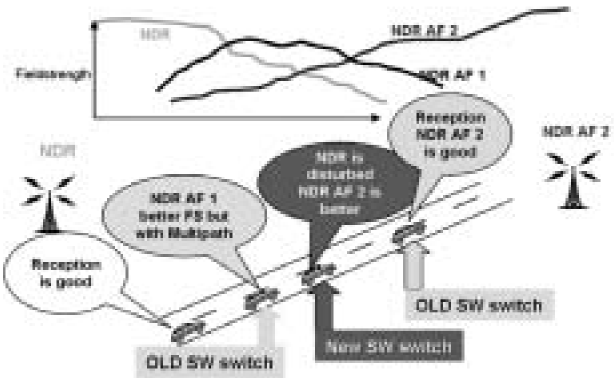


Fig.6 Network Following

The new RDS software controls continuously more than eight different quality indicators of 35 alternative frequencies. They are continuously updated in the background. This process is not audible. In this table the AFs are sorted in order of the value of the quality parameters and it is kept up to date continuously.

A change is initiated if one of the quality indicators reaches a certain threshold. A change is also started if the quality indicators of an alternative frequency are better than the actual one.

Before a change is executed both frequencies are compared. Therefore TCN has invented an algorithm which uses the quality parameters.

The result of this calculation is directly related to the sound impression. A high value guarantees a good sound impression. Only if this value is higher than the actual frequency, software will switch to the alternative frequency. The software is able to switch up to 20 times per minutes between different alternative frequencies.

To prevent that a change between a weak actual frequency to a strong alternative frequency is audible the new software control during the switch high cut and stereo blend. Therefore the change even in this case is nearly not audible.

3.2 The Improvements

- The new software always switches very fast to the best alternative frequency because it compares the total quality of the signal and not only the field strength.
- It switches always to the center frequency as the offset indicator is used.
- There is no miss switch as the table with the AFs is the continuously updated in order of the quality parameter. There is only a change if the quality parameters are better.
- There is no alternating switching between mute and noisy signals in weak signal areas as the software stays

on actual frequency as long as there is no frequency with better quality parameters available.

- In weak signal areas the sound impression is optimized by using high cut stereo blend and bandwidth control.
- During switching between a bad actual frequency and a good alternative frequency the audible impression is reduced by controlling high cut, stereo blend and bandwidth control.

3.3 The tunnel situation

If the tunnel is reached there are two possibilities.

In one case, an alternative frequency is broadcasted in the tunnel. Here the software should switch as soon as possible, that means before the signal becomes too noisy, to the alternative frequency

In the other case, there is no alternative frequency broadcasted. Here the software should reduce the volume before the sound becomes too noisy.

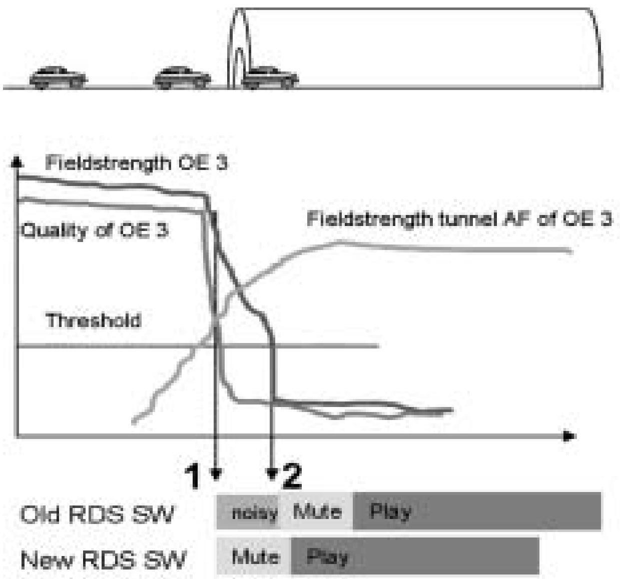


Fig.7 Tunnel with AF

3.3.1 The Tunnel with AF

The old software controls only the field strength. If this value reaches a certain threshold then an AF search is executed.

As this take some time a mute occurs until the alternative frequency is found and the PI is verified. As the AF search is started at a low field strength (2) the sound is noisy before. In principle the same action is executed as in weak signal areas.

The new software controls the quality parameters. In addition it controls how fast and strong the parameters change. If this happened very fast and strong a tunnel situation is considered and an AF search starts (1). This requires also a mute before the alternative frequency is played. The advantage of this new implementation is that a tunnel situation is detected. Due to the fact that quality parameters indicate earlier a tunnel situation than field strength no noisy sound is to be heard before the mute.

3.3.2 The tunnel without AF

The old software behaves in the same way as in a tunnel with AF. But in this case the software does not find an alternative frequency. Therefore it plays the actual frequency again. After some seconds it starts again an AF search and switch back to the original frequency. This continues during the whole drive through the tunnel.

The new software behaves also the same as in a tunnel situation with AF. But the software knows this is a tunnel. So if no alternative frequency is found after the first AF search with a mute, it plays current station with reduced volume. This behaviour is what European customers expect if they drive through a tunnel without alternative frequency.

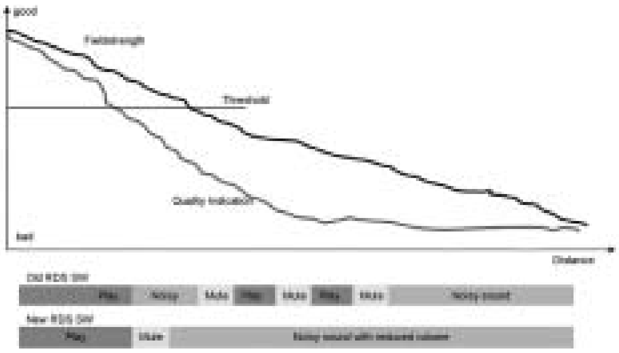


Fig.8 Tunnel without AF

3.4 EON - Enhanced Other Network

The greatest challenge on the realization of the EON feature is to be found in the UK. The national wide available station like BBC1 does not broadcast traffic announcement. But the regional programs of the BBC radio chain like BBC London or BBC Oxford broadcasts traffic announcements.

If one listens to BBC1 and traffic announcement is broadcasted at BBC London, the radio should automatically switch to BBC London. Therefore in the RDS data stream of BBC1, all frequencies of the other BBC stations are transmitted. Unfortunately it is not indicated if this program has sufficient field strength at the place where the radio is at that moment.

The old RDS software stores all frequencies of the stations with traffic announcement. If the radio is on a place where neither BBC London nor the alternative frequencies of BBC London are receivable then the following will happen.

The radio receives the information from BBC1 that a traffic announcement is broadcasted on BBC London. The radio tries to switch to the best frequency of BBC London.

As BBC London is not receivable, the radio tries the alternative frequency. As this frequency is also not receivable, it tries the next alternative frequency. All alternative frequencies are checked in this way. During this period the radio is muted.

After all frequencies are checked and none has been receivable the radio returns to BBC1.

The new RDS software follows a different strategy. All frequencies are stored in a table. The frequencies are checked if they are receivable and how good is their quality. Then the frequencies are stored in a table in order of their quality. This table is continuously updated.

If now BBC 1 indicates a traffic announcement for BBC London, the software checks the quality parameter. If the quality parameter is not good because the station is not receivable, the radio stays on BBC 1 and no mute occurs. The radio switch only if the quality parameter are good.

The advantage is obvious - no mutes happen!

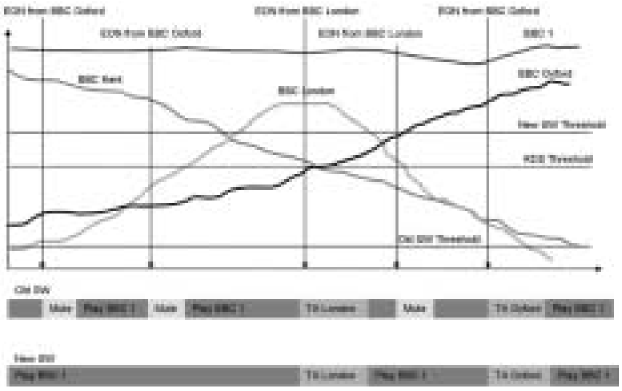


Fig.9 EON

3.5 The Tool NF-Trace

As described before, the quality parameters of the actual frequency and their alternative frequencies have a big influence on the performance of the RDS software. Therefore it is necessary to have a tool which enables developers to monitor these parameters on the bench and during test drives. But not only parameters of the frequencies have to be monitored. It is also important to have the ability to monitor the behavior of the RDS software especially on test drives. For development and improvement it is necessary to control the dynamic behavior of parameters and their influence on the different algorithm of the RDS software. In addition the performance of the stream decoder has to be monitored. To fulfill all these requirements TCN has developed the unique tool "NF-Trace".

3.5.1 NF-Trace

NF-Trace is a software tool which runs under Windows. The PC is connected to the UART of the radio. Specific software in the RDS software takes care of the communication between the tool NF-Trace and the RDS software. This is a real plug and play solution which can easily be used on the bench and during test drives. After starting NF-Trace the display of the PC shows a screen where one can see in real time all required information about RDS while the radio is running in FM Mode and plays the actual station.

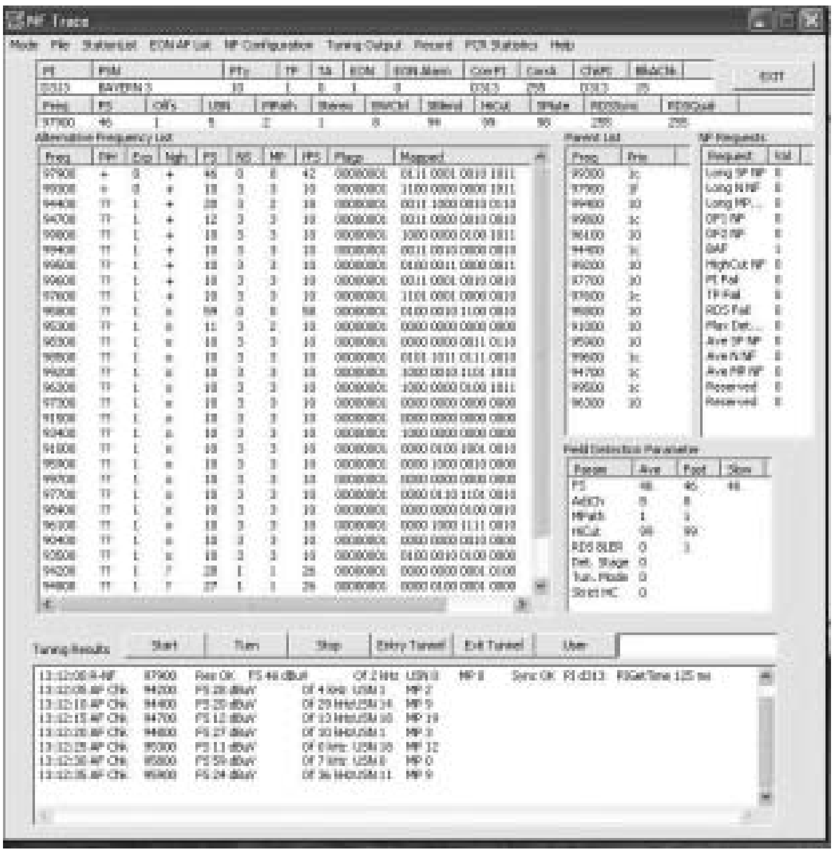


Fig.10 Screen NF Trace

3.5.2 RDS Group Decoder

In the first part of the display one can see on he left side the data of the RDS Group Decoder.

PI	PSN	PTy	TP	TA	EON	EON Alarm
D313	BAYERN 3	10	1	0	1	0

Fig.11 Group Decoder information

PI: This value shows the Program Identifier. Every radio station in Europe has its own PI

PSN: Here the program station name is shown.

PTY: Program Type Here is shown which program type e.g. Pop, Jazz or News this radio station use.

TP: Traffic Program Here is shown if the radio station supports traffic announcements or not.

TA: Traffic Announcement Here is shown if a traffic announcement is currently transmitted or not.

EON: Enhanced Other Network Here is shown if the received radio station belongs to a broadcast chain in which at least one radio station broadcast traffic announcements.

EON alarm: This value indicates if a program of the broadcast chain is broadcasting traffic announcement now.

3.5.3 The Stream Decoder

CorrPI	CorrA	ChkPI	BlkAChk
D313	255	D313	15

Fig.12 Stream Decoder information

One of the main differences between Europe and Asia/America is that radio stations are selected by PI (Program Identifier), not by frequency. Therefore it is obvious that the detection of the PI code is a key for the performance of the radio. This information is normally provided by the RDS Group Decoder. The performance depends mainly on the hardware concept. To become more independent from the hardware performance, TCN developed algorithm to calculate the PI code. This information is displayed on the right side of the screen. Herewith one can monitor if the PI is detected earlier as by the RDS group decoder. This part is mainly used to optimize the algorithm for the PI code.

3.5.4 The actual frequency

For the actual received frequency NF-Trace displays the following information.

Freq: Frequency. This value show the actual frequency in kHz

FS: Field strength. This value shows how strong the actual frequency is received.

OFFs: Offset. This value indicates if the tuner is exactly tuned on the center frequency or how many KHz aside. The expected value is "0".

USN: Ultra Sonic Noise or adjacent channel. This value indicates if the received signal is disturbed by ultra sonic noise and by how many percent.

Mpath: Multipath. This value indicates if and how much the actual frequency is disturbed by multipath in percent.

Stereo: Stereo. This value indicates if the received frequency transmits mono or stereo information.

BWCtrl: Bandwith Control. This value indicates if Bandwith Control is activated. The values are going from 0 to 8. Value "8" means that the maximum and "0" means that the smallest bandwith is active.

SBlend: Stereo Blend. It indicates if Stereo blend is activated and the ratio between stereo and mono

HiCut: High Cut. It indicates if the high cut function is active and how strong.

SMute: Soft Mute. This value indicates if soft mute is active and how strong.

RDSSync: RDS Synchronization. This value indicates if RDS stream is synchronized by value "255" or not.

RDSQual: RDS Quality. This value indicates how good the quality of the RDS stream is.

Within one line one can monitor the status of the actual received frequency. This information is used during test drive to control for example, if the high cut function is activated because the received frequency is disturbed by multipath and/or ultrasonic noise. So it is possible to control if the different algorithm of the RDS logic works according expectation. If they do not work according expectation it can easily be investigated what is the root cause. With the knowledge of the root cause the algorithm can be improved.

3.5.5 The Alternative Frequency List

Similar information is also available for all alternative frequencies. The main difference to the quality parameters of the actual frequency is that the values are weighted according specifically developed algorithm.

Freq: Frequencies. In this column in the first position, the actual frequency is displayed in kHz. Below follow all alternative frequencies sorted in order of their quality.

PIH: Program Identifier History. This value indicates if there is a history of this frequency available

Exp: Expired. This value indicates if the data of this frequency are reliable or not

Ngh: Neighbourhood. This value indicates if this frequency has a direct (+), indirect (o) or no (?) relation to the actual frequency.

NS: Noise. This parameter is a weighted value of the noise.

MP: Multipath. This parameter is a weighted value of

Freq	FS	Offs	USN	MPath	Stereo	BWCtrl	SBlend	HiCut	SMute	RDSSync	RDSQual
97900	46	1	5	2	1	8	94	99	98	255	255

Fig.13 Actual Frequency Parameter

multipath distortion.

FFS: Filtered Field Strength. This value is the field strength value but filtered according to a specific algorithm.

With this information one can monitor the actual frequency and the alternative frequencies. It is easily to be seen during test drive if the actual frequency is still the best or if there is an alternative frequency which is better. With this tool, it is also possible to control if the software updates the information of the alternative frequencies often enough. On the test courses TCN engineers know exactly the status of every frequency. Therefore it is also possible to judge the performance of the hardware due to the values of fieldstrength, noise and multipath.

Alternative Frequency List

Freq	PiH	Exp	Ngh	FS	NS	MP	fFS
97900	+	0	+	46	0	0	42
99300	+	0	+	10	3	3	10
94400	??	1	+	20	3	2	18
94700	??	1	+	12	3	3	10
99800	??	1	+	10	3	3	10
99400	??	1	+	10	3	3	10
99500	??	1	+	10	3	3	10
99600	??	1	+	10	3	3	10
97600	??	1	+	10	3	3	10
95800	??	1	o	59	0	0	58
95300	??	1	o	11	3	2	10
98300	??	1	o	10	3	3	10
98500	??	1	o	10	3	3	10

Fig.14 Alternativ Frequency List

With NF-Trace it is possible to monitor the behaviour of the RDS software during test drives. Test drives require a lot of time and resources. To cover most of RDS cases one has to drive to Germany, Belgium, Switzerland, Austria, Italy, and United Kingdom. Most of the improvements in hardware and software require new test drives. To improve the efficiency and to reduce the total development time the NF-Trace tools offer the possibility to record a lot of parameters of the actual frequency and their alternative frequencies.

TCN has up to now investigated more than 60 different test courses in Europe. These data are used for analysis and evaluation on the bench.

3.6 Analysis

Every parameter of the actual frequency and their alternatives are recorded with a time stamp. Based on this, TCN engineers can evaluate what is the best frequency at the moment and at what time the software has to switch to the alternative frequencies. Below there is an example with three frequencies with a few parameters. In reality more frequencies and parameters are analyzed.

According this example at 01:00 the actual frequency is 97.6MHz. Alternative at 87.6MHz is not acceptable due to ultra sonic noise and multipath. Alternative 98.8MHz is a good one.

At 01:01 actual frequency at 97.6MHz is disturbed by multipath. Alternative at 87.6MHz is still not good. Alternative 92.6MHz is good. Software has to switch to this frequency.

At 01:02 frequency at 97.6MHz is disturbed by ultra sonic noise. Alternative 87.6MHz is good. Actual frequency is still good. The software should not switch.

At 01:03 actual frequency at 92.6MHz is disturbed by multipath. Alternative at 87.6MHz is good. The software has to switch.

Time	Freq.	USN	Mpath	FFS	Result
01:00	97,6	0	0	39	ok
	87,6	30	50	10	nok
	92,6	10	20	32	ok
01:01	97,6	20	30	39	nok
	87,6	35	45	8	nok
	92,6	5	10	35	ok
01:02	97,6	35	25	39	nok
	87,6	10	20	30	ok
	92,6	5	5	38	ok
01:03	97,6	35	15	30	nok
	87,6	0	10	35	ok
	92,6	20	35	39	nok

Fig.15 Parameters for Analysis

3.7 Evaluation

With the information out of the analysis and the NF-Trace tool, it is now possible to control the behaviour of the software on the test course. During the test drive the parameters are controlled. It can easily be checked if the software performs as expected. If not TCN engineers can analyse the cause with NF-Trace.

This kind of evaluation consumes still a lot of time and resources. To improve the efficiency of the development, TCN has developed a simulation of their RDS-software. The simulation behaves like a normal radio. The main difference is that there is no tuner and DSP. They are replaced by the data stream of the frequencies and their parameters.

To simulate a certain test course the data are fed into the simulation. NF-Trace tool can also be connected to the simulation. So it is now possible to monitor the behaviour of the RDS software in real time. This simulation offers two main advantages:

- Improvement on the RDS software can now be evaluated at the bench.
- It can be easily be evaluated if the improvement for a certain test course have any side effects on other courses. The data stream of the other test courses has only to be fed into the simulation. With NF-Trace it can be evaluated if these improvements have any side effects. If any, it can be investigated why and what possible countermeasures are.

4 Test Drives Results

The performance of a FM/RDS radio system depends on Hardware, Software and Antenna systems of the car. This can be checked on the bench with TCN tools and standard measurement equipment. But the customer judges the performance of the radio only while he is driving. Therefore it is absolutely necessary to go to the field test on a known test course and compare radio units in the real world under real conditions with a reference system.

Car and radio manufactures test there units on different test courses for different items. In the past TCN analyzed many of those courses in Europe to get detailed information and data. This Information is available in the so called "TEST BIBLE". Up to today TCN has detailed informations from more than 60 test courses used by European and Japanese car and radio manufacturers.

Every one of those test course has difficult reception conditions with one or more special items to test like: weak signal behaviour, strong signal behaviour, multipath, EON, network following, mute/miss change, and tunnels.

The target to drive on these courses is to check the performance of the radio under normal and extreme difficult conditions.

4.1 How to score?

For European customer the most important issue is the sound quality of the radio system. European customers do not accept strong noise distortion. The sound should not be disturbed by noise. In addition mutes and miss changes are not accepted at all.

Table 1 Scoring of Noise

Score	Detail
5	Excellent, perfect, No noise over the whole test course
4	Good: almost clear (most people can't recognize)
3	Acceptable, noise or abnormality can be recognized, but acceptable
2	Strong noise, but listener is able to hear the content of broadcaster
1	Strong noise, therefore listener cannot hear the content of Broadcaster (Claim level)

Table 2 Scoring of Sound

Score	Detail
5	Excellent, Perfect sound (good stereo separation, no high cut)
4	Good sound (smooth mono/stereo blend)
3	Acceptable / normal sound sometimes high cut or smooth stereo - mono blend
2	Bad sound, a lot of mono-stereo switching happened, strong high cut,
1	Worst sound (normal not used)

Scoring Mute / Miss Change

Normal no mute and no miss change (switch for a short time to wrong station) is allowed. The algorithms of software should switch to AF's (alternative frequencies) without audible mute. IF an AF is not known the software could do the following:

- **Mute and check PI code**
- **NF (network following - switch to an alternative frequency) > if PI code is wrong switch back miss change appears.**
- **If mute or miss change appears please note how often, how long.**

Note: European customers prefer mutes instead of miss changes!

4.2 Dedicated test drive results.

The new RDS software has been compared with the old software at many different test courses and on the way to and from these courses. Reception data was traced and logged with above described TCN test tools. The results of the most difficult test courses have been selected to show the improvement of the new RDS software.

4.2.1 Forchheim

Test Items: Sound, Noise, Multipath, Adjacent, Mute / Miss Changes and Network following.

Radio station BAYERN 3 is selected for testing. At start point frequency 97.9MHz has the best reception performance. After about 800m the field strength of this frequency decrease and signal is disturbed by multipath. Here the frequency 99.4MHz has strongest field strength, but this frequency is disturbed by adjacent interference from 99.3MHz. The best performance is now given on 99.8 MHz. The field strength for this frequency is lower than field strength of 99.4 but there are no disturbances. So the radio should switch to 99.8 MHz.

Reaching town Ebermannstadt, frequency 97.9MHz is very weak, best frequency is 99.4MHz although this frequency is disturbed by adjacent channel. Due to the adjacent channel indicator it is known that this distortion is very little. At Streitberg we have strong multipath and we can check noise reduction under this condition.

Table 3 Scoring at Forchheim

Forchheim	Network-following	Sound	Noise	Mute/ Misschange	Adjacent
Reference	3.5	3.5	4.5	0/0	4.0
New RDS	3.5	3.0	4.0	2/0	3.5
Old RDS	3.0	3.0	2.5	4/1	3.0

4.2.2 Bacharach

Test items: Ultra weak signal, Mute / Miss Changes, Noise

Bacharach test-course offers one of the most difficult reception conditions in Europe. For test drive radio station SWR3 has to be selected. 5 frequencies could be used for radio station SWR3 but most time for all of these frequencies the field strength of the signal is very low. Inside town Manubach radio could receive only one valid frequency of SWR3, field strength is less than 5dBμV. Only with a space of 100 kHz another station with a different PI code is broadcasted. At this place it is absolutely required that the radio does not do a miss change to the station with the different PI code.

Very important on this course is the strategy of noise reduction system like high cut, and soft mute to achieve an acceptable sound impression.

Table 4 Scoring at Bacharach

Bacharach	Network-following	Sound	Noise	Mute/ Miss change
Reference	3	3-	3	3/0
New RDS	3	3-	3	1/0
Old RDS	2.5	3-	2.0	6/3

4.2.3 Austria, Tauern motorway

Test items: Tunnel network following, Multipath, Network following

Fig.16 Tauern Motorway

This course has a typical reception condition for the Alps region in Italy, Austria, France, Germany and Switzerland. Left and right hand side from the road there are high mountains. During test drive we enter 6 tunnels in each direction. Inside 4 tunnels there are transmitters for the tested radio station OE3. But sometimes the frequency of this transmitter is different. It depends from which side the tunnel is entered. Therefore it is necessary to detect a tunnel situation and select the right alternative frequency. Target is that radio switch very fast, without mute and noise to the tunnel frequency.

Another Item on this test-course is to check network following to frequency with best sound and noise condition (sometimes frequency with best field strength is strongly disturbed by multipath) and to check the performance to prevent multipath noise.

Table 5 Scoring at Austria

Tauern	Network-following	Sound	Noise	Mute/ Misschange	MP	Tunnel -NF
Reference	3	3	3.5	2/0	3+	3.0
New RDS	3	3-	3.5	1/0	3	3.5
Old RDS	2.5	3	2.5	3/2	2.5	2,5

4.2.4 UK EON Network following.

Test Items: EON

This course is used to verify the functionality of the RDS option EON. During the drive on the M 25 it is tested if the radio switches to the right alternative frequency for traffic announcements. It is checked how often mutes occur and how often the radio switch to stations with bad reception and noisy sound.

The results on the most difficult test courses in Europe give the evidence that the new RDS software has improved a lot. Sometimes it already has the same performance as the software of the reference radio!

5 Conclusion

RDS is the most complex technology worldwide to receive analog broadcasted radio stations. But it offers the most convenience for the user. It offers even more convenience than some digital standards.

With RDS the user can drive around and listen to his favourite radio station. In the background the radio with RDS takes care that he receives always the frequency with the best performance. Normally the user does not notice if the performance of the RDS software is good or bad, but he will notice it, if he changes, for instance, the car brand.

Then he becomes aware that this radio receives his favourite radio station on certain places with a lot of noise or even worse with mutes. If this happened on his daily way to work he notices everyday that this car has a radio with poor performance. Therefore it is most likely that he will also consider the performance of the radio if he decides from which car manufacturer he will buy his next car.

This is one of the reasons why European car manufacturers spend so much effort to test radios from their suppliers. Radio reception is one of the key items in the JDP report.

Every European car manufacturer is watching the rating of this report carefully. They take an action immediately if they do not achieve the expected scoring.

To develop software for the RDS technology it is not sufficient to understand the specification. It requires

Table 6 Scoring at UK

M25	EON-Switching	NF Mute/Miss change		EON Mute		Reg. Func.
	Score	Times of Mute/Miss	score	Times of long EON mute	Score	Score
Reference	4	1/0	3.0	1	4	5
New RDS	3.5	2/0	3.5	1	4	5
Old RDS	3	2/1	2.5	4	2.5	5

much more. First of all, one has to understand the needs and expectations of the customers. Secondly, one has to know what the problems are in the field. Where is the reception difficult, what are the reasons for the poor performance.

For this analysis one has to develop specific tools as they are not available on the market. Last but not least engineers with high skill and experiences are required. They have the responsibility to develop software which fulfills all the above mentioned requirements. In addition, this software has to be robust and reliable. No car manufacturer accepts that his customer have any complaints only while the radio does not work or while the performance is not sufficient.

All these requirements - know how, tools, and skilled engineers - are available at the Technical Center in Nuremberg. They have proven that they have the ability to develop RDS software which is state of the art. Together with state of the art hardware, Fujitsu Ten has now the possibility to develop radios for European market which fulfil the needs and expectations of European customers.

With RDS software developed by TCN, Fujitsu Ten are approved for the "Production Part Approval Process (PPAP)" for a European Radio for the first time by General Motors.

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