Local Radio in the 26 MHz Band using DRM - Results of the Nuremberg Field Trial and General Considerations

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Abstract

Using DRM in the 26 MHz band is an interesting option for local braodcasting. A field trial was set up with two low power DRM transmitters in the area of Nuremberg.
Mobile reception was found to be possible at distances of up to 20 km to the transmitter. However, audio dropouts due to flat fading in the multipath channel were frequently observed at low vehicle speed.
Fixed reception with outdoor antennas was found to be possible at distances of more than 40 km. An overall availability of the audio signal of 99.2 % was achieved at seven different locations during ten days. Long term recordings of several hundreds of hours at one location showed that audio availability was better than 97% in many cases but was reduced at times by local sources of noise and interfering signals from distant stations when ionospheric scattering was possible due to high solar activity and sporadic E layers.
Based on these findings it is concluded that for service planning the same procedures as for VHF transmitter networks can be applied. However to avoid interference by ionosperic scattering, co-channel transmitter must be seperated by at least 2500 km. Therefore, only one channel will be available in each place.

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Introduction

The digitisation of terrestrial audio broadcasting is in progress. DAB, the digital radio system for the VHF broadcasting bands is already established in many countries. DAB is best suited for a situation where a large area, e.g. a whole country is to be covered by typically 5 – 7 programmes, because it bundles several programme services in what is called an "Ensemble". This programme multiplex is transmitted by an OFDM system using a bandwidth of 1.536 MHz. In VHF (normally Band III, around 225 MHz), large area Single Frequency Networks (SFNs) are possible and have already been implemented in several countries. When using such SFNs, DAB is quite effective in terms of spectrum usage and required transmitter power. In most countries, however, there are also local broadcasting stations which now use VHF- FM or AM in the medium wave band. For the transition to digital broadcasting, in bigger cities, normally several of these stations can be bundled to form a DAB Ensemble. In Germany and Canada, e.g., such local DAB Ensembles are broadcast in the L-Band (1452 – 1492 MHz) in many cities. Due to the propagation characteristics in this frequency range, however, high power and antennas on high towers are required and in-door-coverage is particularly difficult to achieve. Especially the coverage of outer suburbs of bigger cities needs the use of gap fillers or coverage extenders [1]. In many situations, however, the capacity provided by a DAB Ensemble will not match the needs of local broadcasting. If for instance in a bigger city there are eight or nine local broadcasters, this would require operating two DAB networks, where the capacity of both networks is used only partially. If in a smaller town or rural area there is only a single local station, a DAB network would be used only to 1/6 of its capacity. This will not be possible in an economically reasonable way and will be a waste of spectrum.
Therefore the question arises if the digital transmission system for the broadcasting bands below 30 MHz, i.e. long wave (LW), medium wave (MW), and short wave (SW) developed by the DRM consortium could be an attractive solution for single local stations in situations where DAB can not offer an ideal solution. This report briefly reviews the properties of the DRM system and the propagation conditions in the above mentioned broadcasting bands. After this the setup and the findings of a field trial which is currently carried out at the Georg-Simon-Ohm-Fachhochschule Nürnberg are reported. From these results a possible scenario for local broadcasting in particular in the 26 MHz broadcasting band using the DRM system is developed and the foreseeable limitations of such a service are lined out.

The DRM system

The DRM consortium has developed a digital broadcasting system for the broadcasting bands below 30 MHz, shortly referred to as the DRM system. Its specification is public [2] and transmissions on the respective bands have started some years ago. The main concern of DRM was to improve the audio quality of broadcasts in the LW, MW, and SW broadcasting bands. Another important target was to improve the user friendliness of receivers by sending station identification and tuning information along with the audio in a separate channel. The main features of the DRM system are described in the DRM consortium's Broadcaster's User Manual [3] and several review articles [4-6].
Concerning the issue of local broadcasting, the DRM system is able to offer high audio quality by using the MPEG AAC coding scheme with Spectral Band Replication (SBR). This coding algorithm allows to achieve an audio quality which subjectively comes close to that of VHF-FM in many cases, even though only a data rate of approximately 20 kbit/s available in a 10 kHz wide DRM transmission is used. In the ground wave propagation situation which will most likely occur in local broadcasts only a small overhead for error correction is needed and hence DRM can provide a high data rate for audio. However, in such a configuration, the required signal-to-noise-ratio (SNR) at the receiver input may be as high as 20 – 30 dB, which will be difficult to achieve when mobile and in-door-reception is desired and low power transmitters are used by local stations.
The DRM system offers all service information features known from e.g. the Radio Data System (RDS) of VHF-FM or DAB such as service label, programme type, and announcement switching (similar to the TA/TP mechanism of RDS, but with extended functionality). Besides that, text messages can be sent along with the audio, and even the transmission of multimedia data such as electronic newspapers and slide shows is possible and has been demonstrated, although the loading time is significant (several minutes) due to the limited data rate available if high audio quality is to be maintained.
Therefore, a local service broadcast on DRM would not appear much different to the listener than a service broadcast on VHF-FM with RDS or on DAB, except that the audio quality will be slightly reduced

(e.g. no stereo or restricted audio bandwidth to e.g. 11 - 15 kHz) and the data rate available for programme associated data is considerably lower (e.g. in the order of 1 kbit/s instead of e.g. 16 kbit/s in DAB). When considering the use of portable or "kitchen radios" these differences will not matter, for mobile reception some more detailed consideration is necessary because the audio system in high level cars is quite developed and the difference in sound quality between a DRM and DAB broadcast will be perceivable – the same will of course be true for home HiFi equipment.

Choice of frequency for DRM local broadcasts

The most important question in the context of using the DRM system for local radio is the availability of channels and the propagation characteristics of the broadcasting bands in the range DRM is designed for, i.e. below 30 MHz.

Medium wave

Many local stations today use MW frequencies (525 – 1605 kHz). The MW band however shows very different propagation during day time and night time. During day time, only ground wave propagation occurs with higher attenuation of the frequencies near the upper end of the band than for the frequencies at the low end. Therefore, for local broadcasting, the range around 1500 kHz seems to be most appropriate, because the channels can be re-used in a short distance from a transmitter. This however is different at night. Then, in addition to ground wave propagation, sky wave propagation allows propagation over several hundreds to thousands of kilometres. The re-use distance of MW channels during night time would therefore have to be several thousands of kilometres – this however can not be accommodated in planning. Therefore, co-channel interference occurs during night time which significantly reduces the day time coverage area. First results from field trials in the Medium Wave band confirm these considerations and show a strong reduction in service area during night time [7].
Other problems encountered with MW are the requirement of high antenna towers and a significant level of man-made-noise especially in urban areas.

Short wave

A number of broadcasting bands are available in the short wave part of the spectrum (2 – 30 MHz). Ground wave propagation is normally not used in these bands due to the high attenuation. The coverage is solely achieved by sky wave propagation. Most of the bands allow for propagation to a specific target area only for some time of the day, and this changes with the daily conditions of solar activity, seasonally and in conjunction with the 11 year sunspot cycle. Therefore, in international broadcasting, several frequencies in different bands are used in parallel and not all bands can be used during all times of the day and the year.
For the use of local broadcasting those bands can be used which do not allow for long distance coverage for most of the time. They are hardly used by international broadcasters and for most of the time there is no co-channel interference from distant stations through ionospheric scattering.
This is true in particular for the 11m broadcasting band (25670 – 26100 kHz). Therefore our study aims at this frequency range. In addition to setting up two experimental low power DRM transmitters we performed an analysis of the restrictions with regard to channel assignment and planning if this band were widely used for local broadcasting as is suggested by the DRM consortium (Ref. [3], p. 47).

The Nuremberg / Dillberg field trial

Setup of the field trial

Due to the propagation conditions in the 26 MHz band, reasonable results concerning the reliability of coverage can only be obtained in a long term test covering all seasons of the year. Of course issues related to the 11 year sunspot cycle can only be investigated at much longer time periods and can not be expected to show up in the results for only 2 years of operation.
Other important topics that were addressed in our study are:

- to show that DRM local broadcasting stations can be set up with minimal hardware effort,

- to study the interference from sky wave propagation phenomena at different seasons of the year.
- to investigate mobile reception in the 26 MHz band,
- to investigate stationary reception, in particular in-door-reception and the impairments resulting from local noise sources.

We obtained two licenses for experimental transmissions in the 26 MHz band from two transmitter sites. The main features of the two transmitters are listed in Table 1.

Table 1. Characteristics of the transmitters used in the trial

	FH - Nuremberg	Dillberg
Location	49°27'10'' N 11°05'40'' E	49°19'28'' N 11°22'55'' E
Height a.s.l.	300 m	600 m
Frequency	26012 kHz	26000 kHz
Antenna	Half wave dipole	Vertical half wave antenna
Height of Antenna above ground	30 m	5 m
E.I.R.P	10 W	100 W
Operation	March 2003 – January 2005	Since February 2004

Both transmitters are usually operated with the following parameters:

Robustness Mode	A
SDC Mode	4 QAM
MSC Mode	16 QAM
Spectrum Occupancy	3 (10 kHz band width)
MSC Cell Interleaving	2 s
Equal Error Protection,	code rate 0.62.
Audio: Mono signal	18 kbit/s using AAC-SBR
Programme service:	FH Nuernberg Campus Radio.

The details of the transmitter and receiver hard- and software setup have already been published [8] and can also be found in the internet [9].

Results of the field trial

Mobile reception

After setting up the transmitters we investigated their respective coverage areas by mobile reception tests. A short vertical dipole antenna (1m long) was used together with a DRM – modified Yaesu FRG 100 receiver and the DREAM or DRM software radio for decoding the signal on a notebook computer which was operated on its internal battery to avoid noise. Some of the tests were made using a RF systems DX 500 short active antenna and a DRM – modified AOR 5400 receiver. In the area where both setups were used there was no significant difference in reception performance.

The main emphasis on this investigation was on audio quality, because field strength is not a sufficient planning parameter due to different noise levels and dropouts due to multipath fading. Therefore we took the percentage of correctly decoded audio frames which is also logged by the DRM software receivers as a measure for the quality of reception. In the maps (Figs. 1 & 2) the results are coded by their colour: green: > 75% of audio frames decoded correctly, yellow: > 50% of audio frames decoded correctly and red: <50% of audio frames decoded correctly.

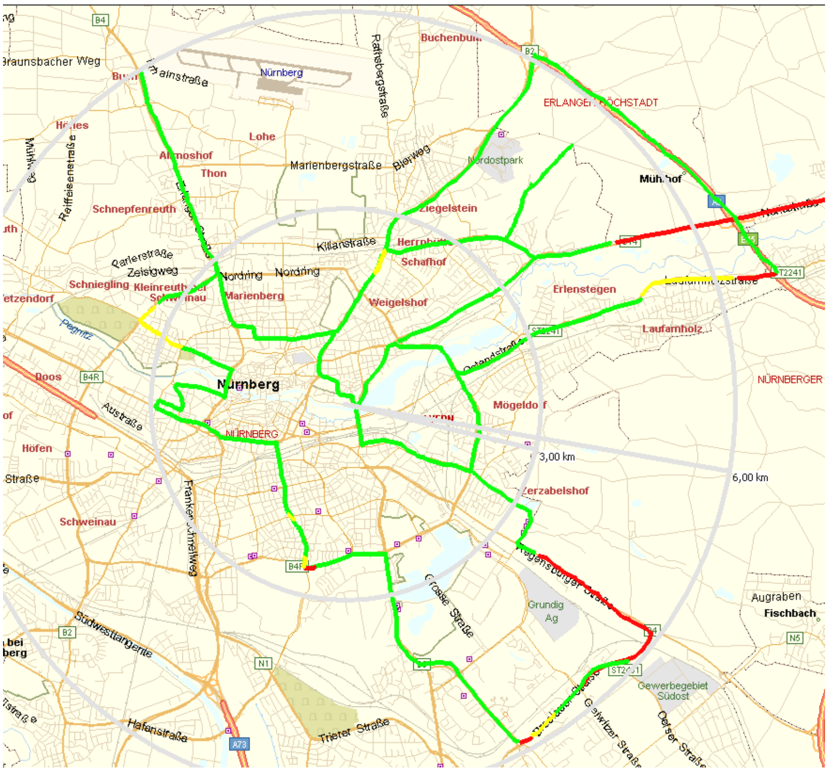

Fig. 1: Service quality within the range of the Nuremberg Transmitter.

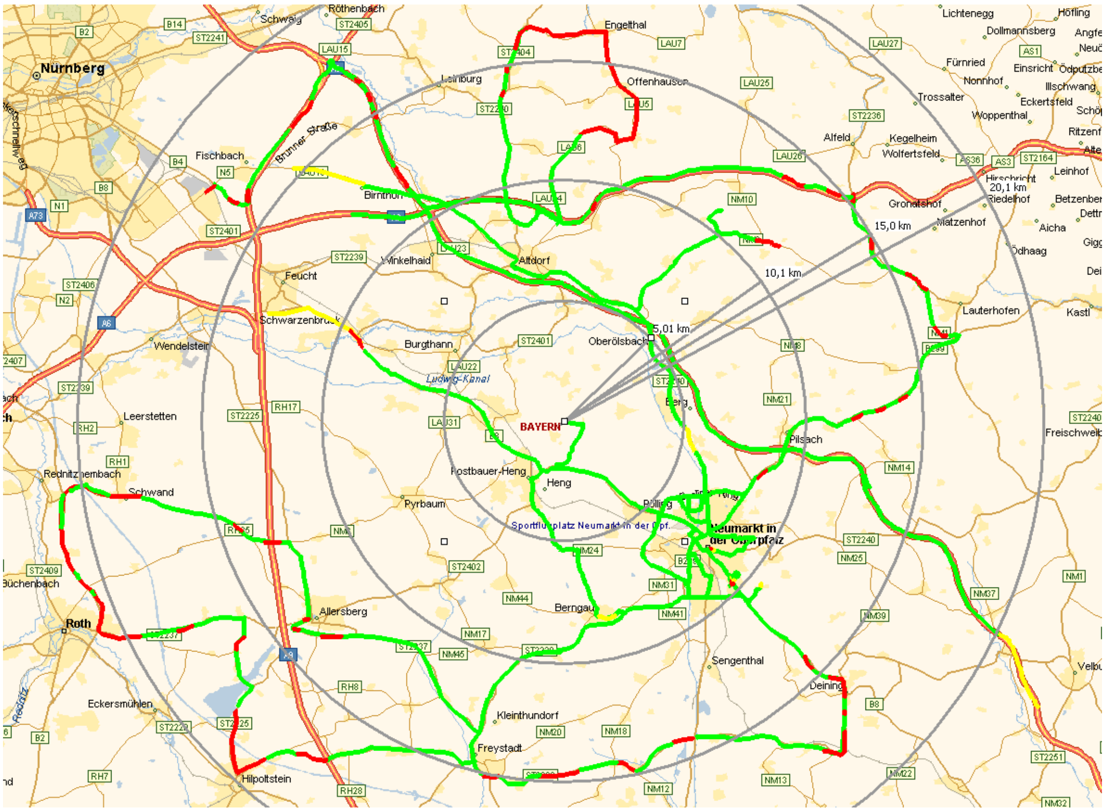

Fig. 2: Service quality within the range of the Dillberg transmitter.

In practice, however, we find sharp transitions from perfect reception (100% correctly decoded frames) and total dropout. The areas where interrupted reception occurs are very small, usually in the order of few hundreds of metres at the fringe of the coverage area.
The results shown in Figures 1 and 2 show that the transmitters have a range of approximately 3-5 km (Nuremberg) and up to 15 km (Dillberg), depending on the terrain and density of buildings. In particular the landscape is rather flat towards the south and west of Dillberg, while it is rather hilly to the north and east. This corresponds to a wider coverage range towards the south west (extending to almost 25 km for mobile reception) while the range is limited to the line-of-sight slopes of the hills in the north and east. This concerns the areas of Deining, Lauterhofen and Engelthal – Offenhausen, which are rather close to the transmitter but are shaded by hills in the direction of the transmitter site. It was also noticed that reception was generally better in areas without dense woods and that at the same distance to the transmitter shadowing from trees impaired reception (e.g. in the Hilpoltstein and Freystadt area, at the south fringe of the mobile range of the Dillberg transmitter).
Both the results for Nuremberg and the Dillberg area are in good agreement with data gained by Deutsche Welle in the same area [10]. They were also able to measure field strength using a calibrated setup with a Rohde & Schwarz HE010 vertical active antenna and a Rohde & Schwarz EB 200 measurement receiver.
Their results indicate that audio reception (threshold: 60% of the audio frames decoded correctly) is possible when the field strength is above 23 to 26 dBμV/m which is somewhat higher than the value of 17.6 dB(μV/m) which the ITU proposes as a planning parameter for the DRM mode used in our transmission [11]. This may be due to the higher man made noise in the city of Nuremberg and along the motorway where most of the field strength values were actually measured, in addition, due to multipath fading (see below) a higher level is required for reception than for stationary reception.
Generally we find reception problems in villages and in particular in the bigger cities (Nuremberg, Neumarkt). This is apparently due to the higher noise level and possibly also caused by multipath propagation due to reflected signals from buildings. We investigated this issue further by recording receiver input power along several streets at different distances from the Nuremberg transmitter.
Fig. 3 shows the locations of the measurement sites, Fig. 4 shows a typical result. The occurrence of fading can clearly be seen. The statistical analysis shows that the results in most locations can be interpreted as caused by a Rayleigh channel (Fig. 5). This means that the received signal is a superposition of scattered components without a direct ray. This is plausible because of the relatively low height of the transmission antenna above ground. Due to the small bandwidth of the signal this fading is not frequency selective but flat (Fig. 6). This is caused by the fact that due to the low transmitter powers only reflected signals from the vicinity of the receiver contribute to the received signal leading to a delay spread in the order of only few microseconds. Hence the coherence bandwidth of the channel is in the range of several hundred kilohertz. This indicates that at the frequency of 26 MHz we must consider reflections from buildings leading to flat fading as a main cause of reception problems in cities.

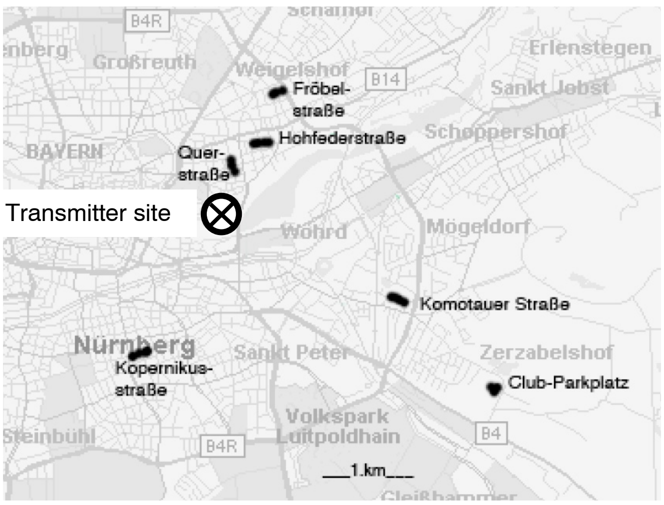

Fig. 3: Sites in Nuremberg where receiver input power along ways of several hundred metres was recorded [12].

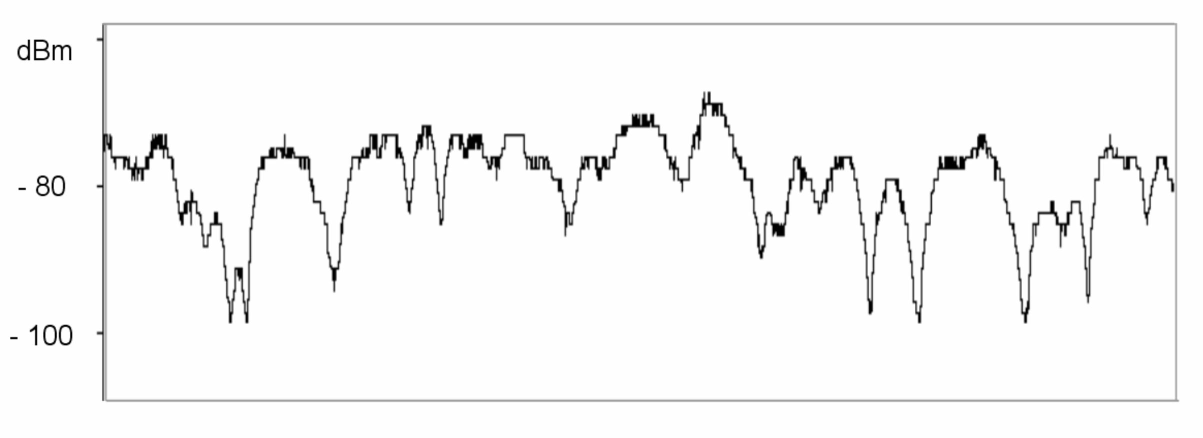

Fig. 4: Receiver input power along a route of 200m at Club-Parkplatz [12].

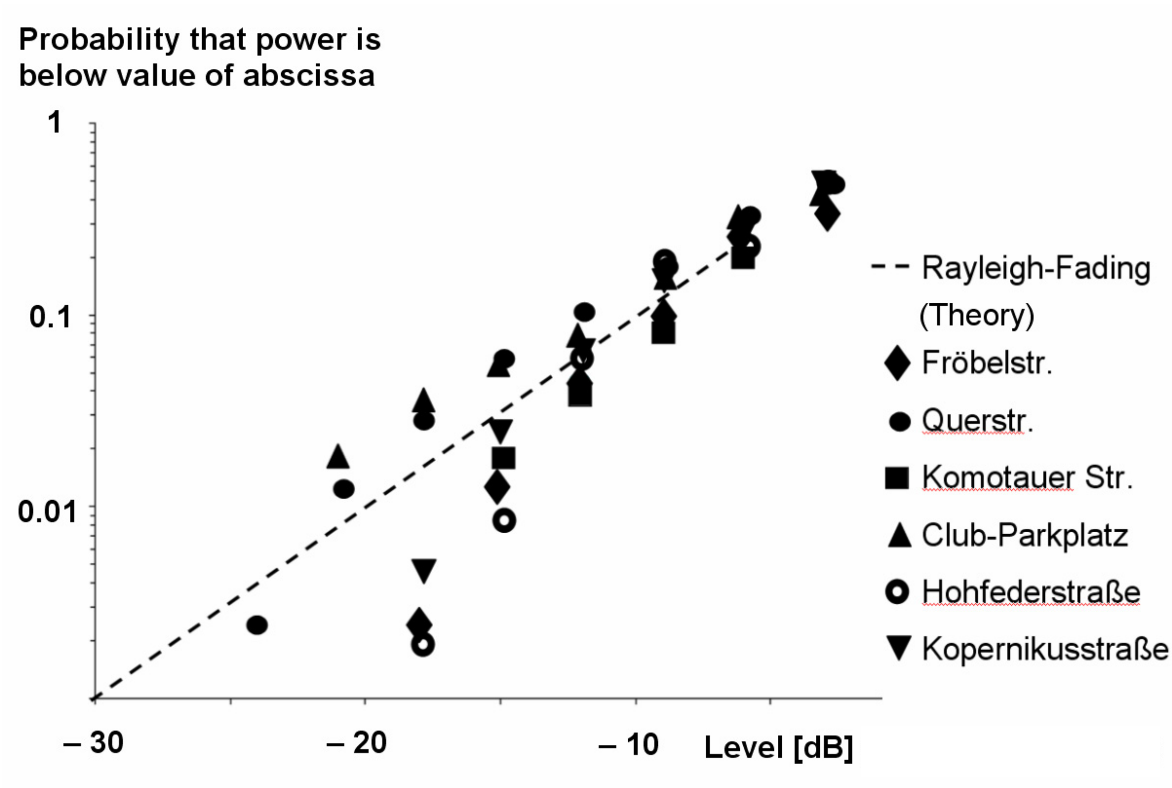

Fig. 5: Result of statistical analysis (Rayleigh-plot) showing that Rayleigh fading can in most cases be assumed to cause the fading observed in measurements of receiver input power [12].

Stationary Reception

The transmissions from both transmitter sites were monitored at the home of the author in a suburb of Nuremberg (Altenfurt, see Fig. 8) at about 8 km distance from Nuremberg transmitter and at about 18 km from Dillberg transmitter for several periods of time during March 2003 – August 2005. A number of voluntary persons, in particular students of our Fachhochschule who were equipped with receivers and radio amateurs joined these monitoring efforts to achieve parallel reception at different sites during several days.

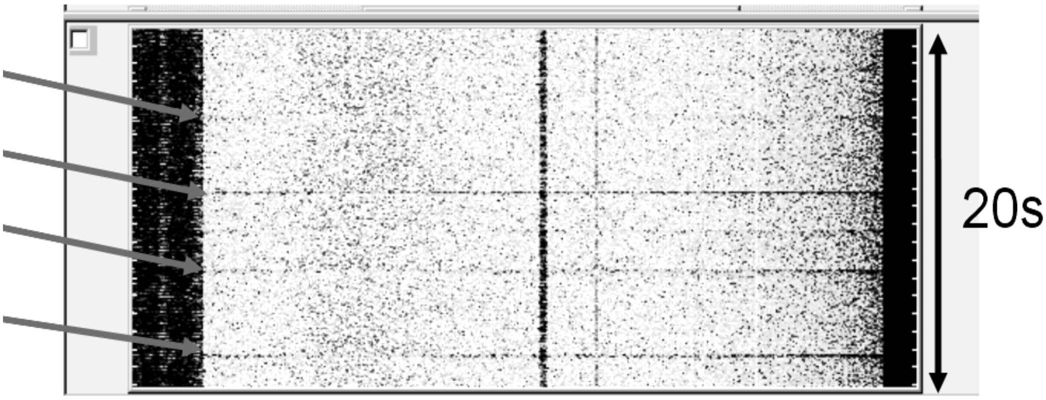

Fig. 6: Waterfall diagram of received signal along a route of 20 s in Fröbelstraße indicating that the fading of the signal is not frequency selective but flat.

A number of observations were made which concern the reliability of reception in the 26 MHz broadcasting band which are summarised here. The main mechanisms that lead to reception impairment are:

- Interference from FM radio from eastern Europe, when long distance propagation is possible
- Local sources of interference, e.g. man – made – noise.

To separate both mechanisms we compared the results (SNR and percentage of correctly decoded audio frames) of simultaneous recordings of reception at different sites.
Fig.7 shows an example of such a set of recordings. During the whole day of January 10th, 2004, the Nuremberg transmitter was received at four different sites at different distances from the transmitter (Wöhrd: 0.5 km, Meistersingerhalle: 1.5 km; Stein: 8 km, Altenfurt: 8 km). While reception close to the transmitter (Wöhrd) was unimpaired all over the time, reception at the other sites suffered from interference from about 9 to 13 UTC. It was found that this interference is caused by signals from remote transmitters, probably from an FM radio network operating in Eastern Europe. The impairment due to the interfering signals is worse when the signal from the DRM transmitter is rather week (Meistersingerhalle, due to shadowing by buildings) and does not occur when the wanted signal is strong (Wöhrd, close to the transmitter) and the interfering signals are much weaker than the wanted signal. At Stein there is apparently also a local source of impairment which caused dropouts between 4 and 5 UTC, which were not observed at the other sites.

We performed such comparative measurements on ten days between January and May, 2004, on eight of which reception from both transmitters was studied at up to seven sites of reception. Basically, the findings for all were similar to those presented in Fig. 7. Depending on the season of the year we occasionally observed simultaneous interference from distant transmitters, however only during daytime, never during the night, but we always found uncorrelated impairments due to local sources of noise both at daytime and nighttime. We recorded reception parameters (SNR and availability of audio) for a total of 1434 hours (all sites summed up). We received unimpaired audio signals (100% availability) for a total of 1004 hours. For the remaining time, i.e. when interference occurred, the average audio availability was still 96.2%. Hence the average audio availability over the whole time and at all sites was 99.2%.

Another measurement campaign was performed in December 2004 and January 2005. The receiving sites for Dillberg transmitter are shown in Fig. 8, and a typical set of results is shown in Fig. 9.

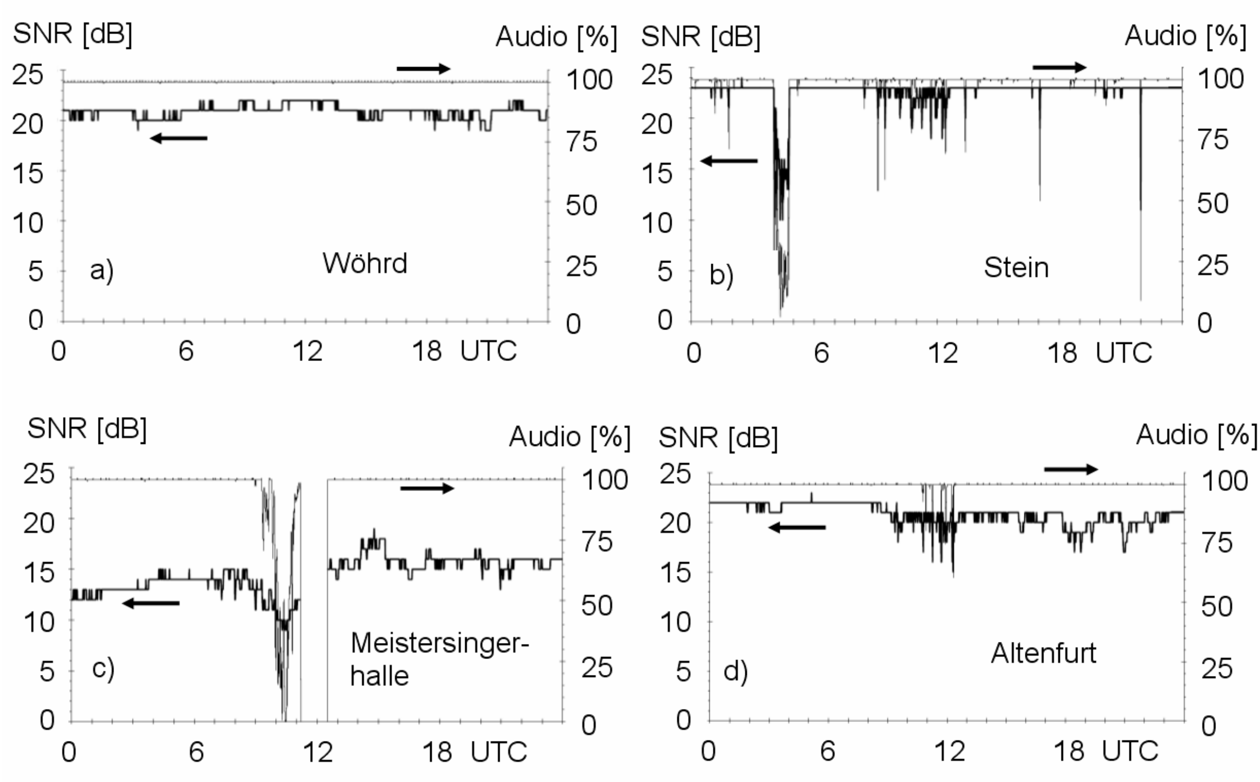

Fig. 7: Results of four recordings of the transmission from Nuremberg transmitter on January 10th, 2004 [12].

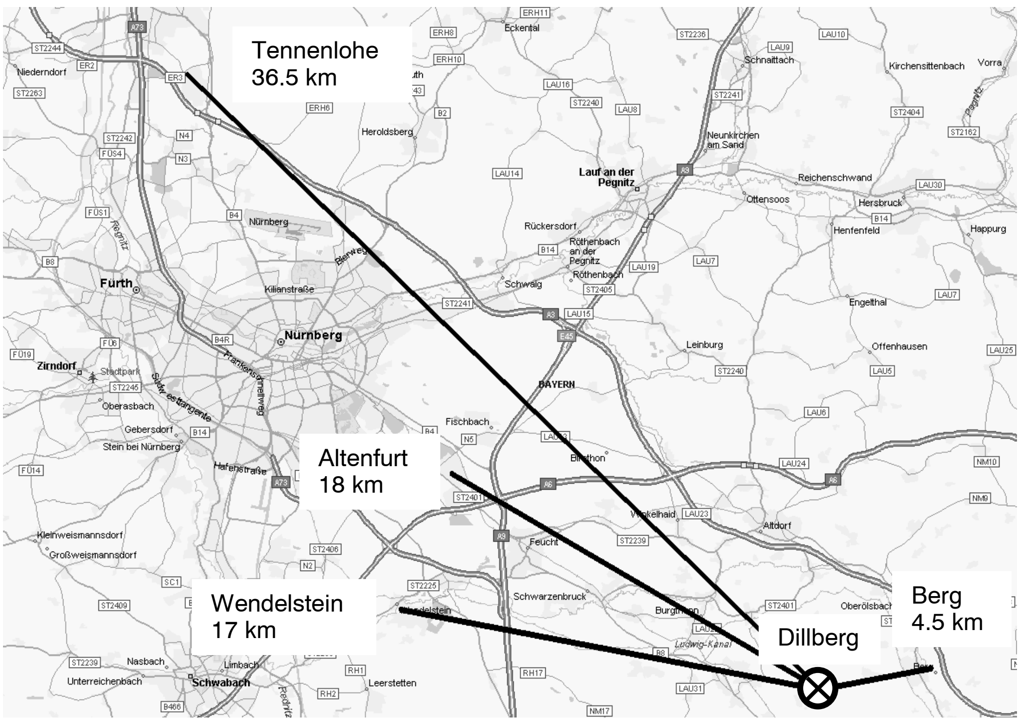

Fig. 8: Location of receivers and their distances from Dillberg transmitter during the measurement campaign in December 2004 – January 2005

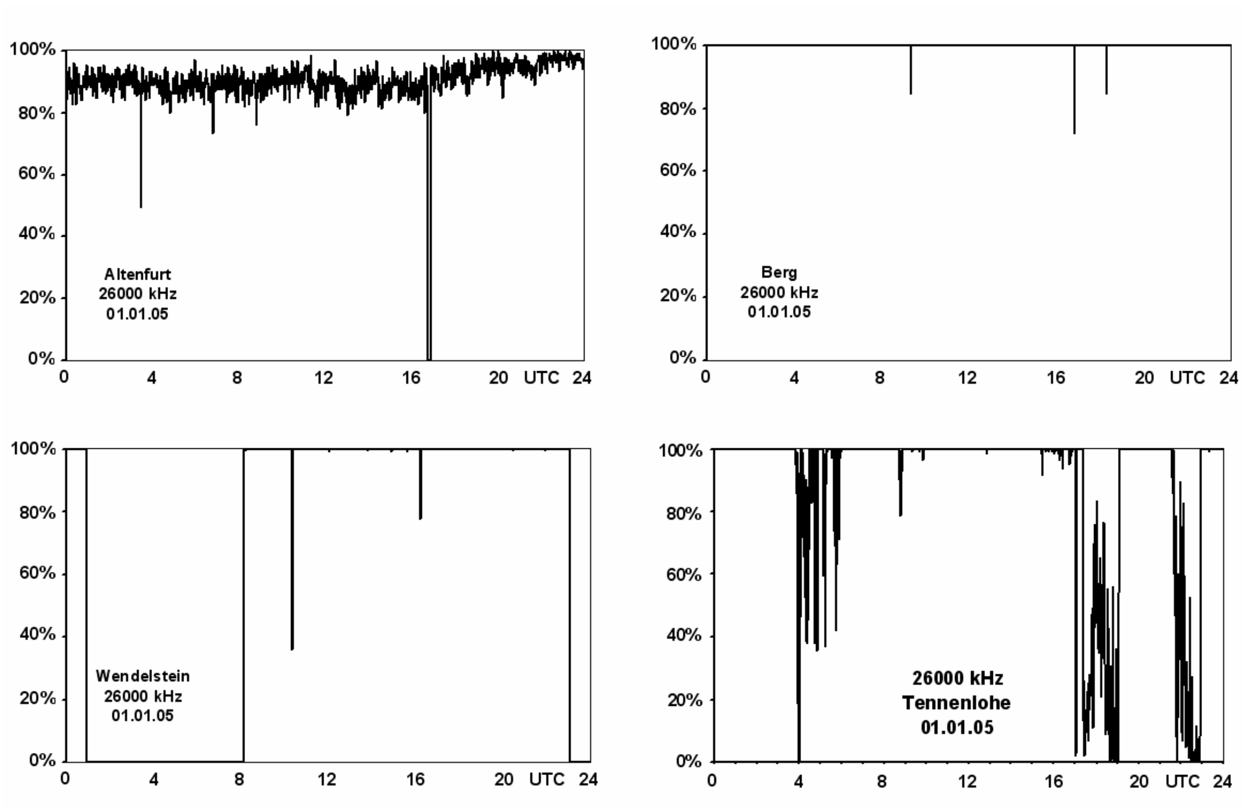

Fig. 9: Typical results of audio availability from Dillberg transmitter during December 2004 – January 2005

Again we notice that most of the reception problems are due to local interference, in particular at Altenfurt and Tennenlohe. At Tennenlohe, where the receiver was placed in an industrial zone, the impairments occurred on all days at the same time and were probably caused by some electrical applicance which is always operated at the same time of the day.

From December 2004 to July 2005 we performed long term recordings of reception from both transmitters, again at Altenfurt. The respective results are presented in Table 2. Concerning the rather low values in January and February 2005 we observed that this was due to a local source of noise at Altenfurt, similar to the pattern shown in the Altenfurt part of Fig. 9, while reception at other sites was unimpaired.

It is interesting to note that the result from June 2005 is quite low although the local source of noise leading to the low values during January to March was usually not present at that time (Fig. 11a). However, sporadic E layers in the ionosphere frequently occur in the northern temperate zones during May to July leading to interference from distant sources. To proof that the impairment was non-local, again receivers at two locations (Altenfurt and Stirn, about 40 km south of Altenfurt) were operated simultaneously for two weeks in May 2005. Fig 10 shows the results from two days – one without presence of sporadic E (Figs. 10 a) and c)), the other where impairments were observed at both locations at the same time attributed to the occurrence of a sporadic E layer (Figs. 10 b and d).

During summer 2004 and 2005 we also received a number of reception reports for the Dillberg transmitter from short wave listeners from several European countries (Fig. 11 a). We ourselves could receive a DRM transmission from Rennes on 25775 kHz several times with SNR good enough for audio decoding (Fig. 11 b). This also shows the relevance of sporadic E layer propagation at this frequency range.

Table 2. Results of long term recording of reception parameters at Altenfurt.

Month	Nuremberg Transmitter		Dillberg Transmitter	
	Total time of recording (hours)	Audio availability	Total time of recording (hours)	Audio availability
December 2004	239	99.9%	315	97.6%
January 2005	315	98.6%	455	91.3%
February 2005	–	–	558	90.6%
March 2005	–	–	354	92.9%
April 2005	–	–	497	99.5%
May 2005	–	–	605	97.3%
June 2005	–	–	427	93.9%
July 2005	206	99.6%	381	97.0%

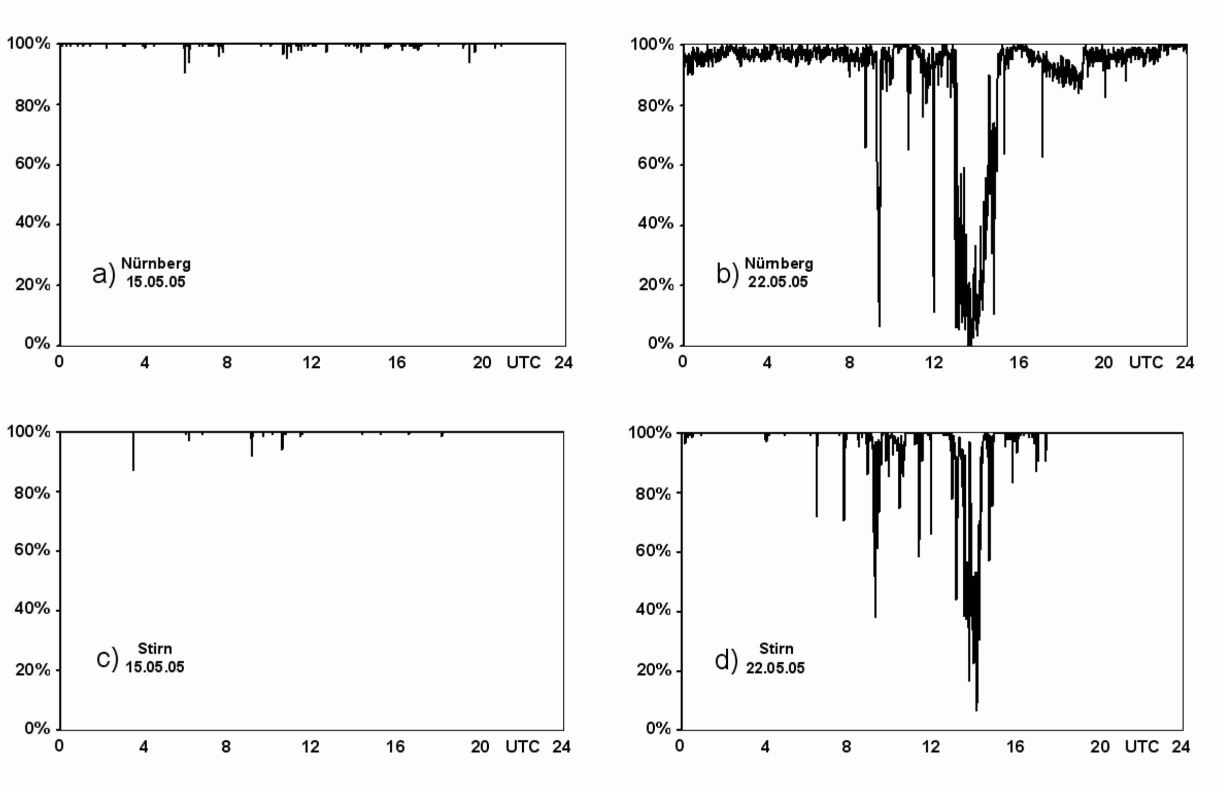

Fig. 10: Audio availability from Dillberg transmitter at two receiving sites on two days during the sporadic E season in May 2005.

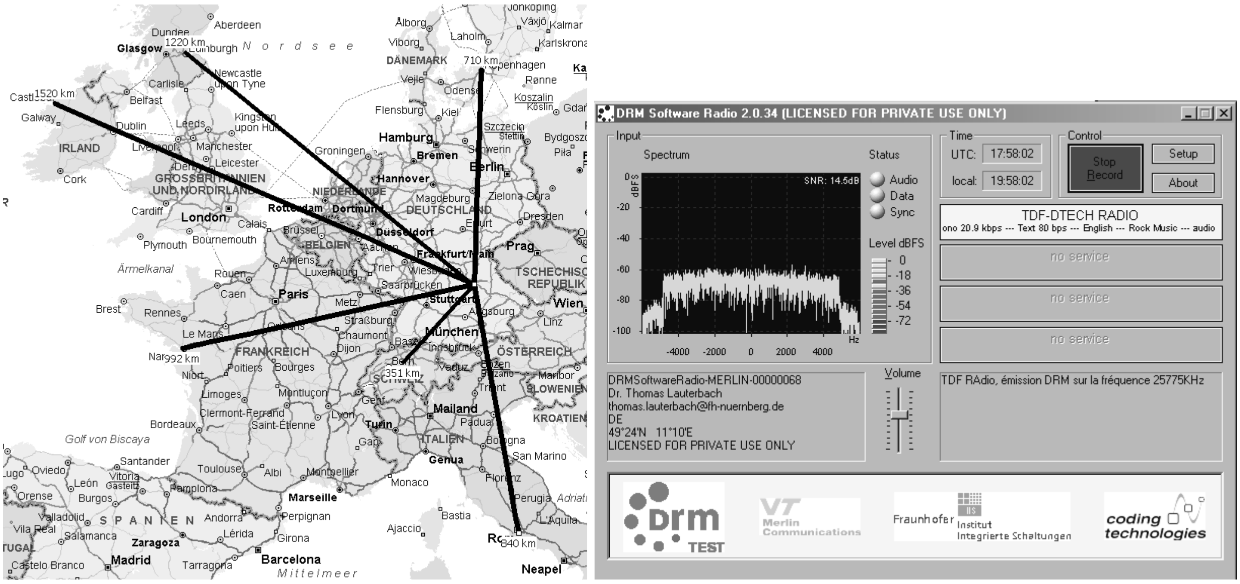

Fig. 11: a) sites from which reception reports for the Dillberg transmitter were received during Summer 2004 and Summer 2005. b) Screenshot of reception of a DRM transmission from Rennes in Nuremberg (distance: 950 km) on June 27th, 2004.

Considerations for planning local services in the 26 MHz band

Planning the service area

The results from our field tests suggest that local sound broadcasting services may well be operated in the 26 MHz shortwave band. For planning the service area of such stations, the same method as for planning VHF networks may be used, because the useful service area will be determined by direct propagation from the transmitter site to the receivers. Propagation conditions do not seem to be very different from the VHF range, in particular with respect to shadowing by terrain and buildings and reflections leading to multipath propagation.

The measurements of field strength that have been carried out in the Nuremberg and Dillberg area by Deutsche Welle [10] support this view. It was found by them that a minimum field strength of 23 dbμV/m was required for appropriate audio decoding. The range for uninterrupted mobile reception of the Dillberg transmitter was found to be 15-20 km (Fig. 2). This is consistent with the VHF prediction curves of ITU-R Rec. 370 [13]: for a 1 kW transmitter with an antenna height of 150 m (this corresponds well to the Dillberg situation because the antenna is at 605 m a.s.l. while the surrounding terrain is at approximately 350 – 400 m a.s.l.) the predicted field strength at 20 km distance for 50% of locations and 50% of time is 63 dBμV/m. Since the transmitter only uses 100 W, this value must be reduced to 53 dBμV/m. Because reception is uninterrupted at this distance from the transmitter, we must consider a location probability of 99%, which means that the predicted value must be reduced by another 18 dB, resulting in 35 dB μV/m. This predicted value however is an aerial 10 m above ground level at the receiving site. At car antenna level, i.e. 1.5 m above ground, the field strength is expected to be lower by approximately 13 dB [13], which leads to 22 dBμV/m, in good agreement with the measured values.

Mobile reception

If a service, however, is to be received by mobile and portable receivers, the flat fading conditions of the 26 MHz multipath channel would lead to audio dropouts at certain spots. This may be relevant in particular for mobile and portable receivers at low speed, e.g. radios in cars in traffic jams or stopping at traffic lights and for portable receivers, i.e. in situations where time interleaving does not improve reception due to the slow time variance of the channel. It is important to remember that the DRM system is not designed to operate in such channels. Therefore these dropouts cannot be avoided by increasing power or other measures. However, reception may improve in single frequency networks when receivers receive uncorrelated signals from at least two transmitters.

Planning to avoid interference

In contrast to VHF, where the same prediction curves may be used for planning the service area and the field strength caused by potential co-channel interferers, long distance propagation issues related to ionospheric F layer and sporadic E layer scattering must also be considered for planning in the 26 MHz band in order to prevent mutual interference of such services.

F layer propagation

The most relevant phenomenon for long distance propagation in the short wave range is scattering from the F layers of the ionosphere. These layers are approximately 300 km above the surface and show critical frequencies f_0 (i.e. the highest frequency which is scattered back from the ionosphere at vertical incidence) of typically several megahertz. The highest frequency which is scattered back from the ionospheric layers at the flattest angle of incidence is referred to as the maximum usable frequency (MUF). The relation between the critical frequency and the MUF is given by

$$f_{\mathrm{MUF}} = \frac{f_0}{\sqrt{1-\left(\dfrac{\cos\varphi}{1+h/r_E}\right)^2}}$$

In this equation, h is the (virtual) height of the ionosperic layer (300 – 400 km in case of the F layer), r_E is the radius of the earth and φ is the angle at which the wave is radiated from the ground. The highest value of f_{MUF} is obtained for $\varphi = 0$, i.e. for a wave radiated towards the horizon. In this case the MUF will be about 3.4 times as high as the critical frequency. Hence a 26 MHz wave will be scattered back from the ionosphere when the critical frequency of the F layer is above about 8 MHz. The critical frequency of the F layer depends on the time of the day, the season and the solar activity. A median value of 8 MHz is well exceeded during the winter season and during day time in the years of the sunspot maximum, because this value for f_0 correlates to a sunspot number (gliding average) of R $\approx$ 80. In a particular sunspot cycle, for instance, a value of 80 of the sunspot number was exceeded from January, 1956 to January, 1961, i.e. for five years (Fig. 12). During this period of time, which is periodic every 11 years, long distance propagation in the 11 m shortwave band will occur especially in directions where the whole path is on the day side of the earth. Due to the lower angle of incidence of the solar rays on the ionosphere the critical frequency and hence the MUF is higher in winter. Therefore, excellent long distance propagation will occur along the day paths in winter, for instance from Europe to the U.S. during the afternoon in Europe (morning in the US) and from Europe to the far east during the morning in Europe. During the summer, long distance propagation will be possible on transequatorial paths, e.g. from Europe to South Africa and South America. It should be noted that during the relevant period the sunspot number is not constant nor is f_0F_2. For well established local radio with many stations operating in this band world-wide, however, interference from co-channel stations would be probable in particular on winter days during the years near the sunspot maximum.

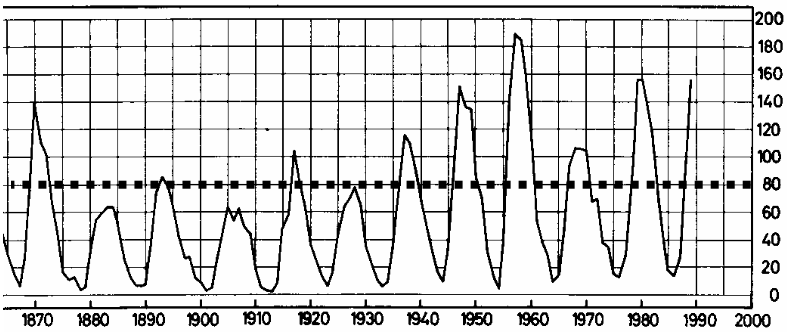

Fig. 12: Sunspot relative numbers R [14]. For R > 80, F layer propagation at 26 MHz is possible.

A propagation prediction was performed to find out under which conditions mutual interference from local radio stations using the same channel in the 26 MHz band would occur. The relevant criterion is that impairment will occur if the field strength of the interferer is higher than around 0 dBμV/m assuming that the minimum field strength of the wanted signal is higher than 20 dBμV/m and a minimum signal to interference ratio of 20 dB is sufficient to suppress any audible impairment.
The simulations were performed using the software “Funk – Prognose Version 3.3.2” by Uwe Runte. This software generates maps of field strength values of a given transmitter which are predicted to be exceeded for 50% of time. The following parameters were used: Transmitter location: Munich, Germany, E.I.R.P. 1 kW, vertical angle of radiation 10°, corresponding to the vertical pattern of a vertical half-wave antenna at 10 m above ground. The simulation were performed for different values of the sunspot relative number (150, 100, 50, 15), different times of the day (0.00, 4.00, 8.00, 12.00, 16.00, 20.00 UTC) and different seasons (January, April, July, October). A single result of such a simulation is shown in Fig. 14.
It can be seen from this example, but also from the results of all simulations that only in the area where the transmitted wave hits the ground after a single ionospheric hop a field strength high enough to generate interference is to be expected.
The results of all simulations are summarised in Table 3 which shows under which conditions mutual interference would occur if transmitters at arbitrary distance are operated on the same channel. It is evident that even when sunspot numbers are rather low interference would occur for some hours of the day. This is in good agreement with our experimental observations regarding interference from eastern European radio communications which occurred even at sunspot numbers as low as 34 and 26 [8].
Therefore, co-channel transmitters should not be located at distances of about 1500 – 2500 kilometres if mutual interference is to be avoided.

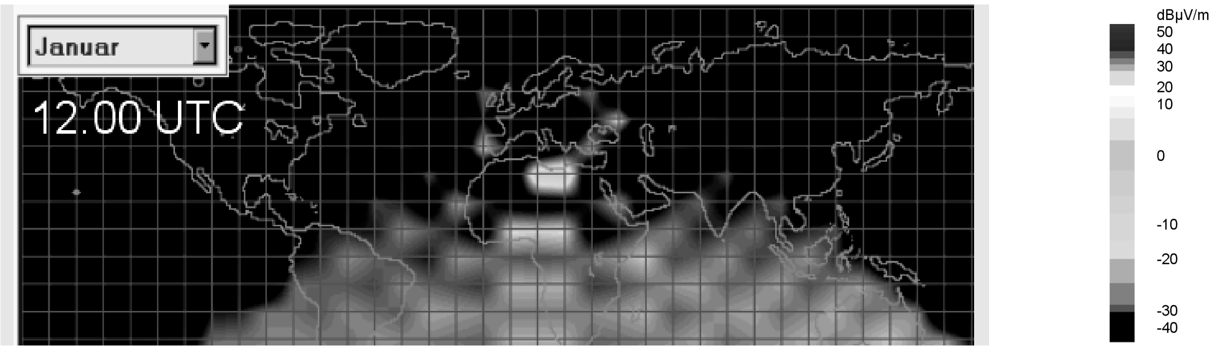

Fig. 13: Example result of a prediction of field strenght of a 1 kW transmitter operated from Munich, Germany. R = 50 (maximum of sunspot cycle).

Table 3: Conditions under which mutual interference of transmitters operating in the 26 MHz range is to be expected (Central Europe).

	January						April						July						October					
UTC	0	4	8	12	16	20	0	4	8	12	16	20	0	4	8	12	16	20	0	4	8	12	16	20
R=150			■	■	■				■	■	■	■			■	■					■	■	■	
R=100				■					■	■	■					■					■	■	■	
R=50										■	■											■		
R=15																								

Sporadic E Layer propagation

The E layer of the ionosphere is normally only relevant for frequencies below about 10 MHz. However, especially during summer, highly ionised spots in the E layer, called sporadic E layers, occur. Their critical frequencies are above 7 MHz for 5% of the time and above 9 MHz for 1 % of the time in northern termperate zones during May to August, 8^h-23^h local time [15]. In contrast to F layer propagation, sporadic E layer propagation will also occur during periods of lower solar activity.

Statistical data concerning the frequency of occurrence of sporadic E layers in different zones of the world and a method for calculating the field strength are given in [15]. From the data provided there, we calculated the field strength that a co-channel interferer would generate during the occurrence of sporadic E propagation. The result is shown in Fig. 14. Field strength that would cause interference may be reached at distances from 400 to 2000 km, and at the same distances even reception of the signal should be possible. Again our experimental observations and reception reports for our transmissions support this result (see Figs. 11 and 12). If this type of interference is to be avoided, co-channel transmitters should not be placed at distances between 400 km and 2000 km if interference should not occur for more than 1% of the time during summer (May – August in the northern temperate zones). It should be noted, however, that this prediction is for a single pair of transmitters. If there are several transmitters at the same distance from the wanted one but in different directions, the occurrence of sporadic E layers will not be correlated and hence the probabilities for their occurrence have to be added up. Thus interference will be more frequent.

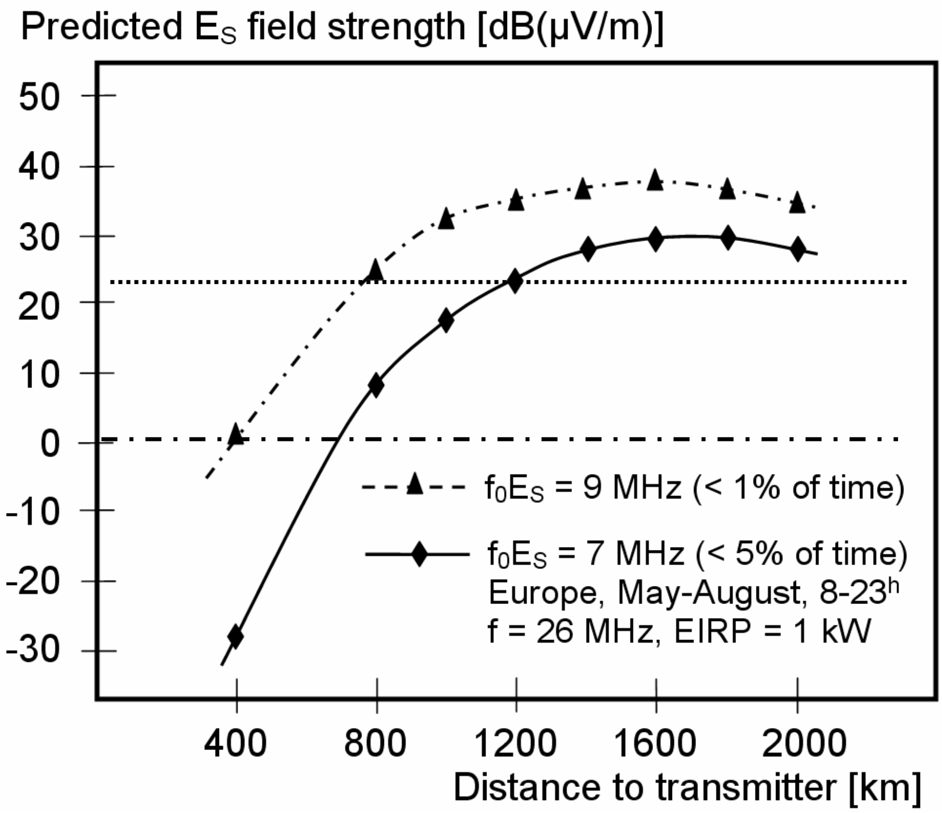

Fig. 14: Predicted field strength according to [15] for propagation via sporadic E layers for 1 kW transmitters operating on 26 MHz. Thresholds for interfernce (0 dBµV/m) and reception (23 dBµV/m) are indicated.

Conclusions from propagation issues and development of a planning scenario

From the properties of ionospheric propagation reviewed above it must be concluded that if the 26 MHz short wave band were widely used for local broadcasting without international channel assignment, a situation would arise where during daytime in the years around the sunspot maximum a number of co-channel stations at distances of up to several thousands of kilometres would generate a significant level of interfering field strength. The coverage area of the wanted transmitter would then shrink dramatically. In summer, due to sporadic E propagation, there will be additional interference from stations nearby (as close as 400 km) even in the years of the sunspot minimum.

Therefore a careful planning method is required. A safe recipe seems to be not to place co-channel stations at distances from 400 km to 2500 km to each other. An example for this is given in Fig. 15. In each of the dark spots with diameters of approximately 400 km the same channel could be used. However, in a large area around each transmitter the same channel should not be used if mutual interference is to be excluded. Since the 26 MHz band only has a bandwidth of 430 kHz, there are only 43 channels in total. To reasonably fill the diamond-shaped area between four adjacent areas where the same channel can be used, a number of 57 channels would be needed (Fig. 16). Therefore some additional channels would be required e.g. in the 21 MHz band (13 m – Band) for which similar propagation conditions can be envisaged, or the assignment of a wider frequency range in the 26 MHz band would be required. Even if this can be achieved, it would mean that in each area only a single channel would be available for local broadcasting. If more channels are required in one area, they must be taken from the surrounding areas or mutual interference with other services at least during some time must be accepted.

It should be noted however that the problems caused by mutual interference from distant stations are complementary on medium wave and in the 26 MHz band. Therefore a solution for local broadcasting in the bands below 30 MHz could be to switch frequencies twice a day using a 26 MHz frequency during night time and a medium wave frequency during day time. Then many more channels would be available. Future DRM receivers are expected to be able to seamlessly follow such a switch with no interruption of audio output, because it can be signalled in advance and the same DRM parameters could be used (e.g. DRM mode A with 9 kHz bandwidth), because the service on short wave will also rely on ground wave propagation. The proper time to switch can either be derived from propagation predictions or using monitoring receivers at the fringe of the desired coverage area. However the cost of operating such a dual transmitter site will be significantly higher than that of a single station.

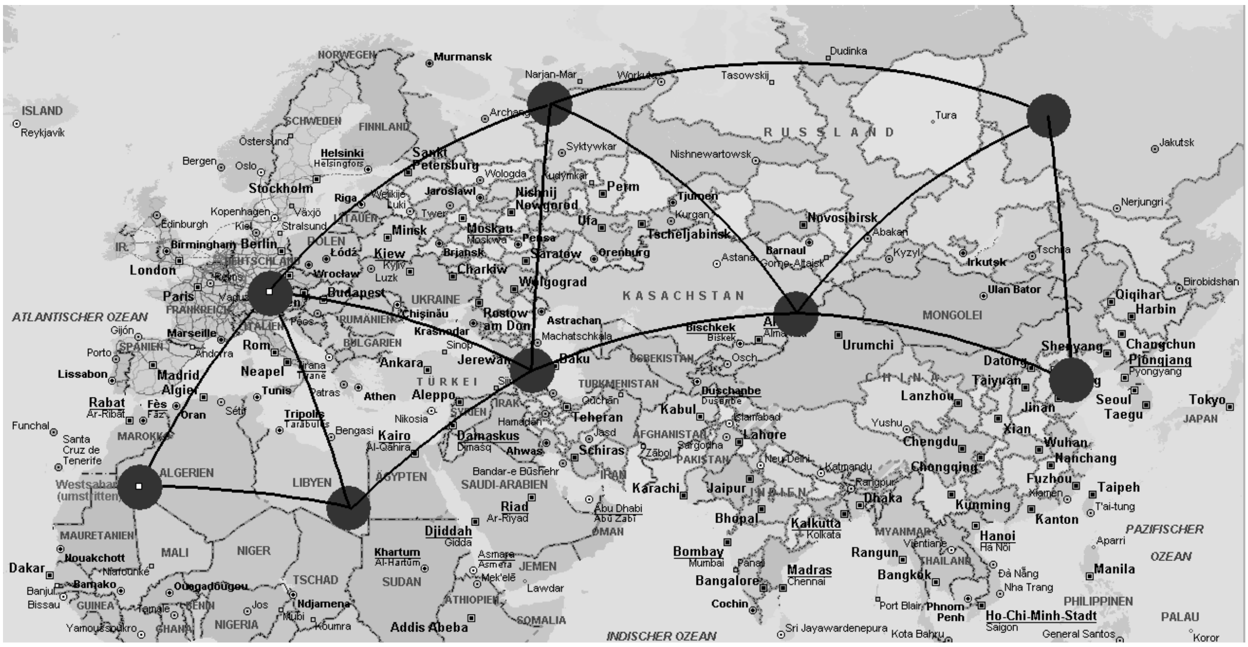

Fig. 15: Example of areas with diameters of 400 km each (dark spots) where the same channel in the 26 MHz could be used. The spacing between these areas is 2900 km to guarantee a minimum distance of 2500 km between co-channel transmitters which the predictions suggest is sufficient to avoid mutual interference.

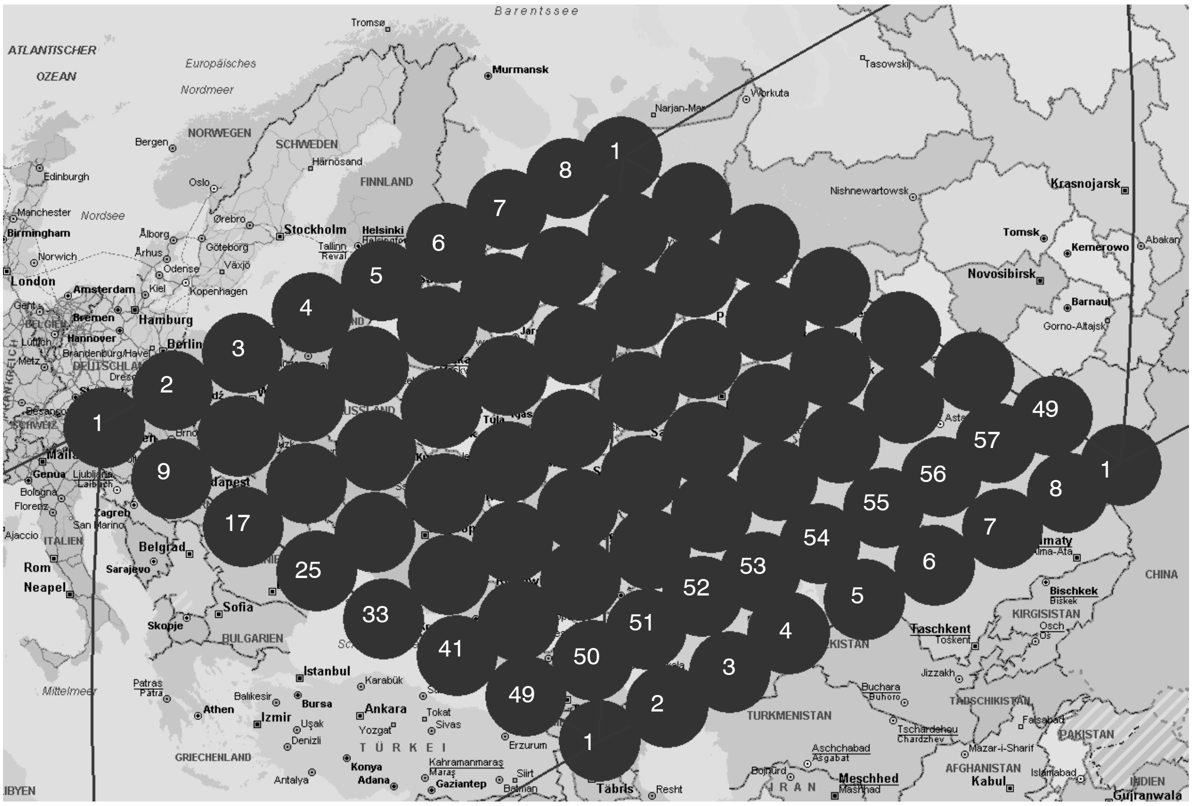

Fig. 16: Example of how the diamond-shaped areas between adjacent spots using the same channel could be filled using other channels. However, the 57 channels which would be needed are not available in the 26 MHz band.

Conclusions

From the results from our field trial and the considerations regarding a planning model, the following conclusions with respect to local broadcasting in the 26 MHz band using DRM can be drawn:

- Low power DRM transmitters including transmission antennas can easily be set up and operated and do not require great financial resources.
- The coverage area of such transmitters (operating at 100 W E.I.R.P. at an appropriate site) will be up to 20 km for mobile reception and up to 50 km for fixed reception using rooftop antennas.
- Portable and mobile reception at the fringe of the service area will suffer from flat fading due to multipath propagation, at least in cities.
- The sound quality that can be achieved will be sufficient for most audio material typically sent by local stations, although only an audio bandwidth of approximately 11 kHz can be expected.
- Indoor reception is frequently limited by man-made-noise which may occur for an unpredictable amount of time depending on the electromagnetic environment of the receiving site.
- Due to the propagation conditions in the 26 MHz frequency range attention must be paid to the fact that even when low transmitter powers are used co-channel interference will be frequent both during the time of the sunspot maximum and in summer when sporadic E layer propagation will frequently occur. Therefore either the reliability of services will be limited or only one channel will be available in each region of about 400 km in diameter. International coordination of channel assignment will be required in this case.
- A possible remedy to the problems caused by long distance propagation could be to use the 26 MHz band only during night time and use a medium wave frequency during day time.

Based on these findings we believe that widespread use of the 26 MHz band for local broadcasting can only be recommended for services which are well aware of and can tolerate the severe limitations to the reliability of reception quality which cannot be avoided when operating in this frequency range. For other services the use of the envisaged DRM plus system in the VHF broadcasting bands will be better suited to their demands of quality of service.

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