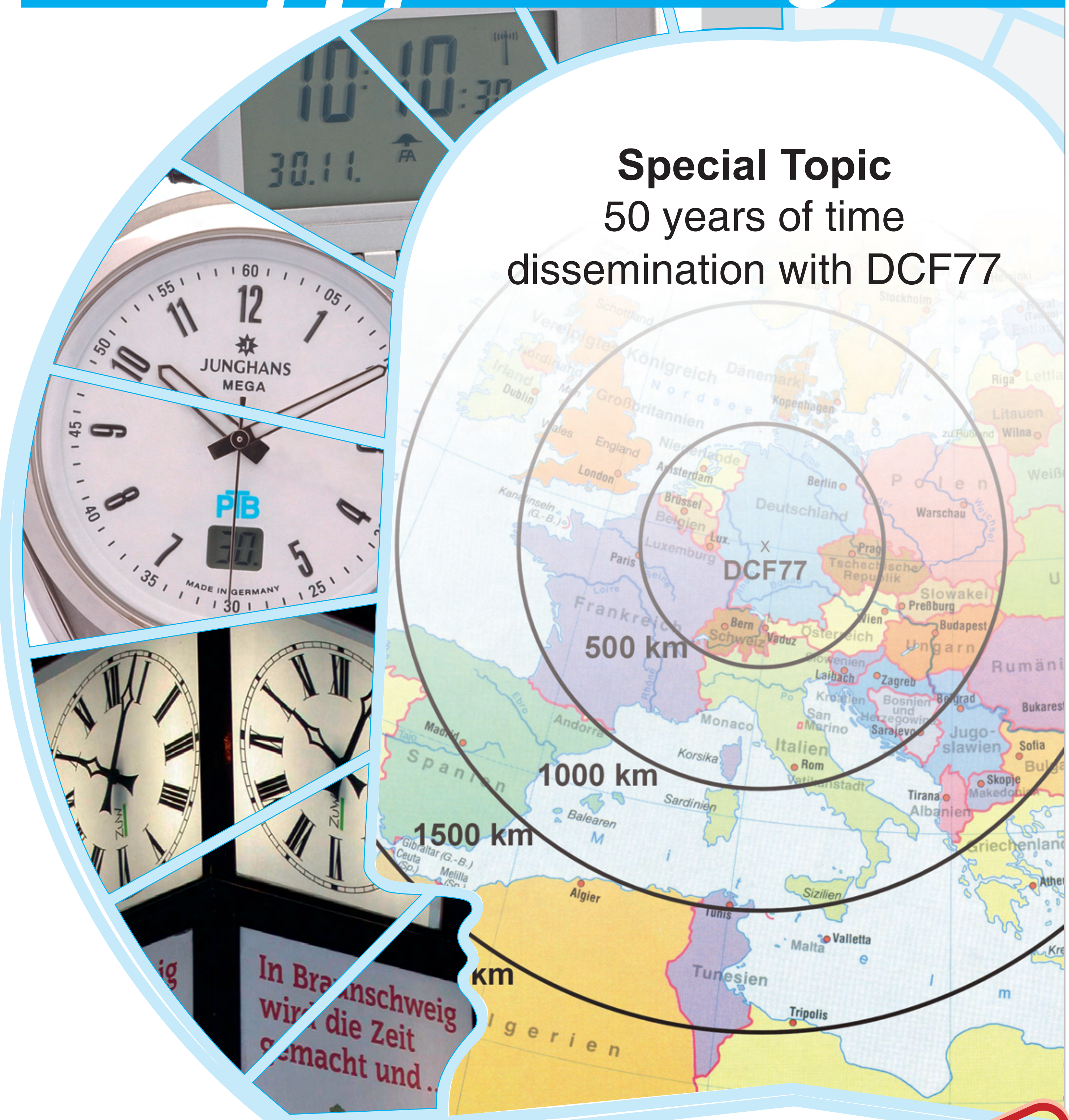
Fachorgan für Wirtschaft und Wissenschaft

PTB mitteilungen

Special Topic
50 years of time dissemination with DCF77



Special Issue

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Fachorgan für Wirtschaft und Wissenschaft

Amts- und Mitteilungsblatt der Physikalisch-Technischen Bundesanstalt Braunschweig und Berlin

Special Issue
Volume 119 (2009) No. 3

Contents

Title picture:

"On 1 January 1959, PTB started the dissemination of standard frequency and time marks using the transmitter DCF77 operated by Deutsche Bundespost," announced Dr. Udo Adelsberger in the *Nachrichtentechnische Zeitschrift*. With this step, an ongoing success story took off which was recollected during a colloquium at PTB in March 2009. This Special Issue of *PTB-Mitteilungen* contains the contribution of PTB made on that occasion.

Imprint

The *PTB-Mitteilungen* are the metrological specialist journal and official information bulletin of the Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin. As a specialist journal, the *PTB-Mitteilungen* publishes scientific articles on metrological subjects from PTB's fields of activity. As an official information bulletin, the journal stands in a long tradition which goes back to the beginnings of the Physikalisch-Technische Reichsanstalt (founded in 1887).

Publisher
Wirtschaftsverlag NW
Verlag für neue Wissenschaft GmbH
Bürgermeister-Smidt-Str. 74–76,
27568 Bremerhaven
Postfach 10 11 10, 27511 Bremerhaven
Internet: www.nw-verlag.de
E-mail: info@nw-verlag.de

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Frequency of publication and prices
The *PTB-Mitteilungen* are published four times each year. An annual subscription costs Euro 55.00, one issue costs Euro 16.00, plus postage costs. The journal can be obtained from bookshops or from the publisher. Cancellations of orders must be made to the publisher in writing at least three months before the end of a calendar year.

Printed in Germany ISSN 0030-834X

Time and Frequency Dissemination with DCF77: From 1959 to 2009 and beyond

Andreas Bauch[1], Peter Hetzel[2] and Dirk Piester[3]

Summary

Fifty years ago, on 1 January 1959, transmission of time signals and standard frequencies officially began with the DCF77 low frequency transmitter – the impetus for this article. The Physikalisch-Technische Bundesanstalt (PTB) was decidedly involved in these transmissions from the beginning, and today the responsibility for the DCF77 broadcasting programme lies solely with PTB. On its behalf, the transmitting facilities are operated by Media Broadcast GmbH as successor of Deutsche Bundespost and Deutsche Telekom AG. The main focus of this article is the description of the current broadcasting programme, altered a number of times over the years, and the current characteristics of the transmitted signals. Furthermore, an overview is given of the technical equipment currently used for transmitting and monitoring. The advantages of DCF77 – wide range and reception with low-cost receivers – have led to the use of millions of DCF77 radio-controlled clocks which provide Germany and a considerable portion of Europe with exact time. Thus, DCF77 has meanwhile become an important component of the state-funded infrastructure of Germany.

1 Impetus for this article

In Issue 5 of 1959 of the Nachrichtentechnische Zeitung NTZ, PTB announced the official commencement of the emission of time signals and standard frequency via the DCF77 low frequency (LF) transmitter. Thus began a new era of the emission of such signals in Germany and Europe. In the sixties, the DCF77 time signal and standard frequency transmissions were not yet operated all day long, but followed a three-hour day and night schedule. The extension of the broadcasting time to 24-hour continuous operation starting from 1 September 1970 coincided with a simplification of the broadcasting programme for a broader use. Particularly the commencement of the continuous emission of coded time information, starting in June 1973, led to broad acceptance of the time information disseminated by DCF77 and was the precondition for the success story of the radio-controlled clock in Germany and Europe. Thus, the number of DCF77 receivers produced from 2000 to 2008 is estimated to be about 100 million, whereby the largest portion by far falls into the "consumer-oriented" radio-controlled clock category.

This article is an updated version of an earlier, summarized presentation [1] and is published on this occasion, together with papers by Dr. Johannes Graf [2] and Klaus Katzmann [3]. It is based on earlier works by one of the authors [4, 5] and not every step in the development of the DCF77 is given a quote from the literature current at the time of its introduction. More detailed literature is only given if it contains essential information extending beyond the characteristics of the DCF77 transmission described here. The three conference volumes [6] published by W. Hilberg on the occasion of the "Funkuhrentagungen" (Radio-controlled Clock Conferences), held at the Technical University of Darmstadt and PTB between 1983 and 1993, offer a rich selection of original works and source information, on whose basis particularly the development of the radio clock can be followed. The authors have attempted to provide more detailed information – in the form of some supplements to [1] – on the questions asked repeatedly by DCF77 users about the dissemination and reception of the DCF77 signals.

The task of providing legal time is undertaken today by the *Time Dissemination* Working Group in the *Time and Frequency* Department of PTB (Internet: http://www.ptb.de/time). Under the indicated address, hints about the two other time services of PTB are to be found, the Telephone Time Service with modem via the public telephone network as well as the NTP Time

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Service via the Internet; this article, however, shall not go into greater detail here.

This article is structured as follows: First of all, in chapters 2 and 3, the essential terms of time determination and transmitting time information are explained and the fundamentals of legal time and the international time system are presented. Following the historical outline on the development of the DCF77 in chapter 4, the current characteristics of the DCF77 transmitter are described (chapters 5 to 7). Detailed responses to some basic questions on the dissemination and the reception of DCF77 signals are given in chapters 7 and 8. Then the development of the radio-controlled clock (chapter 9) is briefly traced and the longwave time services similar to the DCF77 in other countries of the world are presented (chapter 10). In summary, the advantages of the reception of low frequency signals are discussed.

2 How long? How often? When?

"Time measurement" is just as much a part of our daily lives today as it is a part of many fields of science and technology. This term is used for the measurement of the length of time intervals (keyword: stopwatch), for the recording of the frequency of events during a particular interval of time (keyword: frequency), and for the dating of events on a time scale (keyword: time of day). An aside at this point: Colloquially, one would say the clock is wrong or right. If two clocks show different times, then first of all, this is not a measure of their **rates** but rather of **reading deviations**. If, e. g., the reading deviation of two quartz clocks is currently 10 s, and 24 hours later it is 11 s, then the difference in the rate of these clocks is one second per day. The best atomic clocks differ in their rate by a few billionths of a second per day. Later we will talk about rate instability, a measure of how the rate of clocks changes in the course of time. The entire subject, particularly also the historical change from astronomical to atomic time determination, has been dealt with a number of times elsewhere [7–11].

The dating of events and the coordination of the various activities in a modern society are recognized as being so important that in many countries it is regulated by law how legal time is to be stated – as is the case also in Germany. Border-crossing traffic and communications require that the thus determined times of day of the countries are to be coordinated with one another. The basics for this were once laid down by the Washington Standard Time Conference, at which the position of the zero meridian and the system of the 24 time zones at 15° geographic longitude each were determined. This occurred in October 1884, thus 125 years ago, another "time anniversary" in 2009!

Since 1 April 1893, mean solar time at the 15th degree longitude east is in force in Germany (i. e. "German Reich", at that time) as standard time, as is stated in the "Reichsgesetzblatt" (Reich Law Sheet) copied in Annex 1. With the Time Act of 1978, this regulation was transferred to the "atomic age" and in 2008, it was combined with other regulations to form the Units and Time Act (EinhZeitG) (Annex 2).

For the counting of days, the Gregorian calendar is used in Germany and in many countries of the world. Useful specifications as regards time, calendar, numbering of weeks and notation of date and time can be found in the standard ISO 8601 as well as in the appropriate German and European standard DIN EN 28601. Only four details should be gone into here as they repeatedly bring up questions. The aforementioned standard stipulates, among other things:

- A day begins at the point in time 00:00 and ends at the time 24:00. The times 00:00 of a beginning day and 24:00 of the ending previous day are identical. To record events ongoing or beginning exactly at midnight, the time 00:00 is recommended and for events ending, 24:00 is recommended.
- Monday is the first day of the calendar week.
- The first calendar week of a year is the first one in which at least **four** days of the new year fall, which means that in this Week 1 of the new year, the **first Thursday** of the year will fall.
- The year number of a leap year is divisible by four an integer number of times. However, a centennial year is not a leap year unless its year number is divisible by fourhundred an integral number of times. February of this year then has only 28 days. 2000 was thus a leap year, 2100 will not be one.

3 Legal time for Germany

3.1 Legal groundwork

Following the redefinition of the second based on atomic-physics quantitites in 1967, also in Germany the regulation regarding legal time had to be adapted. That came about with the Time Act of 1978. Here, PTB, which has already been entrusted with the realization and dissemination of the units in metrology, was charged to realize and disseminate the standard time for public life in Germany. Central European Time (CET) or, in the case of its introduction, Central European Summer Time (CEST) were determined as legal time. CET and CEST are derived from the Coordinated Universal Time UTC (for details, see next paragraph) realized at PTB, by adding one or two hours:

$$CET(D) = UTC(PTB) + 1h,$$
$$CEST(D) = UTC(PTB) + 2h.$$

The Time Act also authorizes the German Federal Government to introduce, based on statutory ordinance, Summer Time between 1 March and 31 October of each year. The dates for the beginning and end of CEST are determined by the Federal Government in accordance with the currently valid directive of the European Parliament and the Council of the European Union and are published in the Federal Law Gazette. By reason of the latest Summer Time Act of 12 July 2001 (Annex 3), valid for Summer Time in future – until revoked –- is the last Sunday in March until the last Sunday in October of each year. The Bundesministerium für Wirtschaft und Technologie (Federal Ministry of Economics and Technology) publishes the Summer Time dates in advance for the following years (Annex 4). The Time Act of 1978 and the Law on Units in Metrology of 1985 were combined in the new Units and Time Act passed in 2008 (Annex 2), whereby all regulations governing time determination were adopted as they stand.

3.2 Coordinated Universal Time

The "Time, Frequency and Gravimetry" Department of the Bureau International des Poids et Mesures (BIPM) is entrusted with the calculation and dissemination of a universally valid time reference*. For this purpose, the BIPM calculates a time reference on the basis of approximately 400 atomic clocks – among these approximately 10 so-called primary clocks (see below) – from approximately 70 time institutes distributed all over the world. First of all, the BIPM determines the rate instabilities of these clocks and assigns statistical weights to them. With these statistical weights, the clocks are taken into account in the calculation of an averaged time scale. A clock with a stable rate is assigned a high statistical weight, and a clock with an instable rate is assigned a low weight. The mean value obtained in this way is called the "free atomic time scale" (abbreviation: EAL, from: "Echelle Atomique Libre"). Due to the properties of the clocks used, the mean value of the seconds realized by them deviates from the duration of the SI second as defined. "SI second" designates the base unit of time in the International System of Units SI (System International) [12, 13]. Therefore, in a second step, the international atomic time TAI (Temps Atomique International) is obtained from EAL by means of a rate correction. Thereby, the scale unit of TAI is adjusted in such a way that it agrees as well as possible with the SI second, as it would be realized at sea level. At present, the rate correction is derived from the comparison of EAL with the primary clocks of the time institutes in France, Great Britain, Italy, Japan, South Korea, the USA and Germany. TAI had different predecessors [10], but the fictive initial point of TAI has been fixed in such a way that 1 January 1958, 00:00 h TAI, coincided with the respective moment in the mean solar time at the zero meridian, called UT1 (Universal Time). UT1 was the basis of the time determination world-wide as long as it was based on astronomic observations (see Annex 1).

UTC is derived from TAI. Hereby, a proposal of the International Telecommunication Union (ITU) has been taken into account according to which the time signals should be emitted in a "coordinated" way – i. e. related to a common time scale with the SI second as the scale unit – which is kept in approximate agreement with the universal time UT1 which is proportional to the rotational angle of the Earth [9, 10]. The difference UTC minus UT1 is limited by leap seconds in UTC to less than 0.9 seconds.

UTC was started on 1 January 1972. At that time, the difference between TAI – UT1 was 10.04 s and TAI – UTC was determined to be 10 s. Also before this date, emitted time signals derived from atomic clocks had already been steered to follow the astronomic time – however not everywhere in the same way and, moreover, by adaptation of the rate of the atomic clocks and, additionally, by time steps. This will be dealt with in more detail in chapter 4.5. The introduction of UTC put an end to this. As stair curve shown in Figure 1, UTC – TAI follows the monotonous change of UT1 – TAI. The leap seconds are inserted (a) as the last second of 31 December or (b) as the last second of 30 June in UTC. This means in Germany: on 1 January, before 01:00 a. m. CET, or on 1 July, before 02:00 a. m. CEST. The decision on this is taken by the International Earth Rotation and Reference Systems Service (IERS) (Internet: http://hpiers.obspm.fr or http://www.iers.org). This institution collects and evaluates the observations communicated by a network of earth-bound observation stations whose positions are determined relative to quasars and to the satellites of the American Global Positioning Systems (GPS). These furnish the parameters of the Earth's rotation, the position of the axis of rotation and the period of rotation. The irregular insertion of leap seconds (Figure 1) reflects the irregular rotational speed of the Earth.

Following the recommendations of several institutions, UTC was adopted in practically all countries as the basis for the "civil", "official" or "legal" time used in the respective time zone. However, in analogy to TAI, UTC is published only in the form of calculated time differences with reference to the time scales UTC(k) realized in the individual time institutes k. The scales UTC(k) are to agree as well as possible with UTC – and, consequently, also among themselves. In mid 2010, 45 time scales with a

* Until 1988, this task was performed by the Bureau International de l'Heure BIH.

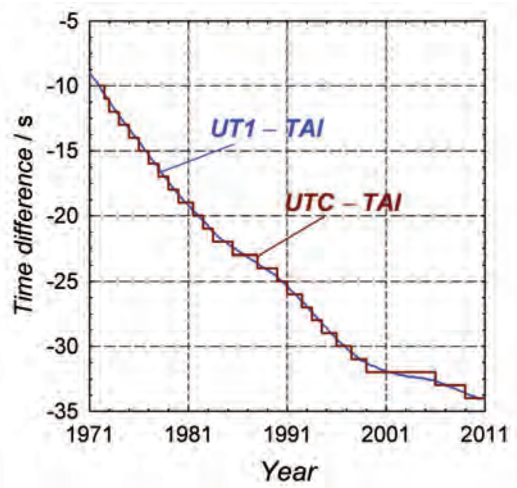


Figure 1:
Comparison of (astronomical) Universal Time UT1 and Coordinated Universal Time UTC with International Atomic Time TAI

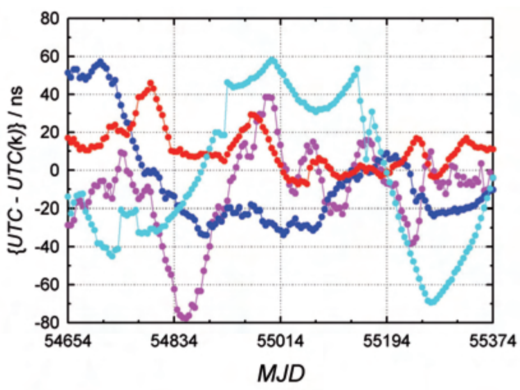


Figure 2:
Comparison of Coordinated Universal Time UTC with the atomic time scales UTC(k) realized in four European time-keeping institutes (k) over two years until and including June 2010; MJD 55374 designates June 27, 2010.

- Istituto Nazionale di Richerca di Metrologia, INRiM, Turin;
- NPL, Teddington, UK;
- LNE SYRTE, Observatoire de Paris;
- PTB.

deviation UTC – UTC(k) of less than 100 ns were available worldwide, among them the time scale of PTB. Figure 2 shows the difference between UTC and the realizations in four European time institutes over a period of 2 years up to, and including, June 2010. Here, as in other figures, the Modified Julian Date, MJD, a continuous counting of days, is used as the time axis. The 27 June 2010 is referred to as MJD 55374.

3.3 The atomic clocks of PTB

PTB operates a group of atomic clocks to realize the atomic time scale UTC(PTB) with a high stability and reliability. This group comprises some commercially manufactured atomic caesium clocks, hydrogen masers and the so-called primary clocks CS1, CS2, CSF1 and CSF2 which have been developed at PTB in the last decades [14, 15]. The time scale UTC(PTB) has been directly derived from CS2 until the end of January 2010, now a steered hydrogen maser is the source of UTC(PTB). Currently, the best commercial atomic caesium clocks realize the SI second with a relative uncertainty of a few 10^{-13} and a relative frequency instability of a few 10^{-14} over an averaging period of one day [16]. They are used in the fields of navigation, geodesy, space flight and telecommunications as well as at the time institutes (such as the PTB). The primary Cs clocks developed at PTB allow clearly smaller uncertainties to be achieved. The term "primary clock" is used because there is at any time an estimate available which indicates to what extent and with which probability the realized second deviates from the SI second. Figure 3 shows PTB's two primary clocks CS1 and CS2, whose relative uncertainty amounts to only $0.7 \cdot 10^{-14}$ and $1.2 \cdot 10^{-14}$, respectively [14] (probability: 67 %). The relative frequency deviation and the rate are quantities which correspond to each other: A constant relative frequency deviation of $1 \cdot 10^{-14}$ corresponds to a rate of approximately one billionth of a second per day.

4 DCF77: From the beginnings until today

4.1 A short history of radio time transmission

Already at the beginning of the last century, radio waves were recognized as being a suitable means of time transmission, and this is also the subject of the article by Dr. Johannes Graf [2]. The first tests with regard to a wireless transmission of time were carried out in 1903 by the United States Naval Observatory in Washington, and in 1904 by the Geodetic Institute Potsdam. From 1910 to 1916, the coastal radio station Norddeich already transmitted – as the first German time service – regular time signals which were based on time determinations of the Imperial Marine Observatory Wilhelmshaven. Then, starting in 1917, the large transmitting station Nauen emitted one time signal twice a day on long wave 3 900 m (≅ 77 kHz). After these beginnings of wireless time transmission, a worldwide network of time signal stations has been set up in the course of time in different wavelength ranges – mainly on myriametric wave, long wave (corresponds to low frequency) and short wave. In the past three decades, the dissemination of time with terrestrial transmitters has been complemented by time transmission via satellites. This has opened up completely new possibilities for intercontinental precision time comparisons,

Figure 3:
View of PTB's primary clocks CS1 and CS2.

position determination and global navigation. A survey of the whole field of precision time transmission can, for example, be found in [17].

4.2 Transmitting radio station Mainflingen

The transmitter DCF77 is located at the radio station Mainflingen (coordinates: 50°01' north, 09°00' east), approximately 25 km south-east of Frankfurt am Main. In 1949, this station transmitted – at the instigation of the Deutsche Bundespost – for the first time, news on long wave by means of a transportable – formerly military – transmitter. As, after the war, the large transmitting station Nauen was located in the Soviet zone of occupation, it could no longer be used by the newly founded Federal Republic of Germany, and the radio station Norddeich was, due to its geographic position at the edge of the Federal Republic, not suited for new nation-wide services. This is why the establishment of the radio station Mainflingen was started early in the fifties on the premises of a former small airport. In the following years, the two transmitter houses, which still exist there today, a number of antenna masts up to 200 m in height, and the associated antenna houses were constructed. At a depth of approx. 25 cm in the earth, an earthing network was laid which covers many kilometres and which furnishes – together with the high ground water level which is due to the terrain being located in the plain of the river Main – a high ground conductivity and, thus, favourable radiation conditions.

In 1954, emissions were already performed on six frequencies between 46 kHz and 123 kHz. From this time, also the registration of the transmitter DCF77 as a fixed service in the International Frequency List of the International Telecommunication Union (ITU) originates. The following data were registered: carrier frequency 77.5 kHz, bandwidth 2.4 kHz, call sign DCF77, the coordinates of the radio transmitting station as indicated above, first use on 15 August 1953 and under the responsibility of Germany. In chapter 10, regulations and protection provisions of the ITU are dealt with in connection with similar radio services in other countries.

4.3 Transmitter designation

Where does the call sign DCF77 come from? According to the regulations of the ITU, in particular Article 19 of the *Radio Regulations, "Identification of Stations"* [18], all transmitters whose ranges exceed the frontiers of their respective country, must be marked with a call sign which has to be in accordance with the call sign series assigned to each country, and must be registered in the International Frequency List. The call sign series which has been assigned to the Federal Republic of Germany begins with DAA and ends with DRZ. For the transmitter DCF77, the call sign has been determined as follows: In accordance with the call sign series assigned, D stands for Deutschland. The letter C was selected to identify long-wave transmitters. As third letter, the letter F was determined for the long-wave transmitters on the premises of the transmitting station Mainflingen (due to its vicinity to Frankfurt am Main). To distinguish the different transmitters of this station, two numbers were added to the three letters DCF, in the case of the DCF77 in accordance with the carrier frequency used. This does not apply to the transmitter DCF49 on 129.1 kHz used by the Europäische Funk-Rundsteuerung GmbH for radio ripple control , which is also operated at the Mainflingen transmitter station.

4.4 The development of the use of DCF77 for time emission

In the mid-fifties, representatives of the Deutsches Hydrographisches Institut (DHI), of the Fernmeldetechnisches Zentralamt (FTZ) and of PTB met to jointly establish a time signal and standard frequency transmission in order to "comply with official tasks". The institutes belonged to the business areas of different Federal Ministries which were responsible for traffic, post and economy, respectively. This cooperation reflects the situation prevailing at that time in the Federal Republic of Germany, where legal time was still determined on the basis of astronomic observations of the DHI, whereas the unit of time "second" was already realized with superior accuracy by PTB as the National Metrology Institute, and the Deutsche Bundespost Telekom had the monopoly for the operation of transmitters. The latter agency offered the transmitter DCF77 to be used for the transmission of standard frequencies and time information with a transmission power of initially 12.5 kW. In the basement of transmitter house 1, PTB installed high-precision quartz clocks and the signal generation facility, and the DHI provided time signals on an astronomic basis (see below). The first transmission attempts were started in 1956. On 10 October 1958, PTB was authorized by the Federal Post Ministry to perform regular test transmissions until the end of the year 1958. In the respective letter of approval, the 1 January 1959 was, in addition, determined to be the official starting day of time signal and standard frequency transmissions via the transmitter DCF77.

Until the end of 1969, besides time signals and standard frequency, sporting news of the Deutscher Sportverlag (DSV) were transmitted intermittently via the DCF77. The time signals and standard frequencies were transmitted every working day, in a morning and in a night program, with a duration of approx. 3 hours each. As different organizations and users of this new service approached PTB with the request for a longer broadcasting time, PTB filed, early in 1967, the application for a prolongation of the broadcasting time to 24 hours. As a result, the DSV was assigned the new frequency 46.25 kHz, and on 1 December 1969, the time for sending time signal emissions was extended to – initially – 16 hours. At the same time, the responsibility was completely passed over to PTB, which had now also to pay fees for the use of the transmitter DCF77. Continuous 24-hour operation with a transmitter power of 50 kW was finally started on 1 September 1970. The changes brought about by this for the broadcasting program will be dealt with in the next chapter.

Until the privatization of the Deutsche Bundespost, transmission via DCF77 was performed on the basis of an informal agreement between the Ministry of Economics and the Federal Post Ministry. After that, a contractual agreement on the operation of the DCF77 transmitting facilities was made in April 1996 between PTB and the German Telekom AG. The contract contains agreements on the scope of services to be rendered by the operator of the transmitter and the fees to be paid by PTB. Meanwhile, some provisions of the contract have been revised and the duration has been extended until the end of 2013. For some time, the company T-Systems Media Broadcast was the partner in the contract with PTB. Now, it is Media Broadcast GmbH.

4.5 Development of the broadcasting program

The broadcasting program used until 1970 was rather confusing and contained, among other things, two types of time marks, the so-called "time measuring marks", for which PTB was responsible, and the "coordinated" time signals, which were in the responsibility of DHI. In addition, the program scheme provided for the transmission of several standard frequencies, the carrier frequency 77.5 kHz and the modulated frequencies 200 Hz and 440 Hz (standard pitch a). What was the difference between the different time marks? Already since 1962, PTB has been regulating the interval of successive time measuring marks and the carrier frequency in accordance with the atomic definition of the unit of time (implemented in 1967) on the basis of the value of 9 192 631 770 Hz determined for the hyperfine structure transition frequency in ^{133}Cs [19]. For this purpose, PTB operated in Braunschweig an "atomichron" [20], and the frequencies of the quartz clocks at PTB and in Mainflingen were regulated according to its output signals. Since 1967, the clocks of PTB have also been compared at regular intervals with the clocks of the National Bureau of Standards (NBS)* in the USA by transporting atomic clocks at regular intervals by airplane and by phase time comparisons of myriametric waves. As in the case of the transmitter WWVB, for which NBS was responsible [21], the time marks of PTB emitted by DCF77 were – as "stepped atomic time" – kept in agreement with the Universal Time UT1: first in steps of 0.05 s, then in steps of 0.1 s, and later in steps of 0.2 s. The time signals of the DHI, on the other hand, represented the time scale UTC in its form valid at that time. Their scale dimension was redefined annually in advance and in such a way that UTC and UT1 were to approximately agree during the whole year. The interval between successive time marks was, thus, not in accordance with the valid unit of time. When it turned out at the

* Today, this is called the National Institute of Standards and Technology NIST.

end of a year that the forecast of the period of the Earth's rotation had not been sufficiently correct, the time difference between UTC and UT1 was compensated by a "time step" in UTC. Many regarded this realization of UTC as obsolete. This is why time signal emission of the DHI was terminated on April 1, 1970, and the broadcasting programme was simplified. From this moment on, only the carrier frequency of 77.5 kHz (as standard frequency) and amplitude-modulated second marks were emitted. Until 1972 they corresponded to the "Official Atomic Time Scale" of PTB and, since 1972, they have also been in agreement with the new UTC time system with leap seconds, as it has been used until today and has been described in chapter 3.2. The duration of the second marks was extended from 50 ms to 100 ms. In view of the users who utilized DCF77 as a standard frequency transmitter, the carrier was, from now on, no longer keyed to zero for the duration of the second marks, but only reduced to a residual amplitude of 25 %. The identification of the minute marks was maintained in the way it had been originally introduced: By omitting the 59th second mark, it is announced that the next mark is the minute mark.

The continuous emission of the standard frequency and of time marks, which started on 1 September 1970, opened up the possibility of operating automatically corrected standard frequency oscillators and of keeping clocks synchronized. Due to the ambiguity of the minute marks, radio-controlled clocks had, however, still to be manually adjusted accurately to the minute. What was still missing for the introduction of automatically setting radio-controlled clocks was the emission of complete time information in an encoded form. This was done for the first time on 5 June 1973, by which the decisive step towards developing the broadcasting programme to today's state of the art was made. Except for the supplements made as a reaction to the introduction of daylight saving time (typically called "summer time", "Sommerzeit" in German) in Germany in 1980 and the announcement of leap seconds, the time code introduced at that time has been used unchanged until today. In chapter 5.2, it is shown separately.

Since June 1983, a pseudo-random phase shift keying has been modulated onto the carrier of DCF77 in addition to the amplitude modulation (AM). When suitable receivers are used, the instant of arrival of the DCF77 signals modulated in this way can be determined with less sensitivity to interferences than is possible under usual receiving conditions with the AM time marks. Thereby, the accuracy of the time dissemination with the DCF77 is increased for selected applications. A great number of receivers of this type are used and work very satisfactorily. On the whole, however, less use is made of phase modulation than had been expected at the time of its introduction. The reason for this is the worldwide availability of the signals of the satellite navigation system GPS (Global Positioning System). Due to the GPS signal structure and the larger bandwidth available, the GPS reception would, in principle, achieve an uncertainty of the time transmission which is lower by at least one order of magnitude than the uncertainty which can be achieved with DCF77 receivers. For lack of space, phase modulation will, therefore, not be dealt with in closer detail in this paper. The current status has been described in [1], and the respective publications [22, 23] can be obtained from PTB.

5 The DCF77 broadcasting programme today

5.1 Carrier frequency

As has already been mentioned, the carrier frequency of DCF77 amounts to 77.5 kHz. It is derived from an atomic clock of PTB, whose output frequency (10 MHz) agrees within $\pm 2 \cdot 10^{-13}$ with the nominal value and whose relative daily frequency fluctuations are approx. $5 \cdot 10^{-14}$. When the carrier frequency is used over short measuring times – e. g. when an oscillator is disciplined to the received signal with a time constant of a few seconds only – the phase time deviations from the mean value must be taken into account which are due to the pseudo-random phase modulation and to transients caused by the transmitting antenna in the rhythm of the time signals. Over long measuring times, these phase time variations average out and can be disregarded. Compared to that, phase time variations of the emitted carrier and of the phase-coherent modulated time signals at the place of transmission caused by temperature variations and slight detunings of the antenna adaptation are slow. These can amount to up to approx. ± 0.1 µs, related to the output signals of the atomic clock from which they are derived. Averaged over one day, a relative uncertainty* of $2 \cdot 10^{-12}$ thus results for the emitted carrier frequency at the place of transmission. By controlling the frequency and the phase time of the DCF77 carriers, the uncertainty for frequency comparisons over very long measuring times can be further reduced. Consequently, frequency comparisons over 100 days are, on average, possible with a relative uncertainty clearly below $2 \cdot 10^{-13}$. In section 6.2, it will be described in which way this controlling is effected.

* Here and in the whole paper, the uncertainties indicated correspond to the expanded uncertainty (k = 2), which corresponds to a confidence interval of 95 %.

5.2 Amplitude modulation (AM)

The carrier of DCF77 is amplitude-modulated with second marks. At the beginning of each second – except for the last second of each minute, which serves as identification for the beginning of the next minute – the amplitude is reduced phase-synchronously with the carrier oscillation for a duration of 0.1 s or 0.2 s. Figure 4 shows the falling edge of the envelopes of the carrier oscillation emitted by DCF77 (curve a) at the beginning of a second mark and the associated control signal (curve a‘). The blanking interval of 250 µs in the drive signal causes a faster decay of the antenna circuit, so that the obtained decay rate is practically identical with that which would be obtained for a drive signal completely without residual amplitude. For comparison, the broken line curve b shows which steepness would be obtained if the drive signal was reduced directly to the residual amplitude without blanking interval [curve b‘]. The steeper the falling edge, the more exact is the determination of the beginning of the carrier reduction which is defined as the beginning of the second. For a further improvement of the signal-to-noise ratio of the AM second marks, the residual amplitude has meanwhile been reduced to approx. 15 % .

The phase of the drive signal (a‘ in Figure 4) and of the emitted signals are controlled and, if necessary, corrected now and then with an uncertainty of < 0.01 µs by means of an atomic clock, representing UTC(PTB) which is transported from Braunschweig to the transmitter station. For this purpose, the occurrence of the falling edge of the DCF77 time signals is determined at the modulator unit, on a measuring probe between transmitter output and transmitting antenna and in the near field of the transmitting antenna with reference to the signal of the transportable atomic clock. The modulator

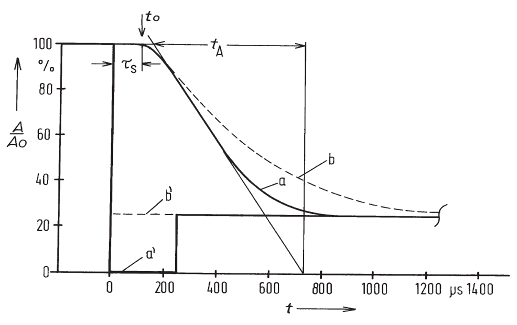


Figure 4:
Falling edge of the carrier envelopes emitted by DCF77 at the beginning of a second mark
A/A_0: relative amplitude,
a’: drive signal with blanking interval,
b’: drive signal without blanking interval,
a: irradiated flank to a’;
b: irradiated flank to b’;
τ_S: propagation time through transmitter and antenna;
t_0: defined second start in CET or CEST;
t_A: decay time.

unit is adjusted in such a way that the emitted reference phase corresponds to UTC(PTB). In the case of broad-band reception, the uncertainty with which the beginning of the descending slope, which is defined as the beginning of the second, can be determined in situ from the near field amounts to approx. ± 25 µs (approx. two periods of the carrier oscillation). To compensate the signal propagation and processing times τ_S in the transmission facilities, the DCF77 drive signal must be ahead of UTC(PTB) to ensure that it complies with UTC(PTB) in the near field. Whenever clocks were transported to the transmitting radio station, no changes of τ_S worth mentioning were detected.

5.3 Time Code

The different durations of the second marks serve for the binary encoding of time and date: second marks with a duration of 0.1 s correspond to the binary zero, and marks with a duration of 0.2 s to the binary one. Once during each minute, the numbers of the minute, the hour, the day, the day of the week, the month and the year are transmitted using BCD coding (BCD: Binary Coded Decimal, every digit of a number is encoded separately). From the calendar year, only the unit place and the decimal place are transmitted, i. e. the year 2010 is transmitted only as 10. The emitted code contains the information for the minute that follows. The temporal sequence of the bits and their significance are explained by the encoding scheme shown in Figure 5. For its determination many years ago, PTB acted on the assumption that the code should be compatible with the signal structure used in the years before and that it should be easily decodable with the electronic means available at that time. Before its implementation, the coding technique was discussed with different authorities, scientific institutes and companies. Different coding proposals as to which information should be emitted and which coding type (binary or BCD) should be used were put up for discussion. The wish of the clock industry to emit – in addition to the time and the date – also the number of the day of the week was, for example, taken into account. In all later amendments and complements of the coded time information or of the signal structure, it was always made sure that the function of DCF77 time service instruments already in use was not affected, in order to provide planning reliability to the users of DCF77 and to the manufacturers of radio-controlled clocks. The code determined in 1973 for the second marks 20 – 58 has not been changed since its introduction. Only the coding scheme has been supplemented by the announcement bits and the time zone bits:

The time zone bits Z1 and Z2 (second mark Nos. 17 and 18) indicate which time system the

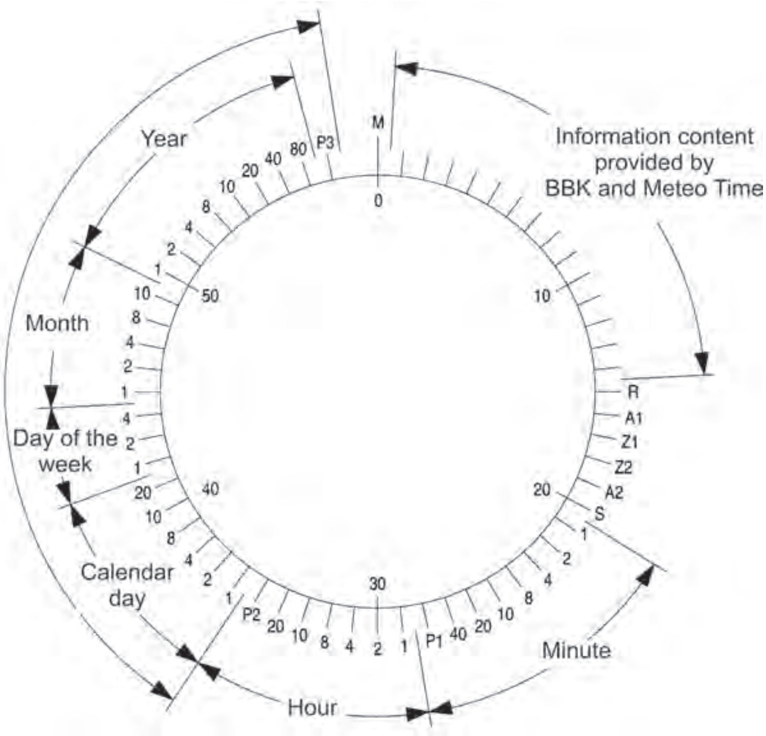


Figure 5:
Coding scheme of the time information transmitted with DCF77;
M: minute mark (0.1 s),
R: call bit,
A1: announcement bit of an imminent change from CET to CEST, or vice versa,
Z1 (Z2): time zone bits,
A2: announcement of an imminent leap second,
S: start bit of the encoded time information (0.2 s),
P1, P2, P3: parity check bits.
Details are explained in the text.

time information transmitted after second mark 20 refers to. For the emission of CET, Z1 has the state “zero” and Z2 has the state “one”. When CEST is emitted, this is the other way round. The reception of the time zone bits also allows the Coordinated Universal Time to be indicated at any time and is, therefore, useful when DCF77 receivers are utilized as timers for Internet time services and for so-called Time Stamping Authorities.

Announcement bit A1 (No. 16) indicates an imminent change in the time system. Prior to the transition from CET to CEST or back, A1 is emitted for one hour each in the state “one”: Prior to the transition from CET to CEST (CEST after CET) from 01:00:16 a. m. CET (02:00:16 a. m. CEST) to 01:59:16 a. m. CET (02:59:16 a. m. CEST).

Announcement bit A2 (No. 19) indicates the imminent introduction of a leap second. A2 is also emitted for one hour in state “one” before a leap second is inserted. Before a leap second is inserted on 1 January (1 July), A2 is therefore emitted sixty times from 00:00:19 a. m. CET (01:00:19 a. m. CEST) until 00:59:19 a. m. CET (01:59:19 a. m. CEST) in state “one”.

The announcement bits A1 and A2 serve to inform the processors in radio-controlled clocks which use the regularity of time counting for the purpose of fault recognition, about the irregularity in time counting to be expected. Without the evaluation of A1 or A2, the irregularity could be interpreted as an erroneous reception, with the result that the changed time counting would not be used immediately.

The day of the week is coded in accordance with standard ISO 8601 or DIN EN 28601, Monday being day 1 (one) of the week. The three parity check bits P1, P2 and P3 complement the preceding information words (7 bits for the minute, 6 bits for the hour and 22 bits for the date, including the number of the weekday) to an even number of “ones”. A protection of the code beyond the three parity bits has been dispensed with in view of the regularity of the time information transmitted. The known rules of time counting allow transmission errors to be detected at any time by a comparison of successive time telegrams.

When the UTC system with leap seconds was introduced, there were demands from various sides that time signal transmitters should emit the DUT1 code in accordance with a CCIR (Comité Consultatif International des Radiocommunications) recommendation. DUT1 is the difference between Universal Time UT1 derived from the rotation of the Earth and UTC, rounded to 0.1 s. Since 1 January 1972, this code has also been emitted by DCF77 with the second marks 1 to 14. For this reason, the time code was placed in the area of the second marks 20 to 58. However, it soon turned out that the interest in the DUT1 code was low so that after a survey in May 1977, PTB discontinued to emit the DUT1 code.

Instead, for many years, the free second marks 1 to 14 were used to transmit operational information about the DCF77 control facility. Although prolonged second marks in this area generally signalized an irregularity in the control or transmitting facilities, they did not, however, imply that the emitted time information was erroneous. Fortunately, such indications of malfunction were transmitted only in extremely rare cases, so that some developers of DCF77 decoding software wrongly acted on the assumption that these bits never transmit any information. Since the middle of 2003, this has no longer been the case. This will be dealt with in the following chapter. At present, second mark 15 is still being used as a "call bit" to signalize irregularities in the control facilities. The correctness of the emitted time information is, however, also guaranteed in the case of a prolonged bit 15. If required, this bit can in future also be used for other purposes.

Figure 6 shows examples of the signal received in Braunschweig. Top: the transmission of the month and the year, bottom: a minute change, recorded in July 2003. For coding of the month July (07), binary "ones" are assigned to the BCD bits of the units 1, 2 and 4 and binary "zeros" to the BCD bit 8 and to the tens place.

In the case of AM second markers, the insertion of a leap second is performed as follows: The 59th second mark which precedes the mark 01:00:00 a. m. CET or 02:00:00 a. m., CEST is – different than usual – emitted with a duration of 0.1 s. After that, the inserted 60th second mark is emitted without carrier reduction.

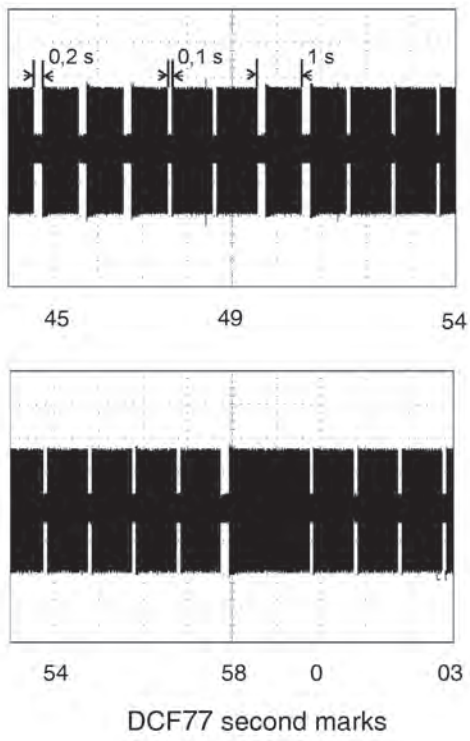


Figure 6:
Registration examples of the DCF77 carrier envelopes; top: second marks 45 to 54, in accordance with calendar month 7 (July), calendar year 03 (2003); bottom: second marks 54 to 03 (minute change).

5.4 New data contents

At the suggestion of a federal agency responsible for civil protection, it was investigated in the third and fourth quarter of 2003 whether the emission of "time signals" with DCF77 can also be used to transmit warning information, and whether DCF77 could be an element in a warning system of the Federal Government, which passes the warning information generated in the warning centres of the federal states and of the Federal Government in different ways (radio, television, Internet, DCF77 and GSM/UMTS) on to the population via a satellite-based and a terrestrial communication system. HKW-Elektronik GmbH was entrusted with the realization and evaluation of a field test in which fictive warning information was emitted with the second marks 1 to 14, which are not directly important for time transmission. The DCF77 control facilities have been extended in such a way that the fictive warning information received in the transmitting station with a satellite terminal could be integrated into the broadcasting program. With approx. 900 radio alarm clocks specifically modified, the alarms received were recorded at different distances from the transmitter and under different receiving conditions. In its final report, HKW demonstrated that the alerting time and the reachability of the different radio receivers were uniformly good in our country. The environment (country, city region, internal or external receiver) and the distance to the transmitter had only a slight influence on the reception probability. In contrast to that it turned out that the place that is chosen for the installation of stationary clocks and/or the way in which wrist watches are worn have a considerable influence. The number of false alarms was, all in all, negligibly small. Although it has been demonstrated in this way that the technical possibility of using DCF77 signals for the intended purpose exists, no decision has been taken so far to actually make use of this possibility. At present, the second marks 1 – 14 are, instead, used to transmit weather information of the Swiss company MeteoTime GmbH. This does not, however, rule out a future use for population warning. At present, the weather information is also being transmitted in an identical coding via the Swiss longwave time service HBG (75 kHz) (see chapter 10). Information about this novel service can be found under http://www.meteotime.ch. The provision of weather data does not lie in the area of responsibility of PTB, but is contractually regulated by Media Broadcast GmbH. Radio-controlled clocks that have been manufactured without the specific feature of decoding the data contents in bits 1 – 14 will not be affected by the extension of the scope of broadcasting, but they cannot make use of this information either.

Figure 7:
Transmitting radio station Mainflingen of Media Broadcast GmbH, in the foreground: antenna house 4 (made of red bricks) with DCF77 operating antenna, in the background: transmitter house 2 (white building)

6 Technical equipment and installation: Control and transmission facilities of DCF77

6.1 Facilities at the place of transmission

The drive signal is not – as often assumed – transmitted via cables from Braunschweig to the transmitting radio station Mainflingen, but generated at the place of transmission with a facility designed by PTB and monitored from Braunschweig. Figure 7 shows a recent photo of transmitter house 2 where – since October 2006 – the control facilities of PTB (see Figure 8) have been accommodated in an air-conditioned room on the ground floor. In the foreground, antenna house 4 and the DCF77 main operating antenna can be seen.

For reasons of operational reliability, the control signal is generated in three independent channels. At present, the carrier signal (77.5 kHz) and the second marks modulated on it, together representing the drive signal, are, in all three channels, derived from a respective caesium atomic clock. In addition, a rubidium atomic clock is available on site. Each control channel has a battery-buffered power supply of its own. Figure 9 shows the block diagram of the DCF77 control facility and of the monitoring facilities in Braunschweig (see chapter 6.2).

To avoid erroneous emissions, the generated drive signals are compared in two electronic switch circuits. If this comparison shows that the signals of the channel which controls the transmitter disagree with those of the two reserve channels, automatic switch-over to one of the two reserve channels is performed. If one channel fails, each electronic switch circuit continues to provide an output signal only as long as the controlling channel and the remaining reserve channel are in agreement. In the case of contradictions between all three channels, the control

Figure 8:
DCF77 control facilities of PTB. The atomic clocks, the drive signal generators and the electronic converters are installed in the racks 1 to 3. Rack 4 contains the local measuring equipment and the interface for communication between Mainflingen and Braunschweig. Rack 5 contains the interface for feeding in alarm and weather information.

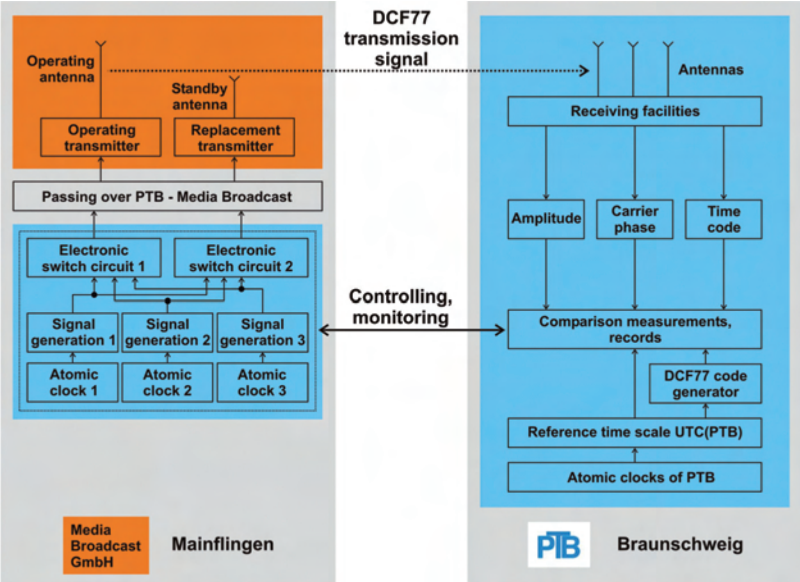


Figure 9:
Block diagram of the control and transmission facilities of the transmitter DCF77 and of the monitoring systems at PTB in Braunschweig.

signal is interrupted automatically. If the test results of the two switch circuits disagree, the output signal is also switched off.

The DCF77 control signal that has been generated with the facilities of PTB is then passed over to Media Broadcast. This company is responsible for the emission. Since January 1998, a modern, air-cooled 50-kW semiconductor transmitter has been available as operating transmitter. Its final amplifier is fitted with 48 amplifier modules of the same type, which have an output power of a little more than 1 kW, and the single output voltages of the 48 amplifier modules are added. The 50-kW vacuum-tube transmitter used in earlier years remains available as a replacement transmitter. It is connected with a standby antenna which can be switched over in case of a failure or if maintenance work becomes necessary on the operating transmitter or on the antenna.

The two transmitting antennas are vertical, omnidirectional antennas with top-loading capacity. The standby antenna is 200 m in height. The operating antenna has a height of only 150 m, but has – for compensation – a larger top-loading capacity. Radiation characteristics of the transmitting antennas measured some years ago have shown that the deviations from the characteristic of an ideal omnidirectional antenna are not larger than 2 dB in any direction. Both transmitting antennas radiate approximately the same power and are located in a neighbouring position on the same antenna field, i.e. on the antenna field of the transmitting radio station. It is estimated that the radiated power EIRP (Equivalent Isotropic Radiated Power) lies at approx. 30 to 35 kW.

6.2 Facilities in Braunschweig

The received carrier phase time and the phase of the second marks (determined from the amplitude modulation and from the phase modulation) are compared with the nominal values given by UTC(PTB). As examples, Figure 10 shows the continuous recording of the signal amplitude and of the carrier phase on one day in June 2008 and on one day in January 2009. The pronounced phase variations of the DCF77 signal received during the night hours will be discussed in the next chapter. On the selected winter day, there was hardly any period with a calm phase curve. In the summer, however, the day/night differences come out very clearly. The

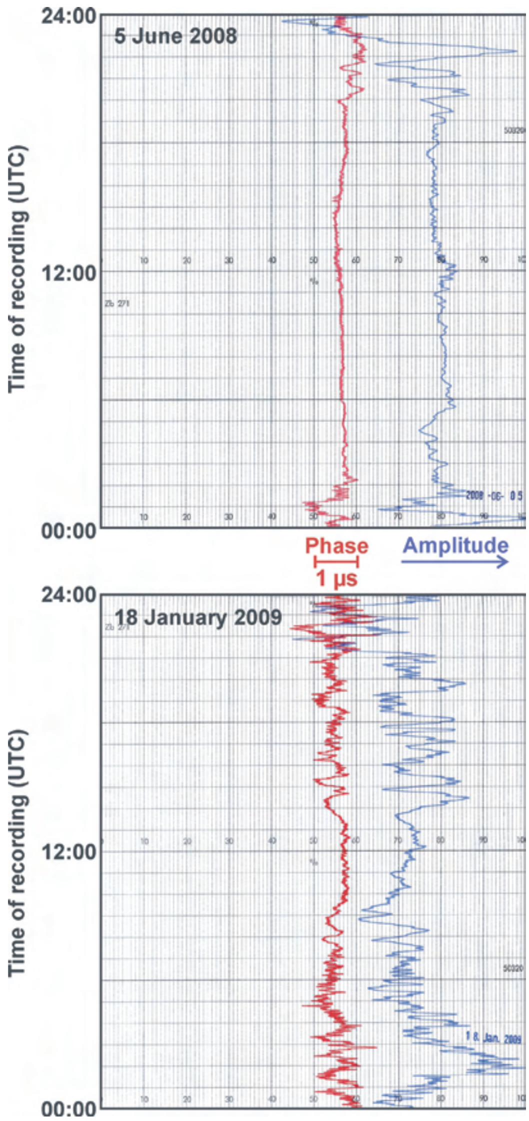


Figure 10:
Amplitude and phase of the received DCF77 signal recorded at PTB, Braunschweig, on June 5, 2008 (top) and on January 18, 2009 (bottom); Amplitude: amplitude of the carrier envelopes determined by linear rectification with a time constant of approx. 600 s, linear scale, uncalibrated, zero point on the left edge of the figure, phase: the full representation width corresponds to 10 µs, i.e. 0.1 µs per small scale mark, nominal value at 55 scale marks.

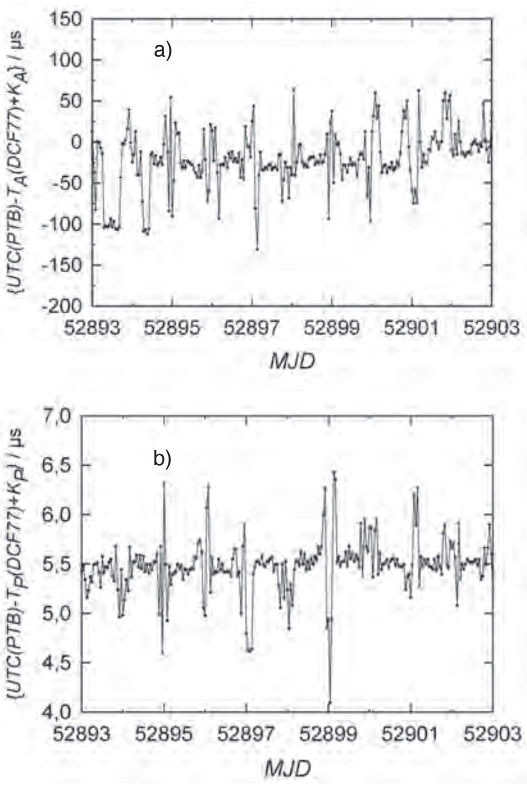


Figure 11:
The time differences *UTC(PTB) – T(DCF77) + K*;

a) recorded in Braunschweig: time difference between UTC(PTB) and the arrival time T_A(DCF77) of the received second marks, *K*: propagation time constant; detection of T_A(DCF77) from the falling edge (triggering point 60 %) of the AM second marks received with a bandwidth of 440 Hz; smoothening of T_A(DCF77) with a step-by-step controller; hereby, a locally generated 1 PPS sequence follows the signals received after a period of 4 seconds, in steps of |1 µs|.

b) Difference between UTC(PTB) and the phase time TP(DCF77) of the received carrier. Here, T_P is determined by a phase time comparison of the received carrier with a pulse sequence of 77.5 kHz derived from UTC(PTB); K_P: delay constant.

time differences between the local reference time scale UTC(PTB) and the arrival time T_A(DCF77) of the AM second marks (Figure 11a) and the received phase time *T*P(DCF77) of the carrier (Figure 11b) are shown as additional examples. The almost constant propagation time along the transmission path of 0.91 ms over the section of 273 km from Mainflingen to Braunschweig and the signal delays in the receiver of approx. 1 ms due to the narrow-band filter have been taken into account by means of the delay constants K_A and K_P, respectively, which are determined by the mentioned comparison with a transportable atomic clock. The measurements of the time difference which are performed continuously at PTB are used to control and, if necessary, to correct the phase time of the emitted carrier and thus the phase of the second marks emitted by the transmitter. If deviations result which are significantly larger than the typical variations, the required corrections are performed from Braunschweig via a remote control system. For this purpose, the phase of the generated carrier and of the second marks can be shifted in each of the control channels in steps of ± 0.1 µs. The remote control system also allows operating data to be retrieved from the caesium clocks and from devices generating the drive signal. In this way, different error sources can be identified and causes of malfunction be determined.

Not least, the agreement between the received time code and a nominally identical time code generated by independent devices is compared and documented in Braunschweig. Here, it is quite normal that received individual time signal "bits" are disturbed and, therefore, recognized as being "not correct" (e. g. 0 instead of 1). An error alarm is given when the same logic error is detected in succession within a period of several minutes. This has, up to now, never been the case. An alarm is also given when call bit 15 is received in state "one", when the received signal is permanently too small, or when the phase of the received carrier oscillation deviates from the nominal value by more than a defined amount. The temporal availability and the properties of the received signals will be dealt with in the next chapters.

7 Propagation of the DCF77 signal

The DCF77 signal emitted by the transmitting antenna reaches the place of reception in two ways: On the one hand, it propagates as ground wave along the Earth's surface and, on the other hand, it reaches the place of reception as sky wave after reflection on the ionospheric D layer. Two models have been developed for the description of the sky wave propagation: the reflection model and the waveguide model [24]. In the case of the reflection model ("wave hop" method), a reflection of the long wave on the lower edge of the D layer is assumed, whose height is estimated to amount to 70 km by day and to 90 km by night. According to the waveguide model ("waveguide mode" method), however, the sky wave propagates analogously to the propagation of electromagnetic waves between two surfaces along a waveguide. Here, the Earth's surface and the D layer are regarded as two concentric, conductive sphere surfaces between which a series of wave types (modes) propagates.

For the frequency of 77.5 kHz and for distances of $d < 2000$ km, the reflection model has proved to be more suitable. Figure 12 illustrates the propagation of the ground wave and of the sky wave according to this model, and Figure 13 shows which delay differences are caused by the propagation paths varying in length. In the case

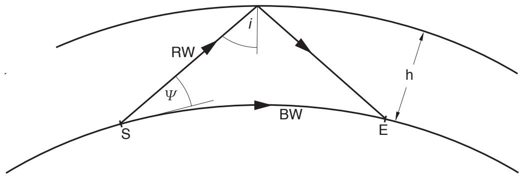


Figure 12:
Schematic view of the propagation of the ground wave and the sky wave between the transmitter and the receiver;
h: height of the ionospheric D layer,
ψ: elevation angle,
i: angle of incidence onto the D layer.

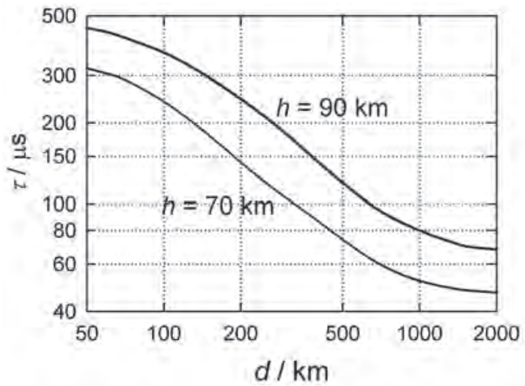


Figure 13:
Delay differences τ between ground wave and sky wave for two different heights *h* of the ionospheric D layer as a function of the distance *d* from the transmitter [26].

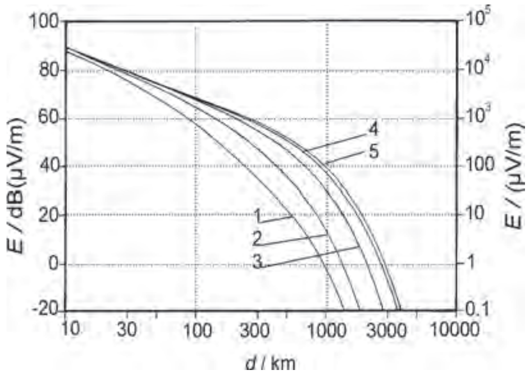


Figure 14:
Dependence of the field strength *E* of the ground wave on the distance *d* from the transmitter and the ground conductivity σ (curves 1 – 5), combined from Figures 1 – 11 in [25] and designated as indicated there. Assuming an irradiated power of 1 kW, the field strength amounts to 30 mV/m at d = 10 km, corresponding to E(dB(µV/m)) = 20 · $\log_{10}\{3 \cdot 10^4\}$ = 89.5;
1: $\sigma = 10^{-4}$ S/m (very dry ground),
2: $\sigma = 3 \cdot 10^{-4}$ S/m (dry ground),
3: $\sigma = 10^{-3}$ S/m (medium-dry ground),
4: $\sigma = 3 \cdot 10^{-3}$ S/m (land),
5: σ = 5 S/m (seawater, mean salt content). Converted into the power of approx. 30 kW irradiated by DCF77 of approx. 30 kW, the curves would be higher by approx. 15 dB.

of a straight propagation and *one* reflection (one hop), the maximum propagation distance of the DCF77 sky wave is obtained when the wave leaves the place of transmission tangentially ($\psi = 0$) to the Earth's surface and also comes in again tangentially. On these assumptions, the propagation distance amounts to approx. 1900 km by day and to approx. 2100 km by night. In this model, the DCF77 signal reaches places of reception which are farther away only after several reflections (e. g. two reflections on the D layer, one reflection on the Earth's surface) which does, however, imply a stronger decrease in the field strength.

Over an infinitely well-conducting ground, the field strength of the ground wave E_{BW} of the far field (i. e. *d* much larger than the wave length) can be calculated as a function of the distance *d* from the transmitter and the radiated power *P* on the basis of the relation

$$E_{BW} = 300\ \sqrt{(P / d)} \qquad (1)$$

[25], where E_{BW} is obtained in mV/m if *P* is entered in kW and *d* in km. The values of the field strength determined in accordance with this formula must be multiplied by a damping coefficient which takes the finite ground conductivity into account. For different values of the ground conductivity, the decrease in the field strength of the ground wave with increasing distance d can be derived, which is shown in Figure 14 for the frequency 75 kHz. For the DCF77 frequency, practically the same relations are valid.

Much more difficult is the prediction of the field strength of the sky wave. Assuming an infinitely well-conducting ground at the place of transmission, a sky wave with the field strength ERW is radiated to the ionosphere as a function of the elevation angle ψ

$$E_{RW} = E_{BW} \cdot \cos\psi. \qquad (2)$$

The reflection coefficient *R* towards the place of reception depends on various influences:

- on the time of the day and on the season,
- on the solar activity, and
- on the angle of incidence *i* of the sky wave on the D layer.

A simple relation for the dependence of *R* on these influences is not known. In [26], diagrams and calculation examples are given from which the values to be expected for the field strength of the sky wave can be determined. From this and from (1) and (2), field strength values to be expected for the DCF77 signal have been determined, and the results are shown in Figure 15. They are based on the assumption of a radiated power of 30 kW. The field strength of the sky wave is indicated as a function of the time of day and of the season. It is valid for a sunspot minimum. In the case of a sunspot maximum, the field strength of the sky wave can – at distances of up to approx. 800 km from the transmitter – be larger: in particular during the day in winter (by approx. 5 to 10 dB) and during the night (by approx. 3 dB).

The area of DCF77 reception is shown graphically in Figure 16. Showing lines of identical

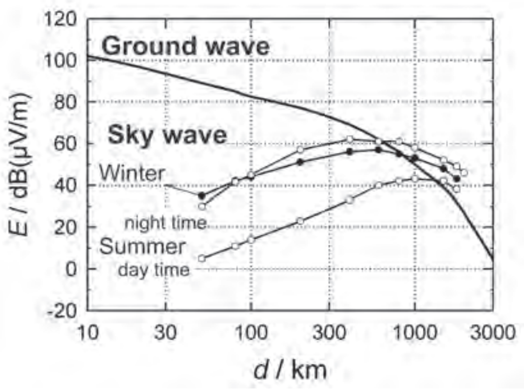


Figure 15:
Field strengths of the ground wave and of the sky wave as a function of the distance d from the place of transmission, calculated in accordance with [25, 26] assuming an irradiated power with DCF77 of 30 kW. For the ground conductivity, $3 \cdot 10^{-3}$ S/m were assumed; a distinction is made between propagation in summer (open symbols) and in winter (full symbols).

field strengths as circles is surely a simplification; together with Figure 15 it allows, however, an orientation as to the places at which DCF77 reception can be expected and where this is not probable.

8 Reception of the DCF77 signal

8.1 Legal aspects

In the Federal Republic of Germany, the legal basis for the selling of standard frequency receivers and radio-controlled clocks is the *Law on Radio Installations and Telecommunication Facilities* (FTEG). This law is the national implementation of EU Directive 1999/5/EC (RTTE Directive), and from this law, rights and obligations can be derived for manufacturers or marketing companies, importers or resellers. The fundamental requirements mentioned in Section 3 FTEG, i.e.

- health protection and safety for the user and other persons,
- protective requirements concerning electromagnetic compatibility,

are to be fulfilled by the devices.

In addition to the provision of a technical documentation in which the intended use of the device is clearly specified (for the respective country in the EU/EEA, in its own national language), and in addition to the Declaration of Conformity provided by the manufacturer or distributor to the user, the devices have to be marked with the CE marking [Article 12 (1–4) Directive 1999/5/EC]. With the EU Declaration of Conformity, the manufacturer confirms that these devices fulfil the basic requirements of the Directive and of the law. If the Declaration of Conformity is based on harmonized standards, it can be assumed that the basic requirements have been complied with.

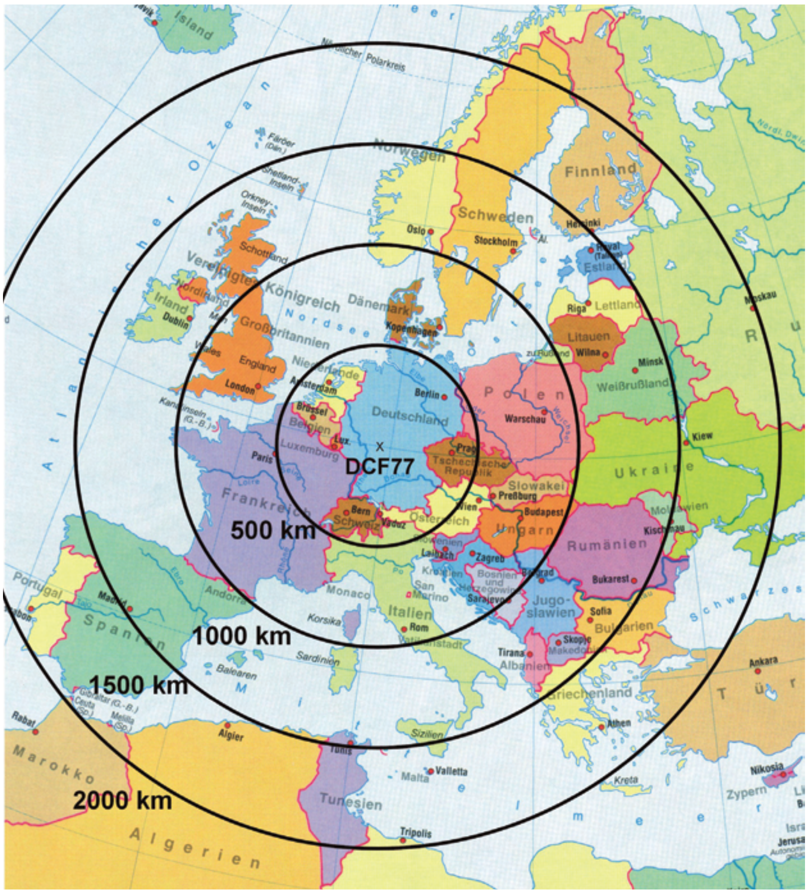
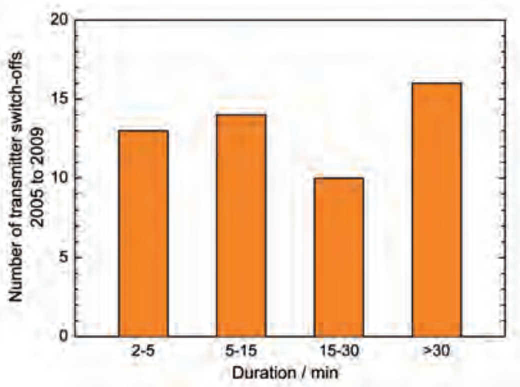


Figure 16:
Schematic view of the reach of the DCF77 transmission.

Class 1 radio installations (this includes DCF77 receiver equipment) can be placed on the EU/EEA market without restrictions and without announcinge this to the regulating authorities of the individual countries. Further information about this subject can be found on the Internet pages of the Federal Network Agency (Bundesnetzagentur BNetzA) [27].

8.2 Temporal availability of the transmission

DCF77 transmits in continuous operation (24 hours). With Media Broadcast GmbH, a temporal availability of the DCF77 transmission of at least 99.7 % every year has been agreed upon. Due to the fact that a replacement transmitter and a standby antenna are available, there are no shut-downs for maintenance work at regular intervals. Short interruptions of up to a few minutes must, however, be expected when switch-over to the replacement transmitter and the standby antenna is required in the case of unexpected irregularities or due to maintenance work. Since summer 1997, it has no longer been necessary to interrupt the DCF77 transmission for extended times – not even in the case of thunderstorms at the place of transmission. The antenna leads in the antenna houses were equipped with sphere spark gaps and UV sensors. If a breakthrough with development of an



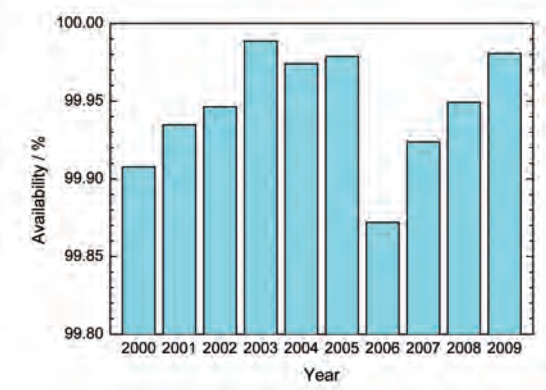


Figure 17:
Top: Frequency distribution of the interruptions of the DCF77 transmission of a specific duration in the years 2005 to 2009.

Bottom: Annual availability, leaving switch-offs having a duration of less than 2 minutes unconsidered.

arc discharge occurs on a sphere spark gap after a lightning stroke, this is detected by the UV sensor and notified to an electronic monitoring system. As, due to the high voltage of the signal furnished by the transmitter, the arc would not extinguish by itself, the electronic monitoring system interrupts the output signal of the transmitter for a short time, by which the normal state is restored. In the case of thunderstorms at the place of transmission, short-time interruptions of the DCF77 transmission must, therefore, be expected so that the reception of some successive second marks may be disturbed.

According to the distribution shown in Figure 17, switch-offs with a duration of more than 2 minutes have been observed in the past few years. The temporal availability over several years is shown in Figure 17. The most frequent cause of interruptions of longer duration was the electric detuning of the antenna resonance circuit by displacements of the antenna in heavy storm and freezing rain. When the mismatch becomes too large, the transmission is interrupted. Since July 1999, the transmitting radio station has no longer been staffed outside the regular working hours. During that time, the transmitter is monitored from Frankfurt am Main. At PTB, guards are present outside of regular working hours. In the case of larger disturbances on the control and transmitting facilities – e. g. when the automatic monitoring systems switch off the drive signal or the transmitter – it can, therefore, take a longer time outside of working hours until employees of Media Broadcast or PTB can be reached and can take measures for disturbance elimination. Radio-controlled clocks in applications which require a high degree of safety should, therefore, be able to run in a holdover-mode for several hours based on a high-quality quartz oscillator and internal signal generation.

8.3 Properties of the received signals

The – very stable – ground wave has a broad reach. Up to distances of a few hundred kilometres, its receiving field strength is clearly larger than that of the sky wave. At distances of less than 500 km from the transmitter, field strengths of the ground wave of more than 1 mV/m can be expected.

In a distance range between approx. 600 and 1100 km, ground wave and sky wave can occasionally be equal. As shown by the pointer diagram in Figure 18 , it depends on the ratio of the amplitudes of the ground wave and of the sky wave and on the phase angle between the two field components which phase angle displacement the resulting total signal experiences, related to the phase of the ground wave, and which total amplitude is reached. If amplitude and phase fluctuations of the carrier and (periodically-) temporal displacements of the time signals are observed at the place of reception, these have their cause in the varying fraction of the sky wave as a result of changes in the reflection coefficient, and in changes in the propagation delay of the sky wave when the height of the D layer changes at dawn from approx. 70 to approx. 90 km and vice versa. Which uncertainties can be achieved in the reception of the DCF77 standard frequency and of the time signals, depends therefore decisively on the distance of the place of reception from the transmitter, on the time of day and on the season.

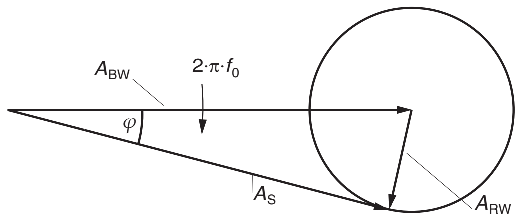


Figure 18:
Phasor diagram for clarification of the vectorial overlapping of ground wave and sky wave at the place of reception;
A_{BW}, A_{RW}, A_S: amplitudes of the ground wave and of the sky wave and of the resulting composite signal,
φ: resulting phase angle displacement of the composite signal from the ground wave. In the vector diagram, all vectors rotate with the angular speed $2\pi f_0$; f_0 is the carrier frequency and φ remains constant under stationary conditions.

On the other hand, a temporal, great increase in the field strength is possible also in the case of an identical phase position. Both phenomena have already been observed in Braunschweig (d = 273 km) (see Figure 10). In this connection, it is important to know that this "beat" between the ground wave and the sky wave is a slow process (taking a quarter of an hour and longer) and that there is, thus, enough time for a radio-controlled clock to receive the DCF77 time information. Figure 15 suggests in particular that disturbances in the reception occur more frequently in the winter months. This agrees with the larger number of inquiries addressed to PTB in this season due to observed disturbances in the reception.

At distances of more than 1100 km, the ground wave fraction decreases more and more, and the sky wave, whose propagation is rather constant at large distances, especially during the day, predominates. At distances between 1100 and 2000 km, field strengths of the sky wave between a few hundred and approx. 100 μV/m are to be expected. According to Figure 15, broad reaches are probable above all in winter. Quasi as a confirmation of this, there were reliable reports in January 2009 of two commercially available radio-controlled alarm clocks in Montreal, Canada, receiving DCF77.

8.3.1 Reception of the standard frequency

If the carrier of DCF77 is used for the monitoring or for the automatic control of standard frequency generators, the frequency and/or phase time comparisons between the local oscillator signal and the received DCF77 carrier signal, which are required for this purpose, are affected by the phase fluctuations caused by the propagation and the PRN code. Which phase time and/or frequency fluctuations occur in Braunschweig, 273 km away from the place of transmission, has been investigated repeatedly at PTB; the example presented here is from autumn 2003. The registration of the phase time between September 1 and October 21 (50 days) showed an averaged relative frequency deviation of $< 1 \cdot 10^{-14}$ between the DCF77 carrier frequency and UTC(PTB). The relative standard deviation of the daily mean values amounted to $1.5 \cdot 10^{-12}$ for the measurement interval from 12:00 UTC to 12:00 UTC. If the instability of the recorded carrier frequency is determined as a function of the measurement time, the dependence shown in Figure 19 is obtained. The shown variations σ of the single measurements were obtained, related to the nominal value specified by UTC(PTB), as a function of the time of day of the measurement and of the selected averaging time. For short averaging times, uncertainties can be achieved which are smaller by day than by night. On the other hand, the frequency fluctuations caused by the influence of sky waves largely average out if the measurements are carried out with sufficiently long averaging times. Typically, the situation is more favourable in summer than in winter.

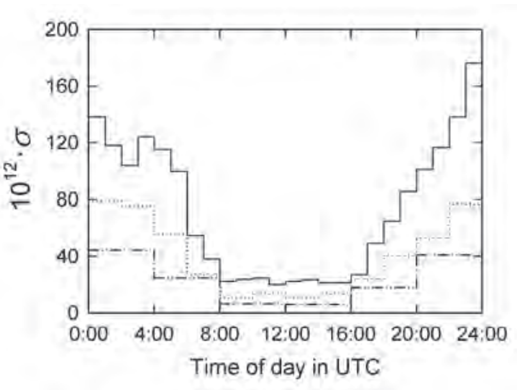


Figure 19:
Standard deviation σ of the relative deviation of the DCF77 carrier frequency received in Braunschweig from the nominal value as a function of the time of day and of the averaging period T (continuous line: T = 1 h, dotted line: T = 2 h, dashed-dotted line: T = 4 h), based on 50 days in late summer of 2003.

The frequency fluctuations determined for Braunschweig can serve as reference points for all places of reception at which the ground wave still has a predominantly larger amplitude than the sky wave. However, in the distance range in which the ground wave and the sky wave can become equal, frequency comparisons are more difficult due to a possible "cycle slipping". At very large distances, when the sky wave prevails, the ratios are constant again. Here, frequency comparisons should possibly be performed only by day or by night, i. e. at a stable sky wave propagation, so that changes in delay by the wandering of the D layer at dawn will not be interpreted as changes in the local frequency generator.

Industry offers DCF77 standard frequency receivers for the automatic correction of quartz standards and of atomic frequency standards. In such frequency controllers, the output signal of the standard to be corrected is converted into the DCF77 carrier frequency or into a subharmonic of it, and the phase times of the received DCF77 signal and of the controlled signal are compared. From the time-dependent change of the phase difference between the two signals, a control signal for the automatic correction of the frequency standard is deduced. If such frequency controllers are combined with frequency standards of a high intrinsic stability – such as, for example, temperature-controlled quartz oscillators or atomic frequency standards – large control time constants can be selected, so that the phase time variations due to the propagation are largely averaged out. As has been confirmed by measurements in different calibration laboratories, frequency standards can in this way be linked up with PTB's atomic frequency standards with average uncertainties of $1 \cdot 10^{-11}$ in the long run

– and even less – without losing their short-time stability. Rubidium atomic frequency standards in temperature-stabilized measurement rooms are controlled best with time constants between one day (at least) and several days.

8.3.2 Reception of amplitude-modulated time signals

The reception of time signals is often impeded by disturbances which are due to various causes. The 5th harmonic of the line frequency of television receivers (625 Hz above the DCF77 carrier frequency) as well as pulse disturbances of switching-regulated power supplies and electric machines have, for example, proved to be particularly disturbing. Atmospheric disturbances which are, for example, caused by discharges in the case of thunderstorms, can lead to a strong impairment of the time signal reception. To keep the influence of the different irregularities on the time signals as small as possible, receive circuits with a very small bandwidth are used in many radio-controlled clocks. Although this allows the susceptibility to interferences to be largely reduced, the narrowing of the reception frequency range causes, on the other hand, a flattening and rounding of the signal flanks. Measurements of the frequency spectrum performed at the place of transmission, as well as an estimate of the transmission bandwidth Δf from the decay time t_A of the falling edge of the carrier envelope shown in Figure 4 according to the relation $\Delta f = 1/t_A$, have shown that Δf is in the order of magnitude of 850 Hz. The larger the fraction that is cut off from this frequency range on the receiving side, the larger the statistic uncertainty with which the arrival time of the DCF77 signal can be indicated. To guarantee a reception free from interferences, many of the radio-controlled clocks on the market work with bandwidths around 10 Hz and uncertainties of approx. 0.1 s, which is regarded as sufficient for this purpose.

To achieve smaller uncertainties, steeper flanks – i. e. a larger receive bandwidth but, at the same time, a larger susceptibility to interferences – must be used. Suitable demodulation and averaging procedures to cope with interferences are, for example, synchronous demodulation, quadrature probing [28], step control with unit steps [29] (used, e. g., for the measurement values represented in Figure 11a) or carrier-synchronous, digital time signal averaging by probing of the amplitudes of the carrier oscillation in the range of the signal flank. When applying these techniques in practice, uncertainties between 50 and 100 µs have been achieved for distances in which the ground wave clearly prevails. Various contributions in the proceedings of the meetings on radio-controlled clocks [6] deal with this subject. In [3], details of disturbances in the reception for radio-controlled wrist watches are being dealt with.

9 Radio-controlled DCF77 clocks

The idea to transmit time information via radio waves is almost as old as the technique of the "radio" itself. In a publication rich in anecdotes, Michael A. Lombardi of the National Institute of Standards and Technology (NIST), USA, tells the story of the radio-controlled clock in the USA [30]. Here is an extract from it:

At the end of the 19th and at the beginning of the 20th century, Guglielmo Marconi experimented with radio waves. In 1899, he succeeded in realizing communication across the British Channel and, in 1901, across the Atlantic Ocean. In a lecture held before the Royal Dublin Society in 1898, Sir Howard Grubb, the engineer and manufacturer of optical instruments, made reference to the "Marconi waves" when he predicted the development of portable radio-controlled clocks:

"There is something very beautiful in this action of the Marconi waves. In a city supplied with this apparatus we should be conscious as we hear each hour strike that above us and around us, swiftly and silently, this electrical wave is passing, conscientiously doing its work, and setting each clock in each establishment absolutely right, without any physical connection whatsoever between the central distributing clock, and those which it keeps correct by means of this mysterious electrical wave.

We might go even still further, and although I do not put it forward as a proposition likely to be carried out in any way, except as an experiment, yet it undoubtedly would be perfectly possible to carry an apparatus in one's pocket, and have our watches automatically set by this electrical wave as we walk about the streets." [31]

In Germany, Professor Dr.-Ing. Wolfgang Hilberg ranks among the pioneers in the development of radio-controlled clocks. In 1967 he described – at that time as an engineer in the research institute of the company AEG Telefunken in Ulm – the principle of a time distribution system for everybody with the aid of a transmitter and digitally working radio-controlled clocks under the title "Wireless controlled clocks with standard time digital display" [32]. In 1971, he showed that the bandwidths required for the time transmission are so small that the emission of time information would be possible, for example, at the edges of FM radio (UKW) channels [33]. As a possible radio-controlled clock for time transmission with radio stations, he presented the test set-up of a commercially available modified radio to which a receiver circuit with Nixie indicator tubes, easy to realize, had been attached for time indication. Although it is technically possible, the direct dissemination of time via radio stations or television transmitters has never been realized – except for the emission of time signals on the hour or the showing of clocks prior to the news on TV.

After the DCF77 had taken up operation in 1970, there were considerations at PTB to start with the emission of encoded time information. In addition to Hilberg's work, the development of the time signal transmitters WWV and WWVB in the USA, where the emission of encoded time information had been started in 1960 and 1965, respectively, was followed [21]. Simultaneously with the beginning of the emission of the time code via DCF77, PTB presented prototypes of radio-controlled clocks. These are shown today – if they are not still in operation – in the Deutsches Museum (Munich and Bonn) and at PTB. The circuit of these first DCF77 radio-controlled clocks was first published in an article in 1974 [34]. It met with great interest, and a great number of readers of that article built their own copies of the circuit.

In the following years, scientific support in the further development of the radio-controlled clock came – apart from PTB – from the universities of Darmstadt and Stuttgart. Especially at Darmstadt Technical University, where Professor Hilberg had obtained a chair of "Digital Circuits" in 1972, new receiving procedures were developed and small, efficient radio-controlled clocks developed, with the aim of achieving mass production at low manufacturing cost. Early in 1980, the researchers from Darmstadt presented, at the Institute for Horology and Precision Engineering of Stuttgart University, a fully functional radio clock receiver with a small internal antenna and a digital display of the size of today's radio-controlled alarm clocks to a committee from German industry. In the mid-80s, the companies KUNDO and Junghans placed their first radio-controlled clocks – KUNDO SPACE TIMER and Junghans RC-1 – on the market. In 1987, Darmstadt Technical University presented the prototype of a radio-controlled wrist watch with an incorporated antenna. The first commercial radio-controlled wrist watch was brought onto the market in 1990 by Junghans, whose MEGA 1 was said in Lombardis's essay to be *"one of the most momentuous horlogical events ever"* [30]. Today, the MEGA 1 is already an exhibit in clock museums and in technical museums.

10 Time and standard frequency services on longwave

In the *Radio Regulations* of the ITU, the frequency ranges 20.05 – 70 kHz and 72 – 84 kHz in region 1 (Europe and Africa) are assigned to so-called *primary fixed services* [35]. Article 5.56 states in addition that the radio services to which these above-mentioned frequency ranges have been assigned, can emit standard frequency and time signals. These services have protection rights vis-à-vis any disturbing interferences that are caused by emissions of *secondary services*. Other frequency bands are, however, exclusively reserved for the emission of the standard frequency and are specially protected (e. g. around 2.5 MHz, 5 MHz, 10 MHz). In the following, we will only give a survey of the services in the low frequency range. The annex of the ITU recommendation ITU-R TF768-5 *Standard Frequencies and Time Signals* contains a list of the different services.The annex of ITU recommendation ITU-R TF583-6 contains the coding schemes presently used for the transmission of time information. Whereas the texts of the recommendations themselves can be obtained only against payment of a charge from ITU (http://www.itu.int/rec/R-REC-TF/e), the above-mentioned annexes, which are updated annually, are available free of charge [36]. The properties of the time services on longwave are summarized in Table 1, which is based on information originating from October 2008.

The time code emitted by the Swiss transmitter HBG is almost identical with the DCF77 code, except for the identification of the minute. In the second marks, the amplitude is traced to zero – not to 15 %, as in the case of DCF77. Unfortunately, it was announced that HBG will cease operation at the end of 2011 [37]. All other services use other time codes. Table 1 contains the presently published parameters of the new Chinese time service BPC [38] which is operated by the National Time Service Centre, Lintong, Shanxii Province, People's Republic of China and for which, meanwhile, also commercial radio-controlled clocks can be obtained. All in all, it is planned to set up 3 stations in that country for the transmission of the standard frequency and of time signals. The Taiwanese government, too, has decided to establish a longwave time service. In the last decade, considerable sums have been invested in the setting up of the two Japanese stations JJY and the modernization of the WWVB of NIST [39]. Apparently, there is a strong public interest in many countries in having the exact time available, and emission via longwave is regarded as being an adequate means for this.

11 Concluding remarks

With the longwave transmitter DCF77 controlled by PTB at 77.5 kHz, a reliable time signal and standard frequency transmitter has been available for many years, which can be received in many parts of Europe. Radio-controlled DCF77 clocks can be manufactured at low cost, and millions of them are in use. Today, approximately half of all "large electrical clocks" (table clocks, mounted clocks, wall clocks and alarm clocks) sold in the private sector are radio-controlled clocks. In addition, more than half a million of radio-controlled industrial clocks are in use, among them clocks which make use of the pseudo-random phase shift keying of the carrier phase.

The carrier frequency of the DCF77 is used to calibrate or to automatically correct standard frequency generators. In traffic, e.g. in railway and air-traffic control, DCF77 plays an important role. Parking meters and traffic lights are synchronized by DCF77. In an ever increasing number of buildings, heating and ventilation systems are controlled by DCF77, and roller shutters are closed or opened by DCF77. In the telecommunication and energy-supply industries, DCF77 radio-controlled clocks are used to allow time-related tariffs to be correctly billed. Numerous NTP servers feed the time received from DCF77 into computer networks, and all radio and television stations receive the exact time from DCF77. These are just a few examples for the application of DCF77, but they make clear the considerable development that has been achieved in the past fifty years – also in the "old" technique and in the dissemination of time via longwave. And radio-controlled clocks are still used to an ever increasing extent. To have the correct time without having to set one's watch is something people appreciate very much. The success story of the radio-controlled clock has, in particular, something to do with the properties of the longwave. Compared to the time signals of satellites, low frequency signals have one decisive advantage: they penetrate into buildings, and their reception is not significantly impeded by barricades such as trees or tower buildings. They can be received without an outdoor antenna, with small ferrite antennas which are incorporated in radio-controlled clocks. This property of the longwave allows inexpensive, compact, radio-controlled clocks, operated by battery or solar cells, to be manufactured and operated without any cable connections to an external antenna. To receive signals of the navigation system GPS and, in future, of the European pendant

Table 1:
Longwave stations transmitting the standard frequency and encoded time information (as of October 2008 [35]).
The time code used in the respective case can be found under the ITU Internet address indicated in the text in chapter 9 or under "operators".

Call sign	**Country**	**Site**	**Carrier frequency** (kHz)	**Rel. uncertainty of the carrier frequency** (1σ, over 1 day)	**Transmitter power** (actually emitted power (kW))	**Mode of operation**	**Internet address** http://+
BPC	China	**Pucheng** 34° 56.9' north 109° 33.1' east	68.5		20		www.ntsc.ac.cn
DCF77	Germany	**Mainflingen** 50°01' north 09°00' east	77.5	$1 \cdot 10^{-12}$	30	Continuous	www.ptb.de
HBG	Switzerland	**Prangins** 46°24' north 6° 15' east	75	$2 \cdot 10^{-12}$	25	Continuous	www.official-time.ch or www.metas.ch
JJY	Japan	**Ohtakadoyayama** 37° 22' north 140° 51' east	40	$1 \cdot 10^{-12}$	12.5	Continuous	jjy.nict.go.jp
JJY	Japan	**Haganeyama** 33°28' north 130° 11' east	60	$1 \cdot 10^{-12}$	22.5	Continuous	jjy.nict.go.jp
MSF	UK	**Anthorn** 54° 55' north 03° 15' west	60	$2 \cdot 10^{-12}$	17	Continuous except during announced service switch-off	www.npl.co.uk
WWVB	USA	**Colorado Springs** 40° 40' north 105° 02' west	60	$1 \cdot 10^{-11}$	65	Continuous	tf.nist.gov

Galileo reliably requires, in contrast, an antenna with a view to the sky as unblocked as possible. If this antenna can be installed, then – undeniably – smaller uncertainties are achieved in the transmission of time [17]. In future, time transmission via satellites and time dissemination on longwave will, therefore, not replace – but rather complement – each other.

DCF77 thus continues being the most important medium for the dissemination of legal time by PTB.

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Annex 1

— 93 —

Reichs-Gesetzblatt.

№ 7.

Inhalt: Gesetz, betreffend die Einführung einer einheitlichen Zeitbestimmung. S. 93.

(Nr. 2075.) Gesetz, betreffend die Einführung einer einheitlichen Zeitbestimmung. Vom 12. März 1893.

Wir Wilhelm, von Gottes Gnaden Deutscher Kaiser, König von Preußen ꝛc.

verordnen im Namen des Reichs, nach erfolgter Zustimmung des Bundesraths und des Reichstags, was folgt:

Die gesetzliche Zeit in Deutschland ist die mittlere Sonnenzeit des fünfzehnten Längengrades östlich von Greenwich.

Dieses Gesetz tritt mit dem Zeitpunkt in Kraft, in welchem nach der im vorhergehenden Absatz festgesetzten Zeitbestimmung der 1. April 1893 beginnt.

Urkundlich unter Unserer Höchsteigenhändigen Unterschrift und beigedrucktem Kaiserlichen Insiegel.

Gegeben Berlin Schloß, den 12. März 1893.

(L. S.) Wilhelm.

Graf von Caprivi.

Herausgegeben im Reichsamt des Innern.

Berlin, gedruckt in der Reichsdruckerei.

Reichs-Gesetzbl. 1893. 16

Ausgegeben zu Berlin den 16. März 1893.

Annex 2

The current determination of legal time and the role of PTB is part of the Units and Time Act which was revised in 2008, Federal Law Gazette, volume 2008, part I, No. 28, July 11, 2008.

In this law, the following is laid down (extracts):

Article 1 Scope of application

(1) In official and commercial transactions, quantities must be indicated in legal units if for them, units have been laid down in a legal ordinance in accordance with this Act. For the legal units, the specified names and unit symbols must be used.

(2) In official and commercial transactions, the date and the time must be used in accordance with legal time.

Article 4 Legal time

(1) Legal time is Central European Time. This time is determined by Coordinated Universal Time plus one hour.

(2) For the period of its introduction, Central European Summer Time is legal time. Central European Summer Time is determined by Coordinated Universal Time plus two hours.

Article 5 Authorization for the introduction of Central European Summer Time

(1) For a better utilization of daylight and to adapt time counting to that of the neighbouring states, the Federal Ministry of Economics and Technology is granted the authorization to introduce (by legal ordinance which does not require the consent of the Federal Council (Bundesrat)) Central European Summer Time for a period between March 1 and October 31.

(2) Central European Summer Time shall begin and end on a Sunday. The Federal Ministry of Economics and Technology determines – in the legal regulation according to Section 1 – the day and the time at which Central European Summer Time will begin and end, as well as the designation of the hour which will appear twice at the end of Central European Summer Time.

Article 6 Physikalisch-Technische Bundesanstalt

(2) The Physikalisch-Technische Bundesanstalt has the following tasks:
1. to realize and disseminate the legal units and to develop the procedures required for this purpose,
2. to realize and disseminate legal time,
5. to make public the procedures according to which nonembodied units, including the unit of time and the time scales as well as the temperature unit and the temperature scales, are realized.

Annex 3

Ordinance on the Introduction of Central European Summer Time from 2002* on (Summer Time Ordinance SoZV) of July 12, 2001

On the basis of Section 3 of the Time Act of July 25, 1978 (Federal Law Gazette I, p. 1110, 1262) which has been amended by the law of September 13, 1994 (Federal Law Gazette I, p. 2322), the Federal Government decrees the following:

Section 1

From 2002 on, Central European Summer Time (Section 1, Subsection 4 of the Time Act) is introduced for an indefinite time.

Section 21

(1) Central European Summer Time begins on the last Sunday in March, at 02:00 a.m. CEST. At the moment of the beginning of summer time, the clock is put forward by one hour from 02:00 a.m. to 03.00 a.m.

(2) Central European Summer Time will end on the last Sunday in October at 03:00 a.m. CEST. At the moment when summer time ends, the clock is put back one hour from 03:00 a.m. to 02:00 a.m. The hour from 02:00 a.m. to 03:00 a.m. appears twice. The first hour (from 02:00 a.m. to 03:00 a.m. CEST) is designated with 2A and the second hour (from 02:00 a.m. to 03:00 a.m. CET) with 2B.

Section 3

Beginning with the year 2002, the Federal Ministry of the Interior announces the beginning and the end of summer time in the Federal Gazette for five successive years, starting with the year 2002.

Annex 4

Announcement in accordance with Section 3 of the Summer Time Ordinance[1]

According to Section 3 of the Summer Time Ordinance of July 12, 2001 (Federal Law Gazette, I p. 1591), amended by Art. 4 of the law of July 3, 2008 (Federal Law Gazette I, p. 1185), the Federal Ministry of Economics and Technology announces for the years 2010 to and including 2014, the beginning and the end of summer time as follows:

- 2010: Beginning: Sunday, March 28; end: Sunday, October 31,
- 2011: Beginning: Sunday, March 27; end: Sunday, October 30,
- 2012: Beginning: Sunday, March 25; end: Sunday, October 28,
- 2013: Beginning: Sunday, March 31; end: Sunday, October 27,
- 2014: Beginning: Sunday, March 30; end: Sunday, October 26.

Berlin, March 2009
Federal Ministry of Economics and Technology

* This announcement also serves for the implementation of the communication of the Commission 2006/C61/02 acc. to Section 4 of Directive 2000/84/EC of the European Parliament and of the Council of January 19, 2001 for regulation of summer time (document EC 2006 No. C 61, p. 2).