INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

XIIIth PLENARY ASSEMBLY

GENEVA, 1974

VOLUME VII

STANDARD FREQUENCIES AND TIME SIGNALS
(STUDY GROUP 7)

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
GENEVA, 1975

INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

XIIIth PLENARY ASSEMBLY

GENEVA, 1974

VOLUME VII

STANDARD FREQUENCIES AND TIME SIGNALS
(STUDY GROUP 7)

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
GENEVA, 1975

ISBN 92-61-00081-9

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

STANDARD
FREQUENCIES
AND TIME SIGNALS

RECOMMENDATIONS AND REPORTS

QUESTIONS AND STUDY PROGRAMMES,
DECISIONS, RESOLUTIONS AND OPINIONS

(Study Group 7)

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

DISTRIBUTION OF TEXTS OF THE XIIIth PLENARY ASSEMBLY OF THE C.C.I.R. IN VOLUMES I TO XIII

Volumes I to XIII, XIIIth Plenary Assembly, contain all the valid texts of the C.C.I.R. and succeed those of the XIIth Plenary Assembly, New Delhi, 1970.

1. Recommendations, Reports, Decisions, Resolutions, Opinions

1.1 *Numbering of these texts*

Recommendations, Reports, Resolutions and Opinions are numbered according to the system in force since the Xth Plenary Assembly.

In conformity with the decisions of the XIth Plenary Assembly, when one of these texts is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. For example: Recommendation 253 indicates the original text is still current; Recommendation 253-1 indicates that the current text has been once modified from the original, Recommendation 253-2 indicates that there have been two successive modifications of the original text, and so on.

The XIIIth Plenary Assembly adopted a new category of texts known as Decisions, by which Study Groups take action, generally of an organizational nature, relative to matters within their own terms of reference, particularly the formation of (Joint) Interim Working Parties (see Resolution 24-3, Volume XIII). Although the Plenary Assembly did adopt in the form of Resolutions a number of texts which fell into the category of Decisions after amendment of Resolution 24-2, these texts are published in the Volumes of the XIIIth Plenary Assembly as Decisions, for practical reasons. When one of these texts is so published, a reference to the Resolution on which the text is based, is given in parenthesis below the title.

The tables which follow show only the original numbering of the current texts, without any indication of successive modifications that may have occurred. For further information about this numbering scheme, please refer to Volume XIII.

1.2 *Recommendations*

Number	Volume	Number	Volume	Number	Volume
45	VIII	310, 311	V	436	III
48, 49	X	313	VI	439	VIII
77	VIII	314	II	441	VIII
80	X	325-334	I	442, 443	I
100	I	335, 336	III	444	IX
106	III	337	I	445	I
139, 140	X	338, 339	III	446	IV
162	III	341	I	447-450	X
166	XII (CMV)	342-349	III	451	XII (CMTT)
182	I	352-354	IV	452, 453	V
205	X	355-359	IX	454-456	III
214-216	X	361	VIII	457-460	VII
218, 219	VIII	362-367	II	461	XII (CMV)
224	VIII	368-370	V	462, 463	IX
237	I	371-373	VI	464-466	IV
239	I	374-376	VII	467, 468	X
240	III	377-379	I	469-472	XI
246	III	380-393	IX	473-474	XII (CMTT)
257, 258	VIII	395-406	IX	475-478	VIII
262	X	407-416	X	479	II
265, 266	XI	417-418	XI	480	III
268	IX	419	X, XI	481-484	IV
270	IX	421	XII (CMTT)	485, 486	VII
275, 276	IX	422, 423	VIII	487-496	VIII
283	IX	427-429	VIII	497	IX
289, 290	IX	430, 431	XII (CMV)	498, 499	X
302	IX	433	I	500, 501	XI
305, 306	IX	434, 435	VI	502-505	XII (CMTT)

1.3 *Reports*

Number	Volume	Number	Volume	Number	Volume
19	III	275-282	I	424-426	V
32	X	283-289	IX	428	V
42	III	292, 293	X	429-432	VI
79	X	294	XI	433-437	III
93	VIII	298-305	X	438, 439	VII
106, 107	III	306, 307	XI	440	(1)
109	III	311, 312	XI	441	XII (CMV)
111	III	313	XII (CMTT)	443-446	IX
112	I	315	XI	448, 449	IX
122	XI	318, 319	VIII	451	IV
130	IX	321	XII (CMV)	453-455	IV
137	IX	322	(1)	456	II
176-189	I	324-330	I	457-461	X
190	X	335	XII (CMV)	463-465	X
192, 193	I	336	V	467, 468	X
195	III	338	V	469-473	XI
196	I	340	(1)	476-485	XI
197, 198	III	341-344	VI	486-488	XII (CMTT)
200, 201	III	345-357	III	490, 491	XII (CMTT)
202	I	358, 359	VIII	493	XII (CMTT)
203	III	361	VIII	495-498	XII (CMTT)
204-208	IV	362-364	VII	499-502	VIII
209	IX	366	VII	504-513	VIII
211-214	IV	367-373	I	515	VIII
215	IX	374-382	IX	516	X
216	VIII	383-385	IV	518	VII
222-224	II	386-388	IX	519-534	I
226	II	390, 391	IV	535-548	II
227-229	V	393	IX	549-551	III
233-236	V	394	VIII	552-561	IV
238, 239	V	395, 396	II	562-570	V
241	V	398-401	X	571-575	VI
245-251	VI	403	X	576-580	VII
252	(1)	404, 405	XI	581-603	VIII
253-256	VI	409	XI	604-615	IX
258-266	VI	410-412	XII (CMTT)	619-622	X
267	VII	413-415	(1)	623	X,XII (CMTT)
269-271	VII	417-420	I	624-634	XI
272, 273	I	422, 423	I	635-649	XII (CMTT)
				650	XII (CMV)

(1) Published separately.

1.4 *Decisions*

Number	Volume	Number	Volume	Number	Volume
1	I	6-11	VI	17	XI
2	IV	12-14	VII	18	XII (CMTT)
3-5	V	15	VIII	19, 20	XII (CMV)
		16	IX		

1.5 *Resolutions*

Number	Volume	Number	Volume	Number	Volume
4	VI	22, 23	XII (CMV)	43, 44	I
14	VII	24	XIII	48	VI
15, 16	I	26, 27	XIII	59	X
20	VIII	33	XIII	60, 61	XIII
		36, 39	XIII		

1.6 *Opinions*

Number	Volume	Number	Volume	Number	Volume
2	I	29, 30	I	45, 46	VI
11	I	32	I	47, 48	VII
13, 14	IX	34, 35	I	49	VIII
15, 16	X	36	VII	50	IX
22, 23	VI	38-40	XI	51, 52	X
24	VIII	41	XII (CMTT)	53, 54	XI
26-28	VII	42, 43	VIII	55	XII (CMTT)
		44	I		

2. Questions and Study Programmes

2.1 *Text numbering*

2.1.1 *Questions*

Questions are numbered in a different series for each Study Group; where applicable a dash and a figure added after the number of the Question indicate successive modifications. The number of a Question is completed by an *Arabic figure indicating the relevant Study Group*. For example:

— Question 1/10 would indicate a Question of Study Group 10 with its text in the original state;

— Question 1-1/10 would indicate a Question of Study Group 10, whose text has been once modified from the original; Question 1-2/10 would be a Question of Study Group 10, whose text has had two successive modifications.

2.1.2 *Study Programmes*

Study Programmes are numbered to indicate the Question from which they are derived if any, the number being completed by a capital letter which is used to distinguish several Study Programmes which derive from the same Question. The part of the Study Programme number which indicates the Question from which it is derived makes no mention of any possible revision of that Question, but refers to the current text of the Question as printed in this Volume.

Examples:

— Study Programme 1A/10, which would indicate that the current text is the original version of the text of the first Study Programme deriving from Question 1/10;

— Study Programme 1C/10, which would indicate that the current text is the original version of the text of the third Study Programme deriving from Question 1/10;

— Study Programme 1A-1/10 would indicate that the current text has been once modified from the original, and that it is the first Study Programme of those deriving from Question 1/10.

It should be noted that a Study Programme may be adopted without it having been derived from a Question; in such a case it is simply given a sequential number analogous to those of other Study Programmes of the Study Group, except that on reference to the list of relevant Questions it will be found that no Question exists corresponding to that number.

2.2 *Arrangement of Questions and Study Programmes*

The plan shown on page 8 indicates the Volume in which the texts of each Study Group are to be found, and so reference to this information will enable the text of any desired Question or Study Programme to be located.

PLAN OF VOLUMES I TO XIII
XIIIth PLENARY ASSEMBLY OF THE C.C.I.R.

(Geneva, 1974)

VOLUME I	Spectrum utilization and monitoring (Study Group 1).
VOLUME II	Space research and radioastronomy (Study Group 2).
VOLUME III	Fixed service at frequencies below about 30 MHz (Study Group 3).
VOLUME IV	Fixed service using communication satellites (Study Group 4).
VOLUME V	Propagation in non-ionized media (Study Group 5).
VOLUME VI	Ionospheric propagation (Study Group 6).
VOLUME VII	Standard frequency and time-signal services (Study Group 7).
VOLUME VIII	Mobile services (Study Group 8).
VOLUME IX	Fixed service using radio-relay systems (Study Group 9). Coordination and frequency sharing between systems in the fixed satellite service and terrestrial radio-relay systems (subjects common to Study Groups 4 and 9).
VOLUME X	Broadcasting service (sound) including audio-recording and satellite applications (Study Group 10).
VOLUME XI	Broadcasting service (television) including video-recording and satellite applications (Study Group 11).
VOLUME XII	Transmission of sound broadcasting and television signals over long distances (CMTT). Vocabulary (CMV).
VOLUME XIII	Information concerning the XIIIth Plenary Assembly. Structure of the C.C.I.R. Complete list of C.C.I.R. texts.

Note. — To facilitate reference, page numbering is identical in all three versions of each Volume, that is, in English, French and Spanish.

VOLUME VII*

INDEX OF TEXTS

STANDARD FREQUENCIES AND TIME SIGNALS
(Study Group 7)

* Although the working documents mentioned in this Volume bear the reference "Period 1970–1973" for documents published during 1971 and 1972 and "Period 1970–1974" for those published during 1973 and 1974, they are, of course, all documents of the period 1970–1974, between the Plenary Assembly of New Delhi and that of Geneva. For this reason, all references to these documents in this Volume take the form "Period 1970–1974".

STANDARD FREQUENCIES AND TIME SIGNALS

STUDY GROUP 7

Terms of reference:

— to coordinate world-wide services of standard-frequency and time-signal emissions;

— to study the technical aspects of emission and reception including the use of satellite techniques in these services and means to improve the accuracy of measurement.

Chairman: G. BECKER (Germany (Federal Republic of))

Vice-Chairman: J. MCA. STEELE (United Kingdom)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 7

In this introduction, a short review is given of the present situation as regards the work of Study Group 7, according to its terms of reference. Some comments are made concerning the outlook for future developments.

Coordinated Universal Time (UTC)

The UTC time system developed and implemented by Study Group 7 is now in use on a nearly world-wide scale. As presently defined in Recommendation 460-1, it appears capable of accommodating all possible changes of rotation of the Earth in the foreseeable future.

With regard to Opinion 47, General use of Coordinated Universal Time (UTC), which is in line with the Recommendations of U.R.S.I. and I.A.U., it is probable that the General Conference of Weights and Measures (C.G.P.M.) will adopt a Resolution in 1975 recommending UTC as the basis of official time. This will complete a development originated by the atomic definition of the SI (système international) second in 1967 by the C.G.P.M. and will result in the dissemination of time signals and standard frequencies based on the SI second, including the general and official application of UTC to replace Universal Time (UT) in the formation of the Zonal Times.

The Consultative Committee for the Definition of the Second (C.C.D.S.) recommended in July, 1974, the use of the symbol "UTC" in all languages. The C.C.I.R. should also adopt this practice in the future.

Methods for time and frequency dissemination and comparisons

During the discussions of Study Group 7 in March, 1974, it proved to be inadequate, at times, to examine a method solely in terms of either "dissemination" or "comparison". It would be advisable to consider whether the texts of Study Group 7 should be modified so that both aspects, dissemination (or transmission) and comparisons, are reflected together.

Atomic time and frequency standards have improved considerably but at the same time the problems of transmission are becoming predominant. The methods using LORAN-C or television pulses do not yet appear to be fully exploited. In the fields of standard-frequency and time-signal emissions in the LF band, development tends towards the use of carrier phases stabilized with respect to UTC (BIH) or TAI respectively, according to Recommendation 486. This allows the transmissions to be used without applying corrections and the development of receiving sets which combine the reception of more than one station so as to increase reliability. Another trend is the introduction of coded time transmissions by LF stations. Unfortunately, in the absence of adequate C.C.I.R. Recommendations, the code formats used are different. Furthermore, there is no common system according to which the time signals are emitted.

Time and frequency dissemination including time codes by means of television is a promising technique which, unfortunately, is based on diverse systems in different countries. It is desirable that Study Group 7 define its position as regards its generalized use and the optimal format.

Time signals and coded time information can also be disseminated by means of amplitude-modulated sound-broadcast transmitters whose carriers are phase modulated, without any noticeable deterioration of the broadcast programme. This is an interesting new development.

As regards the use of satellites for the dissemination of time and frequency, matters are only as yet in the initial stage. With the availability of frequency bands as allocated for this purpose by the World Administrative Radio Conference for Space Telecommunications, Geneva, 1971, the time has come to define international systems to make use of the new possibilities.

It has also to be realized that a time uncertainty of the order of 1 μs is only achievable over a rather limited area of the Earth, that is to say where LORAN-C is available. There is a strong demand, for example, for scientific applications, to improve the accuracy of time disseminations and to have a world-wide system with an uncertainty of less than 1 μs.

Instability problems

An increasing amount of work is devoted to the problems of instability resulting from fluctuations that occur in oscillators or which are produced by changing propagation times. Mathematical methods for describing these fluctuations are of interest as well as mathematical or technical methods for the optimum averaging of signals. This is an important matter when time scales of different clocks have to be combined or when transmission fluctuations are to be minimized by filtering methods.

Interference

In bands 6 and 7, mutual interference is often observed between emissions on the same frequency. It is hoped that Interim Working Party 7/3 will be able to find a means of reducing this interference problem. Goodwill on the part of those transmitting in these bands will be indispensable.

Reports

The Reports of Study Group 7 contain relevant information on its work in a rather condensed form; great care is called for in their drafting. Experience has shown that during the meetings too much time has to be devoted to drafting work. Administrations should therefore be encouraged to include short summaries in their proposals for draft Reports. Furthermore, the references cited in the texts should be regularly revised and preference be given to published texts which give a good overall view of the subject concerned.

Terms of expression

The difficult work of Interim Working Party 7/2, dealing with forms of expression (terms, symbols and their definition) is very important and deserves to be well supported. It is hoped that the results of this work will be used in drafting C.C.I.R. documents.

Experience has also shown that the present recommendations of relevant international organizations, such as ISO, are not always sufficiently considered in drafting C.C.I.R. documents.

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 374-3

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 1/7)

(1951 – 1953 – 1956 – 1959 – 1963 – 1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the Administrative Radio Conference, Geneva, 1959, allocated the frequencies 20 kHz ± 0·05 kHz, 2·5 MHz ± 5 kHz (2·5 MHz ± 2 kHz in Region 1), 5 MHz ± 5 kHz, 10 MHz ± 5 kHz, 15 MHz ± 10 kHz, 20 MHz ± 10 kHz and 25 MHz ± 10 kHz, requesting the C.C.I.R. to study the question of establishing and operating a world-wide standard-frequency and time-signal service;

(b) that the World Administrative Radio Conference for Space Telecommunications, Geneva, 1971, allocated the frequencies 400·1 MHz ± 25 kHz, 4202 MHz ± 2 MHz (space-to-Earth) and 6427 MHz ± 2 MHz (Earth-to-space), for use by the Standard-Frequency Satellite Service and Time-Signal Satellite Service (Radio Regulations Nos. 312B and 379A);

(c) that additional standard frequencies and time signals are emitted in other frequency bands;

(d) the provisions of Article 44, Section IV, of the Radio Regulations;

(e) the continuing need for close cooperation between Study Group 7 and the Inter-Governmental Maritime Consultative Organization (I.M.C.O.), the International Civil Aviation Organization (I.C.A.O.), the General Conference of Weights and Measures (C.G.P.M.), the Bureau International de l'Heure (B.I.H.) and the concerned Unions of the International Council of Scientific Unions (I.C.S.U.);

UNANIMOUSLY RECOMMENDS

1. that C.C.I.R. Study Group 7 continue its study of world-wide standard-frequency and time-signal service and explore the application of new techniques for this purpose;

2. that existing standard-frequency and time-signal services be operated in conformity with the detailed Recommendations of the C.C.I.R.;

3. that increased efforts be made to reduce the mutual interference between emissions in the allocated bands of item *(a)* above;*

4. that all Administrations consider alternative methods of disseminating standard frequencies and time signals before adding new emissions in bands 6 and 7.

---

* See also Decision 14.

RECOMMENDATION 375-1

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS IN ADDITIONAL FREQUENCY BANDS

(Question 2/7)

(1959 – 1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that precise intercontinental frequency comparison has already been achieved by the use of the frequency-stable emissions operating in band 4;

(b) that for many purposes a world-wide time (epoch) synchronization with an accuracy greater than 1 ms is required;

(c) that synchronization to 1 μs may be extended to ranges greater than 2000 km by means of pulsed ground-wave signals;

(d) that line-of-sight transmissions in bands 8 and 9, and predominantly ground-wave signals in band 5, provide a stable means of distributing time signals and standard frequencies;

UNANIMOUSLY RECOMMENDS

1. that information on the results and methods of measurement of phase stability over paths in bands 4 and 5, should be disseminated as widely as possible;

2. that advantage be taken of the stability and precision of pulsed ground-wave navigation systems, for establishing intercontinental and possibly world-wide time synchronization;

3. that appropriate stations, existing in bands 5 and 6, should be employed as much as possible for distributing standard frequencies by precise control of their carrier frequencies;

4. that existing frequency-modulation sound-broadcasting stations and television stations in bands 8 and 9 should be employed as much as possible for distribution of standard frequency and time signals, which can be added to, or make use of, the existing modulation, without interference to the normal programme;

5. that two bands of 100 kHz, in bands 8 and 9 respectively, are suitable for an effective line-of-sight standard-frequency and time-signal service.

RECOMMENDATION 376-1

AVOIDANCE OF EXTERNAL INTERFERENCE WITH EMISSIONS OF THE STANDARD-FREQUENCY SERVICE IN THE BANDS ALLOCATED TO THAT SERVICE

(Question 1/7)

(1959 – 1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) the importance and increasing use of standard-frequency and time-signal emissions in the allocated bands;

(b) that interference reduces the usefulness of the standard-frequency and time-signal service to a serious degree;

(c) that, despite the efforts made by Administrations and the I.F.R.B. to clear the standard-frequency bands, some registered users, and many unnotified emissions, remain in these bands, which continue to cause interference with the standard-frequency services;

(d) Recommendation No. 31 of the Administrative Radio Conference, Geneva, 1959;

UNANIMOUSLY RECOMMENDS

1. that to avoid external interference, Administrations and the I.F.R.B. should continue their efforts to clear the standard-frequency bands;

2. that, in the territory under its jurisdiction, each Administration should make every effort to prevent all users of the radio-frequency spectrum from operating other stations in the standard-frequency bands, capable of causing harmful interference to the standard-frequency service;

3. that national monitoring stations should carry out a regular search for external interfering stations in the standard-frequency bands and should make every effort to identify each interfering station, if necessary with international cooperation;

4. that, in each case of external interference, the users of standard-frequency emissions should request the monitoring service of their own country to identify the interfering station;

5. that, in cases of external interference with the standard-frequency service, Administrations should apply the provisions of Articles 14, 15 and 16 of the Radio Regulations, and, if desired, should send a copy of relevant correspondence to the I.F.R.B.;

6. that, when interference is observed in the standard-frequency bands, even if the source cannot definitely be identified, representatives of Administrations, participating in the work of Study Group 7, should exchange information from users of standard-frequency and time-signal transmissions and from the monitoring service. This may later permit identification of the interfering station.

RECOMMENDATION 457-1

USE OF THE MODIFIED JULIAN DATE BY THE STANDARD-FREQUENCY AND TIME-SIGNAL SERVICES

(Question 1/7)

(1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that for dating purposes a decimal day count is desirable in connection with the use of radio time signals and radio time codes;

(b) that a decimal day count with reference to Universal Time, the Julian Date (JD), has long been established for dating in astronomy, chronology and related sciences;

(c) that a decimal day count is necessary, by which the start of a day is defined at 0000 hours and not at 1200 hours as in the case of the Julian Date;

(d) that a decimal day count is necessary, in particular in association with the time scales UTC and TAI;

(e) that it is necessary to avoid a proliferation of different dating systems;

(f) that a simple change from the Julian Date mentioned above to a modern decimal day count would be advantageous;

(g) that the existing and established Julian Date, based on the start of the day being Greenwich Mean Noon, should be continued without break;

(h) that a Modified Julian Date (MJD), which meets the requirements stated above, is already in use;

UNANIMOUSLY RECOMMENDS

1. that for modern timekeeping and dating requirements, wherever necessary, a decimal day count should be used; the calendar day should be counted from 0000 hours TAI, UTC or UT and be specified by a number with five significant figures;

2. that this "Modified Julian Date" (MJD) equals the Julian Date less 2 400 000·5 and therefore has its origin, in the case of UT, at 0000 hours UT, 17 November 1858.

RECOMMENDATION 458

INTERNATIONAL COMPARISONS OF ATOMIC TIME SCALES

(Question 1/7)

(1970)

The C.C.I.R.,

CONSIDERING

(a) the need for comparisons between independent local atomic time scales of various laboratories and observatories;

(b) the need for clarity and precision in the communication of data in order to facilitate the work of the Bureau International de l'Heure (B.I.H.) in forming an international atomic scale;

UNANIMOUSLY RECOMMENDS

1. that when a laboratory or observatory "i" keeps both independent local atomic time and an approximation to coordinated universal time, designated herein as AT(i) and UTC(i), the laboratory or observatory should publish the numerical expression of the difference AT(i) — UTC(i) for each period of validity;

2. that the published time comparisons should relate to UTC(i);

3. that the published phase comparisons should relate either to AT(i) or to UTC(i), whichever is appropriate;

4. that the published times of emission of radio time signals conforming to the UTC system should relate to UTC(i);

4.1 in the case of a radio time-signal emission generated directly by the laboratory or observatory "i", the measured delay between the time signals and UTC(i) should be published;

4.2 in the case of a radio time-signal emission controlled by a clock at the transmitting station and measured at the laboratory or observatory "i", it should be stated explicitly whether the published times in relation to UTC(i) refer to reception or emission and what corrections for radio travel time and receiver delay should be or have been applied;

5. that any laboratories or observatories not conforming to the UTC system but desiring to take part in international comparisons and in the formation of an international atomic time scale should publish detailed data compatible, as far as possible, with the principles of §§ 1 to 4.

RECOMMENDATION 459

A NOTATION FOR REPORTING CLOCK READINGS AND FREQUENCY-GENERATOR VALUES

(Question 3/7)

(1970)

The C.C.I.R.,

CONSIDERING

(a) that there exists at present considerable confusion in the practices used to express time differences between clocks;

(b) that there is sometimes uncertainty as to the interpretation of reported times of reception relative to local clocks;

(c) that there also exists ambiguity in the reporting of frequency differences;

(d) that there is an urgent requirement for standardization of terminology and conventions in regard to measurements of frequency and time differences in order to avoid errors;

(e) that the International Astronomical Union (I.A.U.) in its fourth session of 29 August 1967 has adopted a Resolution concerning such conventions (Commission 31, Resolution No. 2) which helps satisfy requirements of clarity, preciseness, and usefulness for application in the field of radio time signals;

UNANIMOUSLY RECOMMENDS

1. that, to avoid any confusion in the sign of a difference in indicated time between clocks, or in frequency between frequency sources, algebraic quantities should be given;

2. that the following definitions and conventions may be used in conjunction with the algebraic expressions:

2.1 the time and location of a clock reading or a frequency measurement should always be designated;

2.2 at time T let a denote the reading of a clock A and b the reading of clock B. The difference of the readings is $a - b$ and will be conventionally designated

$$A - B = a - b \qquad (1)^*$$

2.3 let the frequency of a frequency source C be denoted by f_C and that of a frequency source D by f_D. Then the frequency difference is $f_C - f_D = \Delta f$ and may be conventionally designated as

$$C - D = \Delta f \qquad (2)$$

the nominal frequency of C and D should also be specified;

2.4 the fractional or relative frequency deviation of a frequency source C from its nominal value f_{nC} is defined as

$$F_C = (f_C/f_{nC}) - 1 \qquad (3)$$

* Example: The result of a time comparison between the portable clock, P7, and the time scale UTC of the B.I.H., measured at the B.I.H., would be reported as follows:
UTC(P7) - UTC(B.I.H.) = + 12·3 μs (7 July 1968, 14 h 35 min UTC; B.I.H.).

2.5 the fractional difference in frequency between two frequency sources "H" and "K" is the difference in their fractional frequency deviations

$$S = F_H - F_K$$

and may also be designated conventionally:

$$H - K = S \qquad (4)^*$$

2.6 a time comparison between a clock and a received time signal should follow the conventions given in §§ 2.1 and 2.2 above; a frequency comparison between an oscillator and a radio frequency emission should follow the conventions given in §§ 2.1, 2.3, 2.4 and 2.5.

RECOMMENDATION 460-1

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 1/7)

(1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the Administrative Radio Conference, Geneva, 1959, allocated the frequencies 20 kHz ± 0·05 kHz, 2·5 MHz ± 5 kHz (2·5 MHz ± 2 kHz in Region 1), 5 MHz ± 5 kHz, 10 MHz ± 5 kHz, 15 MHz ± 10 kHz, 20 MHz ± 10 kHz and 25 MHz ± 10 kHz to the standard-frequency and time-signal service, requesting the C.C.I.R. to study the question of establishing and operating a world-wide standard-frequency and time-signal service;

(b) that additional standard frequencies and time signals are emitted in other frequency bands;

(c) the provisions of Article 44, Section IV, of the Radio Regulations;

(d) the continuing need for close cooperation between Study Group 7 and the Inter-Governmental Maritime Consultative Organization (I.M.C.O.), the International Civil Aviation Organization (I.C.A.O.), the General Conference of Weights and Measures (C.G.P.M.), the Bureau International de l'Heure (B.I.H.) and the concerned Unions of the International Council of Scientific Unions (I.C.S.U.);

(e) the desirability of maintaining world-wide coordination of standard-frequency and time-signal emissions;

(f) the need to disseminate standard frequencies and time signals in conformity with the second as defined by the 13th General Conference of Weights and Measures (1967);

(g) the continuing need to make Universal Time (UT) immediately available to an accuracy of one-tenth of a second;

UNANIMOUSLY RECOMMENDS

1. that all standard-frequency and time-signal emissions conform as closely as possible to Coordinated Universal Time (UTC) (see Annex I); that the time signals should not deviate from UTC by more than one millisecond; that the standard frequencies should not deviate by more than 1 part in 10^{10}, and that the time signals emitted from each transmitting station should bear a known relation to the phase of the carrier;

---

* Example: The result of a frequency comparison, related to the previous example, may be reported conventionally, as a relative frequency difference, as follows:
P7 – B.I.H. = $+ 5 \times 10^{-13}$ (7 July 1968, 14 h 35 min to 20 h 30 min UTC; B.I.H.).

2. that all standard-frequency and time-signal emissions should contain information on the difference between UT1 and UTC (see Annexes I and II);

3. that this document be transmitted by the Director, C.C.I.R., to all Administrations Members of the I.T.U., to I.M.C.O., I.C.A.O., the C.G.P.M., the B.I.H., the International Union of Geodesy and Geophysics (I.U.G.G.), the International Union of Radio Science (U.R.S.I.) and the International Astronomical Union (I.A.U.);

4. that the standard-frequency and time-signal emissions should conform to RECOMMENDS 1 and 2 above as from 1 January 1975.*

ANNEX I

TIME SCALES

A. Universal Time (UT)

In applications in which an imprecision of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of UT which should be used:

UT0 is the mean solar time of the prime meridian obtained from direct astronomical observation;

UT1 is UT0 corrected for the effects of small movements of the Earth relative to the axis of rotation (polar variation);

UT2 is UT1 corrected for the effects of a small seasonal fluctuation in the rate of rotation of the Earth;

UT1 is used in this document, since it corresponds directly with the angular position of the Earth around its axis of diurnal rotation. GMT may be regarded as the general equivalent of UT.

B. International Atomic Time (TAI)

The international reference scale of atomic time (TAI), based on the second (SI), as realized at sea level, is formed by the Bureau International de l'Heure (B.I.H.) on the basis of clock data supplied by cooperating establishments. It is in the form of a continuous scale, e.g. in days, hours, minutes and seconds from the origin 1 January 1958 (adopted by the C.G.P.M. 1971).

C. Coordinated Universal Time (UTC)

UTC is the time-scale maintained by the B.I.H. which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with TAI but differs from it by an integral number of seconds.

The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap-seconds) to ensure approximate agreement with UT1.

D. DUT1

The value of the predicted difference UT1-UTC, as disseminated with the time signals is denoted DUT1; thus DUT1 $\approx$ UT1 $-$ UTC. DUT1 may be regarded as a correction to be added to UTC to obtain a better approximation to UT1.

The values of DUT1 are given by the B.I.H. in integral multiples of 0·1 s.

The following operational rules apply:

---

* Report 517 is valid until 1 January 1975; after that date the Report should be considered as cancelled.

1. Tolerances

1.1 The magnitude of DUT1 should not exceed 0·8 s.

1.2 The departure of UTC from UT1 should not exceed $\pm$ 0·9 s.*

1.3 The deviation of (UTC plus DUT1) from UT1 should not exceed $\pm$ 0·1 s.

2. Leap-seconds

2.1 A positive or negative leap-second should be the last second of a UTC month, but first preference should be given to the end of December and June, and second preference to the end of March and September.

2.2 A positive leap-second begins at $23^h\ 59^m\ 60^s$ and ends at $0^h\ 0^m\ 0^s$ of the first day of the following month. In the case of a negative leap-second, $23^h\ 59^m\ 58^s$ will be followed one second later by $0^h\ 0^m\ 0^s$ of the first day of the following month (see Annex III).

2.3 The B.I.H. should decide upon and announce the introduction of a leap-second, such an announcement to be made at least eight weeks in advance.

3. Value of DUT1

3.1 The B.I.H. is requested to decide upon the value of DUT1 and its date of introduction and to circulate this information one month in advance.**

3.2 Administrations and organizations should use the B.I.H. value of DUT1 for standard-frequency and time-signal emissions, and are requested to circulate the information as widely as possible in periodicals, bulletins, etc.

3.3 Where DUT1 is disseminated by code, the code should be in accordance with the following principles (except § 3.5 below):

— the magnitude of DUT1 is specified by the number of emphasized second markers and the sign of DUT1 is specified by the position of the emphasized second markers with respect to the minute marker. The absence of emphasized markers indicates DUT1 = 0;

— the coded information should be emitted after each identified minute.

Full details of the code are given in Annex II.

3.4 Alternatively, DUT1 may be given by voice or in Morse code.

3.5 DUT1 information primarily designed for, and used with, automatic decoding equipment may follow a different code but should be emitted after each identified minute.

3.6 In addition, UT1 — UTC may be given to the same or higher precision by other means, for example, in Morse code or voice, by messages associated with maritime bulletins, weather forecasts, etc.; announcements of forthcoming leap-seconds may also be made by these methods.

3.7 The B.I.H. is requested to continue to publish, in arrears, definitive values of the differences UT1 — UTC, UT2 — UTC.

---

* The difference between the maximum value of DUT1 and the maximum departure of UTC from UT1 represents the allowable deviation of (UTC+DUT1) from UT1 and is a safeguard for the B.I.H. against unpredictable changes in the rate of rotation of the Earth.

** In exceptional cases of sudden change in the rate of rotation of the Earth, the B.I.H. may issue a correction not later than two weeks in advance of the date of its introduction.

ANNEX II

CODE FOR THE TRANSMISSION OF DUT1

A positive value of DUT1 will be indicated by emphasizing a number (n) of consecutive second markers following the minute marker from second marker one to second marker (n) inclusive; (n) being an integer from 1 to 8 inclusive.

$$\text{DUT1} = (n \times 0{\cdot}1)\ \text{s}$$

A negative value of DUT1 will be indicated by emphasizing a number (m) of consecutive second markers following the minute marker from second marker nine to second marker ($8 + m$) inclusive, (m) being an integer from 1 to 8 inclusive.

$$\text{DUT1} = -(m \times 0{\cdot}1)\ \text{s}$$

A zero value of DUT1 will be indicated by the absence of emphasized second markers.

The appropriate second markers may be emphasized, for example, by lengthening, doubling, splitting or tone modulation of the normal second markers.

Examples:

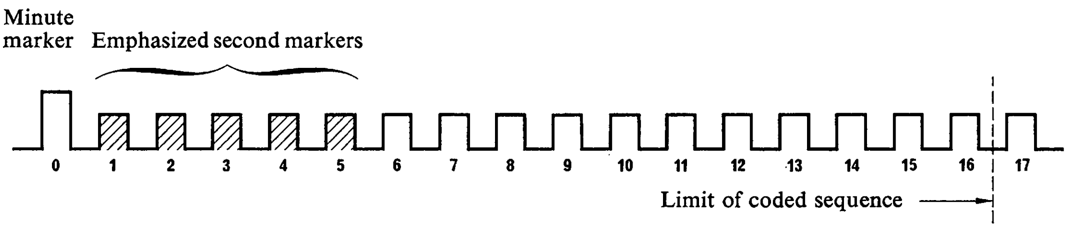


FIGURE 1

DUT1 = +0·5 s

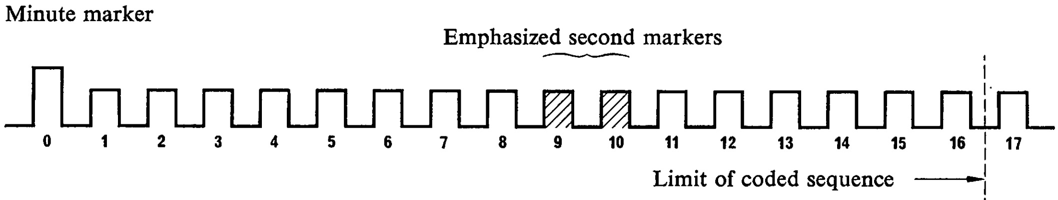


FIGURE 2

DUT1 = −0·2 s

ANNEX III

DATING OF EVENTS IN THE VICINITY OF A LEAP-SECOND

The dating of events in the vicinity of a leap-second shall be effected in the manner indicated in the following figures:

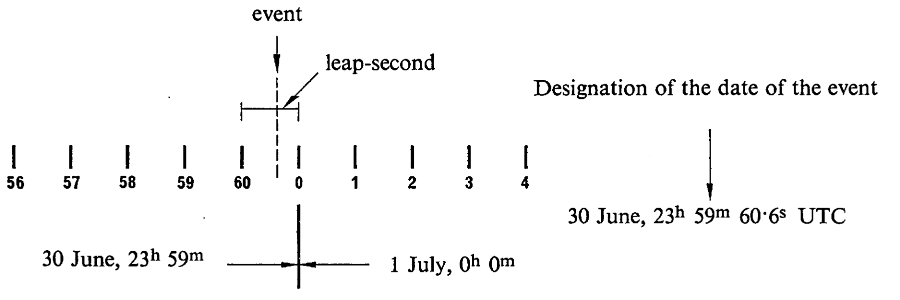


FIGURE 3

Positive leap-second

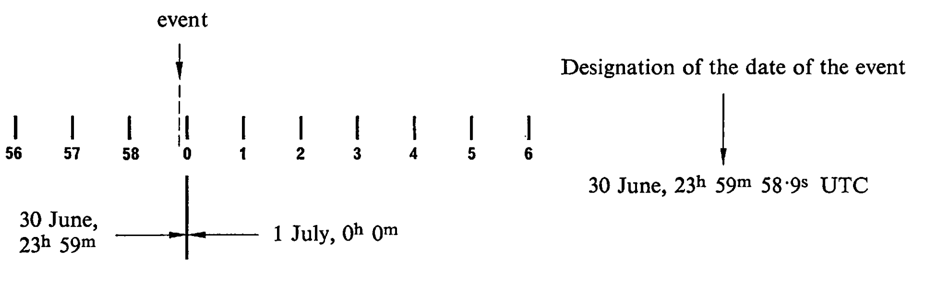


FIGURE 4

Negative leap-second

RECOMMENDATION 485

USE OF TIME SCALES IN THE FIELD OF STANDARD-FREQUENCY AND TIME SERVICES

(Question 1/7)

(1974)

The C.C.I.R.,

CONSIDERING

(a) that the International Atomic Time scale has been defined by the General Conference of Weights and Measures, 1971;

(b) that in accordance with Recommendation 460-1, the UTC time scale has been generally accepted since 1972;

(c) that UTC and TAI are closely related and differ only by a known integral number of seconds;

(d) that the time-service laboratories, in accordance with Recommendation 458, should relate datings to their own time scale UTC(i);

UNANIMOUSLY RECOMMENDS

that time data should be issued wherever possible either with reference to Coordinated Universal Time (UTC) or to International Atomic Time (TAI).

RECOMMENDATION 486

REFERENCE OF STANDARD-FREQUENCY EMISSIONS TO THE INTERNATIONAL ATOMIC TIME SCALE

(Question 3/7)

(1974)

The C.C.I.R.,

CONSIDERING

(a) that for a user, data concerning the error of a standard-frequency and time-signal emission is of great importance;

(b) that the International Atomic Time scale (TAI) has considerable importance as a reference for time and frequency comparisons;

(c) that, in the LF and VLF bands, it is technically possible to adjust a radiated standard frequency so that the variations of phase with respect to TAI or Universal Coordinated Time (UTC) remain within a narrow tolerance $\pm \Delta t$, which is small compared to the period of the carrier frequency;

(d) that equipment is available which is capable of receiving several nearly synchronous emissions, thereby providing alternative operation in case of transmitter interruption;

(e) that extensive synchronous emissions of standard frequencies and time signals on LF and VLF allow phase identification, that is, VLF phases with the aid of LF time signals and LF phases by means of VLF phases;

UNANIMOUSLY RECOMMENDS

1. that the TAI (or UTC) frequency should be used as the ultimate reference for standard-frequency emissions;

2. that data concerning the accuracy of the standard frequency, with reference to the TAI frequency, should be an average of the relative frequency difference over 10 days or more;

3. that the range $\pm \Delta t$ over which the phase of the standard frequency can vary with reference to TAI (or UTC) should be specified for each LF and VLF emission and the values published by the Administrations responsible for the standard time and frequency services.

Reports

REPORT 267-3*

STANDARD FREQUENCIES AND TIME SIGNALS

Characteristics of standard-frequency and time-signal emissions in allocated bands and characteristics of stations emitting with regular schedules with stabilized frequencies, outside of allocated bands

(Question 1/7)

(1956 – 1959 – 1963 – 1966 – 1970 – 1974)

The characteristics of stations appearing in the following tables are valid as of 1 August 1974. For information concerning changes which may have occurred, reference may be made to the Annual Report of the Bureau International de l'Heure (B.I.H.) or directly to the respective authority for each service as listed in Annex I.

* Adopted unanimously.

TABLE I

Characteristics of standard-frequency and time-signal emissions in the allocated bands, valid as of 1 August 1974

Station			Antenna(e)		Number of simultaneous transmissions	Period of operation		Standard frequencies used		Duration of emission		Accuracy of frequency and time intervals (parts in 10^{10})	Method of DUT1 indication
Call sign	Approximate location	Latitude Longitude	Type	Carrier power (kW)		Days/week	Hours/day	Carrier (MHz)	Modulation (Hz)	Time signal (min)	Audio-modulation (min)		
ATA	New Delhi, India	28° 34′ N 77° 19′ E	Horizontal dipole	2	1	6	4	10	1; 1000	continuous	4 in each 15	± 100	
FFH(1)	Paris, France	48° 33′ N 02° 34′ E	Vertical dipole	5	1	5(3)	8½	2·5	1	continuous	nil	± 0·2	C.C.I.R. code by lengthening to 0·1 s
IAM(1)	Roma, Italy	41° 52′ N 12° 27′ E	Vertical λ/4	1	1	6	2	5	1	continuous	nil	± 0·5	
IBF(1)	Torino, Italy	45° 02′ N 07° 46′ E	Vertical λ/4	5	1	7	2¾	5	1	continuous	nil	± 0·5	C.C.I.R. code by double pulse
JG2AR(1)	Tokyo, Japan	35° 42′ N 139° 31′ E	Omni-directional	3	1	1(3)	2(4)	0·02	nil	nil	nil	± 0·5	No DUT1 code
JJY(1)	Tokyo, Japan	35° 42′ N 139° 31′ E	Vertical λ/2 dipoles; (λ/2 dipole, top-loaded for 2·5 MHz)	2	4	7	24(5)	2·5; 5; 10; 15	1(6) 1000(7)	continuous	27 in each 60	± 0·5	C.C.I.R. code by lengthening
LOL(1)	Buenos Aires, Argentina	34° 37′ S 58° 21′ W	Horizontal 3-wire fold-ed dipole	2	3	7	5	5; 10; 15	1; 440; 1000	continuous	3 in each 5	± 0·2	C.C.I.R. code by lengthening
MSF(1)	Rugby, United Kingdom	52° 22′ N 01° 11′ W	Horizontal quadrant dipoles; (vertical monopole, 2·5 MHz)	0·5	3	7	24	2·5; 5; 10	1	5 in each 10	nil	± 1	C.C.I.R. code by double pulse
OMA(1)	Praha, Czechoslovak S.R.	50° 07′ N 14° 35′ E	T	1	1	7	24	2·5	1; 1000(8)	15 in each 30	4 in each 15	± 10	
RAT(1)	Moskva, U.S.S.R.	55° 19′ N 38° 41′ E	Horizontal dipole	5	1	7	22½	2·5; 5	1; 10	39 in each 60	nil	± 0·5	DUT1 + dUT1: by Morse code each hour between minutes 11 and 12(12)
RCH(1)	Tashkent, U.S.S.R.	41° 19′ N 69° 15′ E	Horizontal dipole	1	1	7	22½	2·5	1; 10	38 in each 60	nil	± 2	DUT1 + dUT1: by Morse code each hour between minutes 51 and 52(12)
RID(1)	Irkutsk, U.S.S.R.	52° 46′ N 103° 39′ E	Horizontal dipole	1	1	7	23	5·004; 10·004	1; 10	35 in each 60	nil	± 0·5	DUT1 + dUT1: by Morse code each hour between minutes 31 and 32(12)
RIM(1)	Tashkent, U.S.S.R.	41° 19′ N 69° 15′ E	Horizontal dipole	1	1	7	20½	5; 10	1; 10	38 in each 60	nil		DUT1 + dUT1: by Morse code each hour between minutes 51 and 52(12)
RKM(1)	Irkutsk, U.S.S.R.	52° 46′ N 103° 39′ E	Horizontal dipole	1	1	7	23	10·004; 15·004	1; 10	35 in each 60	nil	± 0·5	DUT1 + dUT1: by Morse code each hour between minutes 31 and 32(12)
RTA(1)	Novosibirsk, U.S.S.R.	55° 04′ N 82° 58′ E	Horizontal dipole	5	1	7	20½	4·996; 9·996; 14·996	1; 10	41 in each 60	nil	± 0·5	DUT1 + dUT1: by Morse code each hour between minutes 45 and 46(12)
RWM (1)	Moskva, U.S.S.R.	55° 19′ N 38° 41′ E	Horizontal dipole	8	1	7	23	10; 15	1; 10	39 in each 60	nil	± 0·5	DUT1 + dUT1: by Morse code each hour between minutes 11 and 12(12)
WWV(1)	Fort Collins, Colorado, U.S.A.	40° 41′ N 105° 02′ W	Vertical λ/2 dipoles	2·5 to 10	6	7	24	2·5; 5; 10; 15; 20; 25	1; 440; 500; 600	continuous (2)	continuous (10)	± 0·1	C.C.I.R. code by double pulse. Additional information on UT1 corrections.
WWVH(1)	Kekaha, Kauai, Hawaii, U.S.A.	21° 59′ N 159° 46′ W	Vertical λ/2 dipole arrays	2·5 to 10	5	7	24	2·5 5; 10; 15; 20	1; 440; 500; 600	continuous (2)	continuous (10)	± 0·1	C.C.I.R. code by double pulse. Additional information on UT1 corrections.
WWVL(1) (9)	Fort Collins, Colorado, U.S.A.	40° 41′ N 105° 03′ W	Top-loaded vertical	1·8	(9)	(9)	24	0·02	nil	nil	nil	± 0·1	
ZLFS	Lower Hutt, New Zealand	41° 14′ S 174° 55′ E		0·3	1	1	3	2·5	nil	nil	nil	± 500	
ZUO(1)	Olifantsfontein, Republic of South Africa	24° 58′ S 28° 14′ E	Vertical monopole	4	1	7	24 (11)	2·5; 5	1	continuous	nil	± 0·1	C.C.I.R. code by lengthening.

Notes to Table I

The daily transmission schedule and hourly modulation schedule is given, where appropriate, in the form of Figs. 1 and 2 supplemented by the following notes:

(1) These stations have indicated that they follow the UTC system as specified in Recommendation 460-1. Since 1 January 1972 the frequency offset has been eliminated and the time signals remain within about 0·8 s of UT1 by means of occasional 1 s steps as directed by the Bureau International de l'Heure.

(2) In addition to other timing signals and time announcements, a modified IRIG-H time code is produced at a 1-pps rate and radiated continuously on a 100 Hz sub-carrier on all frequencies. A complete code frame is 1 minute. The 100 Hz sub-carrier is synchronous with the code pulses, so that 10 ms resolution is obtained. The code contains DUT1 values and UTC time-of-year information in minutes, hours and days of the year.

(3) Each Monday.

(4) From 0530 to 0730 hours UT.

(5) Interrupted from 25 to 34 minutes of each hour.

(6) Pulse consists of 8 cycles of 1600 Hz tone. First pulse of each minute preceded by 655 ms of 600 Hz tone.

(7) 1000 Hz tone modulation between the minutes of 0–10, 20–25, 34–35, 40–50 and 59–60 except 40 ms before and after each second's pulse.

(8) In the period from 1800–0600 hours UT, audio-frequency modulation is replaced by time signals.

(9) Effective 1 July 1972, regularly scheduled transmissions from WWVL were discontinued. Since that date, this station has been broadcasting experimental programmes on an intermittent basis only.

(10) Except for voice announcement periods and the 5-minute semi-silent period each hour.

(11) 2·5 MHz: from 1800–0400 hours UT; 5 MHz: continuous.

(12) The information about the value and the sign of the DUT1 + dUT1 difference is transmitted after each minute signal by the marking of the corresponding second signals by additional impulses. In addition, it is transmitted in Morse code as indicated. UT1 information is transmitted in accordance with C.C.I.R. code. Additional information dUT1 is given, specifying more precisely the difference UT1 − UTC down to multiples of 0·02 s, the total value of the correction being DUT1 + dUT1. Positive values of dUT1 are transmitted by the marking of p second markers within the range between the 20th and 25th seconds so that $dUT1 = + 0{\cdot}02 \text{ s} \times p$. Negative values of DUT1 are transmitted by the marking of q second markers within the range between the 35th and the 40th second, so that $dUT1 = - 0{\cdot}02 \text{ s} \times q$.

Rep. 267-3

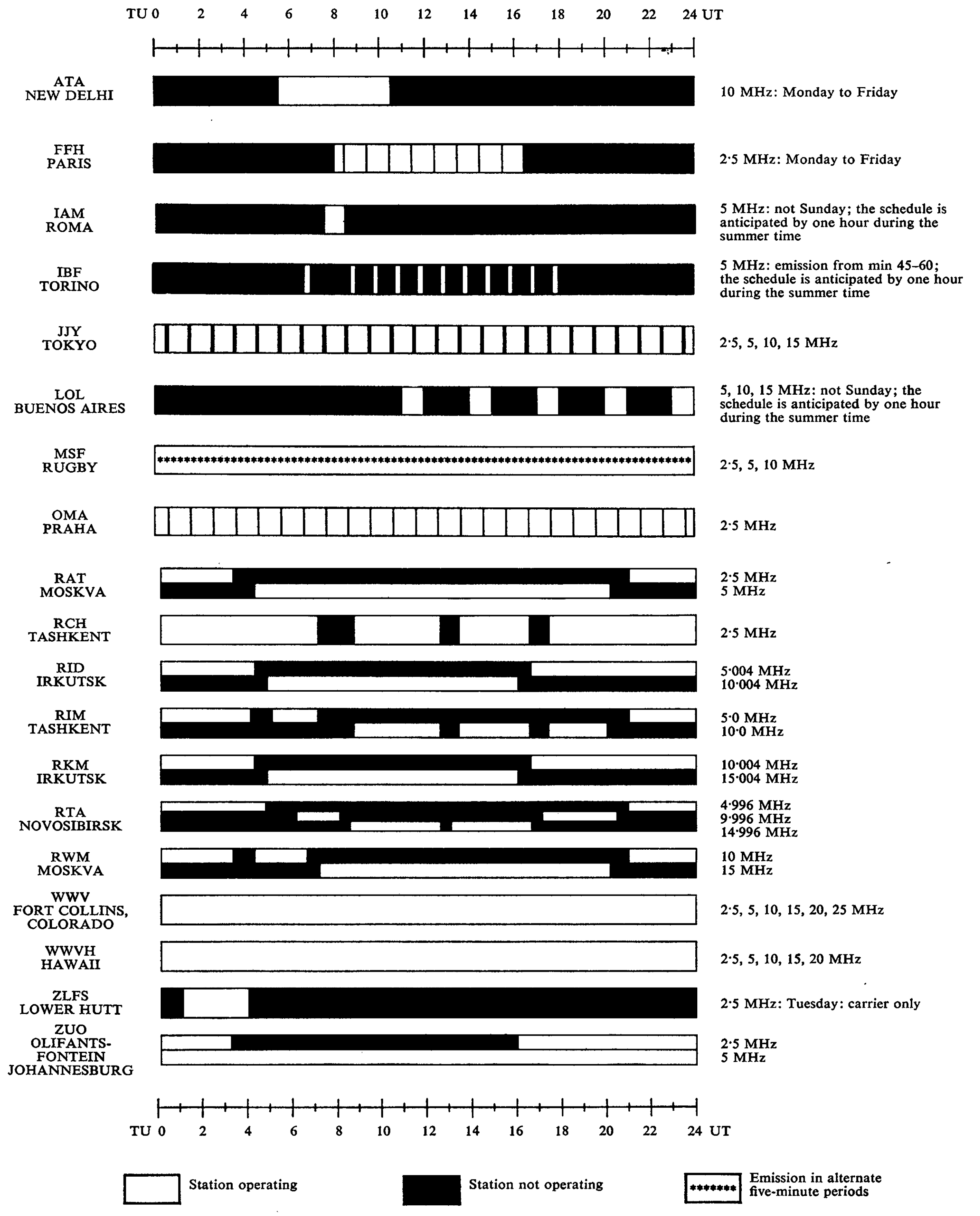
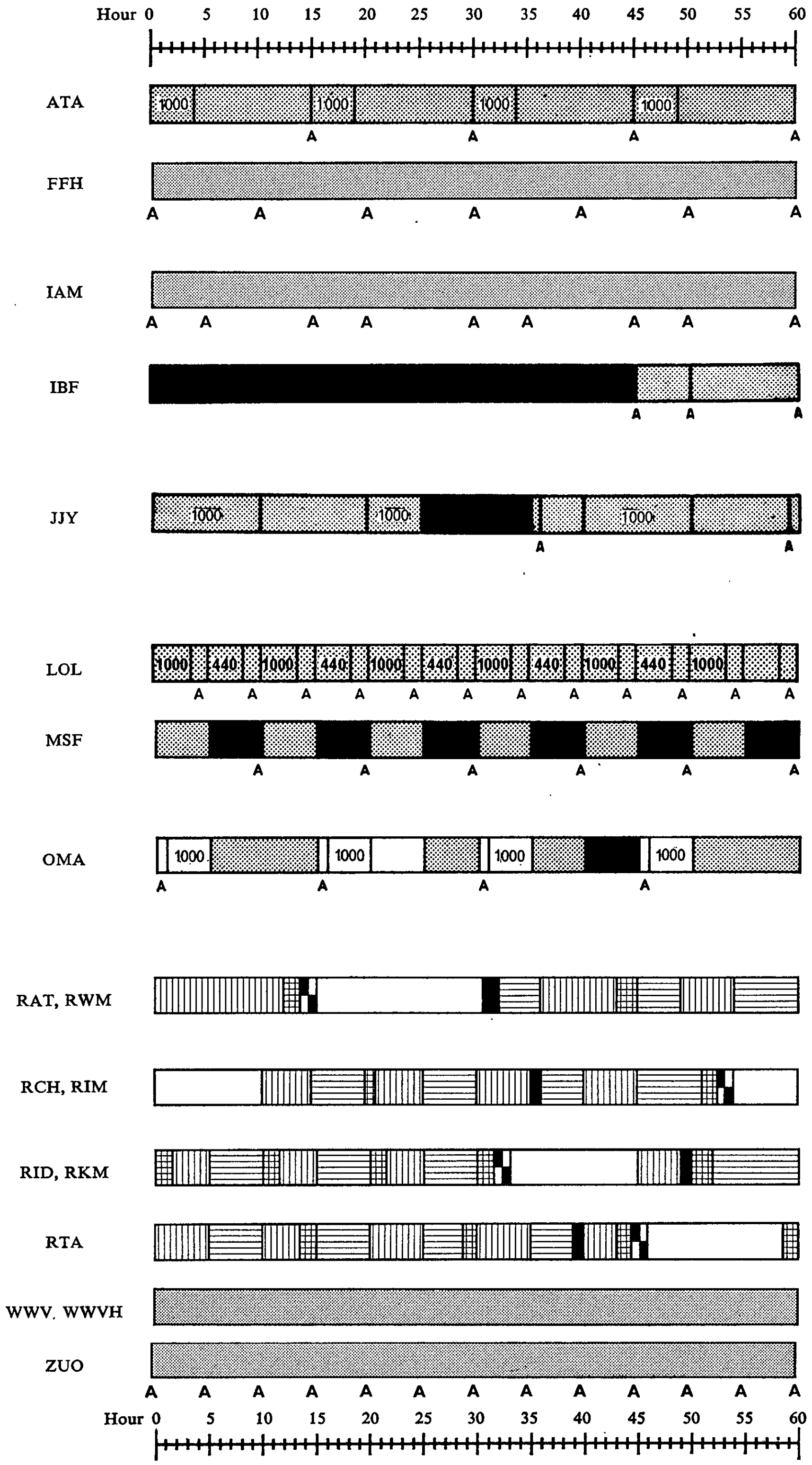


FIGURE 1

Daily emission schedule



Form of second and minute signals: Morse and voice announcements (A).

Pulse of 5 cycles of 1000 Hz tone, lengthened to 100 ms at the beginning of each minute. Call sign and time (UT) in Morse.

Pulse of 5 cycles of 1000 Hz tone: minute pulse lengthened to 500 ms: DUT1 code by lengthened second pulses to 100 ms. Call sign in Morse between the 32nd second and 42nd second of the minutes 0, 10, 20, 30, 40 and 50.

Pulse of 5 cycles of 1000 Hz tone: minute pulse of 20 cycles of 1000 Hz tone. Call sign and time (UT) in Morse and voice identification.

Pulse of 5 cycles of 1000 Hz tone repeated 7 times at minute. Call sign and time (UT) in Morse, voice identification at the beginning and end of emission.

Pulse of 8 cycles of 1600 Hz tone: minute pulse is preceded by a 600 Hz tone of 655 ms duration. Call sign and time (JST) in Morse and voice. Radio propagation warnings in letter code: N (normal), U (unstable) or W (disturbed). DUT1 is indicated by the number and position of the lengthened second's pulses of 45 ms duration, instead of the 5 ms duration of the normal second's pulse.

Pulse of 5 cycles of 1000 Hz tone, 59th pulse omitted. Call sign in Morse: identification and time (UT – 3 h) in voice.

Pulse of 5 cycles of 1000 Hz tone, 100 ms pulse at minute. Call sign in Morse and voice announcement.

Pulse of 5 cycles of 1000 Hz tone, 100 ms pulse at minute and 500 ms pulse every 5th minute. Last 5 pulses in each quarter hour 100 ms long. From minute 55–60 in every 3rd hour 100 ms pulses lengthened to 500 ms at minutes. Call sign in Morse.

The 55th, 56th, 57th, 58th and 59th second signals are omitted in every 5th, 10th, 35th, 40th, 50th, 55th and 60th minute.

The 55th, 56th, 57th, 58th and 59th second signals are omitted in every 10th, 15th, 20th, 25th, 30th, 40th and 45th minute.

The 55th, 56th, 57th, 58th and 59th second signals are omitted in every 5th, 25th and 55th minute.

The 55th, 56th, 57th, 58th and 59th second signals are omitted in every 5th, 10th, 20th, 25th and 35th minute.

see *

Pulse of 5 cycles of 1000 Hz tone, lengthened to 0·5 s at minute. Announcements by Morse code.

* Pulse of 5 cycles of 1000 Hz (WWV) or 6 cycles of 1200 Hz (WWVH) tone, lengthened to 0·8 s at beginning of each minute. An 0·8 s pulse of 1500 Hz begins each hour at both stations. 29th and 59th pulses each minute are omitted. Voice time announcements preceding each minute. 45-second audio tones alternating between 500 and 600 Hz each minute, except when special announcements or station identification messages are given in voice. One 45-second segment of 440 Hz is included each hour at one minute (WWVH) or two minutes (WWV) past the hour. A modified IRIG-H time code, giving day, hour, minute and UT1 information, is broadcast continously on a 100 Hz sub-carrier. DUT1 information is provided by the number and position of doubled second pulses each minute. All modulations interrupted for 40 ms around each second's pulse.

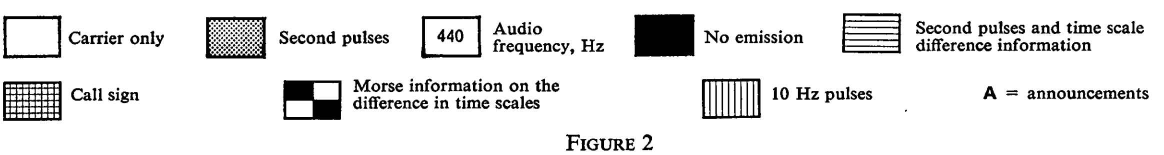


FIGURE 2
Hourly modulation schedule

TABLE II

Characteristics of standard-frequency and time-signal emissions in additional bands, valid as of 1 August 1974

Station			Antenna(e)		Number of simultaneous transmissions	Period of operation		Standard frequencies used		Duration of emission		Accuracy of frequency and time intervals (parts in 10^{10})	Method of DUT1 indication
Call sign	Approximate location	Latitude Longitude	Type	Carrier power (kW)		Days/week	Hours/day	Carrier (kHz)	Modulation (Hz)	Time signal (min)	Audio-modulation (min)		
	Allouis, France	47° 10′ N 02° 12′ E	Omni-directional	500	1	7	24	163·84(33)	nil	nil	continuous A3	± 0·5	
CHU(1)	Ottawa, Canada	45° 18′ N 75° 45′ W	Omni-directional	3; 10; 3	3	7	24	3330; 7335; 14670	1(4)	continuous	nil	± 0·05	C.C.I.R. code by split pulses
	Donebach, F.R. of Germany	49° 34′ N 09° 11′ E	Omni-directional	250	1	7	24	151	nil	nil	continuous A3	± 0·05	
DCF77(1)	Mainflingen, F.R. of Germany	50° 01′ N 09° 00′ E	Omni-directional	38	1	7	24	77·5	1	continuous (6)	continuous (7)	± 0·1	C.C.I.R. code by lengthening to 0·2 s
	Droitwich, United Kingdom	52° 16′ N 02° 09′ W	T	400	1	7	22	200	nil	nil	A3 broadcast continuously	± 0·2	
GBR(1)(31)	Rugby, United Kingdom	52° 22′ N 01° 11′ W	Omni-directional	750 60(2)	1	7	22(8)	15·95 16·00	1(9)	4×5(10) per day	nil	± 0·2	C.C.I.R. code by double pulse.
HBG(39)	Prangins, Switzerland	46° 24′ N 06° 15′ E	Omni-directional	20	1	7	24	75	1(28)	continuous (29)	nil	± 0·2	No DUT1 transmission
JJF-2(1) JG2AS	Kemigawa, Chiba Japan	35° 38′ N 140° 04′ E	Omni-directional	10	1	7 (5)	24 (17)	40	1(21)	continuous (29)	nil	± 0·5	
MSF	Rugby, United Kingdom	52° 22′ N 01° 11′ W	Omni-directional	50	1	7	24	60	1(12)	continuous	nil	± 0·1	C.C.I.R. code by double pulse
NAA(1)(22) (32)	Cutler, Maine, U.S.A.	44° 38′ N 67° 16′ W	Omni-directional	2000 1000 (2)	1	7	24	17·8	nil	nil	nil	± 0·1	
NBA(1)(22) (32)	Balboa, Panama Canal Zone, U.S.A.	09° 03′ N 79° 38′ W	Omni-directional	300 150 (2)	1	7	24(14)	24	nil	(38)	nil	± 0·1	By Morse code each minute between s 56–59
NDT(1)(32)	Yosami, Japan	34° 58′ N 137° 01′ E	Omni-directional	50(2)	1	7	24	17·4	nil	nil	nil	± 0·1	
NLK(1)(32)	Jim Creek, Washington, U.S.A.	48° 12′ N 121° 55′ W	Omni-directional	1200 250(2)	1	7	24 (35)	18·6	nil	nil	nil	± 0·1	
NPM(1)(22) (32)	Lualualei, Hawaii, U.S.A.	21° 25′ N 158° 09′ W	Omni-directional	1000 140(2)	1	7	24(15)	23·4	nil	nil	nil	± 0·1	
NSS(1)(32)	Annapolis, Maryland, U.S.A.	38° 59′ N 76° 27′ W	Omni-directional	1000 85(2)	1	7	24 (36)	21·4	nil	(27)	nil	± 0·1	By Morse code each minute between s 56–59
NWC(1)(22) (32)	North West Cape, Australia	21° 49′ S 114° 10′ E	Omni-directional	1000(2)	1	7	24 (37)	15·5 22·3	nil	(30)	nil	± 0·1	By Morse code each minute between s 56–58 (40)
OMA	Podebrady, Czechoslovak S.R.	50° 08′ N 15° 08′ E	T	5	1	7	24	50	1(9)	23 hours per day(16)	nil	± 10	No DUT1 transmission
RBU(1)	Moskva, U.S.S.R.	55° 19′ N 38° 41′ E	Horizontal dipole	10	1	7	23	66 ⅔	1; 10	6 in each 60	nil	± 0·5	By Morse code each hour between minutes 6 and 7 (41)
RTZ(1)	Irkutsk, U.S.S.R.	52° 18′ N 104° 18′ E	Horizontal dipole	10	1	7	23	50	1; 10	5 in each 60	nil	± 0·5	By Morse code each hour between minutes 6 and 7 (41)
RV/166	Irkutsk, U.S.S.R.	52° 18′ N 104° 18′ E	Horizontal dipole	40	1	7	22	200		nil	broadcast	± 0·5	
SAZ(21)	Enköping, Sweden	59° 35′ N 17° 08′ E	Yagi (12 dB)	0·1 (ERP)	1	7	24	100 000	nil	nil	nil	± 50	
SAJ(21)	Stockholm, Sweden	59° 20′ N 18° 03′ E	Omni-directional	0·06 (ERP)	1	1 (18)	2(19)	150 000	nil	nil	10(20)	± 1	
VNG(1)	Lyndhurst, Victoria, Australia	38° 03′ S 145° 16′ E	Omni-directional	10	2	7	24(23)	4 500 7 500 12 000	1; 1000 (24)	continuous	nil	± 1	C.C.I.R. code by 45 cycles of 900 Hz immediately following the normal second markers
WWVB(1)	Fort Collins, Colorado, U.S.A.	40° 40′ N 105° 03′ W	Top-loaded vertical	13(2)	1	7	24	60	1(3)	continuous	nil	± 0·1	No C.C.I.R. code
ZUO(26)	Olifantsfontein, Republic of South Africa	24° 58′ S 28° 14′ E	Omni-directional	0·05	1	7	24	100 000	1	continuous	nil	± 0·1	C.C.I.R. code by lengthening

Notes to Table II

(1) These stations have indicated that they follow one of the systems referred to in Recommendation 460-1.

(2) Figures give the estimated *radiated* power.

(3) Time code used which reduces carrier by 10 dB at the beginning of each second.

(4) Pulses of 300 cycles of 1000 Hz tone: the first pulse in each minute is prolonged.

(5) From Monday to Saturday, for JG-2AS.

(6) Al time signals (interruptions of the carrier during 100 ms at the beginning of each second except for the second No. 59 of each minute) from the Physikalisch-Technische Bundesanstalt. Since 6 June 1973, the number of the minute, hour, calendar day, calendar month and calendar year, as well as the day of the week, every minute beginning with the 20th second and ending with the 58th second, are transmitted in accordance with the official Time Scale CET (PTB) = UTC (PTB) + 1 h, in BCD code. A 0·1 s wide second marker is equivalent to "binary 0" and a 0·2 wide marker to "binary 1".

(7) Call sign is given by modulation of the carrier with 250 Hz tone three times every hour at the minutes 19, 39 and 59, without interruption of the time signal sequence.

(8) Maintenance period from 1300 to 1430 hours UT each day.

(9) Al telegraphy signals.

(10) From 0255 to 0300, 0855 to 0900, 1455 to 1500 and 2055 to 2100 hours UT.

(11) Maintenance period from 1300 to 1600 UT on the first Sunday of each month.

(12) Carrier interrupted for 100 ms at each second and 500 ms at each minute; from 1430 to 1530 hours UT, A2 pulses are transmitted in the same form as for MSF 2·5, 5 and 10 MHz.

(13) Time pulses occur in groups of 8, one millisecond apart; 20 groups per second.

(14) Except from 1200 to 1800 hours UTC each Monday.

(15) Except from 1700 hours UTC Monday to 0200 hours UTC Tuesday on 1st and 3rd Mondays of each month.

(16) From 1000 to 1100 hours UT, transmission without keying except for call-sign OMA at the beginning of each quarter-hour.

(17) JJF-2: telegraph, JG2AS: from 2330 to 0800 hours UTC.

(18) Each Friday.

(19) From 0930 to 1130 hours UT.

(20) 5 minutes at the beginning and 5 minutes at the end of the transmission for identification purposes only.

(21) Emission of the carrier of 500 ms duration at the beginning of each second where the 59th pulse is omitted each minute.

(22) FKS is used. Phase stable on assigned frequency.

(23) 4500 kHz, from 0945 hours UT to 2130 hours UT, 12 000 kHz, from 2145 hours UT to 0930 hours UT, 7500 kHz, continuous service, with a technical interruption from 2230 hours UT to 2245 hours UT.

(24) Pulses of 50 cycles of 1000 Hz tone, shortened to 5 cycles from the 55th to the 58th second; the 59th pulse is omitted. At the 5th, 10th, 15th, etc. minutes, pulses from the 50th to the 58th second are shortened to 5 cycles; voice identification between the 20th and 50th pulses in the 15th, 30th, 45th and 60th minutes.

(25) Except first minute of each hour.

(26) Transmitter phase modulated; time signals and announcements as for ZUO 2·5 and 5 MHz (see Table I).

(27) Transmissions are temporarily suspended. FSK time signals are planned when transmissions are resumed.

(28) Interruption of the carrier during 100 ms at the beginning of each second; double pulse each minute; triple pulse each hour; quadruple pulse every 12 hours.

(29) In absence of telegraph traffic.

(30) Time signals on FSK during 2 minutes preceding 0030, 0430, 0830, 1230, 1630 and 2030 hours UTC.

(31) FSK is used, alternatively with CW; both carriers are frequency controlled.

(32) This station is primarily for communication purposes; while these data are subject to change, the changes are announced in advance to interested users by the U.S. Naval Observatory, Washington, D.C., U.S.A.

(33) Temporary.

(34) Except from 1400 to 1800 hours UTC each Friday.

(35) Except from 1700 to 2200 hours UTC 1st and 3rd Thursday of each month.

(36) Except from 1300 to 1900 hours UTC each Wednesday.

(37) Except from 0000 to 0300 hours UTC each Monday.

(38) Time signal on FSK 5 minutes before each even hour except 2355 to 2400 hours UTC.

(39) Experimental emission, coordinated time signals.

(40) *DUT1 information in C.C.I.R. code*

dUT1 information. This additional information specifies more precisely the difference UT1—UTC down to multiples of 0·02 s, the total value of the correction being DUT1 + dUT1.

A positive value of dUT1 is indicated by doubling a number (p) of consecutive second markers from second marker 21 to second marker ($20+p$) inclusive; (p) being an integer from 1 to 5 inclusive

$$\mathrm{dUT1} = p \times 0{\cdot}02\ \mathrm{s}$$

A negative value of dUT1 is indicated by doubling a number (q) of consecutive second markers following the minute marker from second marker 31 to second marker ($30+q$) inclusive; (q) being an integer from 1 to 5 inclusive

$$\mathrm{dUT1} = -(q \times 0{\cdot}02)\ \mathrm{s}$$

The second marker 28 following the minute marker is doubled as parity bit, if the value of (p) or (q) is an even number, or if dUT1 = 0.

(41) The information about the value and the sign of the DUT1 + dUT1 difference is transmitted after each minute signal by the marking of the corresponding second signals by additional impulses. In addition, it is transmitted in Morse code as indicated. UT1 information is transmitted in accordance with C.C.I.R. code. Additional information dUT1 is given, specifying more precisely the difference UT1—UTC down to multiples of 0·02 s, the total value of the correction being DUT1 + dUT1. Positive values of dUT1 are transmitted by the marking of p second markers within the range between the 20th and 25th seconds so that dUT1 = + 0·02 s × p. Negative values of DUT1 are transmitted by the marking of q second markers within the range between the 35th and the 40th second, so that dUT1 = − 0·02 s × q.

TABLE III

Characteristics of some navigational aids, valid as of 1 August 1974

Station			Antenna(e)		Number of simultaneous transmissions	Period of operation		Standard frequencies used		Duration of emission		Accuracy of frequency and time intervals (parts in 10^{10})
Call sign	Approximate location	Latitude Longitude	Type	Carrier power (kW)		Days/week	Hours/day	Carrier (kHz)	Pulse repetition in micro-seconds	Time signal	Audio-modulation	
Loran-C SS7-M	Carolina Beach, N.C., U.S.A.	34° 03·8′ N 77° 54·8′ W	Omni-directional	1000(4)	1	7	24	100	(1) 99 300	continuous (5)	nil	± 0·05
Loran-C SS7-W	Jupiter, Florida, U.S.A.	27° 02·0′ N 80° 06·9′ W	Omni-directional	400(4)	1	7	24	100	(1) 99 300	continuous (5)	nil	± 0·05
Loran-C(6) SS7-X	Cape Race, Newfoundland	46° 46·5′ N 53° 10·5′ W	Omni-directional	2000(4)	1	7	24	100	(1) 99 300	continuous (5)	nil	± 0·05
Loran-C SS7-Y	Nantucket Island, U.S.A.	41° 15·2′ N 69° 58·6′ W	Omni-directional	400(4)	1	7	24	100	(1) 99 300	continuous (5)	nil	± 0·05
Loran-C SS7-Z	Dana, Indiana, U.S.A.	39° 51·1′ N 87° 29·2′ W	Omni-directional	400(4)	1	7	24	100	(1) 99 300	continuous (5)	nil	± 0·05
Loran-C SL7-H	Angissog, Greenland	59° 59·3′ N 45° 10·4′ W	Omni-directional	500(4)	1	7	24	100	(1) 79 300	continuous (5)	nil	± 0·05
Loran-C(6) SL3-M	Ejde, Faroe Is.	62° 18·0′ N 7° 04·5′ W	Omni-directional	400(4)	1	7	24	100	(1) 79 700	continuous (5)	nil	± 0·05
Loran-C SL3-W	Sylt, F.R. of Germany	54° 48·5′ N 8° 17·6′ E	Omni-directional	300(4)	1	7	24	100	(1) 79 700	continuous (5)	nil	± 0·05
Loran-C SL3-X	Boe, Norway	68° 38·1′ N 14° 27·1′ E	Omni-directional	200(4)	1	7	24	100	(1) 79 700	continuous (5)	nil	± 0·05
Loran-C(6) SL3-Y	Sandur, Iceland	64° 54·4′ N 23° 55·3′ W	Omni-directional	3000(4)	1	7	24	100	(1) 79 700	continuous (5)	nil	± 0·05
Loran-C SL3-Z	Jan Mayen, Norway	70° 54·9′ N 8° 44·0′ W	Omni-directional	200(4)	1	7	24	100	(1) 79 700	continuous (5)	nil	± 0·05
Loran-C SL1-M	Simeri Crichi, Italy	38° 52·3′ N 16° 43·1′ E	Omni-directional	250(4)	1	7	24	100	(1) 79 900	continuous (5)	nil	± 0·05
Loran-C SL1-X	Lampedusa, Italy	35° 31·3′ N 12° 31·5′ E	Omni-directional	400(4)	1	7	24	100	(1) 79 900	continuous (5)	nil	± 0·05
Loran-C SL1-Y	Targabarun, Turkey	40° 58·3′ N 27° 52·0′ E	Omni-directional	250(4)	1	7	24	100	(1) 79 900	continuous (5)	nil	± 0·05
Loran-C SL1-Z	Estartit, Spain	42° 03·6′ N 3° 12·3′ E	Omni-directional	250(4)	1	7	24	100	(1) 79 900	continuous (5)	nil	± 0·05
Loran-C S1-M	Johnston Is.	16° 44·7′ N 169° 30·5′ W	Omni-directional	300(4)	1	7	24	100	(1) 49 900	continuous (5)	nil	± 0·05
Loran-C S1-X	Upolo Pt., Hawaii, U.S.A.	20° 14·8′ N 155° 53·1′ W	Omni-directional	300(4)	1	7	24	100	(1) 49 900	continuous (5)	nil	± 0·05
Loran-C S1-Y	Kure, Hawaii, U.S.A.	28° 23·7′ N 178° 17·5′ W	Omni-directional	300(4)	1	7	24	100	(1) 49 900	continuous (5)	nil	± 0·05
Loran-C SS3-M	Iwo Jima, Japan	24° 48·1′ N 141° 19·5′ E	Omni-directional	4000(4)	1	7	24	100	(1) 99 700	continuous (5)	nil	± 0·05
Loran-C SS3-W	Marcus Is., Japan	24° 17·1′ N 153° 58·9′ E	Omni-directional	4000(4)	1	7	24	100	(1) 99 700	continuous (5)	nil	± 0·05
Loran-C SS3-X	Hokkaido, Japan	42° 44·6′ N 143° 43·2′ E	Omni-directional	400(4)	1	7	24	100	(1) 99 700	continuous (5)	nil	± 0·05
Loran-C SS3-Y	Gesashi, Okinawa, Japan	26° 36·4′ N 128° 08·9′ E	Omni-directional	400(4)	1	7	24	100	(1) 99 700	continuous (5)	nil	± 0·05
Loran-C SS3-Z	Yap, Caroline Is.	9° 32·8′ N 138° 09·9′ E	Omni-directional	4000(4)	1	7	24	100	(1) 99 700	continuous (5)	nil	± 0·05
OMEGA Ω/N	Aldra, Norway	66° 25′ N 13° 09′ E	Omni-directional	4(2)	1	7	24	10·2-A(3) 11 ⅓-C 13·6-B	nil	(3)	nil	± 0·1
OMEGA Ω/ND	Lamoure, North Dakota, U.S.A.	46° 22′ N 98° 21′ W	Omni-directional	10(2)	1	7	24	10·2-D(3) 11 ⅓-F 13·6-E	nil	(3)	nil	± 0·1
OMEGA Ω/T	Trinidad, West Indies	10° 42′ N 31° 38′ W	Omni-directional	1(2)	1	7	24	10·2-B(3) 11 ⅓-D 13·6-C	nil	(3)	nil	± 0·1
OMEGA Ω/H	Haiku, Hawaii, U.S.A.	21° 24′ N 157° 50′ W	Omni-directional	2(2)	1	7	24	10·2-C(3) 11 ⅓-E 13·6-D	nil	(3)	nil	± 0·1

(1) Time pulses appear in groups of 9 for the master station (M) and groups of 8 for the slave stations (W X Y Z).

(2) Figures give the estimated radiated power.

(3) See Table IV.

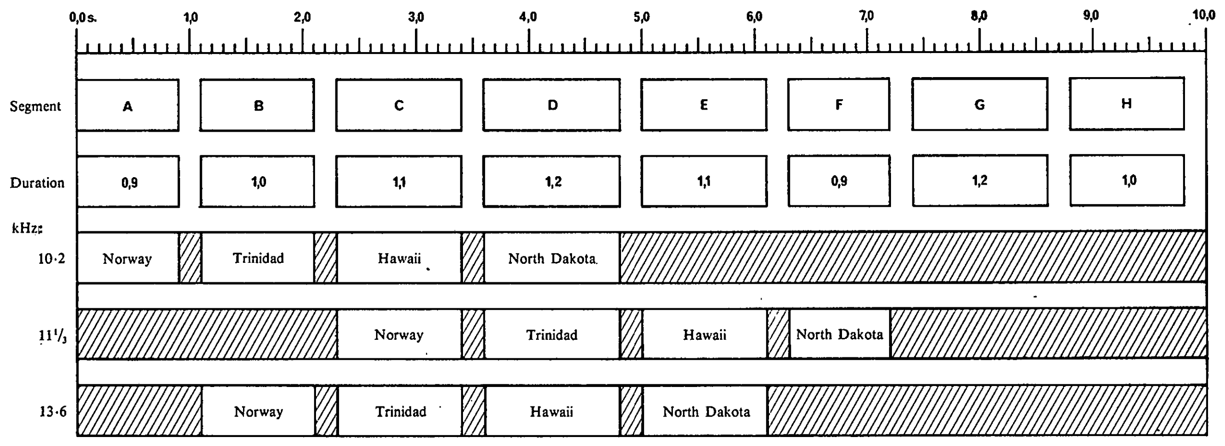
(4) Peak radiated power.

(5) Maintained within ± 5 μs of UTC. Time of Coincidence (TOC) with the UTC second changes with the occurrence of leap-seconds and is designated in TOC Tables issued to interested users by the U.S. Naval Observatory, Washington D.C., U.S.A.

(6) Dual-rated stations also transmitting on rate SL7 with a pulse repetition period of 79 300 microseconds.

TABLE IV

OMEGA signal format



Note 1. — Segment A does not begin at 0·0 second UTC. Time of segments changes with leap-seconds. Segment A begins at 58·0 seconds in January 1973.

Note 2. — The OMEGA stations are primarily for navigation purposes: while these data are subject to change, the changes are announced in advance to interested users by the U.S. Naval Observatory, Washington D.C., U.S.A.

ANNEX I

AUTHORITIES RESPONSIBLE FOR STATIONS APPEARING IN TABLES I AND II

Station	*Authority*
CHU	National Research Council Time and Frequency Section Physics Division (m-36) Ottawa K1A OS1, Ontario, Canada. Attn. Dr. C.C. Costain
DCF77	Physikalisch-Technische Bundesanstalt Laboratorium 1.22 33 Braunschweig Bundesallee 100, Federal Republic of Germany
FFH	Centre National d'Etudes des Télécommunications Groupement Etudes spatiales et Transmissions Département Dispositifs et Ensembles fonctionnels 38, rue du Général Leclerc 92131 – Issy-les-Moulineaux, France
GBR MSF	National Physical Laboratory Electrical Science Division Teddington, Middlesex, United Kingdom
HBG	Service horaire HBG Observatoire cantonal CH-2000 – Neuchâtel, Switzerland
IAM	Istituto Superiore Poste e Telecomunicazioni Viale di Trastevere, 189 00100 – Roma, Italy

Station	*Authority*
IBF	Istituto Elettrotecnico Nazionale Galileo Ferraris Corso Massimo d'Azeglio, 42 10125 – Torino, Italy
JJY, JG2AR, JG2AS	Frequency Standard Division The Radio Research Laboratories Ministry of Posts and Telecommunications Midori-cho, Koganei, Tokyo 184, Japan
LOL	Director Observatorio Naval Av. Costanera Sur, 2099 Buenos Aires, Argentine Republic
NBA, NDT, NPG, NPM, NPN, NSS, NWC	Superintendent U.S. Naval Observatory Washington, D.C. 20390 U.S.A.
OMA	1. Time information: Astronomiský ústav ČSAV, Budečska 6 12023 Praha 2 Vinohrady, Czechoslovak S.R. 2. Standard frequency information: Ústav radiotechniky a elektroniky ČSAV Lumumbova 1 18088 Praha 8, Kobylisy, Czechoslovak S.R.
RAT, RCH, RID, RIM, RKM, RWM	Comité d'Etat des Normes Conseil des Ministres de l'U.R.S.S. Moscou, U.S.S.R. Leninski prosp., 9
VNG	Section Head (Time and Frequency Standards) A.P.O. Research Laboratories 59 Little Collins Street Melbourne, Victoria 3000, Australia
WWV, WWVH WWVB	Frequency-Time Broadcast Service Section Time and Frequency Division National Bureau of Standards Boulder, Colorado 80302, U.S.A.
ZUO	Time Standards Section Precise Physical Measurements Division National Physical Research Laboratory P.O. Box 395 0001 – Pretoria, South Africa

---

REPORT 269-3*

REDUCTION OF MUTUAL INTERFERENCE BETWEEN STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 1/7)

(1963 – 1966 – 1970 – 1974)

The appreciable amount of mutual interference between standard-frequency and time-signal emissions continues to detract from the value of the services operating in the allocated bands. The

* Adopted unanimously.

participation of a larger number of stations in the international system for time and frequency coordination, though a most welcome development, has nevertheless caused difficulty in the identification and use of synchronization signals emanating from different transmitters and being received in an area where the various signals arrive within intervals of only 2 ms or less. The position in Western Europe on 5 MHz, where this applies, has been improved by the decision of IAM, IBF and MSF to coordinate their respective transmission programmes. On 2·5 MHz, on the other hand, the situation has not been improved by the increase in radiated power of Station FFH which can interfere at certain times with the other stations on this frequency, MSF and OMA.

On the other hand FFH is transmitting only during working days for about 8 hours, from 0800 hours UT onwards.

The use of continuous audio-frequency modulation in a number of emissions is a common source of interference with time-signal reception. Audio-frequency modulation is essentially confined to uses which do not require high accuracy, and it appears desirable to restrict the use of this type of modulation.

IAM, IBF and MSF have already eliminated audio-frequency modulations from their programmes; OMA has replaced audio-frequency modulation by time signals during the period from 1800 to 0600 hours UT. Station LOL has reduced the total period of audio-frequency modulation from 44 to 33 minutes in each hour.

Mutual interference between MSF – 60 kHz and WWVB – 60 kHz was observed in the eastern part of the United States. It is particularly severe during afternoon and evening hours.

It must be stressed that at the moment a major source of interference in band 7 lies in the emission of the carrier when no time signals are radiated.

Techniques of mutual interference reduction can be devised, such as frequency staggering, time sharing or the choice of convenient modulation techniques.

Another possible solution to the problem of the coexistence of several time and frequency stations is to introduce a break of some tens of ms in the continuous modulation during which time signals are emitted. This technique is, for instance, employed in Japan by JJY, where the length of the break in modulation is of 85 ms; time signals can consequently be received from other synchronized stations.

The emissions of time signals in band 5 have offered a convenient method of time dissemination in Europe; moreover the frequency stabilization of some broadcasting stations carried on bands 5 and 6 provides an alternative method of frequency dissemination.

Although the Plenary Assemblies of the C.C.I.R. provide the opportunity for useful discussions between Administrations, Study Group 7 has felt that it is desirable to establish an Interim Working Party to study the technical aspects and to consider administrative procedures of the problem and to propose appropriate means to reduce mutual interference between emissions in the standard-frequency and time-signal service.

REPORT 270-2*

FREQUENCY-SPECTRUM CONSERVATION FOR HIGH-PRECISION TIME SIGNALS

(Study Programme 3A-1/7)

(1963 – 1966 – 1970)

There is an increasing number of applications requiring the use of a very precise reference for time-signal synchronization. In an effort to achieve greater precision, it is desirable to make use of a suitable bandwidth up to the limits imposed by:

---

* Adopted unanimously.

— the band allocated;

— the instabilities of the propagation;

— considerations of noise and interference.

A system developed to exploit the characteristics of ground-wave propagation is the navigational system known as LORAN-C operating at 100 kHz. The modulation is chosen to distinguish between the time of arrival of the ground wave and the first ionospheric wave returned from the D-layer. The relative separation of these two components at a distance of about 2000 km has been found experimentally to be 25 to 30 μs. This delay determines the characteristics of the pulse wave form which is limited to a total bandwidth of ± 10 kHz.

The East Coast (of North America), Norwegian Sea, Central Pacific and Northwest Pacific LORAN-C chains have been synchronized to UTC such that the start of the first pulse in each group of pulses emitted by the master stations in these chains is periodically coincident with the UTC second. This is accomplished to an accuracy of ± 5 μs. In addition, a one-pulse-per-second transmission is made from the master stations of synchronized chains to enable the less complicated visual reception technique to be used.

At high frequencies, where long-distance propagation is wholly dependent upon the ionosphere, the precision with which time signals can be received is limited by the characteristics of the propagation medium. The bandwidths in use have been largely determined by administrative rather than technical or scientific considerations. It is to be noticed in Table I (Report 267-3) that all stations, with the exception of RWM-RES, use an audio-frequency modulation as the time signal. This takes the form previously recommended by the C.C.I.R. and consists of n cycles of 200 n Hz audio modulation, leading to a pulse of constant length equal to 5 ms. The value of n can be varied conveniently to distinguish the various emissions.

Thus, WWV and several other stations have adopted a pulse wave form with $n = 5$, i.e., 5 cycles at 1000 Hz. For WWVH, $n = 6$ has been chosen, while JJY has recently adopted a pulse with $n = 8$. The use of this form of pulse does not make it possible to resolve one of the several components of a signal received via more than one path (multipath propagation). It is, however, reasonably economical in bandwidth. Disturbed propagation conditions produce easily recognizable distortions of the pulse wave form.

A method of signal dissemination which does not require the use of excessive bandwidth has been investigated for use in navigation [Casselmann and Tibbals, 1958] and timing [Morgan and Baltzer, 1964]. This method makes use of the interference between two closely-spaced phase coherent carrier frequencies to generate a coarse reference. When this coarse reference can be realized at the receiver with sufficient phase stability it serves to identify one particular cycle of the carrier frequencies and a precise time reference can then be obtained from observations of the carrier phase.

Early experiments using 19·9 and 20·0 kHz over a 1400 km path showed promise for cycle identification. Later experimental studies, including a technique for extracting time using conventional VLF receivers and giving results covering a period of months over a 2400 km path have been reported [Fey and Looney, 1966]. Further studies using several frequency separations and paths have been described [Raules and Burgess, 1967]. An experimental dual-frequency timing receiver has been constructed for use with the 20·0 and 19·9 kHz transmissions of WWVL [Chi and Witt, 1966]. The result of these various investigations suggested that a 100 Hz frequency difference between the carrier frequencies is too small to permit reliable daily cycle identification over arbitrary paths and in a further series of experiments a third carrier frequency was added to the WWVL emission to give frequency differences of 500 and 600 Hz. The results obtained under these conditions are now being evaluated but appear to indicate that, with suitable averaging, cycle identification can be achieved at distances up to 8000 km. An analytical study using information theory techniques indicates that a multiple CW system may be optimum from the bandwidth conservation viewpoint [Jespersen, 1967]. Morgan [1967] has a useful bibliography on the general subject.

Theoretical studies are being made on a similar, very narrow bandwidth system at VLF [C.C.I.R., 1963 – 1966]. Two procedures are being investigated. The first uses a particular wave form, which can be interpreted as the product of two sinusoidal signals of the same amplitude, having frequencies in an integral ratio with a convenient phase relation. This procedure takes advantage of the timing index given by phase modulation of the radio frequency signal [Egidi and Oberto, 1964 a and b] (not of the envelope). The second procedure uses periodic phase inversions of the carrier wave; the cases where inversions occur at zero phase and $\pi/2$ phase have been treated in detail [Egidi, 1968]. This reference also presents the results of calculations giving the relation between time discrimination and the bandwidth of the system. The theoretical results obtained are promising and instrumental developments are proceeding [C.C.I.R., 1966 - 1969a].

A system using multiple carriers at VLF has also been proposed [C.C.I.R., 1966–1969b] which enables the transmission of both 1 s and 10 ms time signals without interruption to the communication service. A theoretical description of the transmissions with three frequencies and of the receiving devices is given in the reference.

There is a limit to the timing accuracy which can be achieved by using two or more closely spaced signals. The limitation arises because the group delay T of the composite signal is given by

$$T = (\varphi_2 - \varphi_1) / 2\pi (f_2 - f_1)$$

where φ_1 and φ_2 are the phase delays experienced by the two frequencies f_1 and f_2. The variation in the phase delays due to propagation can be expected to approach zero as $(f_2 - f_1)$ approaches zero. However the effect of additive noise is essentially independent of the frequency spacing. Under these conditions the standard deviation of the group delay σ_T is given by [Morgan and Baltzer, 1964]:

$$\sigma_T = (\sqrt{2}\, \sigma_\varphi) / 2\pi (f_2 - f_1)$$

where $\sigma_\varphi = \sigma_{\varphi 1} = \sigma_{\varphi 2}$ is the standard deviation of the phase delays due to additive noise. As an example, if $\sigma_\varphi = 1$ µs and $f_1 = 20$ kHz while $f_2 = 20\,001$ Hz, $\sigma_T = 20\,000$ µs; whereas, if $f_2 = 20\,100$ Hz, $\sigma_T = 200$ µs. Thus, as the spacing of the frequencies decreases, the error due to uncorrelated phase fluctuations increases.

References

Casselmann, C. J. and Tibbals, M.L. [1958] The Radux-Omega long range navigation system. *Proc. Second National Convention on Military Electronics*, 385-389.

C.C.I.R. [1963–1966] Doc. VII/65, Italy.

C.C.I.R. [1966–1969a] Doc. VII/45, Italy.

C.C.I.R. [1966–1969b] Doc. VII/34, Japan.

Chi, A.R. and Witt, S.N. [1966] Time synchronization of remote clocks using dual VLF transmission. Telemetering Conference Proceedings.

Egidi, C. [May, 1968] Narrow-band time signals. *Alta Frequenza*, English issue, **37**, 459-469.

Egidi, C. and Oberto, P. [1964a] Modulazione d'ampiezza con le tre righe spettrali aventi ampiezza e fasi qualunque (Amplitude modulation with three spectral lines of random amplitude and phase). *Alta Frequenza*, 334d, 144-156, particularly, Fig. 11.

Egidi, C. and Oberto, P. [1964b] General distorted three spectral lines amplitude modulation. *Archiv elektr. Übertrg.*, 18 H. 9, 525-526, particularly Fig. 10.

Fey, R.L. and Looney, Jr. C.H. [December, 1966] A dual frequency VLF timing system. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-15, 190.

Jespersen, J.L. [November, 1967] Signal design for time dissemination and some aspects. NBS Technical Note No. 357, Boulder, Colo.

Morgan, A.H. [June, 1967] Distribution of a standard frequency and time signals. *Proc. IEEE*, 55, **6**, 827-836.

Morgan, A.H. and Baltzer, O. J. [November, 1964] A VLF timing experiment. *Radio Science*, Vol. 680, **11**.

Raules, A.T. and Burgess, B. [November, 1967] Results of the two-frequency VLF transmission experiments from Criggion GBZ. *Radio Science*, Vol. 2, 1295.

REPORT 271-4*

STABILITY AND ACCURACY OF STANDARD-FREQUENCY AND TIME SIGNALS IN VLF AND LF BANDS AS RECEIVED

(Question 3/7)

(1963 – 1966 – 1970 – 1971 – 1974)

The propagation time (phase delays) of VLF signals from a transmitter to locations thousands of miles distant varies little from day to day but has predominant diurnal and annual cycles created by ionospheric changes related to the solar zenith angle [C.C.I.R., 1963–1966a; C.C.I.R., 1966–1969a; Decaux and Gabry, 1964; C.C.I.R., 1963–1966b]. Empirical and theoretical considerations have permitted accurate predictions of the propagation time which account not only for the diurnal and annual cycle, but also the sunspot number and the conductivity of the lower boundary of the wave guide supporting the VLF transmissions. The propagation time is sporadically altered by generally unpredictable sudden ionospheric disturbances (SID) which typically alter the ionosphere for 20 to 30 minutes and by polar cap absorption events (PCA) which alter the polar ionospheres for up to a week [Pierce, 1955; Reder *et al.*, 1964; Becker *et al.*, 1973a].

It has been observed that the phase shift accumulated during a 24-hour interval does not necessarily cancel, but can be $\pm 2\pi$ or a multiple thereof. The "cycle loss" can occur in several circumstances. For example, for great distances it will occur when the ratio of the amplitudes of the first to second order wave guide modes is less than unity at night and greater than unity during the day [Walker, 1967]. A second case may occur because of excessively large mode conversion at sunrise termination [Ries, 1967]. In addition, when the receiver is at a great distance ($>$10 000 km) from the transmitter, it is possible that signals may be received along the long great circle path instead of the short great circle path for part of the day [Thompson *et al.*, 1963]. If the stability of the local frequency standard is sufficient, this situation is easily recognized and taken into account. Such effects have been observed for the signals of GBR, NBA and NPM in Australia, the signals of NBA and NPM in France and WWVL in the British Isles.

Other sources of variation include the cyclic variations at periods of 27, 29·53 and 14·765 days. The 27-day period is related to the average solar rotation rate and has been observed in ionospheric data [Ratcliff, 1960]. The 29·53 and 14·765-day periods are respectively related to the lunar synodic and semi-synodic tides and have been observed to exist in the lower atmosphere [Appleton and Beynon, 1949; Brady and Crombie, 1963; Rastogi, 1969; Chakravarty and Rastogi, 1970].

The effect of dispersion, which causes the phase and group velocities of VLF and LF waves to be different, must be considered in timing systems. At LF, appreciable dispersion occurs in the ground wave for propagation over ground of finite conductivity. At VLF, two sources of dispersion are important. The first occurs as a result of cut-off effects in the Earth-ionosphere wave guide [Crombie, 1966]. The second [Burgess, 1967] and less predictable source of dispersion is caused by interference between several wave-guide modes at night and thus causes spatially periodic variations in group velocity.

The time service provided by the transmitter HBG on 75 kHz located near Geneva (see Report 267-3, Table II) reaches a large part of Central Europe. Experiments have shown that the time signal of HBG can be received using simple receivers with an accuracy greater than $\pm$ 50 μs at medium distances (100–1000 km) [C.C.I.R., 1966–1969b]. The phase of the carrier is typically stable to better than $\pm$ 2 μs at the distance of 500 km during daylight hours.

An investigation indicates [Becker *et al.*, 1973b] that the standard-frequency and time-signal transmitter DCF 77 on 77·5 kHz can be well received in Central Europe and Scandinavia. During the day-time the carrier phase as received at 300 km distance from the location of the transmitter (Mainflingen

* Adopted unanimously.

near Darmstadt, Federal Republic of Germany) deviates only a few tenths of a microsecond from the average due to propagation changes. This results in a daily average relative frequency deviation of the carrier of $2{\cdot}1 \times 10^{-12}$ and in a weekly average deviation of $0{\cdot}4 \times 10^{-12}$ at a distance of 300 km. The time signals of DCF 77 at noon were received with a spread of 37·5 μs as an average over three years [Becker, 1972; Becker and Hetzel, 1973].

Experiments on the propagation of LF (40 kHz) signals at a distance of 400 km have been reported by Japan [C.C.I.R., 1970–1974]. The standard deviation of the daily phase fluctuations was found to be 1 μs in summer and 2 μs in winter; the seasonal variation in the phase of the signal as received at mid-day amounted to 3·3 μs.

Experimental evidence [Noonkester, 1972] indicates that VLF propagation time is subject to semi-synodic variations that would affect the dissemination of time and frequency information by VLF transmissions. The average amplitude of the lunar semi-synodic period was found to be 0·18 μs at mid-day and 0·52 μs at midnight for one north-south VLF path at 10·2 kHz. The maximum amplitude was found to be 1·3 μs during mid-winter months at midnight. Users of VLF transmissions for time and frequency information should be made aware of the known periodic components so that they may anticipate a certain error range.

As regards the long-term integration of the received phase, the accuracy which can be achieved will depend to a large extent on the complexity of the receiving equipment and measuring procedures. It has been reported [C.C.I.R., 1966–1969 c and d] that when using quartz oscillators at the receiving station the accumulated overall error for path lengths of 1000 to 5000 km is between 25 and 50 μs per year when receiving transmissions in bands 4 and 5. However, when the received phase is referred to an atomic standard and use is made of a receiver which can be calibrated and which does not lose the phase reference [Becker *et al.*, 1969], much improved results can be obtained. Thus, NSS received at a distance of 5000 km and recorded over a period in excess of 450 days shows variations relative to the mean phase of at most $\pm$ 10 μs and generally less than $\pm$ 3 μs. This latter figure is equivalent to a frequency uncertainty of about 1×10^{-13} over a year. Further improvements in the stability of the received phase can be obtained by forming a linear combination of the phase of two emissions at different frequencies to significantly reduce the major solar effects; the improvement is most noticeable when comparisons are made simultaneously for both directions of transmission over the same path at carrier frequencies not too far separated in band 4. Still greater accuracy in the phase reference can be obtained by the application of smoothing techniques based on the statistical character of the phase fluctuations [Becker *et al.*, 1969; Guetrot *et al.*, 1969] but these are effective only over limited periods where the statistical behaviour can be assumed representative of the process.

When LORAN-C became available for precise time comparisons, the variations of propagation delays, and thus time comparison using VLF carrier phase, became easier to measure (for LORAN-C phase values see United States Naval Observatory (USNO) Time Service Announcements, Series 4). Such measurements were made for several years over a path length of about 5000 km between North America and Europe. Three VLF transmissions (NAA, 17·8 kHz; GBR, 16 kHz; OMEGA-Trinidad, 12·0 kHz) were used. Typical results are given in Table I. In Table I, $\sigma_{\Delta t}(2, \tau)$ is the average change (divided by $\sqrt{2}$) of the measured time difference Δt, occurring during the time of measurement τ. This statistical processing technique is due to Kolmogorov [1941], Malakhov [1966 a and b] and Allan [1966]. $\sigma_{\Delta f/f}$ is the relative uncertainty of a frequency comparison in the measuring time τ.

TABLE I

Typical fluctuations of propagation delays of VLF signals between North America and Europe

τ days	$\sigma_{\Delta t}(2, \tau)$ μs	$\sigma_{\Delta f/f}$ 10^{-12}
1	1·9	31
10	2·6	4·2
100	3·7	0·61
1000	5·3	0·09

Similarly, seasonal influences of $\sigma\Delta t$ (2, τ), as well as yearly and half-yearly correlations of the propagation fluctuations, were found. Due to the correlation between adjacent values, the possibility of improving the accuracy of measurement by means of averaging values is limited: in the most favourable case the measuring error is halved (from 2·2 μs to 1·1 μs) by averaging one hundred daily values instead of taking one daily value only.

For restoration of a VLF phase relationship, specific measuring techniques have been developed as well as a calibration technique to measure the time delay of the antenna and receiver [Becker *et al.*, 1973a, Becker, 1973]. This technique uses a test signal which is monitored by a parallel divider chain from which the time scale is generated. If this method is used to re-establish the lost phase relationship, an average error of 1·1 μs results if the break is short, and the values before and after the break are correlated. If the break is long (e.g. longer than 60 days), the measured values before and after the break are uncorrelated and an average error of 4·7 μs results.

Other techniques for cycle identification are available. A new VLF navigation system, Omega, is coming into operational existence. It uses multiple frequency VLF transmissions for the dissemination of time and frequency information. The advantages of this technique are well established [Swanson and Kugel, 1972]. These transmissions should be a useful source of frequency and precise time and should also enhance the status of VLF techniques for time and frequency. A total of eight stations is planned, providing continuous and redundant world-wide coverage. Each station will derive its radiated phase from an ensemble of four caesium frequency standards, and will transmit three primary frequencies on a time-shared basis every 10 seconds. The three primary frequencies are 10·2, 11⅓ and 13·6 kHz. Each station may also radiate additional frequencies spaced 250 Hz apart in the 11·8 to 13·15 kHz region and from which the precise time information is extracted. At present, the first permanent station operating at full power, normally 10 kW radiated power, is being tested in North Dakota, United States of America and the two additional frequencies are 13·10 and 12·85 kHz.

Omega is scheduled for global implementation sometime during the mid-1970's.

Development work on precise-time two-frequency receivers has already taken place [Chi *et al.*, 1972]. Preliminary results reported to date indicate time transfers accurate to a few μs.

Additional effort is being given to extend the inherent timing capabilities to provide identification of the second, minute, hour, day and year by means of a time code, but its introduction into individual Omega stations as an operational time code will be dependent upon its acceptance by the responsible Administrations [Fey, 1972].

References

Allan, D.W. [1966] Statistics of frequency standards. *Proc.IEEE*, **54**, 221.

Appleton, E.V. and Beynon, W.J.G. [1949] Lunar oscillations in the D-layer of the ionosphere. *Nature*, Vol. 164, 308.

Becker, G. [1972] Aussendung und Empfang des Zeitmarken- und Normal-Frequenzsenders DCF 77 (Emission and reception of the time-signal and standard-frequency transmitter, DCF 77). *PTB-Mitteilungen*, **82**, 224.

Becker, G. [1973] Längstwellenausbreitung während der Sonnenaktivität im August 1972 (VLF propagation during the period of the highly active sun in August 1972). *PTB-Mittlg.*, **83**, 147.

Becker, G. and Hetzel, P. [1973] PTB-Jahresbericht 1972 (PTB Annual Report 1972), p. 107. Braunschweig.

Becker, G., Fischer, B. and Kramer, G. [1969] Methoden und Ergebnisse im internationalen Zeitvergleich mit Längstwellen (Methods and results in international time comparison with very low frequencies). Actes du Colloque international de chronométrie, A-22 Série A, Paris.

Becker, G., Fischer, B. and Hetzel, P. [1973a] Langzeituntersuchungen über die Unsicherheit von Zeit- und Frequenzvergleichen mittels Längstwellen (Long-term investigations on the error of time and frequency comparisons by means of VLF). *PTB-Mittlg.* **83**.

Becker, G., Fischer, B. and Hetzel, P. [1973b] Methoden zum Vergleich und zur Verbreitung von Zeitskalen (Methods for the comparison and dissemination of time scales). *Kleinheubacher Berichte*, 16, 5.

Brady, A.H. and Crombie, D.D. [1963] Studying the lunar tidal variations in the D-region of the ionosphere by means of very low frequency phase variations. *J. Geophys. Res.*, Vol. 68, 5431.

Burgess, B. [November, 1967] On the propagation delay of modulated VLF waves transmitted over great distances. *I.E.E. Conference Publication* **36**, 164-168.

C.C.I.R. [1963–1966a] Doc. VII/7, Australia.

C.C.I.R. [1963–1966b] Doc. VII/21, Japan.

C.C.I.R. [1966–1969a] Doc. VII/35, Japan.

C.C.I.R. [1966–1969b] Doc. VII/44, Belgium.

C.C.I.R. [1966–1969c] Doc. VII/40, B.I.H.

C.C.I.R. [1966–1969d] Doc. VII/47, Italy.

C.C.I.R. [1970–1974] Doc. 7/2, Japan.

Chakravarty, S.C. and Rastogi, R.G. [1970] Lunar tide in D-region of the ionosphere near the magnetic equator. *J. Atmos. Terr. Phys.*, Vol. 32, 945.

Chi, A.R., Fletcher, L.A., and Casselmann, C.J. [October, 1972] Omega time transmissions and receiver design. *Proc. National Electronics Conference*, Vol. 27, 268-273.

Crombie, D.D. [March, 1966] The effect of waveguide dispersion on VLF timing systems. *IEEE Trans. Ant. Prop.*, AP-15, 322-323.

Decaux, B. and Gabry, A. [January, 1964] Some particular observations on diurnal phase variations of VLF transmissions received in Paris. *Radio Science Journal of Research NBS/USNC-URSI*, Vol. 68D, 1.

Fey, L. [May, 1972] A time code for the Omega world-wide navigation system. *Proc. IEEE* (Lett.), Vol. 60, 630.

Guetrot, A., Higbie, L.S., Lavanceau, J. and Allan, D.W. [May, 1969] Proc. of the 23rd Annual Frequency Control Symposium, Atlantic City.

Kolmogorov, A.N. [1941] *DAN SSSR*, Vol. 32, 19 and Vol. 30, 299.

Malakhov, A.N. [1966a] Spectral-correlational analysis of signals with non-integrable spectra. *Radiofizika*, Vol. 9, 595.

Malakhov, A.N. [1966b] Shape and width of the spectral line of oscillations in the presence of non-stationary frequency fluctuations. *Radiofizika*, Vol. 9, 625.

Noonkester, V.R. [1972] D-region lunar variations deducted from long path 10·2 kilohertz phase measurements. *J. Geophys. Res.*, Vol. 77, 6592.

Pierce, J.A. [1955] The diurnal carrier phase variations of a 16 kc/s transatlantic signal. *Proc. IRE*, **43**, 584-588.

Rastogi, R.G. [1969] Lunar tidal oscillations in ionospheric absorption at Colombo. *J. Atmos. Terr. Phys.*, Vol. 31, 759.

Ratcliff, J.A. [1960] *Physics of the Upper Atmosphere*. Academic Press.

Reder, F.H., Abom, C.J. and Winkler, G.M.R. [March, 1964] Precise phase and amplitude measurements on VLF signals propagated through the arctic zone. *Radio Science Journal of Research NBS/USNC-URSI*, Vol. 68D, 3.

Ries, G. [June, 1967] Results concerning the sunrise effects of VLF signals propagated over long paths. *Radio Science*, Vol. 2 (new series), 531-538.

Swanson, E.R. and Kugel, C.P. [May, 1972] VLF timing: conventional and modern techniques including Omega. *Proc. IEEE*, Vol. 60, 540-551.

Thompson, A.M., Archer, R.W. and Harvey, I.K. [November, 1963] Some observations on VLF standard-frequency transmissions as received at Sydney N.S.W. *Special International Issue of IEEE*, Vol. 51, 11.

Walker, D. [Novembre 1967] Cycle slipping of VLF signals sunrise and sunset. I.E.E. Conference Publication **36**, 169-173.

REPORT 362-2*

OPERATION WITH VARIOUS COMBINATIONS OF CARRIER AND SIDEBANDS FOR THE STANDARD-FREQUENCY AND TIME-SIGNAL SERVICE

(Study Programme 1B-1/7)

(1966 – 1970 – 1974)

Single-sideband operation with full carrier (A3H) is a class of emission that has been shown in some studies [Rock *et al.*, 1961] to be effective in reducing mutual interference and has the following advantages:

* Adopted unanimously.

— the use of an ordinary receiver for the reception of a single transmitting station;

— the possibility, using more elaborate receiving apparatus, of distinguishing between two stations transmitting on the same carrier frequency but using, respectively, the upper or the lower sideband;

— a certain degree of spectrum economy;

— the reduction of second harmonic distortion if the carrier is subject to fading.

Stations in the U.S.S.R., using frequencies in band 7, are also making experimental transmissions of standard frequencies and time signals using single sideband with full carrier. Other Administrations intend to introduce SSB in their standard-frequency and time-signal transmissions.

REFERENCE

ROCK, A. L. *et al.* [January, 1961] A survey of single-sideband and associated techniques for voice communication. Research Institute, University of Michigan, Ann Arbor.

REPORT 363-3*

INTERCOMPARISON OF TIME SCALES BY VARIOUS METHODS

(Study Programme 3C-2/7)

(1966 - 1970 - 1974)

During recent years, time scale intercomparisons by means of portable clocks and LORAN-C have become important for the formation of International Atomic Time (TAI) at the Bureau International de l'Heure (B.I.H.). A variety of other time comparison methods has been investigated in many laboratories. The differences between these methods in precision, coverage, operational convenience and cost, as opposed to availability, have shown that no single system can satisfy all requirements.

1. Intercomparison using time and navigation signals in bands 4, 5, 6 and 7

These signals are in routine use for time intercomparisons [Bonanomi *et al.*, 1964; Beehler *et al.*, 1965; Morgan *et al.*, 1965; Blair *et al.*, 1967; Mungall *et al.*, 1969; Guinot, 1968, 1969].

With respect to phase comparisons in bands 4 and 5, it is suggested in Report 271-4 that the receivers should be calibrated as a precaution against displacement and phase loss, and that each laboratory should determine the best time of day for phase reading. Under these conditions, time scales can be compared to an accuracy of a few microseconds without introducing cumulative errors. Additional reduction of phase uncertainty can be achieved by means of appropriate smoothing techniques [Becker *et al.*, 1969; Guetrot *et al.*, 1969]. Since synchronization of the LORAN-C Atlantic chains (August, 1968), a few European and American laboratories have been connected with an accuracy within 0·5 μs by the reception of LORAN-C pulses. The results of these intercomparisons have enabled several studies to be made to determine the optimum method of forming a mean atomic time scale on a local or international basis [Guinot, 1968 and 1969; Barnes, 1967]. With LORAN-C receivers, it has been possible to improve the B.I.H. International Atomic Time scale [Guinot, 1969].

Extension of LORAN-C synchronization to the Pacific area has enabled time comparisons to be made between the UTC scale of the Radio Research Laboratories, Tokyo and the corresponding

* Adopted unanimously.

scale of the U.S. Naval Observatory. Using the LORAN-C signals from Iwo-Jima and also a USNO portable clock, an uncertainty of 0·5 μs (1σ) was achieved [C.C.I.R., 1970–1974a].

The results of time-signal comparisons in bands 6 and 7 carried out in Italy [C.C.I.R., 1966–1969] and Japan [C.C.I.R., 1963–1966] during the years 1961–1968, have been reported. When using a comparison system whose accuracy was ± 0·01 ms, the standard deviation for a single reception was found to vary from 0·01 ms at a distance of a few kilometres to about 0·5 ms at distances of about 18 000 km. For intermediate distances the standard deviation ranged from 0·015 ms at 500 km to 0·1 ms at 1000 km. Most signals were found to exhibit little seasonal variation except those from WWV and IAM when reception becomes poor in the northern hemisphere winter.

Further results were obtained in Japan during 1969–1970 making use of photographic integration of the received time-signal phase [C.C.I.R., 1970–1974b]. They indicate that signals propagating via the night-time E- or Es-layer are received at distances of 400 and 1100 km with a stability (1σ) of 6 μs on 2·5 MHz and 14 μs on 5 MHz. The propagation time on 5 MHz at a distance of 400 km was found to vary by approximately 55 μs during the year owing to the seasonal changes in the E-layer critical frequency.

In practical applications the use of HF (band 7) time signals may be hindered by mutual interference. Delay variations due, for example, to receiver tuning and/or bandwidth switching, have to be taken into account.

2. Portable clocks

The intercomparison of time scales by using a transportable clock has come into general use. This is the most accurate method used for calibrating propagation time and instrument delay when required (for example, for the receivers of LORAN-C or television signals). An improvement of this method consists in sychronization by flying clocks without landing [Besson and Cumer, 1969], in which case an accuracy of some tens of nanoseconds is possible.

By using a set of four clocks and intercomparison of these clocks during the trip, it was possible to measure relativistic effects in a global circumnavigation experiment [Hafele and Keating, 1972]. The uncertainty achieved with this method is less than 30 ns. Routine portable clock operations continue to play the role of a calibration service for time comparisons between time scales with an uncertainty of 0·1 to 0·2 μs [Winkler, 1972] depending on the interval between two calibrations. There is some evidence at the USNO that transporting a clock may alter its subsequent performance.

3. Television

Television synchronization pulses are used as common reference markers for many national, and sometimes international, time comparisons. A determination of the propagation delays has to be made by portable clocks. For line-of-sight intercomparisons, using the same television transmitter, the uncertainty of a time difference measurement can be of the order of 10 ns. If different television transmitters are used which are connected by radio links, the uncertainty of time comparisons is generally less than 1 μs, but can reach several microseconds. The propagation delay between stations can also change due to unpredictable path changes in the link network.

Frequency comparisons were performed between Tokyo and Mizusawa (Japan) [C.C.I.R., 1970–1974c]. The colour sub-carrier was phase-compared with a locally generated colour sub-carrier signal. The precision obtained was $6{\cdot}5 \times 10^{-12}$, 4×10^{-12} and $2{\cdot}2 \times 10^{-12}$ for averaging times of 10, 30 and 60 minutes respectively.

Several methods have been developed for television time comparisons. The original method of Tolman *et al.* [1967] involves simultaneous time of arrival measurements of selected synchronization pulses. This system is in wide use in Europe [Rovera, 1972; Allan *et al.*, 1970; Parcelier, 1969 and 1970; Becker and Enslin, 1972], in Japan [C.C.I.R., 1970–1974c] and in the United States of America [Allan *et al.*, 1972; Davis *et al.*, 1971], where it is known as "Line-10".

The National Bureau of Standards (NBS) in the United States of America has developed and tested a method for time dissemination via television, by encoding data in particular lines of the television signal. First, lines 13 to 16, then line 1 and also line 21 were used. A 1 MHz reference signal is also available in this system [Davis *et al.*, 1970; Howe, 1972].

A third method was reported by Lavanceau and Carrol [1971] at the United States Naval Observatory (USNO). It involves stabilization of the colour sub-carrier in reference to a caesium beam frequency standard in the television studio. The line 10 synchronization pulse is also controlled and kept on time by referring to a "Table of coincidences" (TOC) issued by USNO for use with the NTSC system, similar to the LORAN-C TOC.

In contrast to a coherent TOC reference, as used in the weekly reports of the USNO (Time Service Announcements, Series 4), it has been proposed in Japan [C.C.I.R., 1970–1974c] to use the same TOC reference every day.

In the Federal Republic of Germany, precise frequency control has been extended to 82 television stations operating in the frequency range 471·24 to 599·26 MHz. The transmitter frequencies are adjusted relative to a central standard-frequency source and the stations examined showed a frequency deviation of less than 1 part in 10^{10}. Signals received at distances of 46 to 125 km from the transmitter were found, over an interval of 30 s, to have phase fluctuations corresponding to frequency variations of about 1×10^{-11}, in the worst case.

4. Intercontinental clock synchronization by VLBI

It is now within the state-of-the-art of very long baseline radio interferometry to provide intercontinental synchronization with uncertainties less than 0·5 μs. A prototype system [Hurd, 1972], has recently demonstrated resolutions of 50 to 400 ns (1σ), depending on the amount of data used, between NASA stations in Goldstone, California and Madrid, Spain.

The fundamentals of VLBI have been described by Klemperer [1972] who presents an extensive list of references, as well as of the basic accuracies and limitations. Clark [1972] also considered the fundamentals and listed a number of current VLBI experimental programmes. Accuracies in frequency comparisons of 10^{-13} to 10^{-14} and in clock synchronization of the order of 1 ns are apparently possible, although it is not yet feasible to achieve these accuracies.

The 10 to 100 MHz bandwidths required for 1 to 10 ns resolution clock synchronization are achievable by the bandwidth synthesis techniques described by Hinteregger *et al.* [1972] and Rogers [1970].

Hydrogen maser stability is not required for clock synchronization; in fact, the prototype system demonstrations used rubidium oscillators. A series of three experiments has been conducted within the NASA stations between Madrid, Spain and Goldstone, California [Hurd, 1972].

The clock difference estimates obtained in these experiments agree with estimates made each day using LORAN-C, to within the approximate 10 μs accuracy that could be expected. The results also agree with the VLBI platform parameter experiment to the accuracy of that experiment (10 μs).

If a sufficient amount of data is available and if a sufficiently large bandwidth can be obtained (50 MHz) then the VLBI synchronization method seems to be mainly limited in accuracy by difficulties in determination of the overall system delay and, in particular, in the atmospheric (ionospheric) delay.

5. Satellites

Three-clock synchronization experiments have been performed using two-way transmission of timing signals relayed by artificial satellites. The Telstar-I transponder, operating in band 10, was used between the United States of America and the United Kingdom in August, 1962 and an accuracy of

1 μs was achieved [Steele *et al.*, 1964]. Comparisons between the United States of America and Japan were made in bands 9 and 10 in February 1965 using Relay II and employing the method of retransmission of pulses [Markowitz *et al.*, 1966; Radio Research Laboratory, 1965]. An accuracy of synchronization of 0·1 μs was estimated. A VHF comparison between Colorado, California and Hawaii was made in June, 1967 using ATS-1 with an accuracy of 5 μs [Jespersen *et al.*, 1968].

Time transfer using one-way VHF transmissions relayed by a geostationary satellite (ATS-1) between Colorado, California and Alaska was investigated in November, 1967 [Gatterer *et al.*, 1968]. Accuracies of 10 μs were observed.

Another one-way method is the re-broadcasting of time signals as investigated by NBS [Hanson and Hamilton, 1973]. The computation of path delay, which is the major problem in all one-way systems, was simplified through the use of a special purpose circular slide rule. The satellite position was transmitted as part of the voice announcements. Accuracies of 10 to 25 μs were achieved.

One-way transmissions with an on-board satellite clock are in routine use, utilizing the transit navigational satellites with a precision of 5 μs [Laidet, 1972]. The transit clock readings are published weekly by the USNO (Time Service Announcements, Series 17).

In general, the two-way mode using satellites is essentially a point-to-point synchronization of the greatest accuracy potential (10 ns), but at high cost.

The one-way mode, using on-board clocks, is economically feasible only if it is part of a navigation system. Re-broadcasting looks very promising for inexpensive, wide dissemination of time, unaffected by ionospheric disturbances or by interferences, with sufficient accuracy to satisfy many requirements.

6. Other methods

Different time comparison methods can be *combined*. In the Federal Republic of Germany, television pulses have been used in conjunction with the LF standard-frequency and time-signal transmitter DCF 77. The LF second marker allows identification of a television pulse. This pulse, in turn, is helpful in identifying a carrier cycle of DCF 77 [Becker *et al.*, 1973]. Similarly, LF and VLF signals can be used if they are synchronously transmitted.

The use of *power lines* has been suggested as a means of synchronization. Tests at the PTB and in Italy have shown that the precision is usually from 0·25 to 0·5 ms for a distance of 200 km with the possibility of phase changes due to switching of lines [C.C.I.R., 1970–1974 d and e].

Experiments have been made [Norton *et al.*, 1962] on the instability introduced by propagation over a 50 km line-of-sight *microwave link*. The results can be summarized as follows:

Concerning the phase of transmitted wave, the stability degradation due to propagation is less important than the inherent fluctuations in the signal due to the generator noise. For a measurement time interval of 1 s, the contribution of instability due to the propagation can be represented by a fractional standard error of about 3×10^{-12} which decreases to 1×10^{-14} as the averaging time is increased to 10^6 s.

References

ALLAN, D.W., BLAIR, B.E., DAVIS, D.D. and MACHLAN, H.E. [April, 1972] Precision and accuracy of remote synchronization via network television broadcasts, Loran-C, and portable clocks. *Metrologia*, Vol. 8, 64-72.

ALLAN, D.W., LESCHIUTTA, S. and ROVERA, G. [1970] TV frame pulses used for precision time synchronization and their noise distribution. *Alta Frequenza*, Vol. XXXIX, 452.

BARNES, J.A. [June, 1967] The development of an international atomic time scale. *Proc. IEEE*, Vol. 55, 822-826.

BECKER, G. and ENSLIN, H. [1972] Genaue Zeit- und Frequenzvergleiche mittels Fernsehbildimpulsen (Precise time and frequency comparison by television synchronization pulses). *Frequenz*, **26**, 332.

BECKER, G., FISCHER, B. and HETZEL, P. [1973] Methoden zum Vergleich und zur Verbreitung von Zeitskalen (Methods of comparison and diffusion of time signals). *Kleinheubacher Berichte*, **16**, 5.

BECKER, G., FISCHER, B. and KRAMER, G. [1969] Methoden und Ergebnisse im internationalen Zeitvergleich mit Längstwellen (Methods and results in international time comparison with very low frequencies). Actes du Colloque international de chronométrie, Série A.

BEEHLER, R.E., MOCKLER, R.C. and RICHARDSON, J.M. [July, 1965] Caesium beam atomic frequency standards. *Metrologia*, Vol. 1, 114-131.

BESSON, J. and CUMER, J. [1969] Synchronisation précise de base par simple survol (Accurate basic synchronization by simple overflying). Actes du Colloque international de chronométrie, Série D.

BLAIR, B.E., CROW, E.L. and MORGAN, A.H. [June, 1967] Five years of VLF worldwide comparison of atomic frequency standards. *Radio Science*, Vol. 2 (new series), 627-636.

BONANOMI, J., KARTASCHOFF, P., NEWMAN, J., BARNES, J.A. and ATKINSON, W.R. [April, 1964] A comparison of TAI and NBS-A atomic time scales. *Proc. IEEE*, Vol. 52, **4**, 439.

C.C.I.R. [1963–1966] Doc. VII/21, Japan.

C.C.I.R. [1966–1969] Doc. VII/48, Italy.

C.C.I.R. [1970–1974a] Doc. 7/3, Japan.

C.C.I.R. [1970–1974b] Doc. 7/2, Japan.

C.C.I.R. [1970–1974c] Doc. 7/26, Japan.

C.C.I.R. [1970–1974d] Doc. 7/57, Germany (Federal Republic of).

C.C.I.R. [1970–1974e] Doc. 7/82, Italy.

CLARK, T.A. [14-16 November, 1972] Precision timing and very long baseline interferometry (VLBI). Proc. Fourth Annual NASA and Department of Defense Precise Time and Time Interval Planning Meeting, GSFC Report X-814-73-72, 74-89, Goddard Space Flight Center, Greenbelt, Md.

DAVIS, D.D., BLAIR, B.E. and BARNABA, J.F. [August, 1971] Long-term continental U.S. timing system via television networks. *IEEE Spectrum*, Vol. 8, 41-52.

DAVIS, D.D., JESPERSEN, J.L. and KAMAS, G. [June, 1970] The use of television signals for time and frequency dissemination. *Proc. IEEE* (Lett.), Vol. 58, 931-933.

GATTERER, L.E., BOTTONE, P.W. and MORGAN, A.H. [December, 1968] Worldwide clock synchronization using a synchronous satellite. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-17, **4**, 372-378.

GUETROT, A., HIGBIE, L.S., LAVANCEAU, J. and ALLAN, D.W. [1969] Proc. 23rd Symposium on Frequency Control, Atlantic City.

GUINOT, B. [1968 and 1969] Bureau International de l'Heure. *Rapport annuel pour 1967. Rapport annuel pour 1968* (International Time Bureau – Annual Report for 1967, Annual Report for 1968).

GUINOT, B. [1969] Formation de l'échelle de temps coordonné par le Bureau International de l'Heure (Formation of the coordinate time scale by the International Time Bureau). Actes du Colloque international de chronométrie, Série A.

HAFELE, J.C. and KEATING, R.E. [July, 1972] Around the world atomic clocks: observed relativistic time gains. *Science*, Vol. 177, 166-170.

HANSON, D.W. and HAMILTON, W.F. [1973] Time and frequency broadcast experiments from the ATS-3 satellite. NBS Technical Note No. 645, Boulder, Colo.

HINTEREGGER, H.F., SHAPIRO, I.I., ROBERTSON, D.S., KNIGHT, C.A., ERGAS, R.A., WHITNEY, A.R., ROGERS, A.E.E., MORAN, J.M., CLARK, T.A. and BURKE, B.F. [27 October, 1972] Precision geodesy via radio interferometry. *Science*, Vol. 178, 396-398.

HOWE, D.A. [August, 1972] Nationwide precise time and frequency distribution utilizing an active code within network television broadcasts. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-21, 263-276.

HURD, W.J. [14-16 November, 1972] An analysis and demonstration of clock synchronization by VLBI. Proc. Fourth Annual NASA and Department of Defense Precise Time and Time Interval Planning Meeting, GSFC Report X-814-73-72, 100-122. Goddard Space Flight Center, Greenbelt, Md.

JESPERSEN, J.L., KAMAS, G., GATTERER, L.E. and MACDORAN, P.F. [July, 1968] Satellite VHF transponder time synchronization. *Proc. IEEE.*

KLEMPERER, W.K. [May, 1972] Long-baseline radio interferometry with independent frequency standards. *Proc. IEEE*, Vol. 60, 602-609.

LAIDET, L.M. [May, 1972] Worldwide synchronization using the TRANSIT satellite system. *Proc. IEEE* (Lett.), Vol. 60, 630-632.

LAVANCEAU, J.D. and CARROLL, D. [1971] Real time synchronization via passive television transmission. Proc. 3rd Ann. Precise Time and Time Interval (PTTI) Strategic Planning Meeting, 331-366.

MARKOWITZ, W., LIDBACK, C.A., UYEDA, H. and MURAMATSU, K. [December, 1966] Clock synchronization via Relay II satellite. Submitted to *IEEE Trans. on Instrumentation and Measurement.*

MORGAN, A.H., CROW, E.L. and BLAIR, B.E. [July, 1965] International comparison of atomic frequency standards via VLF radio signals. *Radio Science J. of Research NBS/USNC-URSI*, Vol. 69D.

MUNGALL, A., DAAMS, H. and BAILEY, R. [July, 1969] Note on atomic time-keeping at the National Research Council. *Metrologia*, Vol. 5, **3**, 73-76.

NORTON, K.A., BARROWS, E., THOMPSON, Jr. M.C. and JAMES, H.B. [December, 1962] Variance of radio frequency caused by turbulence on line-of-sight transmissions. *IRE Trans.* P.G.I.

PARCELIER, P. [1969] Développement des synchronisations de temps par la télévision (Development of television time synchronization). Actes du Colloque international de chronométrie, Série A.

PARCELIER, P. [November, 1970] Time synchronization by television. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-19, **4**, 233.

RADIO RESEARCH LABORATORY, Japan, Frequency Standard Section and Kashima Branch [September, 1965] Report on clock pulse synchronization experiment by a Relay II satellite. *J. Radio Res. Labs.*, Japan, Vol. 12, **63**, 311.

ROGERS, A.E.E., [October, 1970] Very long baseline interferometry with large effective bandwidth for phase delay measurements. *Radio Science*, Vol. 5, 1239-1248.

ROVERA, G. [1972] On the accuracy of the TV timing method. *Alta Frequenza*, **41**, 822-824.

STEELE, J.M., MARKOWITZ, W. and LIDBACK, C.A. [December, 1964] Telstar time synchronization. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-13, **4**, 164.

TOLMAN, J., PTACEK, V., SOUČEK, A. and STECHER, R. [December, 1967] Micro-second clock comparison by means of TV synchronizing pulses. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-16, **3**, 247-254.

WINKLER, G.M.R. [1972] Recent experiments with flying atomic clocks, LORAN-C etc. for clock synchronization. Report to XVII General Assembly, U.R.S.I., Warsaw.

BIBLIOGRAPHY

HURD, W.J. [15 October, 1973] Demonstration of intercontinental DSN clock synchronization by VLBI. Technical Report 32-1526, Vol. XVII. Jet Propulsion Laboratory, Pasadena, California.

LAIOS, S.C. [May, 1972] Satellite time synchronization of a NASA network. *Proc. IEEE* (Lett.), Vol. 60, 632-633.

NATIONAL BUREAU OF STANDARDS. *NBS Time and Frequency Service Bulletin* (monthly), Boulder, Colo.

REPORT 364-2*

INSTABILITY OF STANDARD-FREQUENCY GENERATORS

(Study Programme 3B/7)

(1966 – 1970 – 1974)

In recent years, the results of a large number of studies have become available concerning the instability of standard-frequency generators. Theoretical treatments of the problem, definitions and experimental procedures for measurement have been widely investigated (see Report 580).

It has been shown [IEEE, 1966; NASA, 1964; Yasuda and Yoshimura, 1964] that the type of noise present in a standard-frequency generator may be classified by the form of the frequency (or phase) spectral density which it produces. Such densities are the Fourier transforms of the related auto-correlation functions and suitable mathematical techniques have been devised for operating on these functions [Blackman and Tukey, 1959; Davenport and Root, 1958]. The effect of the so-called "flicker noise" having a 1/f spectral variation is particularly important in the long-term operation of all forms of frequency standard and special studies have been devoted to this aspect [Beehler *et al.*, 1965].

In both atomic sources and in quartz crystal oscillators, thermal and shot noise will contribute to the short-term instability and, depending upon the mechanism, will produce either a flat or f^2 variation in the frequency spectral density. The intended use of the standard-frequency generator will determine the importance of these effects relative to the instability produced by flicker noise.

---

* Adopted unanimously.

With the increasing availability and use of commercial atomic frequency standards to generate very stable time scales in a number of laboratories throughout the world, a large amount of stability performance data has been accumulated. One conclusion is that commercial caesium beam frequency standards often demonstrate small, but significant systematic frequency shifts.

The appearance of these shifts shows that the fluctuation phenomena of these standards cannot be fully described by the stability measure $\sigma(2,\tau)$ in accordance with Kolmogorov [1941], Malakhov [1966], and Allan [1966]. Even if the value $\sigma(2,\tau)$ is available for every clock of a group, it is still not possible to give the $\sigma(2,\tau)$ for the average of the group. This applies in particular to long time intervals ($>0{\cdot}5$ year). It is believed that this is due to the non-stationary behaviour of some clocks for time intervals which are an appreciable fraction of the clocks' lifetime.

As a typical example, systematic effects in commercial caesium standards have been investigated by the PTB [Becker *et al.*, 1973]. Typical long-term performance of commercial caesium standards in that laboratory consisted of a small relative frequency change of about $-0{\cdot}4 \times 10^{-13}$ on the average during the first 60 days of operation. After that the frequency remained comparatively constant (about $\pm 1 \times 10^{-13}$) for a time interval between 9 months and 3 years, after which the frequency decreased by several parts within a few weeks. Later on the frequency became more and more unstable. On the average more frequency decreases than increases have been observed. This typical negative frequency shift has not, however, been observed in some other laboratories [Winkler *et al.*, 1970].

The PTB has also developed procedures for periodically monitoring and readjusting the magnetic fields in commercial caesium standards. Such procedures appear to produce improved stability performance, especially during the first six months of a clock's life.

Other studies were made at the PTB of the long-term stability of the TAI scale, composed largely of commercial caesium standards, using the PTB primary standard CS1 as the reference. Over a period from 1969 to 1973 the measurements showed the TAI frequency to have decreased on the average by about 1×10^{-13} each year [Becker, 1973]. The stability of the CS1 standard itself has been determined to be:

$\frac{\Delta f}{f} = 2{\cdot}8 \times 10^{-12}/\sqrt{t}$, where t is in seconds, for short averaging times where shot noise in the beam is the predominant effect [Becker *et al.*, 1972], and about 1×10^{-13} for averaging times of days to years.

The particular type of frequency standard to serve as an optimum frequency reference in a given application depends at least in part on the measurement averaging time involved. Thus, hydrogen masers are the preferred frequency reference for use at radioastronomy observatories engaged in long-baseline interferometry as the maser provides the greatest stability over the intervals of 10^3 to 10^4 seconds important for the observations. For longer intervals, greater than 10^5 to 10^6 seconds, a well-developed caesium standard would be expected to generate a more stable reference, while for shorter intervals of less than 10 seconds, the frequency stability of a high quality quartz oscillator has been shown to be competitive with that of quantum devices, which are all subject to a shot-noise limitation [IEEE, 1966].

In view of the small long-term drifts mentioned above, which have been observed both in individual commercial caesium standards and in time scales based on these devices, the role played by the national laboratories' primary reference standards assumes added importance. At the present time, there are three operating primary laboratory-type caesium beam frequency standards located at the PTB in the Federal Republic of Germany [Becker, 1974], NCR in Canada [Mungall *et al.*, 1973] and NBS in the United States of America [Glaze *et al.*, 1973]. These standards have been evaluated with respect to most parameters affecting their output frequency, i.e. experiments and theoretical studies have been performed which yield knowledge about the biases which cause the ouptut frequency to differ from the unperturbed atomic resonance frequency. The accuracy which then results from an analysis of the data is within the 1 to 2×10^{-13} range for all three laboratory standards. International intercomparisons of the three devices, using TAI as a common reference, show agreements to within 2×10^{-13} peak-to-peak variation.

The measurements carried out in 1973 also indicate that the TAI frequency is too high, with respect to the definition of the second, by about 1×10^{-12}. This is due to the fact that TAI is constructed by the B.I.H. in such a way as to maximize its uniformity, thus reasonably maintaining the rate adopted for the scale initiated on 1 January 1958 on the basis of a limited number of contributing clocks.

A new caesium beam tube accuracy evaluation technique has been developed that is applicable to both laboratory and commercial type standards [Hellwig *et al.*, 1973]. The possibility of evaluating the accuracy of commercial beam tubes to about 5×10^{-13} means that many more laboratories could join the group of laboratories owning primary frequency standards, provided they go through certain electronic test procedures with existing caesium beam standards.

Work is in progress in the United States of America aimed towards the development of a frequency standard using conventional atomic beam techniques with atomic hydrogen [Peters, 1972]. The technique, as employed at NASA's Goddard Space Flight Center, achieves relatively long interaction times between the atoms and the microwave excitation field by using "slow" velocity selected atoms rather than by having a storage bulb, as used in the hydrogen maser. The advantage gained is the complete avoidance of the dominant "wall-shift" problem, still under study, associated with hydrogen masers. A further advantage of the present experimental apparatus is that the selectable beam optics system produces a nearly monochromatic beam with only a 1% velocity spread, thus permitting a convenient and very precise determination of the 2nd order Doppler shift. The atomic hydrogen resonance has been observed under a variety of conditions and studied. Based on the preliminary results, it appears that the hydrogen atomic beam standard is one of the promising candidates for a future primary standard.

References

Allan, D.W. [1966] *Proc. IEEE*, Vol. 54, 221.

Becker, G. [1973] Frequenzvergleiche mit dem primären Zeit- und Frequenznormal CS1 der Physikalisch-Technischen Bundesanstalt zwischen 1969 und 1973 (Frequency comparisons with the primary time and frequency standard CS1 of the Physikalisch-Technische Bundesanstalt between 1969 and 1973). *PTB-Mittlg.*, **83**, 319.

Becker, G. [1974] Das Nationale Zeitnormal der Physikalisch-Technischen Bundesanstalt (The national time standard of the Physikalisch-Technische Bundesanstalt). *Kleinheubacher Berichte*, **17**, 81-94.

Becker, G., Kramer, G. and Müller, E. [1972] PTB-Jahresbericht 1971 (PTB Annual Report 1971), p. 103. Braunschweig.

Becker, G., Müller, E. and Schröder, R. [1973] PTB-Jahresbericht 1972 (PTB Annual Report 1972), p. 124. Braunschweig.

Beehler, R.E., Mockler, R.C. and Richardson, J.M. [July, 1965] Caesium beam atomic time and frequency standards. *Metrologia*, Vol. 1, 3.

Blackman, R.B. and Tukey, J.W. [1959] *The measurement of power spectra*. Dover, New York.

Davenport, W.B. and Root, W.L. [1958] *Random signals and noise*. McGraw-Hill, New York.

Glaze, D. J., Hellwig, H., Jarvis, S., Jr. and Wainwright, A.E. [1973] Recent progress on the NBS primary frequency standard, Proc. 27th Annual Symposium on Frequency Control (U.S. Army Electronics Command, Ft. Monmouth, N. J., 07703).

Hellwig, H., Jarvis, S., Jr., Halford, D. and Bell, H. E. [June, 1973] Evaluation and operation of atomic frequency standards using time domain velocity selection modulation. *Metrologia*, Vol. 9.

IEEE [February, 1966] Special issue on frequency stability (IEEE/NASA Symposium). *Proc. IEEE*, Vol. 54, 2.

IEEE [May, 1972] Special issue on time and frequency. *Proc. IEEE*, Vol. 60, 5.

Kolmogorov, A.N. [1941] *DAN SSSR*, Vol. 32, 19; also Vol. 30, 299.

Malakhov, A.N. [1966] Spectral-correlational analysis of signals with non-integrable spectra. *Radiofizika*, Vol. 9, 595.

Mungall, A.G., Bailey, R., Daams, H., Morris, D. and Costain, C.C. [1973] The new NRC 2·1 metre primary caesium beam frequency standard CSV. *Metrologia*, Vol. 9, 113-127.

NASA [November, 1964] Symposium on short-term frequency stability. *Proc. IEEE-NASA*, NASA SP-80.

Peters, H.E. [1972] Hydrogen as an atomic beam standard. Proc. 26th Annual Symposium on Frequency Control (U.S. Army Electronics Command, Ft. Monmouth, N. J., 07703), 230-241.

Winkler, G.M.R., Hall, R.G. and Percival, D.B. [1970] *Metrologia*, Vol. 6, 126.

Yasuda, Y. and Yoshimura, K. [November, 1964] Measurement of short-term frequency instability and frequency spectra of highly stable oscillators. *J. of Radio Res. Labs.*, Vol. 11, 58.

REPORT 366-2*

PROPERTIES OF SYSTEMS WHICH YIELD TIME AND FREQUENCY INFORMATION FROM RADIO EMISSIONS

(Question 1/7)

(1966 – 1970 – 1974)

1. Introduction

The present Report calls attention to some definitions of terms useful for describing time and frequency information emission systems chosen for study to provide both UT and TAI in the same emission [Decaux and Guinot, 1969].

2. Definitions

2.1 By *carrier offset* is meant an intentional fractional frequency deviation from the nominal carrier frequency value.

2.2 A *marker* is a reference signal or other event often repeated periodically at a specified frequency to enable one to assign numerical values to specific events in a time scale.

2.3 By *marker frequency offset* of emitted time signals is meant an intentional fractional deviation of the rate of occurrence of the marker from its nominal value, usually one marker per second.

2.4 By a *time step* is meant an intentional discontinuity introduced at some instant in an otherwise uniform sequence of time intervals. A time step is positive (+) if the clock reading is increased, and negative (—) if it is decreased by making the step.

2.5 A *time scale* is defined either by its initial event and a scale measure (e.g. the second) or a sequence of events. Some time scales are based upon clocks and some also upon astronomical phenomena. For the purpose of making precise time readings of a time scale, and to enable the distribution of a scale by electromagnetic means, a sequence of signals (or markers) is widely used representing special scale values.

2.6 Time scales belonging to the UTC time system are said to be *coordinated* by the use of well-defined synchronization, dissemination, publication, and correction procedures.

2.7 A clock in a set of clocks distributed over a spatial region and synchronized to a reference clock *at a specified location (spatial origin)* is called a *coordinate clock.*

2.8 A time scale is called a *coordinate* time scale if it is disseminated over a spatial region with varying gravitational potentials by some well-defined procedure, so that two spatially separated events are considered to be simultaneous if the coordinate clocks at the events are synchronized by this procedure and have the same reading.

2.9 Any *reading* of a clock or time scale should be denoted by giving the time-scale name followed, in parentheses, by the clock name, transmitting station, astronomical observatory, or standards laboratory such as:

UTC	(Clock number 8)
TAI	(B.I.H.)
UTO	(Tokyo)

The date of a specific reading should be given with its value.

REFERENCE

DECAUX, B. and GUINOT, B. [1969] La mesure du temps. *Que sais-je ?*, **97**, Presses universitaires de France.

* Adopted unanimously.

REPORT 438*

HIGH PRECISION STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 5/7)

(1970)

This Report is based on Doc. VII/53 (U.S.A.), 1966–1969.

1. System for precise time

1.1 Recent advances in the techniques for establishing and maintaining precise time and frequency synchronization between ground and airborne stations [ANTC, 1967] are being investigated to determine to what extent they can meet future stringent requirements for aviation purposes [Transportation Workshop, 1968]. The concept of a time ordered system (TOS) depends on such advanced time/frequency (*T/F*) techniques suitably directed towards future systems' needs. Such TOS concepts require that air-ground equipment should be capable of establishing and maintaining precise synchronization to a world-wide time reference. This precise world-wide time reference is used as the common reference for the exchange of system data between aircraft and between aircraft and ground stations. Appropriate data processing at either ground or airborne stations then provides for many integrated system functions from a single basic system design. Integrated system functions required for aviation needs include airborne collision avoidance systems (CAS), position determination, navigation and communication. The future operational success or failure of such time ordered, integrated systems depends in major part on establishing and maintaining a master or world-wide scale coordinated to the order of 0·1 to 1·0 μs.

1.2 The selection of precise *T/F* techniques [White, 1968] as the basis for the design of air-to-air CAS equipment for airline use constitutes a significant step forward in attaining acceptance by the aviation user of a precise time ordered system for eventual development on a world-wide basis. The design concept recognizes and allows for future, and as yet unresolved, operational requirements in the congested terminal areas [ANTC, 1967]. One preliminary design goal [ANTC, 1967] is the time synchronization of ground stations to a single world-wide standard time to within 0·5 μs (3σ).

1.3 Analyses are now being conducted by the United States Federal Aviation Administration (FAA) to establish what improvements in air traffic management might be achieved by the application of broad, integrated systems of *T/F* technology. The results indicate that appropriate developments of time ordered systems can be expected to meet aviation performance requirements for several decades ahead. Studies to date show that the available methods of achieving system master time, using a world-wide timing reference, are capable of providing adequate performance for distance measuring equipment, navigation, data acquisition, landing aid and station keeping in addition to CAS. This preliminary concept study indicates timing requirements to be of the same order of accuracy as for the CAS function cited above, i.e. about 0·1 to 0·5 μs.

2. System standards

2.1 Consideration has been given to the relationship between CAS performance [Shear, 1968], internal system synchronization [Jaycox, 1968], signals-in-space [Perkinson, 1968], *T/F* technology [Bates *et al.*, 1968], and master timing requirements as they relate to future development of an acceptable world-wide timing reference [Thornburg, 1968]. The problem of distributing time around the world and maintaining common world-wide time in secondary ground reference stations has been analyzed in the development

* Adopted unanimously.

of concepts for future designs of multi-function integrated time ordered systems for aviation. Such considerations have raised several important questions that must be resolved before agreement can be reached on a world-wide timing specification.

2.2 These questions relate, in part, to the selection of a common time scale, standardization of the synchronizing signals, determination of radio-frequency spectrum requirements, compatibility of signals serving single-function (CAS) versus multiple-function aviation systems, and the development of *T/F* system requirements for other world interests. Consideration has been given to the application to CAS of a uniform time scale, such as A.1 [Thornburg, 1968]. Future designs for multi-function time ordered aviation systems and the analysis of other world-wide interests, in addition to aviation, may suggest the use of alternative time scales in the initial development of a world-wide time reference. The common basis of time ordered systems is the need for precise synchronization between all participating stations in the system. Means of standardizing the basic synchronization portion of the signals-in-space from secondary ground station emissions should be considered on a world-wide basis to permit the maximum number of users to benefit from the dissemination of the primary world-wide time reference.

3. System studies

3.1 The system application of precise time and frequency technology is in its infancy and the full performance and economic potential of cooperative integrated systems based on this advanced *T/F* technology has yet to be developed and demonstrated before acceptance of such an approach can be justified by Administrations. Such development and demonstration activity has been initiated by the United States through a broad programme ranging from concept analyses and system designs to flight tests of critical elements, in order to meet the needs of aviation. It is expected that this activity will lead to the formulation of the requirements for gradually extending a precise timing system throughout the world. The necessity for compatible, cooperative *T/F* operation in such systems emphasizes the need for appropriate studies aimed at world-wide timing requirements and the solution of some of the problems cited above.

Such studies should be kept extremely broad in nature and not be limited to the specialized applications of specific Administrations, or users. They might provide a most valuable service by the analysis and definition of the relative benefits of various methods of disseminating and maintaining a world-wide time reference with a synchronization capability of 0·1 μs. An additional advantage to be gained could be that the timing accuracy required for aviation may also meet the needs of other world-wide interests.

References

ANTC [30 June, 1967] Air Navigation/Traffic Control Div., Air Transport Association of America. Airborne collision avoidance system. ANTC Report 117 (Revision Five, 15 April, 1968).

Bates, M.R., Fletcher, H.K., Michnik, L. and Prast, J.W. [March, 1968] History of time-frequency technology. *IEEE Trans. Aerospace and Electronic Systems*, Vol. AES-4, 2, 238-255.

Jaycox, R.L. [March, 1968] Collision avoidance system synchronization. *Ibid.*, 257-264.

Perkinson, R.E. [March, 1968] CAS message format. *Ibid.*, 273-277.

Shear, W.G. [March, 1968] Elements of the ATA collision avoidance system. *Ibid.*, 295-304.

Thornburg, C.O. [March, 1968] Master timing of CAS ground stations. *Ibid.*, 265-272.

Transportation Workshop (Washington) [1968] Report for 1967. Air transportation 1975 and beyond: a system of approach. Trends in air travel, Forecasts, Projections, 33-47; Air traffic control, 265-289; Data processing, 303-305; Integrated systems, 307-308; Collision avoidance system. The outlook beyond 1975, 312-314; System capacity, 331. The M.I.T. Press.

White, F.C. [March, 1968] Airborne collision avoidance system development. *IEEE Trans. Aerospace and Electronic Systems*, Vol. AES-4, 2, 234-237.

BIBLIOGRAPHY

HOLT, J. M. and ANDERSON, R. M. [March, 1968] Analysis of warning times for collision avoidance systems. *IEEE Trans. Aerospace and Electronic Systems*, Vol. AES-4, **2**, 305-314.

STEEN, C. E. [March, 1968] Spectral energy requirements and adjacent-channel crosstalk in CAS. *Ibid.*, 283-289.

STEINBERG, H. A. [March, 1968] Slot length and line-of-sight protection. *Ibid.*, 290-294.

TOERPER, K. E. [March, 1968] Biphase barker-coded data transmission. *Ibid.*, 278-282.

REPORT 439-1*

THE USE OF COORDINATE CLOCKS AND LOCAL STANDARD (METRIC) CLOCKS IN A TERRESTRIAL COORDINATE TIME SYSTEM

(1970 – 1974)

1. Introduction

Coordinate time and metric time (proper time) are both primary concepts in timekeeping and time interval measurement. If several coordinate time systems exist, the relation between them should be known. These relations are called "equations of transformation". The use of atomic standards of time makes possible their systematic employment in the measurement of the properties of coordinate time (and space) systems. Some measurements are now being reported, and are becoming part of a widespread coordinated programme.

A clock, running independently of other clocks, constructed to generate seconds and evaluated for its accuracy, is a metric instrument usable for physical measurement of time intervals and frequencies. Its use as a standard calibration device should be under conditions as nearly ideal as possible, which require a minimum of theoretical assumptions.

A set of clocks distributed over a spatial region, synchronized by physical means, such as radio time signals, constitutes part of a coordinate time system. The system is completed by incorporating a time scale defined at an appropriately chosen spatial origin, means for measuring its operation and procedures for maintaining the system control. To ensure permanence, observations relating the system scale to astronomical scales are desirable.

2. The time scale at the origin

Following the recommendations of the Comité consultatif pour la définition de la seconde [C.C.D.S., 1970], the introduction of an official coordinate time scale was authorized in 1971 by the General Conference of Weights and Measures. This scale, the International Atomic Time (TAI) scale, is formed by the integration of the second (SI) as realized at sea level.

The practical realization of TAI has been entrusted to the Bureau International de l'Heure (B.I.H.) and is in the form of a mean time scale based on the operation of approximately 60 caesium clocks located at 13 laboratories and observatories in Europe and North America. These clocks are intercompared on a daily basis by means of the LORAN-C signals and/or the use of television synchronizing signals and, less frequently, by the physical transport of suitably stable clocks. The B.I.H. combines these data at present using a single statistical model in which weights are assigned to each clock in inverse proportion to the variance of the fluctuations observed in the preceding 12 months (see Report 579, B.I.H. Annual Report for 1973 and [Grandveaud and Guinot, 1972]. The time scale so formed is estimated to have an instability of less than 1×10^{-13} over periods in excess of one year. It is made available to 0·1 μs by publishing the corrections to individual clock times.

---

* Adopted unanimously.

3. Coordinate times

A coordinate clock reading at the i[th] location may be derived from the local standard clock reading by considering the fractional frequency deviation $F(i)$ and a relativistic frequency shift $G(i)$. $G(i)$ is given by:

$$G(i) = g \frac{H(i)}{c^2}$$

where $H(i)$ is the height of the i[th] location above the system origin, g is the acceleration of gravity, assumed uniform, and c is the velocity of light. If

$$Q = \frac{1 - G(i)}{1 + F(i)}$$

and $AT(i)$ is the local standard clock reading, the reading of the coordinate clock is:

$$ATC(i) = Q \times AT(i),$$

the initial readings of these clocks being assumed equal to zero and corresponding to the same instant. The use of the factor Q maintains the synchronization of $ATC(i)$ with the coordinate time of the system.

An additional frequency offsetting procedure for changing the rates of both the coordinate clocks and the local standards of time may be applied in order to maintain approximate synchronization of the coordinate clocks with universal time. This additional procedure is also described by Hudson *et al.* [1969] for a national coordinate time system now being studied in the United States of America.

4. System operation

Carrier and time-signal frequencies emitted from the i[th] location will be equal to the system frequencies at the system origin.

At the system origin, the difference Δ(UT) between universal time and the system coordinate time may be determined. The values of $ATC(i) - AT(i)$ should be made available.

REFERENCES

C.C.D.S. [18-19 June, 1970] Comité Consultatif pour la Définition de la Seconde, 5th Session. Bureau International des Poids et Mesures, Sèvres.

GRANVEAUD, D. M. and GUINOT, B. [1972] *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-21, **4**, 396.

HUDSON, G. E., ALLAN, D. W., BARNES, J. A., HALL, R. G., LAVANCEAU, J. D. and WINKLER, G. M. R. [May, 1969] A coordinate frequency and time system. Proc. of the 23rd Annual Frequency Control Symposium, USAE Com.

REPORT 518-1*

STANDARD-FREQUENCY AND TIME-SIGNAL DISSEMINATION VIA SATELLITES

(Question 2/7, Study Programme 2A-1/7)

(1971 - 1974)

The object of this Report is to review the present situation with regard to the use of satellites for the dissemination of standard frequencies and time signals. General conclusions regarding the use of satellites by the standard-frequency and time-signal service are given in [C.C.I.R., 1970–1974 a and b].

---

* Adopted unanimously.

Standard frequency and time signals in band 7 as received cannot provide, in general, a completely reliable 24-hour/day service from a single station at a single frequency because of propagation characteristics and interference problems. An alternative dissemination system, which has potentially widespread application where higher accuracy, wider coverage, and increased reliability are needed, is the distribution of standard frequency and time signals via, or originating directly from, a satellite.

The World Administrative Radio Conference for Space Telecommunications in 1971 allocated three frequencies in bands 9 and 10 specifically for time and frequency dissemination via satellites: 400·1 ± 0·025 MHz, 4202 ± 2 MHz (space-to-Earth) and 6427 ± 2 MHz (Earth-to-space). (See Radio Regulations Nos. 312B and 379A.)

Most of the recent work has been done in band 9, although earlier experiments in band 10 demonstrated the advantages of the higher frequency for precise time transfer [Steele *et al.*, 1964; Markowitz *et al.*, 1966].

Two general techniques for use with satellite are:

— one-way broadcast operation, and

— two-way operation.

In this context, one-way operation means that the user employs only receiving equipment for the reception of a common transmission originated or relayed by a satellite, reaching a large number of users. Two-way operation is that in which the user employs both transmitting and receiving equipment.

One-way operation has the following characteristics:

— widespread service areas;

— good timing accuracy;

— simple methods for time recovery and operation of the equipment;

— moderate equipment costs and complexity.

In one case [Hanson and Hamilton, 1973] a time transfer accuracy of about 25 μs was demonstrated in band 8 using a geostationary satellite in a one-way mode. In this two-year experiment the propagation delays between the master clock and the receiving clock were available through the use of a special-purpose slide rule when the satellite position and receiver location were known. The satellite position was announced by voice during the broadcasts. Propagation delays could also be determined at lower accuracy by using delay overlays superimposed on an earth map.

Synchronization of widely separated ground stations to accuracies of about ± 25 μs has also been demonstrated using timing signals from on-board clocks in low-altitude, polar-orbiting satellites. In one case world-wide tracking stations in NASA's Spaceflight Tracking and Data Network were synchronized using a phase-modulated 136 MHz carrier transmitted from a GEOS geodetic satellite [Laios, 1972]. Observation of about one satellite pass per day at eight sites proved sufficient to establish network synchronization, both internally and to an external reference, to within about 20 to 30 μs when the propagation delays were based on satellite orbit predictions updated once per week.

Similar results have been reported for satellite synchronization of six stations in a French tracking network, using the orbiting TRANSIT satellite [Laidet, 1972]. By receiving timing information from the on-board clock via two phase-modulated carriers at about 150 MHz and 400 MHz, station clocks were synchronized to the TRANSIT clock to within 20 μs (see United States Naval Observatory (USNO) Time Service Announcements, Series 17).

Two-way operation has the following characteristics:

— demonstrated timing accuracies of the order of 100 ns;

— ease of confinement to limited areas on the Earth, if necessary, when higher frequencies are used;

— may often be the only practicable way to effect time transfers to certain remote areas with an uncertainty of less than 1 μs.

It has been demonstrated experimentally that a time service via satellite could satisfy the needs of various classes of users. Some of these uses are:

— improved service for scientific purposes, such as geophysical and geodetic work;

— service for precise surveying on land or at sea, particularly in remote areas;

— timing requirements of mobile services on a 24-hour/day basis exceeding those of ordinary navigation;

— accurate time comparisons and coordination of time scales such as required by national laboratories and other users;

— aircraft traffic control systems.

In the future the optimum signal formats must be determined and additional work is also required to optimize satellite orbit prediction methods suitable for timing applications.

REFERENCES

C.C.I.R. [1970–1974a] Doc. 7/1, Canada.

C.C.I.R. [1970–1974b] Doc. 7/4, U.S.A.

HANSON, D.W. and HAMILTON, W.F. [1973] Time and frequency broadcast experiments from the ATS-3 satellite. NBS Technical Note No. 645, Boulder, Colo.

LAIDET, L.M. [May, 1972] Worldwide synchronization using the TRANSIT satellite system. *Proc. IEEE* (Lett.), Vol. 60, 630-632.

LAIOS, S.C. [May, 1972] Satellite time synchronization of a NASA network. *Proc. IEEE* (Lett.), Vol. 60, 632-633.

MARKOWITZ, W., LIDBACK, C.A., UYEDA, H. and MURAMATSU, K. [December, 1966] Clock synchronization via Relay II satellite. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-15, **4**, 177-184.

STEELE, J. MCA., MARKOWITZ, W. and LIDBACK, C.A. [December, 1964] Telstar time synchronization. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-13, 164.

REPORT 576*

STANDARD-FREQUENCY DISSEMINATION VIA STABILIZED BROADCAST STATION CARRIERS

(Study Programme 4A/7)

(1974)

Many users of the standard-frequency and time-signal service emissions, particularly in the radio and electronic industries, require a frequency reference with only moderate precision. These users are often located in environments with severe electromagnetic interference which can seriously reduce the usefulness of standard frequencies and time signals in allocated and other bands. Moreover, there is a need for simple and inexpensive equipment to perform such frequency comparisons.

The requirements are met in Europe with a number of standard-frequency and time-signal services operating in band 5 and by the stabilization of some broadcast station carriers (Allouis, 164 kHz;

* Adopted unanimously.

Donebach, 151 kHz; Droitwich, 200 kHz; and Motala, 191 kHz). The carriers of these latter stations are derived from atomic standards and the frequency accuracy of the emitted carriers is usually maintained between 5×10^{-12} [C.C.I.R., 1970–1974a] and 5×10^{-11}.

Due to the propagation characteristics in the LF band, depending on transmitter power, the primary service area can be very large (with a radius of the order of some hundreds of kilometres). In this prime coverage area, frequency comparisons are possible with a precision between 1×10^{-11} and 1×10^{-9}, provided that the measurement is performed during daylight hours and with a sufficiently long measurement interval.

Experiments have been carried out in the United States of America in band 6 [C.C.I.R., 1970–1974b] with the stabilization of a broadcast station carrier at 650 kHz operating with 50 kW carrier power. A frequency comparison precision of 1×10^{-10} was obtained at a distance of 800 km during daylight hours. In Italy all of the requirements to stabilize the carrier of a high-power broadcast station on 899 kHz have been realized [C.C.I.R., 1970–1974c].

In the Federal Republic of Germany more than 100 television transmitters are operating in band 9 with the carriers remotely controlled by the use of one of three different reference frequencies [C.C.I.R., 1970–1974d and e]: a 1 kHz signal supplied via cable; the stabilized carrier of a broadcast station at 151 kHz, and a standard frequency of 10 MHz supplied via the television programme distribution lines set up on radio-relay links. A carrier frequency deviation between $0{\cdot}7 \times 10^{-11}$ and about 3×10^{-10} was observed, depending on which of the three controlling signals was used as the reference. By means of the stabilized carriers, frequency comparisons with a precision of a few parts in 10^{10} are achievable in less than one minute.

The usefulness of stabilizing the carriers of broadcast stations is enhanced by the fact that existing frequency allocations and transmitters are used without degrading their primary purpose. In addition, these stations usually provide a field intensity large enough to ensure a good signal-to-noise ratio.

References

C.C.I.R. [1970–1974a] Doc. 7/66, Germany (Federal Republic of).

C.C.I.R. [1970–1974b] Doc. 7/34, U.S.A.

C.C.I.R. [1970–1974c] Doc. 7/82, Italy.

C.C.I.R. [1970–1974d] Doc. 7/19, Germany (Federal Republic of).

C.C.I.R. [1970–1974e] Doc. 7/63, Germany (Federal Republic of).

REPORT 577*

DISSEMINATION OF TIME SIGNALS BY ADDITION OF PHASE MODULATION ON AMPLITUDE-MODULATED SOUND BROADCASTING TRANSMITTERS

(Study Programme 4B/7)

(1974)

Dissemination of time signals, with an accuracy meeting the requirements of many users, can be achieved without increasing the congestion in the bands allocated to standard-frequency and time-signal emissions, by use of existing transmitters designed for other services.

In particular, it is possible to superimpose a phase modulation, simultaneously carrying second markers and date information (day, hour, minute, second) in coded form, on the conventional amplitude modulation of a sound broadcasting station.

* Adopted unanimously.

A suitable receiver can operate as a remotely controlled time display, the accuracy of which depends only on the accuracy of the time scale at the emission.

An experiment according to this technique has been carried out in France by means of a laboratory simulation of an emission in band 5 [C.C.I.R., 1970–1974a]. It demonstrated that sufficient independence of the two types of modulation can be achieved, provided the phase-modulation characteristic is appropriate.

The transmission of the coded date information requires a 4-second cycle, but the second markers transmission permits the display of the data in the receiver, second by second.

The precision of the received time markers is of the order of some tenths of a millisecond, limited by the restricted bandwidth of the phase modulation, while propagation time variations are well below this limit. The evaluation of the final uncertainty requires a calibration of the time delay in the receiving apparatus (typically 10 ms) and a knowledge of the propagation delay.

This technique is compatible with the use of the carrier frequency dissemination since it is possible to retrieve at reception the unmodulated carrier phase.

It is considered that this technique could provide a means for dissemination of time signals over wide geographical areas; however, practical listening tests should be undertaken to ensure that the additional phase modulation does not disturb the listeners to the broadcast programme [C.C.I.R., 1970–1974b].

References

C.C.I.R. [1970–1974a] Doc. 7/45, France.

C.C.I.R. [1970–1974b] Doc. 10/361.

REPORT 578*

TIME CODES

(Question 1/7)

(1974)

Developments in recent years have emphasized the need for the transmission of more complete time information than is provided by the normal second and minute signals as part of the standard-frequency and time-signal services. Requirements for more complete coded time information, which may include the minute, hour and day of the year, arise in various fields — for example, in providing a common time base for geographically widespread monitoring systems making use of unattended equipment. An increasing number of applications in science, industry and administration is expected.

Standard-Frequency and Time-Signal Station WWV was the first to add complete coded time information to its modulation schedule in about 1960. Time codes were later extended to transmissions from stations WWVH and WWVB (60 kHz). The codes used at present are similar to the H-version of the IRIG (Inter-Range Instrumentation Group) time codes [NBS]. Within each code frame lasting 1 minute, the number of the minute, hour and day is specified by 23 BCD (binary coded decimal) bits. The WWV and WWVH codes use a 1-2-4-8 sequence while the WWVB code employs an 8-4-2-1 sequence. Pulse-width modulation is used for coding with 0·2 s pulses representing binary zeros and 0·5 s pulses representing binary ones. The bit-rate is 1 Hz. The time codes on the high-frequency stations are radiated on a 100 Hz sub-carrier. For WWVB the carrier level is reduced by 10 dB for each binary digit.

In June 1973 a time code was included in the emission of the Standard-Frequency and Time-Signal Transmitter DCF77 (77·5 kHz). The minute, hour, calendar day, day of the week (Monday = 1),

* Adopted unanimously.

month, and year is transmitted in BCD code each minute, beginning with the 20th and ending with the 58th second (see Fig. 1). The coded time information refers to Central European Time, as realized at PTB (UTC(PTB) + 1 hour). Binary zeros are represented by 0·1 s-wide second markers, binary ones, by 0·2 s-wide markers. Three parity check bits are also included [Becker and Hetzel, 1973; C.C.I.R., 1970–1974a]. The choice of the code format was based on enquiries to a variety of users. The coding method chosen is considered to have two essential advantages: the necessary bandwidth is small (less than 30 Hz) and the transmission rate is low, permitting the recording of the decoded markers by simple recorders. Both features of the code are especially useful for remote and unattended stations. Receiving and decoding equipment has been described by Hetzel and Rohbeck [1974].

A time code is also proposed for the 60 kHz MSF transmission [C.C.I.R., 1970–1974b]. This code will also use a BCD format in 8-4-2-1 sequence. Initially 13 bits + 1 parity bit will specify the minute and hour; day-of-year information will be added later by an additional 10 bits + 1 parity bit. The bit-rate will be 100 Hz and the total word length will be inserted in the 0·5 s carrier interruption which constitutes the minute marker. A binary one corresponds to full carrier level and a binary zero to suppressed carrier.

A time code has been studied in the United States [C.C.I.R., 1970–1974c] to simultaneously provide designation of Universal Time (UT1), Coordinated Universal Time (UTC) and International Atomic Time (TAI) in a single BCD code suitable for use with automatic decoding equipment. The complete code specifies the time of occurrence of the frame reference marker in units of 20 ms on the UT1 time scale. The time of occurrence on the UTC scale can be obtained directly by simply rounding upward or downward to the next second, depending on a particular ± rounding bit in the code. As a final step, the occurrence time of the frame reference marker on the TAI scale can be obtained, since the code frame markers are initially synchronized with minute markers of the TAI scale. An additional feature of the code is that the occurrence of a leap-second in the UTC scale can readily be detected, since there will be an immediate corresponding change in the UT1-UTC information included in the code.

Although this code is not presently in use, it may be appropriate for certain future applications that require time signals for use with automatic decoding equipment.

References

Becker, G. and Hetzel, P. [1973] Kodierte Zeitinformation über den Zeitmarken- und Normalfrequenzsender DCF77 (Coded time information from the Standard-Frequency and Time-Signal Transmitter DCF77). *PTB-Mittlg.*, **83**, 163.

C.C.I.R. [1970–1974a] Doc. 7/52, Germany (Federal Republic of).

C.C.I.R. [1970–1974b] Doc. 7/69, United Kingdom.

C.C.I.R. [1970–1974c] Doc. 7/32, U.S.A.

Hetzel, P. and Rohbeck [April, 1974] Digitale Anzeige der vom Sender DCF77 verbreiteten amtlichen Zeit (Digital information of the official time distributed by the transmitter DCF77). *Funkschau*, 46.

NBS: National Bureau of Standards. Special Publication No. 236, revised annually. Boulder, Colo.

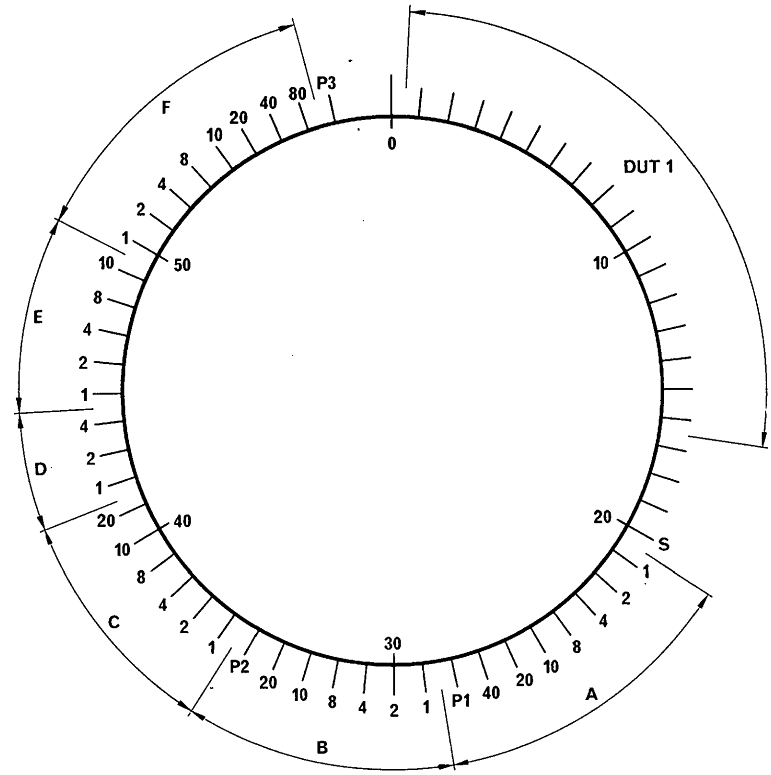


FIGURE 1

Time Coding Plan at DCF 77

P1, P2 and P3 are parity check bits (parity control)
S is a second marker, lengthened to 0·2 s, which designates the start of the time information

A: minute
B: hour
C: calendar day
D: day of the week
E: calendar month
F: calendar year

REPORT 579*

STATISTICAL WEIGHTS OF CLOCKS USED TO ESTABLISH A TIME SCALE — AVERAGING PROBLEMS

(Study Programme 1D-1/7)

(1974)

1. Uniformity

In most laboratories the local independent time scale is obtained from an ensemble of commercial caesium standards and is maintained uniform without reference to the calibrations by laboratory primary standards. To achieve a high uniformity, predicted rate corrections and weighting factors are applied to individual standards.

The simplest and most widespread rate prediction is the mean observed rate during a past interval of time (linear prediction) relative to the clock ensemble. However, it is theoretically justified for white noise frequency modulation only; in particular, it is not an optimum prediction for the flicker noise

* Adopted unanimously.

frequency modulation, which may be predominant in the problem of time scale evaluation. A near-optimum recursive prediction for a realistic model of frequency fluctuations was developed by the National Bureau of Standards [Allan and Grey, 1971; Allan *et al.*, 1973].

Refined methods of weighting are used by the National Bureau of Standards [Allan and Grey, 1971; Allan *et al.*, 1973] and the Commission Nationale de l'Heure in France. In some cases, a simpler weighting procedure is satisfactory: a clock is either considered with full "weight 1" or, in case of unsatisfactory performance, with "weight 0".

Clock averaging procedures which make use of different assumptions concerning clock behaviour and the concept of a uniform time scale are also used [Winkler *et al.*, 1970]. These methods employ iterative procedures with corrections applied which compensate for the contributions of those clocks which have excessively deviated from expected behaviour.

Research at the Physikalisch-Technische Bundesanstalt (PTB) and other laboratories has shown that the random model may not be sufficient to characterize fully long-term performance. Systematic frequency drifts and frequency jumps may occur. Effort has been devoted to the recognition of these non-random effects [Ganter, 1973]. They emphasize the need for precise calibrations of the clocks.

2. Accuracy

The above-mentioned methods may give rise to important frequency deviations in the long term. Frequency corrections must be applied in order to maintain the agreement of the time scale unit with the second.

One of the problems is to evaluate the frequency correction, assuming several calibrations of the time scale frequency with respect to the primary standards are available. Yoshimura [1972] derived the formulae giving the weights of the calibrations for usual models of random noise in the time scales.

At the National Research Council, the calibrations and frequency corrections are made at short intervals (twice a week) [Mungall, 1971]. At the National Bureau of Standards (NBS), only three frequency corrections have been made since 1969. No corrections were made to other local independent atomic time scales.

A continuous adjustment of frequency which would ensure the accuracy without reduction of the short and mean term stability seems to be possible and is being studied. Such a method could be especially useful in dealing with the possible non-random effects.

3. International Atomic Time (TAI)

Until August, 1973, TAI was a mean of 7 local independent atomic times. The weighting of these scales was discussed by Becker and Hubner [1973]; several weighting procedures were tested by these authors and also at the Bureau International de l'Heure (B.I.H.) [Granveaud and Guinot, 1972]. As a consequence of the difficulties in assigning weights to the time scales, the B.I.H. began in August, 1973 to use directly data from individual clocks with a prediction and weighting procedure described in the B.I.H. Annual Report for 1973.

References

Allan, D.W. and Grey, J.E. [1971] *Metrologia*, Vol. 7, 79.

Allan, D.W., Glaze, D.J., Machlan, H.E., Wainwright, A.E., Hellwig, H., Barnes, J.A. and Grey, J.E. [1973] Proc. 27th Annual Symposium on Frequency Control, 334.

Becker, G. and Hubner, U. [1973] PTB Annual Report for 1972, 125.

Ganter, W. [1973] NBS Technical Note No. 636, Boulder, Colo.

Granveaud, M. and Guinot, B. [1972] *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-21, **4**, 396.

Mungall, A.G. [1971] *Metrologia*, Vol. 7, 146.

Winkler, G.M.R., Hall, R.G. and Percival, D.B. [1970] *Metrologia*, Vol. 6, 126.

Yoshimura, K. [1972] NBS Technical Note No. 626, Boulder, Colo.

REPORT 580*

CHARACTERIZATION OF FREQUENCY AND PHASE NOISE

(Study Programme 3B/7)

(1974)

An understanding of the instabilities in frequency generators and received radio signals is of fundamental importance in time and frequency applications.

Random processes as well as systematic and non-stationary processes have to be distinguished. Concerning random processes, considerable work has been done [Allan, 1966; Baghdady *et al.*, 1965; Cutler and Searle, 1966; IEEE, 1966 and 1972].

Following a Special Issue of the Proceedings of the IEEE in 1966, devoted to frequency stability [IEEE, 1966], a sub-committee of the Group on Instrumentation and Measurement (GIM) of the IEEE was formed to prepare an IEEE standard on frequency instability. In 1969 this sub-committee completed a document which is the most definitive work to date for the qualitative and quantitative measurement of frequency/phase instabilities [Barnes *et al.*, 1970].

In this document definitions are proposed for measures of frequency stability. One definition concerns the spectral density $S_y(f)$ where f is the Fourier frequency, where the spectrum is considered to be one-sided on a per-Hertz basis, and where y is the normalized frequency deviation from nominal. The sub-committee also proposed an alternative definition for the measure of frequency stability as the infinite time average of a sample variance of two adjacent averages of y, each of which has been averaged over a nominal period τ. The first measure proposed is a frequency-domain measure of stability and the second, which has come to be known as an Allan variance, is a time-domain measure of stability [Kolmogorov, 1941; Malakhov, 1966]. The above document also presents graphs, charts, and equations which relate the recommended frequency-domain measure of stability with the recommended time-domain measure of stability, and which also permit a calculation of the phase stability.

Note. — In all of the above the word "stability" actually means instability, but since there is seldom any confusion "stability" is often used in relevant publications.

The above recommended measures of instabilities in frequency generators have gained general acceptance among frequency and time metrologists throughout the world. Some of the major frequency standards manufacturers now specify their standards' instability characteristics in terms of these recommended measures.

Since the paper by Barnes *et al.* [1970] was published, some additional significant work has been done; for example, Brandenberger *et al.* [1971] compared measurements taken in the frequency-domain with those taken in the time-domain and also employed some alternative frequency-domain measures of frequency-generator instabilities. Meyer [1970] developed an accurate measuring system for extremely low-level phase instabilities. Baugh [1971] illustrated the properties of the Hadamard variance—a time-domain method of estimating discrete frequency-modulation sidebands—particularly appropriate for Fourier frequencies less than about 100 Hz.

Rutman [1972] has reviewed some aspects of the work of the above sub-committee and has suggested some alternative time-domain measures while still giving general support to the sub-committee's recommendation. As a next stage of refinement, Lesage and Audoin [1973] have shown how to calculate the confidence of the estimate of an Allan variance. De Prins *et al.* [1969] and De Prins and Cornelissen [1971] have proposed alternatives for the measure of frequency instabilities in the frequency-domain with specific emphasis on sample averages of discrete spectra.

A National Bureau of Standards Monograph devotes Chapter 8 to the "Statistics of time and frequency data analysis" [Blair, 1974]. This chapter contains some philosophy, measurement methods, and applications of both frequency-domain and time-domain measures of frequency/phase instabilities in frequency generators. It also describes methods of conversion among various time-domain measures

* Adopted unanimously.

of frequency instability, as well as conversion relationships from frequency-domain measures to time-domain measures and vice versa. Examples of applications are given, and a bibliography of most of the significant publications in the field of frequency instability measurements is included.

The presence of systematic changes of frequencies and phases such as drifts, cannot reliably be detected by applying the statistical methods mentioned above. These effects generally become predominant in the long term. They can be detected by repeated accuracy evaluations.

References

Allan, D.W. [February, 1966] Statistics of atomic frequency standards. *Proc. IEEE*, Vol. 54, 221-230.

Baghdady, E. J., Lincoln, R.N. and Nelin, B.D. [July, 1965] Short-term frequency stability: characterization, theory, and measurement. *Proc. IEEE*, Vol. 53, 704-722.

Barnes, J.A., Chi, A.R., Cutler, L.S., Healey, D.J., Leeson, D.B., McGunigal, T.E., Mullen, J.A., Smith, W.L., Sydnor, R., Vessot, R.F.C. and Winkler, G.M.R. [October, 1970] Characterization of frequency stability. NBS Technical Note No. 394. Also published in May, 1971 in *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-20, 105-120.

Baugh, R.A. [1971] Frequency modulation analysis with the Hadamard variance. Proc. 25th Annual Symposium on frequency control (U.S. Army Electronics Command, Ft. Monmouth, N.J. 07703 (April 26-28, 1971)), 222-225. (Electronic Industries Association, Washington, D.C., 20006).

Blair, B.E. (Ed.) [May, 1974] Time and frequency: theory and fundamentals. NBS Monograph No. 140, Boulder, Colo.

Brandenberger, H., Hadorn, F., Halford, D. and Shoaf, J.H. [1971] High quality quartz crystal oscillators: frequency domain and time-domain stability. Proc. 25th Annual Symposium on frequency control (U.S. Army Electronics Command, Ft. Monmouth, N.J., 07703 (April 26-28, 1971)), 226-230. (Electronic Industries Association, Washington, D.C., 20006).

Cutler, L.S. and Searle, C.L. [February, 1966] Some aspects of the theory and measurement of frequency fluctuations in frequency standards. *Proc. IEEE*, Vol. 54, 136-154.

De Prins, J. and Cornelissen, G. [18–22 October, 1971] Analyse spectrale discrète. Eurocon (Lausanne, Switzerland).

De Prins, J., Descornet, G., Gorski, M., and Tamine, J. [December, 1969] Frequency domain interpretation of oscillator phase stability. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-18, 251-261.

IEEE [May, 1972] Special issue on time and frequency. *Proc. IEEE*, Vol. 60, 5.

IEEE [February, 1966] Special issue on frequency stability (IEEE-NASA Symposium). *Proc. IEEE*, Vol. 54, 2.

Kolmogorov, A.N. [1941] *DAN SSSR*, Vol. 32, 19; also Vol. 30. 299.

Lesage, P. and Audoin, C. [June, 1973] Characterization of frequency stability: uncertainty due to the finite number of measurements. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-22, 157-161.

Malakhov, A.N. [1966] Spectral correlation analysis of signals with non-integrable spectra. *Radiofizika*, Vol. 9, 595.

Meyer, D.G. [November, 1970] A test set for the accurate measurements of phase noise on high quality signal sources. *IEEE Trans. on Instrumentation and Measurement*, Vol. IM-19, 215-227.

Rutman, J. [December, 1972] Instabilité de fréquence des oscillateurs. *L'Onde électrique*, Vol. 52, 480-487.

Bibliography

Shoaf, J. H., Halford, D. and Risley, A. S. [January, 1973] Frequency stability specification and measurement: high frequency microwave signals. NBS Technical Note No. 632, Boulder, Colo.

QUESTIONS AND STUDY PROGRAMMES, DECISIONS, RESOLUTIONS AND OPINIONS

QUESTION 1/7

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(1948 – 1951 – 1953 – 1956 – 1963)

The C.C.I.R.,

CONSIDERING

(a) that the Administrative Radio Conference, Geneva, 1959, called for the study of the establishment and operation of a world-wide standard-frequency and time-signal service;

(b) that a number of stations are now regularly emitting standard frequencies and time signals in the bands allocated by this Conference;

(c) that some areas of the world are not yet adequately served;

(d) that the use of more stations than are technically necessary would diminish the utility of the service by producing harmful interference;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what measures can be recommended for increasing the effectiveness of the existing standard-frequency and time-signal service in the bands allocated by this Conference;

2. what measures can be recommended for the reduction of mutual interference between standard-frequency and time-signal stations operating on the same frequency and whose service areas overlap?

STUDY PROGRAMME 1A-1/7

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(1965 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that Question 1/7 and Recommendation 374-3 call for information on methods for improving the usefulness of the existing standard-frequency and time-signal service;

(b) that standard-frequency stations are operated simultaneously on the same carrier frequency;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. an investigation of the possibilities of reducing mutual interference between emissions in the standard-frequency and time-signal service by:

1.1 shortening the programme of continuous tone modulation and of announcements;

1.2 use of a modulation which gives the required information and accuracy with minimum bandwidth;

1.3 staggering the emitted frequencies in the allocated bands and using a convenient type of modulation;

1.4 a convenient coordinated time-sharing of frequencies for those areas where there is mutual interference;

1.5 avoiding unmodulated carrier emissions, not strictly necessary for the operation of the service;

2. collection of information on how standard-frequency emissions in bands 6 and 7 may be coordinated with emissions in other bands to give the best overall world-wide service.

STUDY PROGRAMME 1B-1/7

SINGLE-SIDEBAND OPERATION FOR THE STANDARD-FREQUENCY AND TIME-SIGNAL SERVICES

(1965 – 1970)

The C.C.I.R.,

CONSIDERING

the measures taken by the I.T.U. urging Administrations to accelerate the conversion of their double-sideband systems, in the frequency bands below 30 MHz, to single-sideband systems, to reduce congestion in these bands;

UNANIMOUSLY DECIDES that the following studies should be carried out:

the improvements that may be obtained in the distribution and use of standard-frequency and time-signal emissions by the use of single-sideband operation, with full carrier, particularly in the 2·5, 5, 10, 15, 20 and 25 MHz bands.

STUDY PROGRAMME 1D-1/7

STATISTICAL WEIGHT OF CLOCKS USED TO ESTABLISH A TIME SCALE — AVERAGING PROBLEMS

(1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that atomic time scales are often obtained by establishing the individual time-scale averages of a large number of clocks or groups of clocks remotely located from each other;

(b) that for many applications it is important that a time scale should be as uniform as possible;

(c) that in addition, the sub-division of the time scales should be made in agreement with the accepted value of the second;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the averaging procedures to be recommended, including the determination of the statistical weight assigned to clocks or groups of clocks used in establishing the time scale.

It should be recognized that the intrinsic accuracy and stability of such clocks may differ, that commercial-type clocks, as well as laboratory models, must be considered and that the clock readings are ascertained with varying degrees of accuracy by those dealing with averaging problems;

2. the procedures to be recommended in cases where the number and/or accuracy and stability of the clocks, used to establish a time scale, changes.

QUESTION 2/7

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS IN ADDITIONAL FREQUENCY BANDS

(1956 – 1963)

The C.C.I.R.,

CONSIDERING

(a) that in certain regions, particularly in industrial centres, it is not always possible to obtain an adequate ratio of the wanted signal to the noise level with the existing standard-frequency and time-signal service;

(b) that the bands allocated for standard-frequency and time-signal emissions are more useful for long-distance distribution than for local distribution;

(c) that a better service is needed in certain areas and this service may be given by use of frequencies in band 8 and higher;

(d) that high-accuracy frequency and time comparisons between distribution centres can be made using frequencies in bands 4 and 5;

UNANIMOUSLY DECIDES that the following question should be studied:

what can be recommended for the distribution of standard frequencies and time signals above 30 MHz and below approximately 100 kHz?

STUDY PROGRAMME 2A-1/7

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS FROM SATELLITES

(1963 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that continuing advances in communications, particularly in space communications and associated science and technology, have increased the requirements for accuracy and service range of standard-frequency and time-signal emissions;

(b) that the work of Study Group 4 describes radiocommunication systems making use of satellites which can be expected to give extensive coverage and satisfactory stability of signals over the Earth's surface;

UNANIMOUSLY DECIDES that the following studies should be carried out:

the technical factors and quantitative measures to be considered in recommending frequencies and in determining the transmitting, modulating and receiving techniques, which are important to the development of standard-frequency and time-signal emissions from satellites.

STUDY PROGRAMME 2B/7

OPERATIONAL METHODS FOR STANDARD-FREQUENCY AND TIME SIGNAL EMISSIONS IN THE VLF AND LF BANDS

(1976)

The C.C.I.R.,

CONSIDERING

that the usefulness of the standard-frequency and time-signal emissions in the VLF and LF bands depends upon the operational characteristics of the transmitters and upon the modulation methods and formats used;

DECIDES that the following studies should be carried out:

the technical and operational methods for transmitters and antennae, the modulation methods and signal formats to be recommended for the dissemination of standard frequencies and time signals using frequencies below about 100 kHz.

QUESTION 3/7

STABILITY OF STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS AS RECEIVED

(1956 – 1959 – 1963)

The C.C.I.R.,

CONSIDERING

(a) that the standard-frequency and time-signal emissions as received are less stable than at the source, owing to phenomena occurring in the propagation of radio waves, e.g. the Doppler effect, diurnal variation and multipath interference;

(b) that errors, which occur during propagation, depend on the geographical location of both the transmitter and receiver, as well as on the nature and condition of the medium, and generally differ in different regions of the radio spectrum;

(c) that special techniques of standard-frequency and time-signal emissions may improve the accuracy with which they can be received;

(d) that the accuracy with which standard-frequency and time-signal emissions can be received may depend upon the design of the receiving equipment;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the causes of the reduction in the stability and accuracy of the standard frequencies and time signals as received by the users;

2. what is the magnitude in statistical terms of the instability introduced by these causes;

3. what are the most suitable techniques for transmitting and receiving standard frequencies and time signals to obtain the best results in the reception of:

— standard frequencies and time signals as used by those requiring moderate accuracy;

— standard frequencies and time signals as used by those requiring the maximum possible accuracy?

STUDY PROGRAMME 3A-1/7

FREQUENCY-SPECTRUM CONSERVATION FOR HIGH-PRECISION TIME SIGNALS

(1959 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that higher precision in the radio distribution of time signals necessitates, with present techniques, the use of an increased bandwidth;

(b) that newly developed techniques may, nevertheless, effect a considerable economy for a given precision;

(c) the effects of noise of all types on system performance;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. an investigation of the relationship between bandwidth required and precision obtainable at present for various signal-to-noise ratios encountered in practice;

2. an investigation of narrow-band techniques to generate and broadcast high-precision time markers;

3. an investigation of the characteristics of the radio paths involved that limit the accuracy of time signals as received, and how these radio-path parameters affect the choice of an optimum method.

STUDY PROGRAMME 3B/7

INSTABILITY OF STANDARD-FREQUENCY GENERATORS

(1965)

The C.C.I.R.,

CONSIDERING

that the employment of high-quality frequency standards in a wide range of applications has given rise to a need to specify, in convenient and precise terms, the various forms of frequency and phase instability which limit performance in relation to the increasingly stringent requirements;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. how may the various forms of frequency and phase instability inherent in a standard-frequency generator be qualitatively described;

2. how may the limitations of precision imposed by various forms of frequency and phase instability in a standard-frequency generator be quantitatively expressed?

STUDY PROGRAMME 3C-2/7

COMPARISON OF STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(1965 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that many stations participate in the coordination of frequency and time, nationally and internationally;

(b) that Resolution No. 2 of the International Union of Radio Science (U.R.S.I.) adopted in Ottawa, 1969, at its XVIth General Assembly and the resolutions of the International Astronomical Union (I.A.U.) adopted in Hamburg, 1964, during its XIIth General Assembly, recommend that international comparisons be made between the scales of time in use;

UNANIMOUSLY DECIDES that the following studies should be carried out:

comparisons between standard-frequency and time-signal emissions by different methods (exchange of standard-frequency and time-pulse generators, transmissions by radionavigation aids, transmissions over radio-relay links, synchronization pulses of television transmissions, transmissions by satellites, etc.).

STUDY PROGRAMME 3D/7

METHODS FOR RELIABLE VERY LOW FREQUENCY PHASE COMPARISONS

(1970)

The C.C.I.R.,

CONSIDERING

(a) that it is often necessary to produce a mean value based on the time scales of distant clocks or groups of clocks and that, for this purpose, extensive use is made of very low frequency (VLF) phase comparisons;

(b) that, in comparisons of VLF phase, the risk exists at present that the phase continuity as received may be lost from time to time, and that each loss of the phase continuity may cause error which cannot be considered negligible;

(c) that it is extremely desirable that organizations contributing to the formation of international time scales by means of VLF phase comparisons should use only calibrated measuring devices;

(d) that the use of calibrated measuring devices is an essential prerequisite for a thorough study of the problems of VLF propagation;

(e) that it is advisable to measure VLF phase values at the most favourable time of the day from the standpoint of the reliability of the received signal phase;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. how to promote the development and application of apparatus which allows for calibration for VLF phase comparisons;

2. investigation of the propagation behaviour at VLF in order to determine the most favourable reception conditions for daily phase comparisons.

QUESTION 4-1/7

DISSEMINATION OF STANDARD FREQUENCIES AND TIME SIGNALS

(1965 – 1970)

The C.C.I.R.,

CONSIDERING

(a) the need for increased accuracy of standard frequency and time signals;

(b) that the present standard-frequency and time-signal emissions, as received, are degraded in accuracy due to effects in the propagation of the radio waves, such as diurnal variations and the Doppler effect;

UNANIMOUSLY DECIDES that the following question should be studied:

what additional techniques can be employed for improving the accuracy of disseminated standard frequencies and time signals?

STUDY PROGRAMME 4A/7

DISSEMINATION OF STANDARD FREQUENCIES BY CARRIER-FREQUENCY STABILIZATION OF BROADCASTING EMISSIONS

(1966 - 1970)

The C.C.I.R.,

CONSIDERING

(a) the need for investigation of additional techniques for the dissemination of standard frequencies and time signals;

(b) that broadcasting of standard-frequency signals is carried out in some countries by stations in the broadcasting bands;

(c) that certain advantages may be obtained by the technique of stabilizing the carrier frequencies of broadcasting stations, namely:

— the possibility of providing good ground-wave coverage, free of Doppler-effect errors, at centres of population and industry;

— the rapid comparison of frequencies at receiving locations by the use of such sufficiently high carrier frequencies; and

— the use of relatively simple receiving equipment;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the accuracy and stability of received signals from such broadcasts;

2. investigation of the influence of the location of transmitting stations on convenience of use and on propagation characteristics of signals;

3. determination of the desirability of establishing a service of this nature;

4. investigation of the relative merits of amplitude and frequency modulation as related to the dissemination of time signals and of the use of the broadcasting bands for the dissemination of standard frequencies by carrier-frequency stabilization.

STUDY PROGRAMME 4B/7

DISSEMINATION OF TIME SIGNALS BY ADDITION OF PHASE MODULATION ON AMPLITUDE-MODULATED SOUND BROADCASTING TRANSMITTERS

(1974)

The C.C.I.R.,

CONSIDERING

(a) the need for wide dissemination of time signals, without increasing the number of transmitters operating on frequencies allocated to the standard-frequency and time-signal services;

(b) the desirability of investigating additional techniques for disseminating time signals;

(c) Recommendation I.3 adopted by the International Union of Radio Science (U.R.S.I.) at its XVIIth General Assembly, Warsaw, 1972;

(d) the wide geographical coverage of amplitude-modulated sound-broadcasting transmitters in bands 5 and 6;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the possibility of superimposing time signals by phase modulation of the carrier of a conventional amplitude-modulated sound-broadcasting transmitter without disturbance to listeners of the broadcast programme;

2. the possibility of implementation of such techniques on amplitude-modulated sound-broadcasting transmitters in bands 5 and 6.

QUESTION 5/7

HIGH PRECISION STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(1968)

The C.C.I.R.,

CONSIDERING

(a) that there is a growing need, particularly in aviation, for accuracies of standard-frequency and time-signal emissions that exceed those currently available;

(b) that to achieve world-wide uniformity, timing requirements for aviation should be closely coordinated with the International Civil Aviation Organization (I.C.A.O.);

UNANIMOUSLY DECIDES that the following question should be studied:

what methods can be internationally adopted to provide, on a world-wide basis, standard-frequency and time-signal emissions with synchronization uncertainties of 0·5 μs or less (3σ)?

QUESTION 7/7

TIME CODES

(1974)

The C.C.I.R.,

CONSIDERING

(a) the need to provide a complete and unambiguous time reference for a variety of scientific and industrial applications;

(b) that a number of stations now transmit time codes giving, at least, minute, hour and day of year information;

(c) that it is very desirable that such codes be compatible with each other and with commonly available commercial equipment;

UNANIMOUSLY DECIDES that the following questions should be studied:

1. what formats can be recommended for the transmission of time code information;

2. what modulation characteristics will best ensure reliable decoding under conditions of noise and interfering signals?

STUDY PROGRAMME 5A/7

REQUIREMENT FOR HIGH PRECISION TIME

(1976)

The C.C.I.R.,

CONSIDERING

(a) that time transfer is continuously available in many areas with a day-to-day standard deviation of 100 ns by means of LORAN C;

(b) that time comparisons effected by two-way satellite links have been reported with uncertainties of 10 to 50 ns;

(c) that with refinements of satellite techniques and with laser techniques a further reduction in the uncertainty by a factor of ten appears to be possible;

(d) that such refinements are costly and their development should be guided by requirements;

DECIDES that the following studies should be carried out:

the present and projected requirements for high precision time for various applications such as: navigation systems, high-speed data networks, very long baseline radio interferometry (VLBI).

QUESTION 8/7

RELIABILITY OF TIME AND FREQUENCY STANDARDS

(1976)

The C.C.I.R.,

CONSIDERING

that for many applications the reliability of time and frequency standards is of great importance;

DECIDES that the following question should be studied:

1. what criteria should be used for the meaningful expression of the reliability of clocks and frequency standards;
2. how reliable in operation are the existing time and frequency standards;
3. what steps can be taken to increase the reliability of time and frequency standards?

DECISION 12

(RESOLUTION 53)

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 1/7)

(1970 - 1974)

The C.C.I.R.,

CONSIDERING

the provisions of Recommendation 460-1;

UNANIMOUSLY DECIDES

1. that the Interim Working Party 7/1, formed at the Interim Meeting of Study Group VII in Boulder, Colorado, should continue its work with the following terms of reference:

1.1 to study and to propose to the next Interim Meeting of Study Group 7 any modifications that may become desirable in the provisions of Recommendation 460-1;

2. that participants in the work of C.C.I.R. Study Group 7 be requested to assess the effectiveness of the UTC system in meeting the needs of users of standard-frequency and time-signal emissions, and to report their conclusions and suggestions to the Director, C.C.I.R., and the Chairman of Interim Working Party 7/1, before 1 January 1976;

3. that this document be transmitted by the Director, C.C.I.R., to all Administrations Members of the I.T.U., to the Scientific Unions: the International Astronomical Union (I.A.U.), the International Union of Geodesy and Geophysics (I.U.G.G.), the International Union of Radio Science (U.R.S.I.), the International Union of Pure and Applied Physics (I.U.P.A.P.) and other organizations such as the Bureau International de l'Heure (B.I.H.), the International Committee of Weights and Measures (C.I.P.M.), the International Civil Aviation Organization (I.C.A.O.) and the Inter-Governmental Maritime Consultative Organization (I.M.C.O.), inviting them to send their comments and proposals to the Director, C.C.I.R., and the Chairman of Interim Working Party 7/1, before 1 January 1976.

ANNEX

Chairman, Interim Working Party 7/1:

Mr. H.M. Smith
Royal Greenwich Observatory
Herstmonceaux Castle
HAILSHAM
Sussex
United Kingdom

DECISION 13

(RESOLUTION 52)

FORMS OF EXPRESSION FOR USE IN THE STANDARD-FREQUENCY AND TIME-SIGNAL SERVICE

(Question 1/7)

(1970 – 1974)

The C.C.I.R.

UNANIMOUSLY DECIDES

1. that the Interim Working Party 7/2 be maintained to study:

1.1 the forms of expression of all kinds (such as terms, symbols and their definitions) and the condition of their use in the standard-frequency and time-signal service;

1.2 to report the conclusions of its work as soon as possible to Study Group 7;

2. that the work shall be carried out as far as possible by correspondence;

3. that the Joint C.C.I.R./C.C.I.T.T. Study Group on Vocabulary (CMV) shall be informed of the progress of this Working Party.

ANNEX

The Administrations of Germany (Federal Republic of), Argentina, Canada, France, Italy, Japan, United Kingdom, United States of America, U.S.S.R., as well as the Bureau International de l'Heure (B.I.H.) and the International Astronomical Union (I.A.U.), have already indicated their intention and desire to participate in the work of Interim Working Party 7/2.

Chairman, Interim Working Party 7/2:

Professor C. Egidi
Istituto Elettrotecnico Nazionale "Galileo Ferraris"
Corso Massimo d'Azeglio 42
I-10125 Torino
Italy

DECISION 14

REDUCTION OF MUTUAL INTERFERENCE IN THE STANDARD-FREQUENCY AND TIME-SIGNAL SERVICES

(Question 1/7)

(1974)

The C.C.I.R.,

CONSIDERING

(a) that the standard-frequency and time-signal services operating on the allocated frequencies in bands 6 and 7 represent one of the most effective and readily available means of time reference for a large number of users;

(b) that the services operating in these bands have become, in many instances, unsatisfactory due to "mutual interference", that is the interference between standard-frequency and time-signal stations operating synchronously and simultaneously;

UNANIMOUSLY DECIDES

1. that an Interim Working Party 7/3 be set up:

1.1 to study the possibility of introducing appropriate technical means to reduce mutual interference, such as:

— elimination or reduction of carriers and modulations other than the time signals,

— use of time sharing,

— use of offset carrier frequencies,

— use of convenient modulation techniques;

1.2 to investigate possible administrative procedures that might be proposed such as:

— regional assignments of allocated frequencies or schedules, through negotiations between the Administrations concerned,

— the use of additional frequencies in bands 6 and 7,

— investigations to determine if the provisions of the Radio Regulations (Article 44, Section IV) are still adequate;

1.3 to report the conclusions of its work to Study Group 7 as soon as possible and before the XIVth Plenary Assembly of the C.C.I.R.;

2. that the work of this Interim Working Party shall be carried out as far as possible by correspondence.

ANNEX

The Administrations of the United States of America, France, Italy, Japan and the United Kingdom have already indicated their intention and desire to participate in the work of Interim Working Party 7/3.

Chairman, Interim Working Party 7/3:

Mr. J.McA. Steele
National Physical Laboratory
Teddington
Middlesex
United Kingdom

RESOLUTION 14-3

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

(Question 1/7)

(1963 - 1966 - 1970 - 1974)

The C.C.I.R.,

CONSIDERING

the provisions of Article 44, Section IV, of the Radio Regulations;

UNANIMOUSLY DECIDES

1. that, whenever an assignment to a station operating standard-frequency emissions is put into service, the Administration concerned shall notify this assignment to the I.F.R.B., in accordance with the provisions of Article 9 of the Radio Regulations; however, no notice should be submitted to the I.F.R.B. until experimental investigations and coordination have been completed, in accordance with Article 44, Section IV, of the Radio Regulations;

2. that, in addition, each Administration should send all pertinent information on standard-frequency stations (such as frequency stability, changes in the phase of time pulses, changes in transmission schedule) to the Chairman, Study Group 7, and to the Directors, C.C.I.R. and B.I.H., for official publication within the shortest possible time;

3. that Study Group 7 should cooperate with the International Astronomical Union (I.A.U.), the International Union of Radio Science (U.R.S.I.), the International Union of Geodesy and Geophysics (I.U.G.G.), the International Union of Pure and Applied Physics (I.U.P.A.P.) and the Bureau International de l'Heure (B.I.H.).

OPINION 26-2

STUDIES AND EXPERIMENTS CONCERNED WITH TIME-SIGNAL EMISSIONS

(Question 1/7)

(1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the standard-frequency and time-signal emissions are used in many fields of pure and applied science;

(b) that Study Group 7 frequently needs the advice of the scientific unions and organizations;

IS UNANIMOUSLY OF THE OPINION

1. that the General Conference of Weights and Measures (C.G.P.M.), the Bureau International de l'Heure (B.I.H.), the International Union of Radio Science (U.R.S.I.), the International Astronomical Union (I.A.U.), the International Union of Geodesy and Geophysics (I.U.G.G.), and the International Union of Pure and Applied Physics (I.U.P.A.P.) should be asked to cooperate with C.C.I.R. Study Group 7;

2. that the Chairman, Study Group 7, should communicate with the Director, B.I.H., and with the Chairmen of the appropriate Commissions of U.R.S.I., the I.A.U., the I.U.G.G., the C.G.P.M. and the I.U.P.A.P., and that the Director, C.C.I.R., should be informed.

OPINION 27

STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS IN ADDITIONAL FREQUENCY BANDS

(Question 2/7)

(1966)

The C.C.I.R.,

CONSIDERING

(a) that in certain areas, particularly in industrial centres, it is not always possible to obtain an adequate signal-to-noise ratio with the existing standard-frequency and time-signal service;

(b) that a better service is needed in certain areas and this service may be given by use of frequencies in band 8 and higher;

IS UNANIMOUSLY OF THE OPINION

that each Administration should, as far as possible, provide for the distribution of standard frequencies and time signals, on a local basis, two bands 100 kHz wide in bands 8 and 9 respectively, the centre frequencies of which should be whole multiples of 5 MHz.

OPINION 28

SPECIAL MONITORING CAMPAIGNS BY THE I.F.R.B. WITH A VIEW TO CLEARING THE BANDS ALLOCATED EXCLUSIVELY TO THE STANDARD-FREQUENCY SERVICE

(1966)

The C.C.I.R.,

CONSIDERING

(a) Recommendation No. 31 of the Administrative Radio Conference, Geneva, 1959, and the results of the special monitoring campaigns organized by the I.F.R.B., with a view to clearing the bands allocated exclusively to the standard-frequency service;

(b) the need for achieving a more complete clearance of those bands;

(c) the difficulty experienced by the I.F.R.B. in identifying stations not belonging to the standard-frequency service, but operating in the standard-frequency bands;

IS UNANIMOUSLY OF THE OPINION

1. that the I.F.R.B. should be asked to increase, as far as practicable, the number of special monitoring programmes per year, covering the bands allocated exclusively to the standard-frequency service;

2. that the I.F.R.B. should urge Administrations of countries where direction-finding facilities are available to take bearings with a view to determining the position of the stations observed.

OPINION 36-1

TIME SCALES

(Question 1/7)

(1970 – 1974)

The C.C.I.R.,

CONSIDERING

that the introduction of the time scale based on the atomic standards will cover fully the necessities of pure and applied physics, while the universal time (UT) scale covers the necessities of astronomy, geodesy and astronomical navigation, being related to the angular position of the Earth;

IS UNANIMOUSLY OF THE OPINION

that the International Astronomical Union (I.A.U.) and the International Union of Geodesy and Geophysics (I.U.G.G.) should be asked to consider whether the UT scale could be considered henceforth as an angular measure and should be differentiated accordingly.

Note. — The Director, C.C.I.R., is asked to transmit this Opinion to the I.A.U., the International Union of Radio Science (U.R.S.I.) and the I.U.G.G.

OPINION 47

GENERAL USE OF COORDINATED UNIVERSAL TIME

(1974)

The C.C.I.R.,

CONSIDERING

(a) that the 14th General Conference of Weights and Measures (C.G.P.M.) in October, 1971 defined the International Atomic Time scale (TAI);

(b) that TAI is neither distributed in the form of time signals nor is it used by the public;

(c) that the Coordinated Universal Time (UTC) system, which in accordance with Recommendation 460-1 was designed for the joint transmission of TAI and UT, is closely and simply associated with TAI;

(d) that the UTC system has proved itself and is used extensively for the specification of dates;

IS UNANIMOUSLY OF THE OPINION

that the International Committee of Weights and Measures (C.I.P.M.) and the C.G.P.M. should be asked to recognize the system of Coordinated Universal Time (UTC).

OPINION 48

TIME-SCALE NOTATIONS

(1974)

The C.C.I.R.,

CONSIDERING

(a) that abbreviations for the terms concerned with time and frequency in the framework of the interests of C.C.I.R. Study Group 7 are used world-wide and it is desirable, therefore, that they should be independent of language;

(b) that the organizations of the Metre Convention have adopted the abbreviation TAI for the International Atomic Time scale;

(c) that there are at present no language-independent abbreviations for Universal Time, Coordinated Universal Time and Atomic Time;

IS UNANIMOUSLY OF THE OPINION

that the international organizations concerned with the use and definition of time should be asked to consider the advisability of:

— the introduction of language-independent notations, or

— the adoption of certain of the currently used abbreviations for all languages.

Note. — The Director, C.C.I.R., is asked to transmit this Opinion to the International Civil Aviation Organization (I.C.A.O.), the Inter-Governmental Maritime Consultative Organization (I.M.C.O.), the General Conference of Weights and Measures (C.G.P.M.) and also to the International Union of Radio Science (U.R.S.I.), the International Astronomical Union (I.A.U.), the International Union of Geodesy and Geophysics (I.U.G.G.), the International Union of Pure and Applied Physics (I.U.P.A.P.), the Bureau International de l'Heure (B.I.H.), the International Organization for Standardization (ISO) and to the Joint Advisory Group of the Institute of Navigation (JAG/ION).

ISBN 92-61-00081-9 PRINTED IN SWITZERLAND