RECOMMENDATION ITU-R TF.1011-1

SYSTEMS, TECHNIQUES AND SERVICES FOR TIME AND FREQUENCY TRANSFER

(Question ITU-R 102/7)

(1994-1997)

The ITU Radiocommunication Assembly,

considering

a) the continuing need in all parts of the world for readily available standard frequency and time reference signals;

b) that different levels of precision and accuracy, ranging from 1 s down to about 1 ns, are required for the large number of diverse applications for time and frequency;

c) that, in many time and frequency applications, the selection of an optimum time and frequency transfer system or technique must also take into account other factors, such as availability, reliability, capabilities for automatic operation, convenience of use and cost;

d) that, throughout the world, many different systems, techniques and services have been used successfully to satisfy a large variety of time and frequency requirements;

e) that useful systems, techniques and services include both those dedicated for time and frequency needs and others that are designed primarily for other functions, such as navigation or communications,

recommends

1 that, when selecting a suitable source of time and frequency reference signals or an optimum technique for time and frequency transfer, each application first be carefully analysed with respect to the relative importance of accuracy and/or precision, geographical coverage, availability (for example, the fraction of time that the signal is available at the stated performance level), ease of use and user costs;

2 that, based on such an analysis of specific requirements and their relative importance, suitable systems, techniques or services could be selected from those listed in Annex 1[*] along with their most important characteristics.

[*] Additional information is also available in the ITU-R Handbook on selection and use of precise frequency and time systems.

ANNEX 1

TABLE 1

Details of various dissemination and comparison methods for time/frequency applications

Type	Typical time accuracy capability, vs universal coordinated time (UTC)	Typical frequency transfer capability	Coverage	Availability	Ease of use	Approximate relative user cost ($US 1992)	Example system	Comments (1992)
HF broadcast	1 to 10 ms	10^{-6} to 10^{-8} (over 1 day)	Global	Continuous, but operator and location dependent	Depends on accuracy requirements	50 to 5 000	Many services worldwide	Accuracy depends on path length, time of day, receiver calibration, etc.
LF broadcast	1 ms	10^{-10} to 10^{-11}	Regional	Continuous	Automatic	3 000 to 5 000	See Recommendation ITU-R TF.768	Depends on distance from the source and diurnal propagation (ionosphere height)
LF navigation (pulsed)	1 µs	10^{-12}	Regional	Continuous	Automatic	12 000	LORAN-C	Northern hemisphere coverage. Stability and accuracy based on ground wave reception
Television broadcast terrestrial links	10 ns for common view	10^{-12} to 10^{-14} (over 1 day)	Local	Dependent upon local broadcast schedule	Automatic	5 000		Calibration required for timing
Navigation satellite, broadcast	50 to 500 ns	10^{-10} to 10^{-12}	Global	Continuous	Automatic	3 000 to 15 000	Global positioning system (GPS) and GLONASS	One day averaging necessary to meet specified frequency transfer capability. Best broadcast system available today with commercial receivers
Navigation satellite, common view	5 to 20 ns	10^{-13} to 10^{-15} 1 to 50 days	Intercontinental	Continuous	Automatic data acquisition Requires post processing	10 000 to 20 000 per site	GPS and GLONASS	Most accurate widely used, time synchronization method that is available today (1992) with commercial receivers for baselines less than 8 000 km
Meteorological satellite, broadcast	100 µs	Not recommended for frequency transfer	Regional (satellite footprint)	Continuous	Automatic	4 000 to 5 000	Geostationary operational environmental satellite (GOES)	May not be available during satellite eclipse

TABLE 1 (*continued*)

Type	Typical time accuracy capability, vs universal coordinated time (UTC)	Typical frequency transfer capability	Coverage	Availability	Ease of use	Approximate relative user cost ($US 1992)	Example system	Comments (1992)
Other geostationary broadcast satellites	20 µs	5×10^{-10}	Regional (satellite footprint)	Continuous	Automatic	4 000	INSAT	May not be available during satellite eclipse
Communication satellite, two-way	1 to 10 ns	10^{-14} to 10^{-15}	Regional (satellite footprint)	Continuous (as scheduled)	Data acquisition can be automatic (depending on satellite). Post processing required	50 000 per site	North American and European networks exist	Most accurate operational method at this time
Telephone time code two-way	1 to 10 ms	10^{-8} (over 1 day)	Telephone calling range	Continuous	Automatic	100	Europe and North America	Phone line must have same path in both directions. Assumes computer and software availability
Optical fibre	10 to 50 ps	10^{-16} to 10^{-17}	Local less than 50 km	Continuous	Automatic	Transmitter and receiver $US 30k per set plus cable and underground installation costs	Dedicated to frequency transfer	Cable must be temperature stabilized, (e.g. 1.5 m underground)
	100 ns	10^{-13} to 10^{-14} (over 1 day)	Long distance 2 000 km	Continuous	Automatic	Not applicable. The equipment is a part of a specific communication system	Synchronous digital hierarchy (SDH)	Part of a digital communication system
Microwave link	1 to 10 ns	10^{-14} to 10^{-15}	Local	Continuous	Automatic	50 000 to 75 000		Sensitive to atmospheric conditions and multipath effects. Must be two-way to achieve stated accuracy and stability
Coaxial cable	1 to 10 ns	10^{-14} to 10^{-15}	Local	Continuous	Automatic	5 to 30 per metre		Sensitive to temperature, voltage standing wave ratio (VSWR), humidity, barometric pressure

Special notes concerning the various dissemination/comparison methods

Attention should be paid to the fact that in order to achieve the stated accuracies, calibration of the user equipment is often necessary.

HF broadcasts

Many of the HF broadcast services make use of the internationally allocated frequencies for this purpose at 2.5, 5, 10, 15, 20 and 25 MHz. Other HF services use frequencies in other bands in order to reduce mutual interference. Such services provide modest accuracy performance but offer advantages in terms of wide geographical coverage, convenience of use (for 1 s accuracy level) and inexpensive user equipment. Recommendation ITU-R TF.768 contains detailed information on formats, broadcast schedules and other characteristics of most HF time and frequency services.

LF broadcasts

Broadcasts of this type, useful for time and frequency applications include:

– various dedicated time and frequency services operating in the 40-80 kHz band; and

– radionavigation system broadcasts, such as Loran-C stations at 100 kHz, which provide highly stabilized and synchronized transmissions. The dedicated time and frequency services often include phase and/or amplitude modulations that provide complete time and date information in coded form. A large number of Loran-C stations exist, principally in the northern hemisphere. Main advantages include good accuracy for both time and frequency, availability of relatively inexpensive receivers and convenience of use. One disadvantage is the undetected occurrence of cycle slips, which degrade the accuracy. Recommendation ITU-R TF.768 contains detailed information on formats, broadcast schedules and other characteristics of many LF transmissions.

VLF broadcasts

VLF broadcasts in the 10-30 kHz range are useful primarily for frequency applications. Stable propagation characteristics and long-distance coverage make such signals useful for frequency comparisons at the 1×10^{-11} level or better. VLF broadcasts do not normally contain complete time-of-day information. Recommendation ITU-R TF.768 contains detailed information on formats, broadcast schedules and other characteristics of some useful VLF transmissions.

Television broadcasts

A number of methods for using television broadcasts for time and frequency dissemination and comparisons have been tried and some are in current use. These include the insertion of coded time and frequency information into the television signal, the stabilization of television carrier frequencies and synchronization pulses and the common-view reception of a single television transmission in a local area. The most commonly used method today involves the common-view method allowing timing systems to be compared within a local station coverage area to within about 10 ns.

Navigation satellite (broadcast)

This technique employs the direct reception of timing information from navigation satellite systems such as the Global Positioning System (GPS) and the GLONASS system. Information is included in the satellite signals which allows the user to compensate approximately for the propagation delays and apply corrections for differences between the local satellite clock and UTC. Accuracies of better than 500 ns for time and 1×10^{-12} for frequency comparisons are possible, even in the presence of intentional degradation of the signals, known as selective availability. Principal advantages include: widespread availability of commercial receivers; global coverage from multiple satellite (21-24 per system); automatic operation; high accuracy and use of onboard atomic standards.

Navigation satellite (common-view)

With this technique the same GPS or GLONASS satellite is observed from two different timing sites at precisely the same time. Subtracting the results from the two sites eliminates effects of the satellite clock and at least partially compensates for ephemeris errors. Intentional degradation of the satellite signals may or may not degrade the common-view time comparisons, depending on how it is implemented. Time comparison uncertainties of better than 20 ns for widely separated sites are routinely possible. This approach offers higher accuracy than the direct method but requires special coordination arrangements among the sites being compared. Bureau international des poids et mesures (BIPM) publishes schedules to enable the required coordination. To achieve the 10^{-15} uncertainty, integration times up to 50 days are required.

Meteorological satellite

Two geostationary satellites of the geostationary operational environmental satellite (GOES) system have been used since 1974 to disseminate a UTC time code to the region of North and South America and the surrounding ocean areas. Complete time and date information is transmitted continuously along with satellite position information for automatic path delay compensation by the user's receiver. Uncertainties of less than 100 µs can normally be achieved. Geographical coverage from the GOES satellites may be somewhat limited beyond North and South America until the satellite constellation is replenished with newer satellites, scheduled for the 1994-1995 period.

Other geostationary broadcast satellites

Other satellite systems have also been used for transmitting time signals in a one-way mode. Currently, the multi-function INSAT satellites transmit a complete time code to a coverage area within and around the Indian subcontinent. Satellite position information is also included in the format, allowing users with automatic receivers to compensate for path delay within an accuracy of about 20 µs.

Communications satellites (two-way mode)

At present, the two-way exchange of timing signals through communication satellites offers the most accurate technique for comparing remote timing sites. Much experience has been gained throughout the world with this technique and an increasing number of timing centres are using, or preparing to use, this technique for operational international time transfers to an accuracy level that approaches 1 ns. Advantages include the high accuracy capability and the availability of many suitable communication satellites in all regions of the world. Disadvantages include the need for users to both transmit and receive timing signals and the relatively high equipment costs. At the highest accuracy levels the careful calibration of ground-station equipment delays is a difficult, but necessary, requirement. Specialized time-transfer modems, optimized for high accuracy and stability, are being developed for timing applications. Ten days of integration are required to reach the 10^{-15} accuracy.

Telephone time code

Several timing centres in North America and Europe have established services designed to disseminate coded time information over telephone lines in an automated mode. Typically, computers and other automated systems are programmed to dial such services as needed, receive an ASCII time code, reset the local clock and automatically correct for the path delay involved through the telephone system. The path delay compensation can be performed either by the timing centre's equipment or at the user's site. Accuracies in the range of 1-10 ms are possible in many cases. Advantages include simplicity, very low user cost and suitability for automated systems. The principal disadvantage is the limited accuracy.

Optical fibre (local)

Two types of fibres (multimode and single mode) are in use today. Multimode is generally used to transmit digital data and low frequencies over a relatively short distance (e.g. 1 km). Single mode is best for a longer distance (e.g. 50 km) and is wideband (e.g. 5 MHz to 100 GHz). Single mode fibre with a 1 300 nm laser is required to meet the performance stated in the table. The nominal coefficient of delay with respect to temperature is 7×10^{-6}/°C. In order to meet the stated performance, the cable must be temperature stabilized, i.e. put underground 1.5 m for any reasonable length (e.g. 50 m or more). Insertion loss is approximately 0.5 dB/km.

Optical fibre (remote)

The accuracies stated in Table 1 have been achieved in optical fibres over a distance of 2 400 km in a digital telecommunication system. Carefully minimizing cable length asymmetry in the round-trip transmission path can achieve sub-microsecond time accuracy and time stability of about 1 ns. The terminal delay of a particular system adhering to Recommendations ITU-T G.707, ITU-T G.708 and ITU-T G.709 was controlled to within 5 ns.

Microwave link

Microwave links are generally limited to line-of-sight unless repeaters or billboard reflectors are utilized. Generally, a dedicated channel rather than time-share multiplexing is required for short-term, continuous operation. To meet the stated requirements in Table 1, two-way operation to null-out phase fluctuations is required. This means a feedback system and a continuously operating channel. Microwave links are sensitive to atmospheric conditions (rain, snow, antenna vibration, etc.) and multipath effects.

Coaxial cable

To meet the stated performance, factors such as temperature stability, length and type of coaxial cable must be considered. Insertion loss is dependent on cable length, type and frequency involved. Solid dielectric cables have a coefficient of delay of 250×10^{-6} (or even greater at 25° C); air dielectric is 15×10^{-6}, but must be dry-nitrogen pressurized with a dual-stage pressure regulator in a temperature-controlled environment. Cable temperature must be stabilized by installing the cable 1.5 m underground or in an environment with less than 1° C variation. Coaxial cables should be considered only for reasonably short lengths of less than several hundred metres.