A TELEPHONE-BASED TIME DISSEMINATION SYSTEM

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ABSTRACT

Telephone time dissemination can serve a broad spectrum of users who require time accuracy in the millisecond range and who are reluctant to use radio time dissemination services. A system which uses a simple protocol for telephone loop-delay correction is presented.

The protocol uses ASCII characters transmitted by the frequency shift keying techniques of standard 300 baud modems. The protocol is designed for the transfer of the correct time from a master clock to a slave clock. The slave clock places the telephone call, puts the master clock into a prompt echo mode, measures the loop delay time, and applies half the loop delay time as a correction to the time it receives from the master clock. The precision and accuracy of this protocol are discussed and measurements are presented on the precision of time transfer using Leitch CSD-5300 units as master and slave clocks.

The capabilities of the full system, and the Leitch CSD 5300 units which are used at each distribution node, are discussed as possible solutions to questions that are often addressed (or misaddressed) to "Precise Time" research groups.

Introduction

NRC (National Research Council of Canada) maintains and disseminates the basis for legal time in Canada. In Canada time dissemination by telephone has been viewed as a valuable adjunct to radio-based service. It avoids the real and perceived problems of antenna placement and signal availability which trouble some potential clients. Two-way telephone data communication can correct the received time for signal propagation delays if the telephone link has approximate reciprocity. Previous NRC experiments some ten years ago showed that the loop delay (of up to $\frac{1}{2}$ second for a one-hop satellite link) could be measured and corrected for to permit millisecond accuracy in time transfer using Bell 103 compatible 300 baud frequency shift keying modems. This accuracy is possible over even a relatively low-grade telephone link. The prototype nodes for the time dissemination system that were developed at that time for NRC were not brought into production. Other recent studies in Japan [1] and North America [2] have also shown a potential accuracy of a millisecond or better.

NRC's plans for a telephone time dissemination network were reactivated when it was learned that Leitch Video planned to market a unit which could be used to disseminate time with an accuracy of several milliseconds. Leitch Video is a manufacturer of broadcast television equipment. Leitch has been supplying clock system drivers for the clock systems of radio and television stations world wide for approximately ten years. In the broadcast industry an accuracy of ± 3ms (approximately 1/10 of one frame of video) is sufficient for most applications. This order of accuracy seems acceptable to many industries, and is potentially interesting to many more if it can be delivered reliably, conveniently and at low cost. Computer and telecommunications networks might well profit from this level of accuracy for time dissemination. Other users will want traceability to UTC, and may even want certification - remote certification appears feasible only in a time dissemination system that uses two-way communications.

Node Hardware

With encouragement and suggestions from NRC, Leitch Video designed the clock system driver CSD-5300 shown in Fig. 1. It is now in full production. It is based on an ovenized crystal oscillator which can be phase locked to an external 5 MHz or 10 MHz atomic frequency standard. Two levels of battery backup are provided. It can conveniently be synchronized to a UTC 1 pps to within about 20 μs, and has a 1 pps TTL output: it is very much at home in a precise time laboratory. It can also distribute accurate time locally in its rack, room, building and community.

For example the CSD-5300 can directly drive the impulse clocks of a building that has been so equipped. For these venerable building clock systems, of course the hands of each clock face must still be initially set manually - but thereafter the time would be controlled by the CSD-5300. Leap seconds can be corrected for in seconds, and a change from/to standard to/from daylight saving time can be completed in an hour.

Desk, wall, and rack mount analog and digital clocks are also available from Leitch Video. They use the SMPTE (Society of Motion Picture and Television Engineers) time code[3] which the CSD-5300 provides in real-time. The SMPTE time code is a 2400 baud Manchester encoded (or split-phase or bi-phase) synchronous signal of 80 bits including a 16 bit sync word, provided 30 times per second. This time code (and variants) are in extremely widespread use in video based systems. The variants are the EBU or European Broadcast Union standard, (using 25 rather than 30 frames per second), and the drop-frame SMPTE code which accounts for the fact that the NTSC (National Television System Council) video standard used in North America specifies not quite 30 frames per second. The SMPTE time code bit pattern is shown in Fig. 2. For the CSD-5300, six of the 32 user bits of the SMPTE time code are used to specify an auxiliary offset for the remote clocks driven from the CSD-5300 in half-hour increments. Thus the CSD-5300 may be kept on UTC with its remote clocks on local time. This output can be transmitted over a simple twisted pair. It can feed mainframe computer channels directly, or be separated into a NRZ (non-return to zero) bit stream and 1x clock with simple hardware to drive standard serial input ports.

The time code is also available from the CSD-5300 as a clocked serial stream (time bits only), and as parallel BCD (time bits only). The time is also available using a simple protocol using the CSD-5300's RS-232-C port at 300 baud, or via telephone using the CSD-5300's integral direct-connect Bell-103 compatible modem at 300 baud. In this way local and remote computers can set their internal clocks. Anecdotal evidence suggests a standard deviation of 15 seconds for computer clocks that are independently set by computer operators strictly adjured to set the computer clock to the "correct time". By telephoning a CSD-5300, an accuracy for setting a computer clock of better than 10 ms is easily achieved: the time is sent to an ASCII character string that terminates with a carriage return, and the end of the stop bit of the carriage return marks the time that has just been sent by the CSD-5300. The full protocol is described in Fig. 3.

A CSD-5300 that is remote from a precise time laboratory can be commanded to telephone a CSD-5300 in a precise time laboratory to extract the correct time, and the time so obtained can be passed on to other CSD-5300's in a hierarchical time dissemination system. CSD-5300 units can be set to not answer incoming telephone calls, and so a CSD-5300 can share its telephone line.

A password-protected "system mode" may also be enabled or disabled for the CSD-5300 units. In this mode a precise time laboratory can telephone a remote CSD-5300 and command it to have leap seconds or daylight saving/standard time changes armed to occur at a particular time. The system mode allows full remote control over the CSD-5300, including time adjustments with millisecond resolution and adjustments to its telephoning program. The system mode is an important asset to the manager of any system with remote CSD-5300's.

Delay Reciprocity

For any system attempting accurate time dissemination by telephone, one major concern is the reciprocity of telephone line delay. It is easy to measure the sum of the two line delays - i.e. the loop delay. One would like to assume reciprocity, and from the loop delay deduce the line delay in the telephone line from the master clock to the slave clock.

With the Bell 103 standard frequency shift keyed modems, the originating modem transmits frequencies of 1070 and 1270 Hz, while the answering modem transmits 2025 and 2225 Hz. Some degree of non-reciprocity will be introduced by any dispersion - i.e. variation in the group velocity with audio frequency. Since this dispersion degrades speech clarity it is rather well controlled by the telephone companies. It was not necessary to use a special protocol to swap frequencies and to measure the loop dispersions to meet our goals. Thus any Bell 103 standard modem can be used to access the full precision of the time dissemination system. For short distances, telephone companies use "two-wire connections", but for longer distances they will generally use a "4-wire connection" - i.e. a separate voice channel operating in each direction. While this can be a significant factor, whose effects have been observed in some of our tests, it does not appear to be a preclude millisecond accuracy even in the worst case. The worst case is a satellite link one way (~ $\frac{1}{4}$ s delay) and a ground link the other way (with an uncertain line delay of some 10's of milliseconds). Our experiments have shown that this condition occurs very infrequently and randomly on repeated calls between the same two points. Since these occurrances are easily identified by a range of loop delay times which are not otherwise encountered (~ 200 ms to ~ 300 ms), it is possible to consider any such call to be a failure and to abort it. This is done automatically by the CSD-5300 unit, and after any call is aborted the unit will attempt up to seven more calls at randomized intervals over a period of one hour. The same sequence of events is used for calls aborted for other reasons such as a busy signal or a poor connection. To date we know of no case where a CSD-5300 has been unable to correctly get the time due to reciprocity problems.

NRC Network: Plans and Tests

NRC has planned a Canada-wide time dissemination network using the Leitch CSD-5300 units. The master station has been designed and implemented using three slightly modified CSD-5300 units in a triple redundant configuration. Each CSD-5300 is phase locked to a different NRC Cs clock. The clocked serial time code of each unit is checked 30 times per second against the other two CSD-5300's to identify and latch any differences in time-of-day. The same unit will also identify and latch any drift by ± 1/2 bit or ± 208 μs. As long as two (or more) units have active time codes which agree and have agreed since the last "reset", one of these is designated to answer the telephone and control the master node. Any error condition is latched and requires an operator to identify and correct the source of the error, and to manually reset the comparator.

The triple redundant master node has been in operation for eight months. It forms the apex of the pyramidal telephone time dissemination network that we are implementing. We plan to have a Leitch CSD-5300 sub-master in each major centre of population in Canada, which will be programmed to originate a call to the master station in order to update its time every day or so. In the same way, layers of the pyramid below the sub-master will each be programmed to call the layer immediately above it. The pyramid is illustrated in Fig. 4.

In the master station there is a network control computer which will be able to call the sub-master nodes (and other client nodes who wish to have this NRC time calibration service) in the password-protected "system" mode to arm leap-seconds and to arm changes to and from daylight saving time. The computer is also interfaced to a "checking" Leitch CSD-5300 which can be commanded to interrogate any remote clock. Immediately after a remote clock is interrogated by the checking CSD-5300 at the master station, the time offset of the checking CSD-5300 with respect to UTC(NRC) is measured by a time interval counter. A system-mode call (or calls) from the master station can then be scheduled as required to set the time in the remote clock with 1 millisecond resolution. This call re-initializes the software timer that schedules the next call to be originated by the remote sub-master. For remote sub-master stations the call originate mode will serve as a backup mode in the absence of service from the checking computer. The operational advantage of this mode is that time coherence is maintained during the reset, so that the checking computer can monitor the sub-master oscillator frequencies to 10^{-9} or better, and can calculate the day and time at which the next 1 ms time offset is to be applied in order to correct for the measured frequency offset.

This "checker" mode has been used to measure the distribution of time extracted from remote CSD-5300 units over different telephone links. The results are shown in Fig. 5-a - 5-d. In each case 500 calls (each of about 30 sec. duration) were made from the NRC time laboratory over the course of some six hours. Fig. 5-a shows the time distribution for calls back to the master station in the NRC time laboratory with a variance of 34 μs. For calls across the city (about 15 km), the distribution is bimodal as shown in Fig. 5-b, with a variance of 45 μs. For long-distance calls made by leased-line (Fig. 5-c) and public-access lines (Fig 5-d) to Toronto (350 km) the variances were 135 μs and 307 μs respectively. We anticipate millisecond precision to be achievable throughout the planned network.

For the planned network around each major centre of population, the sub-master in turn will serve as master for the next layer of the pyramid. We expect the sub-masters to serve local customers' Leitch CSD-5300's. There are two other kinds of service which are envisaged for this network to deliver using CSD-5300's one layer below the sub-master layer.

The first is talking-clock service, largely for automated telephone time-of-day announcements. It will be possible technically to offer talking-clock service with 10 ms accuracy in all six time zones across Canada. To this end NRC has built microprocessor-based English and French talking clocks, and interfaced these units to the Leitch CSD-5300.

The other service is time dissemination to computers, to set the internal time-of-day clocks with better than 10 ms accuracy. It is simple to use the Leitch protocol with any computer having a Bell 103 compatible modem. The protocol is indicated in Fig. 4. A naive user will receive the time-of-day for three successive seconds as three ASCII strings each terminating with a carriage return. At the transmitting CSD-5300, the end of the stop bit of the carriage return is the time indicated by the ASCII string. A user who with very modest sophistication can interrogate for the date and time at will, and a user with somewhat more sophistication can program an approximate timing loop to measure the loop delay, verify that it is a legal loop delay, and apply a correction to the received time. A user who is telephoning the master or sub-master via a local rather than a long-distance telephone call will normally not need to do a loop delay measurement, unless the ultimate in performance is being sought. For a computer user who is willing to exercise considerable care in the timing for the serial port service routine, it should usually be possible to approach the resolution of the serial port - which is commonly 1/8 of the baud rate (for serial ports with $\times 8$ clocks that check the state of the asynchronous serial input eight times per bit) or about 0.4 ms. Computer users trying to get accurate times from their computers' clocks must be prepared to set the clock rates by hardware or software. They must also be prepared for peculiarities in their systems: for example the popular IBM-PC normal time-of-day clock will run at one rate when DOS is loaded, and at a noticeably different rate when the most popular versions of BASIC are loaded.

Summary and Conclusions

A telephone time dissemination system giving millisecond accuracy has been presented. The nodes of the system are based on Leitch Video CSD-5300 units. It uses standard asynchronous telecommunications signals (Bell 103 compatible at 300 baud) and a public-domain protocol to transmit date and time and to measure the loop delay of the telephone link. Even in the worst case encountered, it has been possible to obtain adequate reciprocity of the one-way telephone line delay to permit millisecond accuracy for time transfer. Some of the ancilliary capabilities of the Leitch CSD-5300's have been pesented, and plans for a Canadian telephone time dissemination network have been discussed.

Acknowledgements

It is a pleasure to acknowledge the many contributions of C.C. Costain to the development both of the CSD-5300 and the Canadian telephone time dissemination system.

References

1) Time Comparison Using Telephone Line, M. Aida, T. Sato and S. Yamamori, Rev. Radio Res. Lab. (Japan) 31, p. 115-124 (1985)

2) D. Jackson, private communication.

3) Society of Motion Picture and Television Engineers: Journal 88, p. 497-501 (1979).

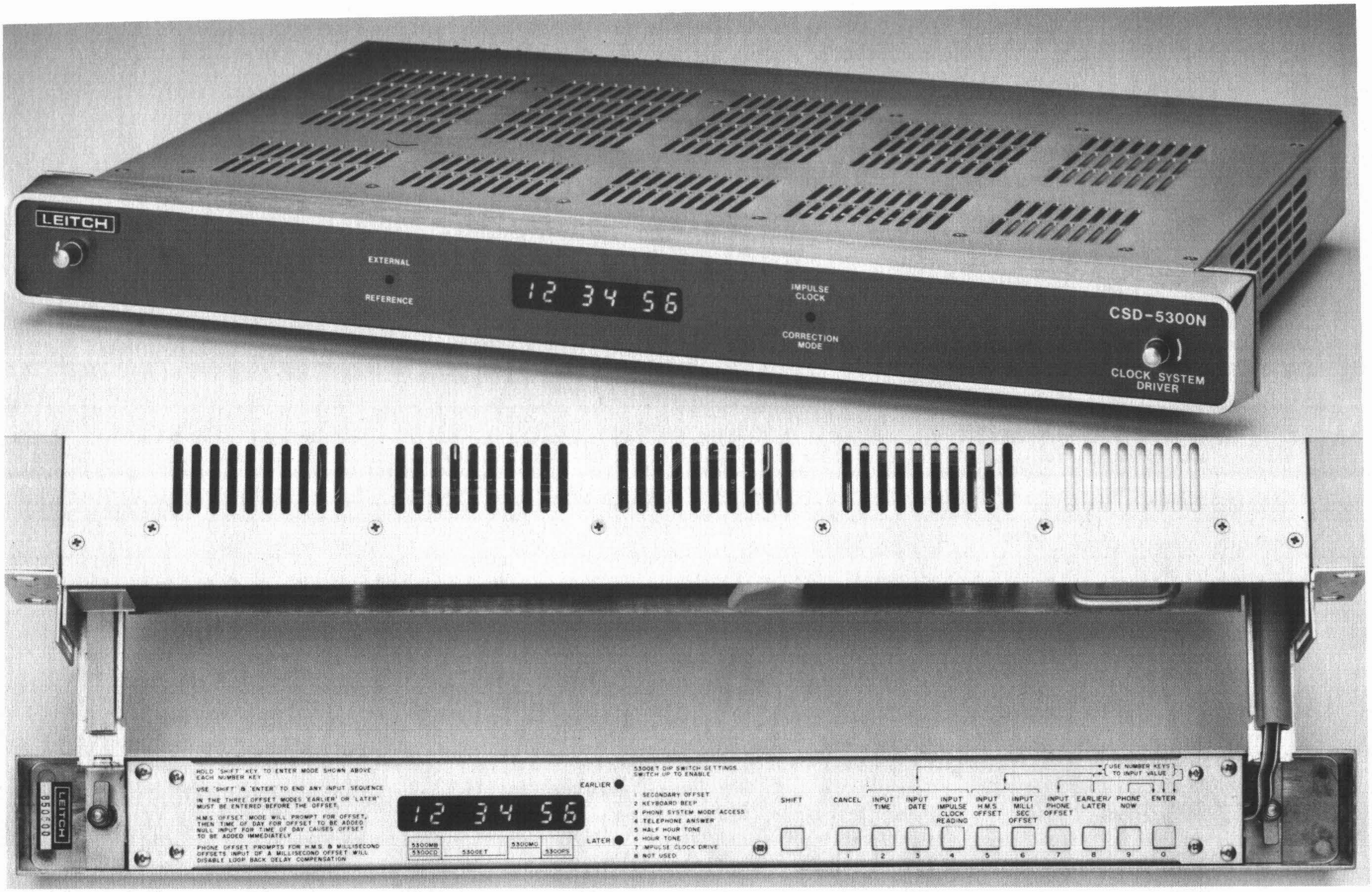

Figure 1. A Leitch Video CSD-5300 telephone time dissemination unit, showing the front panel control keyboard·up and down.

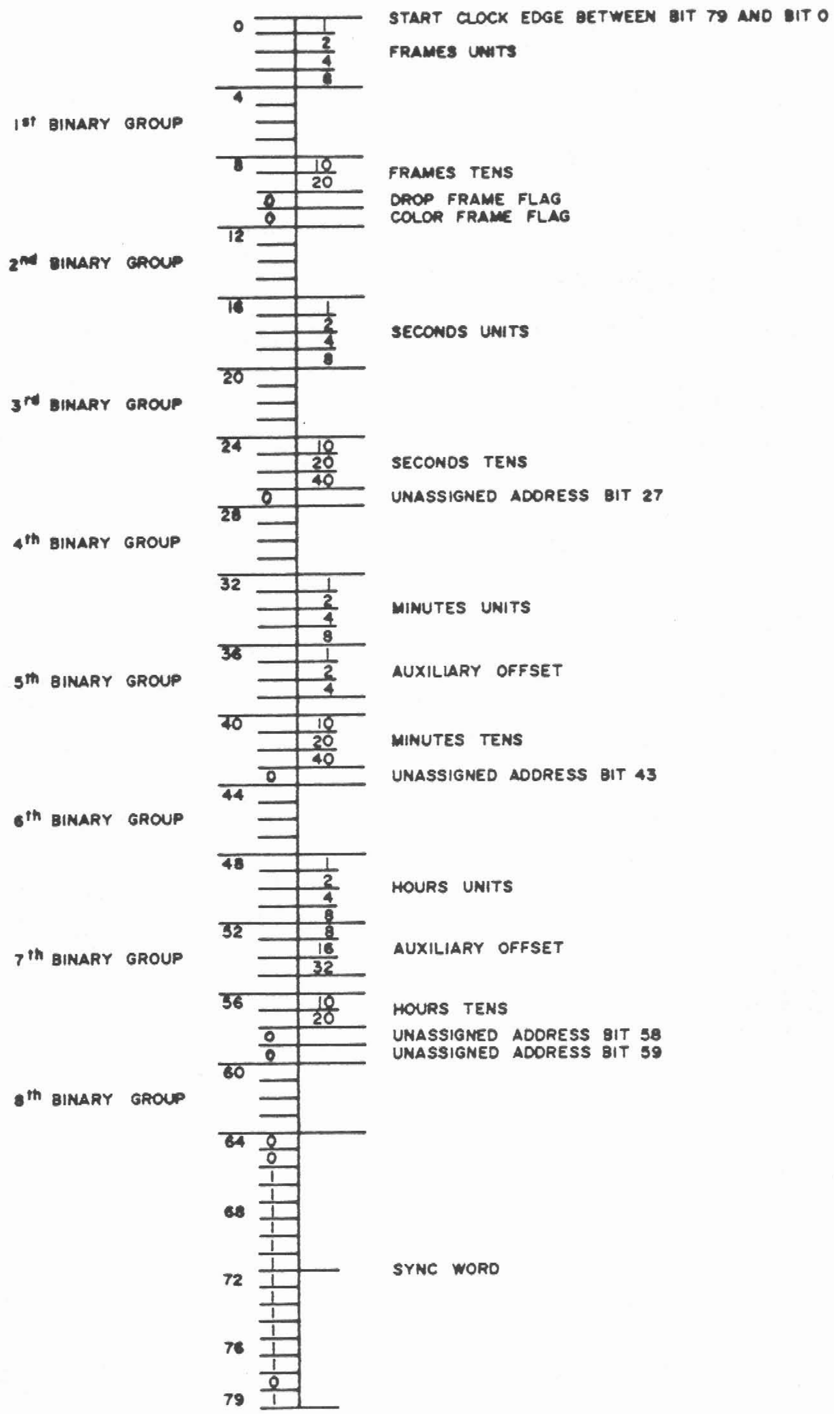

Figure 2. The 80-bit, 2400 baud Society of Motion Picture and Television Engineers (SMPTE) time code. For non-video use the time code is called "non drop-frame", and each "frame" is intended to be exactly 1/30 s. The time code uses 26 bits as binary coded decimal numberals for the frame count (0-29, the seconds (0-59 normally), the minutes (0-59), and the hours (0-23). There are six other bits reserved by the SMPTE standard, and there are 32 user bits, arranged in 8 binary groups, which can be used without restriction. The interleaving of time code and user nibbles ensures that there can be no accidentally generated 16-bit sync word for any combination of user bits. Six of the user bits have been assigned by Leith Video to code an auxilliary clock offsèt in binary, in half-hour increments (0-47 coding 0h to 23h 30 m).

Leitch CSD−5300 Protocol

- **Public Domain**
- **Used in NRC telephone time dissemination network**
- **ASCII characters used. 8 data bits, no parity bit, 1 stop bit. Bell 103 compatable modem at 300 baud.**

Originating Unit		Answering Unit
T C_R	*Time*	hhmmss C_R
		hhmmss C_R
		hhmmss C_R ***(stop bit of C_R marks the second)***
D C_R	*Date*	YYMMDD C_R
L C_R *X*	*Loop−back Echo*	*X* ***(any character "X")***
S C_R	*Status*	G C_R ***(good)***
		D C_R ***(diagnostics failed)***
		T C_R ***(time not set)***
		P C_R ***(lacks phone update)***
HU C_R	*Hang up*	***(hangs up)***

Figure 3. The telephone time transfer protocol used in the Leitch CSD-5300 and the NRC telephone time dissemination network. The symbol C_R is used above to indicate the ASCII character for "carriage return".

NRC Canadian Telephone Time Dissemination Network

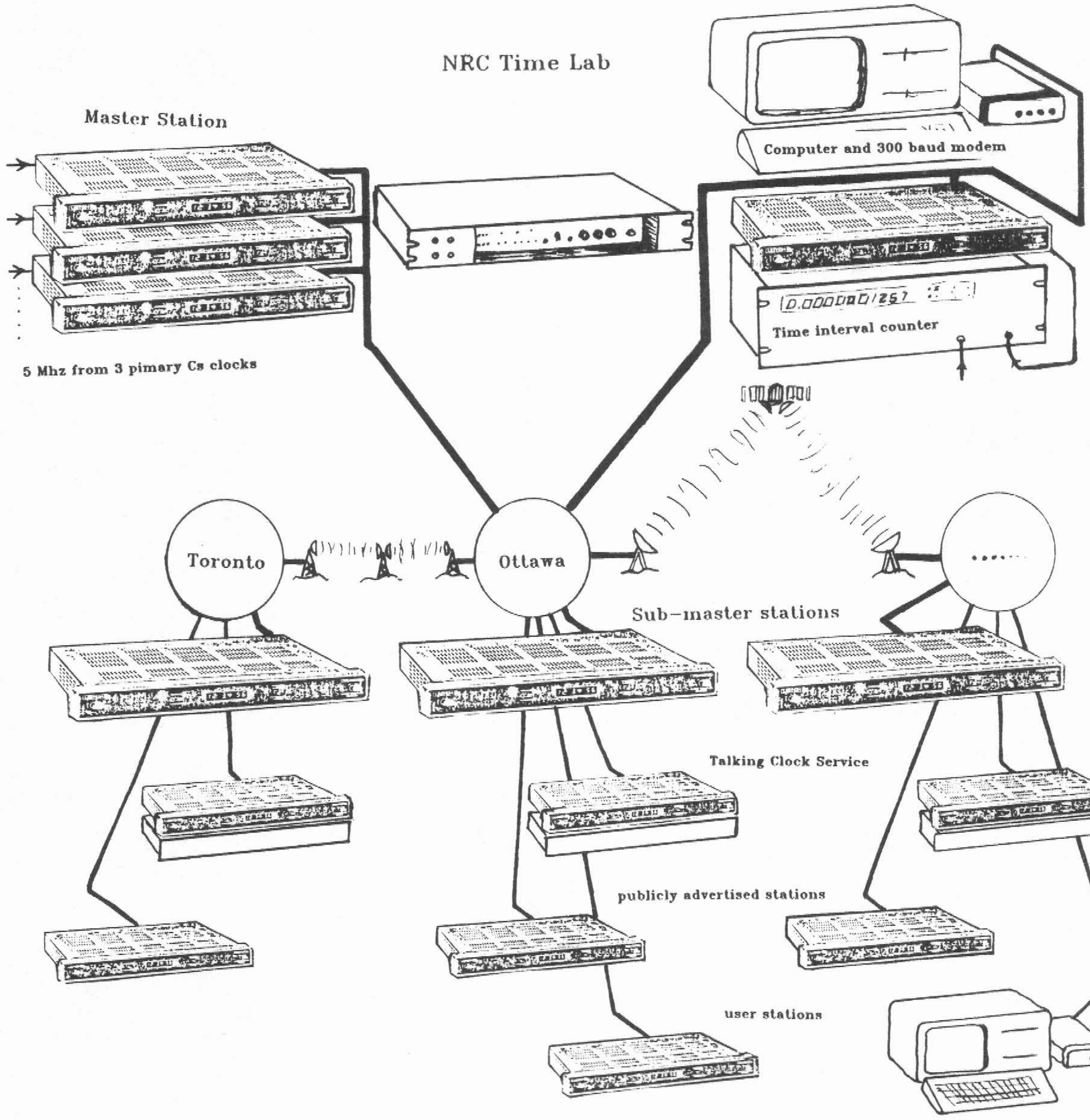

Figure 4. The planned Canadian telephone Time Dissemination Network. NRC will be the triple-redundant master station and majority-logic comparator. Also at the NRC time laboratory will be the checking node. These units will set and monitor the sub-master stations, to be established in major cities across Canada. User CSD-3500's will have access to these sub-master stations, and both talking clock service and publicity advertised computer time service could be set from the local sub-master stations.

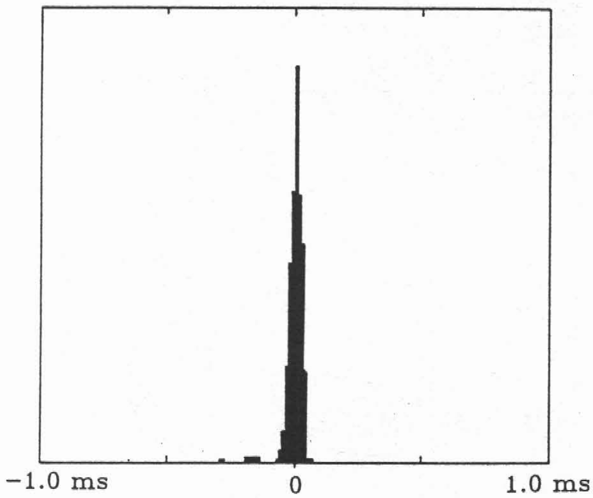

Figure 5a. Calls from NRC time laboratory to NRC time laboratory. σ = 34 μs.

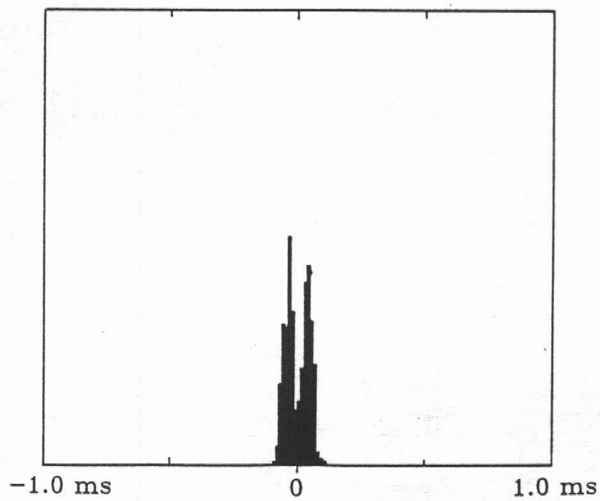

Figure 5b. Calls from NRC time laboratory to a station 15 km away. σ = 45 μs.

Figure 5. Histograms showing the precision of one Leitch CSD-5300 setting its time by telephone from a remote Leitch CSD-5300. Five hundred calls were made for each histogram.

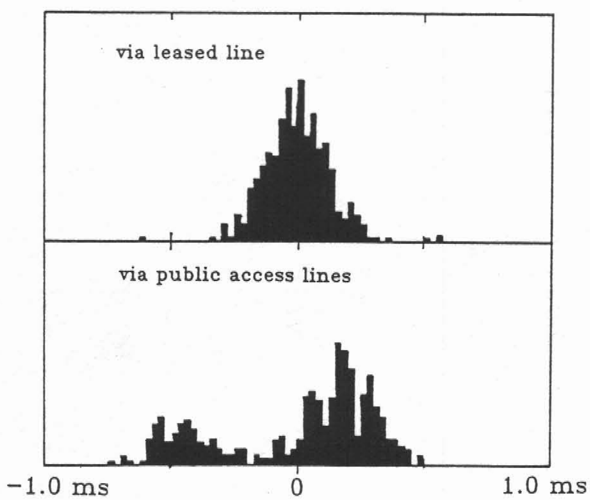

Figure 5c (Top). Calls from NRC time laboratory to a station 350 km away by leased line. σ = 135 μs.

Figure 5d (Bottom). Calls from NRC time laboratory to a station 350 km away by public access lines. σ = 307 μs.

QUESTIONS AND ANSWERS

GERNOT WINKLER, UNITED STATES NAVAL OBSERVATORY: Your comment about access by private computer users prompts me to say that we have such a telephone number too. It operates at 1200 baud. We have a program in basic which is on-line and the user can download it. It is in HP basic, so there would be some translation to use it with other basics. We have the same facilities of loop back testing etc.

MR. JACKSON: There is a program on COMPUSERVE to access our system.