Long-term continental U.S. timing system via television networks

Not only is there now a 10-μs time-synchronization system available in the United States at a nominal user cost, but the system can be improved by nearly an order of magnitude and expanded to a worldwide scale

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Hundreds of atomic frequency standards and precision crystal oscillators exist in remote locations throughout the continental U.S. that are synchronized through fairly complex and costly means. Today, however, an inexpensive synchronization system is available in the form of live television broadcasts by commercial networks. In precision and accuracy, the television method is comparable to the portable atomic clock and/or Loran-C, with average day-to-day differential delays less than 1μs. Based on the results of the tests presented here, the use of nearly any solid-state television receiver and a low-cost horizontal sync pulse generator can provide 10-μs synchronizations at all times. The operation of a TV line-10 timing system, including the circuitry of auxiliary equipment, is also included. This article gives about 1½ years of substantiating data for the three major commercial networks (ABC, CBS, and NBC). There is also provision for synchronization with the NBS and/or USNO Coordinated Universal Time (UTC) scales through regularly published reports.

The need for microsecond clock synchronizations* at widely separated points is becoming increasingly important to space research, defense activities, and the varied uses of private industry. Much previous work has shown the feasibility of using television signals for time comparison, especially in Europe, where the method originated and now is used quite regularly.[1–5] This article shows how some timing needs in the 10-μs region can be met throughout much of the United States by using live broadcasts originating from the New York City studios of any or all of the three commercial television networks (ABC, CBS, and NBC). The originating networks incorporate independent atomic frequency standards (rubidium) for stabilization of the horizontal sync pulses; these pulses, received at distant points, can be used to synchronize precision clocks within limitations of the distribution mediums resulting from many independent microwave links, repeater reroutes, VHF propagation, etc. The originating network signals, broadcast without auxiliary time coding, traverse varied and lengthy paths that include hundreds of microwave radio links. Such network distribution systems have given clock synchronizations within a range of 10 μs at all times for a 1½-year period. Our data were recorded at the U.S. Naval Observatory (USNO), Washington, D.C.; Newark Air Force Station (NAFS), Newark, Ohio; and the National Bureau of Standards (NBS), Boulder, Colo.

This version of television timing employs line-10 (tenth line of the odd field) in the 525-line system *M* (FCC standard for the U.S. and one of some 12 worldwide systems; see Westman[6]) as a passive transfer pulse. Almost any type of television receiver, black and white or color, is suitable for reception of signals for synchronization. Auxiliary equipment includes a line-10 synchronized pulse generator (available at a cost of about $165), a 10-MHz digital counter-printer, and a precision clock with a stability of 10^{-9} or better and having an output of 1 pps (pulse per second). This article portrays the system, including the distribution paths for the three networks, the line-10 identification circuitry, and reception results for the three labs over a period of about 1½ years. In addition, both advantages and disadvantages of the system are outlined.

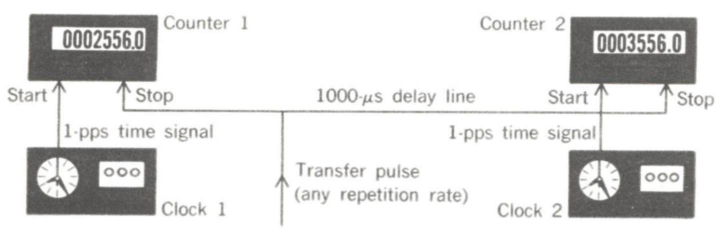
Basic concepts

For an introduction to clock comparison, consider two clocks side by side in the same laboratory, each one connected to a digital counter as shown in Fig. 1. When the 1-pps time ticks from both clocks are coincident, counters 1 and 2 will start at the same instant. Now, with a 1000-μs delay line connected between the stop inputs, the first received transfer pulse will stop counter 1 1000 μs before counter 2. The actual counter readings have no real significance; however, the *difference* in readings will be a constant 1000 μs. Conversely, a known delay would enable synchronization of clocks that may not be on time. It is possible to transfer this basic concept to precise clocks separated by several kilometers but within the service area of the same television transmitter. Once the radio propagation path has been calibrated, the television

* Synchronization is used in this article to denote simultaneity of clock readings within some frame of reference. We do not mean to imply that the method can be used to set clocks at remote locations in the absolute calibration sense.

timing system can be used to compare two or more clocks quite readily. NBS has used television horizontal sync pulses routinely since May 1968 to coordinate the clocks at stations WWV/WWVB/WWVL, Ft. Collins, Colo., with the NBS master clock at Boulder.[7] Since the horizontal sync pulses occur at 63.5-μs intervals, there is a system ambiguity over this time spacing. Such an interval corresponds to a distance of approximately 19 km (the signal travels at the velocity of light). Although the NBS radio station complex at Ft. Collins is separated by about four horizontal sync pulse periods from the Boulder Labs, the clocks agree within a small fraction of the ambiguous interval. The accuracy of such data is better than 1 μs with an rms day-to-day deviation of about 30 ns.[8]

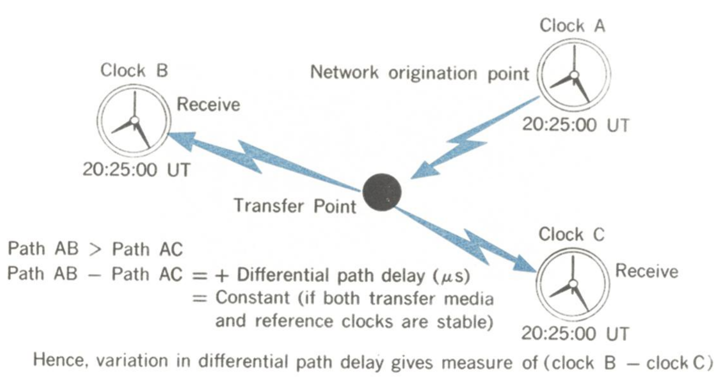
Extending the clock-comparison system one step further, we arrive at the system described in this article. Figure 2 gives the basic concept of the TV line-10 differential delay system. In our study, there is a modified television receiver, a line-10 pulse generator, a clock, and a counter at three remotely located laboratories. At the same time of day to the nearest second, counters are started at all laboratories with a 1-pps tick from their local atomic clocks. Close to this time, a horizontal sync pulse is broadcast from one of the originating television transmitters in New York City. After diverse delays through both common and separate microwave links, the sync pulse is received (live) at different times by the three laboratories and stops the appropriate counters. As in the two-clock situation in one laboratory, the difference between each pair of counter readings remains constant within the bounds of propagation delay stability of the distribution mediums and gives an accurate comparison between clocks separated by thousands of kilometers. Similarly, any laboratory can compare its clocks with NBS and USNO time scales through use of a duplicate reception system once the clock has been initially compared with a master clock and the propagation path delay has been calibrated. (Note that the clocks must be accurate to within one television picture frame or approximately 30 ms for this system to perform.)



Case 1 (Lab): Counter 2 − Counter 1 = 3556.0 μs − 2556.0 μs = 1000 μs
Case 2 (TV): Counter 2 − Counter 1 = differential path delay + clock difference (2 relative to 1)

FIGURE 1. Basic clock comparisons with delay times.

FIGURE 2. Concept of television line-10 differential measurements.



Originating television transmission

Color television broadcasters have found that they need extremely close tolerances with regard to the phase of the color burst frequency in their televised signal.[9] To accomplish this, they have installed rubidium frequency generators at the originating New York City stations of each of the networks (ABC, CBS, and NBC). The frequency control system locks the repetition rate of the horizontal synchronization pulses, as transmitted, to the stability of the atomic reference source, and this stability can be realized by receivers at distant points. Television signals originating in New York City for national distribution are frequency-modulated, translated to microwave frequencies, and transmitted via a directional antenna to the first of a long chain of microwave repeater stations throughout the United States.

Television distribution system

Figure 3 diagrams how a television signal from an originating transmitter reaches a receiver that is thousands of kilometers away. The propagation mediums and microwave radio relay stations are the main sources of delay. This relay system consists of a chain of broadband radio links encompassing the continental United States at line-of-sight distances of some 40 to 60 km between repeaters. The estimated routing for television signals of the three networks studied in this article is shown in Fig. 4. This mapping shows that a New York City originating signal follows quite diverse paths for the three different networks in arriving at Denver, Colo.; Newark, Ohio; and Washington, D.C.

The microwave relay system carrying over 95 percent of U.S. intercity television programs is known as the TD-2 system.[10] The Bell Telephone Company developed the initial TD series in the late 1940s, and it has grown with major improvements to its present nationwide coverage of about 67 000 route-kilometers.[11] Since a detailed description of the TD-2 (vacuum-tube) system or a later modification called the TD-3 (solid-state) system is beyond the scope of this article, the reader is referred to Berger,[10] Dickieson,[12] and Sherman.[13] In brief, the system consists of hundreds of microwave repeater stations that both receive and retransmit signals in the 3.7–4.2-GHz frequency band. The initial system handled 12 RF channels, six of which were beamed forward and six backward to the appropriate repeater relay station by means of oppositely directed microwave antennas. Recent improvements have doubled this channel capacity. At each relay station the signals are processed, including amplification and delay equalization. The repeater stations are unattended, and they include standby power facilities together with automated alarm and execution systems for alerting personnel, correcting faults, and rerouting paths through special maintenance centers. At a terminating station, such as an affiliate local transmitter, the microwave signal from the closest repeater station is translated to a 70-MHz FM carrier and converted to a video signal

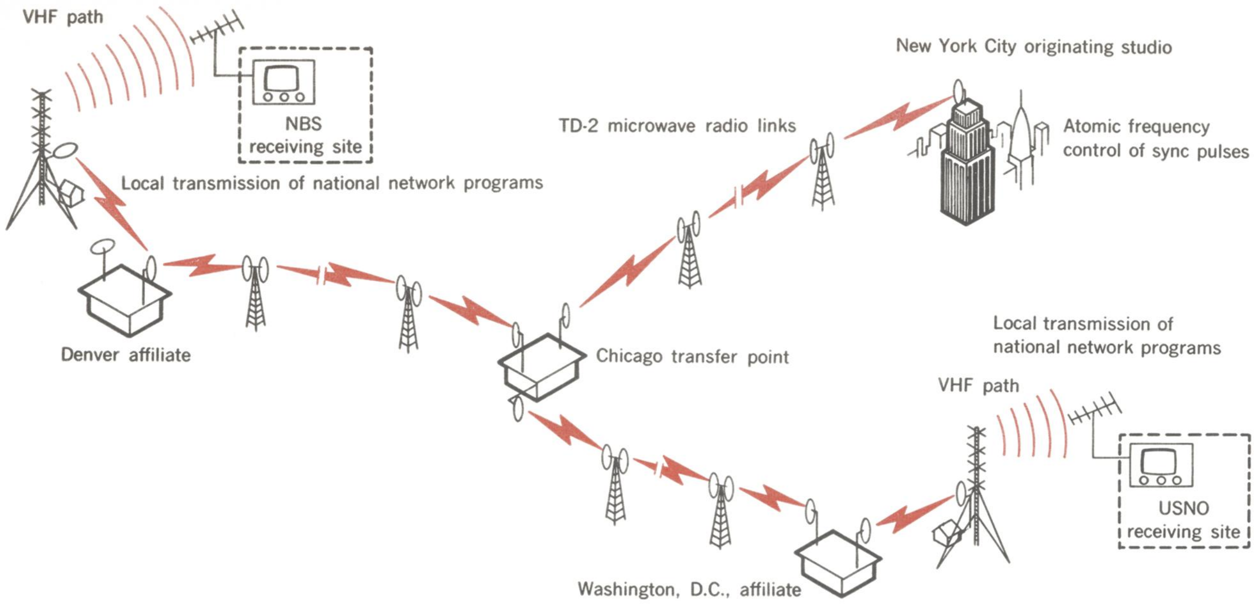


FIGURE 3. Typical routing of television signals from New York City to distant receivers. Microwave path from New York to Denver ≈ 4000–6400 km (depending on network). VHF path from Denver transmitter to NBS ≈ 30 km.

FIGURE 4. Estimated microwave radio relay routing across the continental United States for the three commercial television networks (ABC, CBS, and NBC), and the Pacific and Southern Canadian networks.

for retransmission in the VHF or UHF frequency bands (commercial television) to a local area. The reception of such local television signals at NAFS, NBS, and USNO provides the fundamental data for this article. The long-term stability shown in these data documents the possibility of disseminating accurate time via this system.

Local television reception

Figure 5 gives an overview of the television timing method and shows the equipment needed for line-10 clock synchronization at a local receiving point. The line-10 identification will be described in more detail; additional requirements for line-10 clock comparisons are:

1. All line-10 time interval measurements at different locations are made while all receiving sites are looking at the same program originating from a common source and at the same time to the nearest second. (Currently, some four hours of television programming originate from the three network stations in New York City and can be viewed simultaneously at Boulder, Colo.; Washington, D.C.; and various points in between.)

2. Since the line-10 sync pulses are ambiguous to about 33 ms, clocks at receiving points must be synchronized at least this well to ensure that the same pulse is being measured.

3. To relate remote clocks to the NBS and/or USNO time scale, it is necessary to have a measure of the differential RF delay between a receiving site and NBS or the USNO, as the case may be.

4. A highly directional television antenna is strongly recommended in areas where multipath interference can or does exist. It is believed that a 5000-μV signal level is adequate for line-10 measurements. "Ghosting," caused by secondary carrier reflection, as well as "snow" or noise in the received signals are factors to be avoided. We have experienced erroneous readings when either of these conditions existed. Quite often, realignment of the directional antenna and/or installation of a preamplifier will remedy such conditions. In addition, anomalous propagation may influence the usefulness of this television timing method in some parts of the United States. Tropospheric effects, caused by moisture and temperature inversions, called "ducting," can interfere with local television reception, particularly along the U.S. coasts. Similar interference can occur from ionospheric effects, such as sporadic *E*.

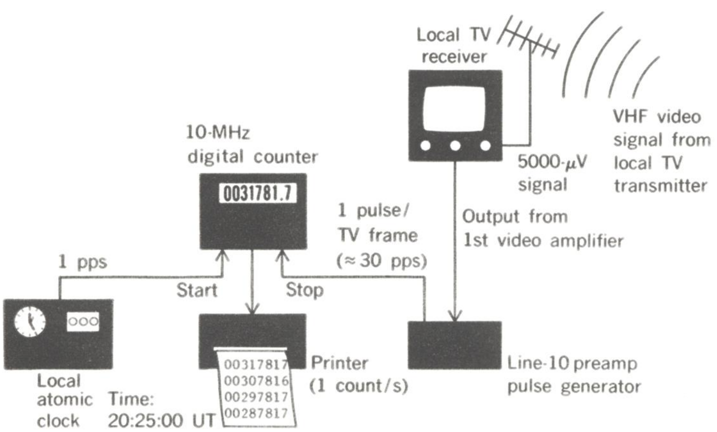


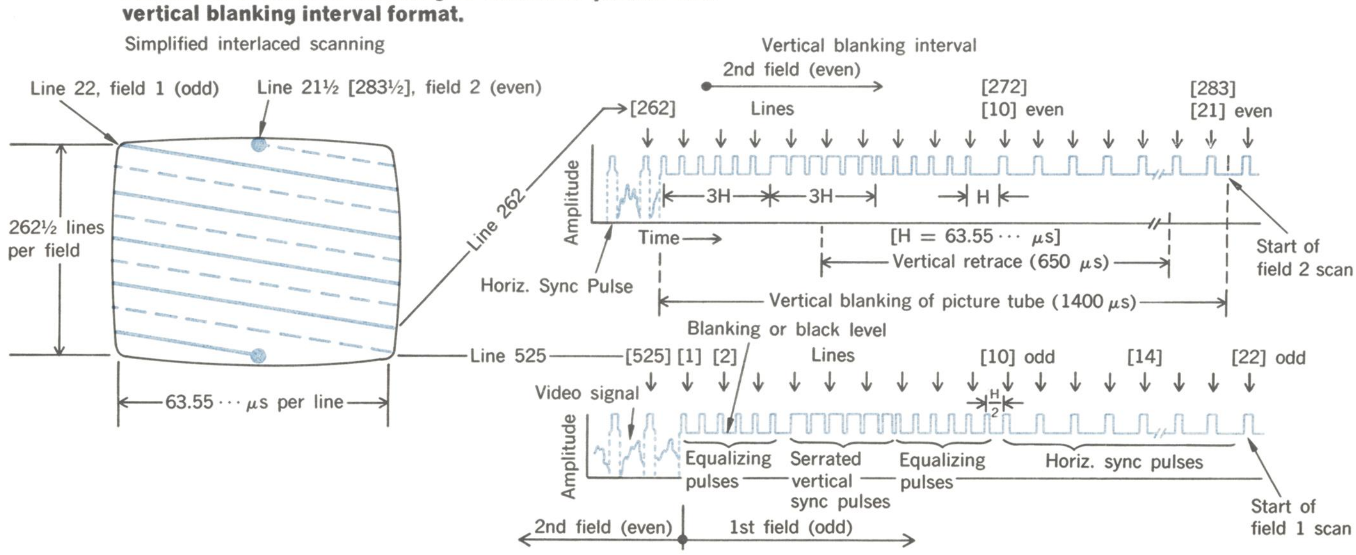
FIGURE 5. Overview of receiving laboratory instrumentation for TV line-10 synchronization.

Theory of line-10 operation

For a moment, let's consider the method used to synchronize and interlace a received television picture, as depicted in Fig. 6. A television receiver uses two sweep circuits—one to sweep the electron beam horizontally across the screen and return at a rate of 15 734.26··· Hz (63.55··· μs per line for color), and another to sweep the beam vertically down the screen and return at approximately 59.94 Hz or in 16 683.33··· μs of UTC (1970).[6] In this country, 525 lines per frame of picture is standard. However, to minimize flicker effects the frame is scanned twice in two fields with half the total number of lines in each field. Thus field 1 (or odd field) consists of 262.5 horizontal lines that scan the screen from top to bottom and return in 16 683.33··· μs of UTC (1970). On the second (even) field of display, the vertical sync pulse is displaced one-half horizontal line so that the retrace begins sooner and sandwiches or interlaces the horizontal lines of field 1. After each vertical scan of the beam tube between successive fields, the television screen is blanked for 1250 to 1400 μs. During this time, vertical retrace of the beam occurs, and signals are received in lines 1 through 9 of either odd or even fields, which contain equalizing and vertical sync pulses. Lines 10–20 also are held at the black or blanking level; however, line 10 was chosen for synchronization as it is the first horizontal sync pulse after the equalizing and vertical sync pulses and therefore is easy to identify with simple logic circuits.

The line-10 identification circuitry was designed to generate one pulse for each frame (525 lines) of video. To accomplish this, it is necessary to distinguish between line 10 of the odd and even fields. Our synchronization circuitry identifies the trailing edge of line 10 in the odd

FIGURE 6. Interlaced scanning of television picture and vertical blanking interval format.



field and, as indicated in Fig. 6, this can be easily accomplished through the time relationship of line 10 to the equalizing pulses of the successive fields.

Line-10 identification (ID) is effected by integrated circuitry such as is shown in Fig. 7. The major components consist of a combination preamp–sync stripper, an odd-field line-10 pulse generator, and a power supply. The input to the preamp is a composite video signal taken from the first video amplifier emitter follower of a typical solid-state television receiver. (Nearly any television set can be used provided the signal level, impedance, and video polarity are compatible; older tube-type sets require additional impedance-matching circuitry.) The video signal at this stage is positive (negative-going sync) with a peak-to-peak amplitude of 0.6 to 1.0 volt. The operation of the line-10 ID circuitry is described in some detail in the appendix. Several options of this unit are available locally; a completely assembled and tested unit (preamp, line-10 pulse generator, and power supply) costs about $165 (the cost of parts alone is about $50).

Data acquisition

The line-10 data are obtained from the instrumentation that is shown in Fig. 5. Only one reading is recorded for a given network and time. Actually, we record readings for the 39 seconds after the specified starting time at one-second intervals to average the variation in the 0.1-μs column. A typical printout is shown in Fig. 8. Measurements of NBC, for instance, are commenced at 20:25:00 UT and each second thereafter until 20:25:39 UT. The 40 readings are averaged to minimize error in the 0.1-μs column. In this particular example, the reading for 20:25:00 would be reported as 32 440.3 μs. Note that for each second the count increases by 1000 μs until the modular frame interval of 33 366.66··· μs is exceeded. This results from the relationship of the television frame rate relative to 1 pps. That is, 30 vertical frames occur for 1.001 000··· seconds of UTC (1970). The relationship is

$$\text{Period of 1 line} = \frac{1}{\text{Horiz. scanning freq.}}$$

$$= \frac{1}{\dfrac{2}{455}\left[\dfrac{63}{88} \times 5 \times 10^6\right]} = 63.55\cdots\ \mu\text{s}$$

with the term in brackets equal to the chrominance subcarrier frequency; and

$$\text{Period of 30 frames (525 lines/frame)}$$

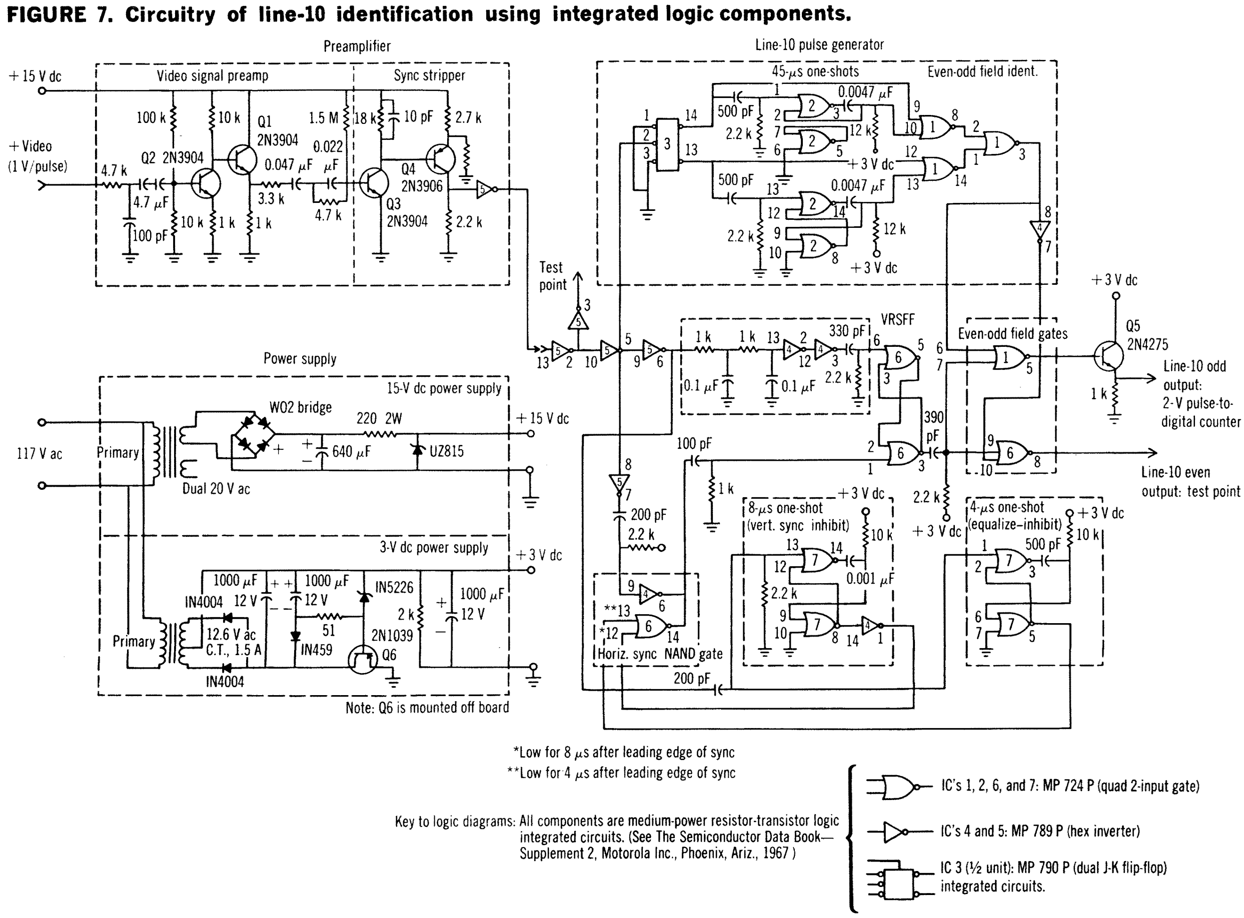
$$= \frac{1}{\left[\dfrac{2}{455} \times \dfrac{63}{88} \times 5 \times 10^6\right]} \times 525 \times 30$$

$$= 1.001\,000\cdots \text{ seconds of UTC (1970)}$$

In the printout of Fig. 8, the set B readings can be converted to an extension of set A by adding one modular frame interval to each reading.

To use TV line-10 synchronization, it is necessary to resolve ambiguity to less than the period or module of

FIGURE 7. Circuitry of line-10 identification using integrated logic components.



one television frame. In our present studies, a maximum differential delay of about 24 800 μs occurs for the CBS network if one monitor is in New York City and the other in Boulder. Assume clocks at Boulder and New York City are on time and that both monitors start their respective counters simultaneously. The next line-10 sync pulse (corresponding with 1 pps) that originates from the New York City transmitter will stop the New York City counter. About 24 800 μs later the same sync pulse would stop the NBS counter unless a pulse was in transit at the time both counters were started. In such a case, the NBS counter would be stopped before the New York City counter. To use such data from the two counters, one must increase the NBS value by the period of one television frame to compensate for path delay. Note the following example:

TV Reading	
NBS 2 748.2 μs	2 748.2 μs
NYC 11 314.9 μs	+33 366.7 μs
(NBS plus corr.)	36 114.9 μs
minus N.Y.C. to NBS delay	−11 314.9 μs
Differential delay ± clock error =	24 800.0 μs

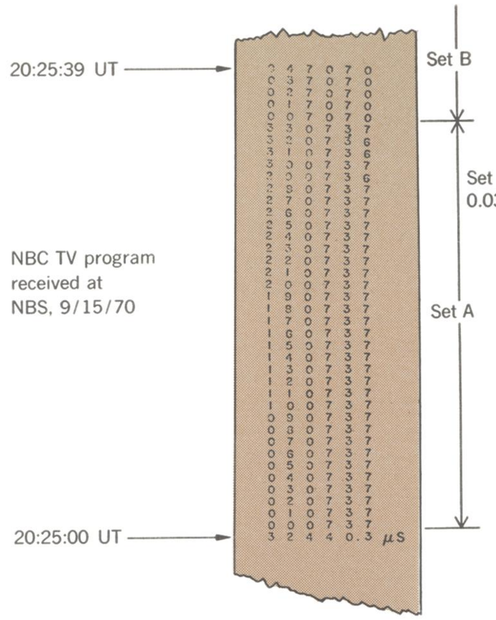


FIGURE 8. Sample printout of TV line-10 (NBS) counter readings in terms of clock 8.

Results of line-10 synchronization

During the past 15 to 18 months, television timing measurements were made via the three networks at NAFS, NBS, and USNO as outlined in Table I. Note that two measurements are made for each network, both before and after the half-hourly station breaks. This is done to study the effects of national-to-local switching and to determine if a consistent time interval elapses when the national network program resumes. In many cases the time of return is many microseconds removed from the computed counter reading based upon the frame modular count for the 6-minute interval. This could occur from minor rerouting of signal path, replacing sync generators, sync generators randomly jumping, or other causes that are unknown at this time. In any event, if the change is seen simultaneously at all monitoring stations, it will not affect the differential measurement or the actual clock comparison. From day to day, the 6-minute differential measurements can vary by several tenths of a microsecond. Some results of differential timing measurements at the three laboratories have been plotted in Fig. 9 for June 1969–December 1970. Variations in the differential delays result from differences between the controlling clocks as well as contributions from the measurement system. During this time there were seven apparent network reroutes not common to all receiving sites. The data reflect deviations from nominal; where reroutes occur, adjustments were made. Because the chances for simultaneous rerouting of each of the three networks are remote, nominal delay times can be adjusted based on the stability of the other two networks.

The NBS–NAFS data (Fig. 9A) show good agreement for the three network paths. From September 1969 to December 1970, these data fall within a maximum range of 6 μs. This variation is believed to reflect mainly the differences between the two clocks at these laboratories. The NBC data for the NBS to NAFS path show no major network rerouting and, during 1970, they fall within a maximum deviation range of 6 μs. Typically, the monthly standard deviation about the mean nominal differential delay is about 0.5 μs. Through averaging of the three network results and eliminating extraneous values, we feel that standard deviations of 0.2 μs should be possible for a monthly set of data.

The NBS–USNO data (Fig. 9B) similarly agree for the

I. Characteristics of television receiving sites

		NAFS, Ohio				NBS, Colorado				USNO, Washington, D.C.			
Network	Measurement Time, UT*	Channel	Frequency, MHz	VHF Path Dist., km	Trans. Bearing, degrees	Channel	Frequency, MHz	VHF Path Dist., km	Trans. Bearing, degrees	Channel	Frequency, MHz	VHF Path Dist., km	Trans. Bearing, degrees
NBC	20:25:00 20:31:00	4	66–72	47.5	270.9	4	66–72	29.5	175.6	4	66–72	2.6	326.3
CBS	20:26:00 20:32:00	10	192–198	47.4	263.5	7	174–180	29.6	175.8	9	186–192	2.9	305.5
ABC	20:27:00 20:33:00	6	82–88	46.2	249.7	9	186–192	29.6	175.6	7	174–180	3.5	339.4

*One hour earlier during Daylight Saving Time in the summer.

DAILY TELEVISION TIME TRANSFER MEASUREMENTS**

Listed below are the daily readings (for the three major U. S. networks) of the difference between UTC(NBS) and the trailing edge of the next line 10 (odd) horizontal synchronization pulse as received in Boulder, Colorado, at the times specified. Note: These pulses have been observed for a sufficient period of time to merit their consideration as a source of time transfer due to their low scatter. This schedule will be followed in succeeding months.

	UTC(NBS) - Line 10 (odd) (in microseconds)					
Sept.	NBC		CBS		ABC	
1970	19:25:00*	19:31:00*	19:26:00*	19:32:00*	19:27:00*	19:33:00*
1	04324.4	30659.2	05569.6	31902.9	09152.5	02119.7
2	18057.4	11023.7	19263.3	12230.0	10421.1	15844.9
3	31787.1	03844.2	32958.1	25924.7	03236.5	29569.8
4	12152.3	05120.2	13285.7	06252.3	16961.9	09928.7
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
8	21231.0	14198.6	01328.6	27661.7	05130.3	31463.8
9	01598.0	27930.5	15022.7	07989.3	18855.6	11822.5
10	15328.0	08296.0	29527.1	22493.8	32581.3	08644.3
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	-	-	-	-	-	-
14	-	08970.6	05859.2	32193.6	20751.4	13718.5
15	32440.2	25406.6	19554.7	12521.3	01111.1	27444.6
16	24844.8	17621.1	33249.4	26216.1	14837.1	07803.8
17	05019.6	31352.7	13577.8	06544.5	28563.3	21530.1
18	07311.0	00279.3	27273.1	20239.9	20769.8	01890.7
19	-	-	-	-	-	-
20	-	-	-	-	-	-
21	15513.3	08479.8	01625.4	27958.7	16736.3	09703.2
22	29246.0	22212.6	15320.6	08287.2	30462.9	23429.8
23	09613.3	02579.6	29015.7	21982.4	10823.1	30800.9
24	23346.2	16312.9	09344.5	02311.2	24549.9	17516.7
25	03711.1	30042.9	23039.9	16006.5	04910.4	31243.8
26	-	-	-	-	-	-
27	-	-	-	-	-	-
28	16583.7	09615.5	30758.5	32050.7	12724.1	05691.0
29	30380.3	23348.4	09253.9	02220.6	26451.3	19417.8
30	-	-	-	-	-	-

The above data is being published as a service to users of television timing systems. It in no way implies a guarantee of results from using such a timing system, nor does it signify any control of the emission times of synchronization pulses by the NBS.

*Universal Time

**See Section 8 of Bulletin No. 151 - June 1970.

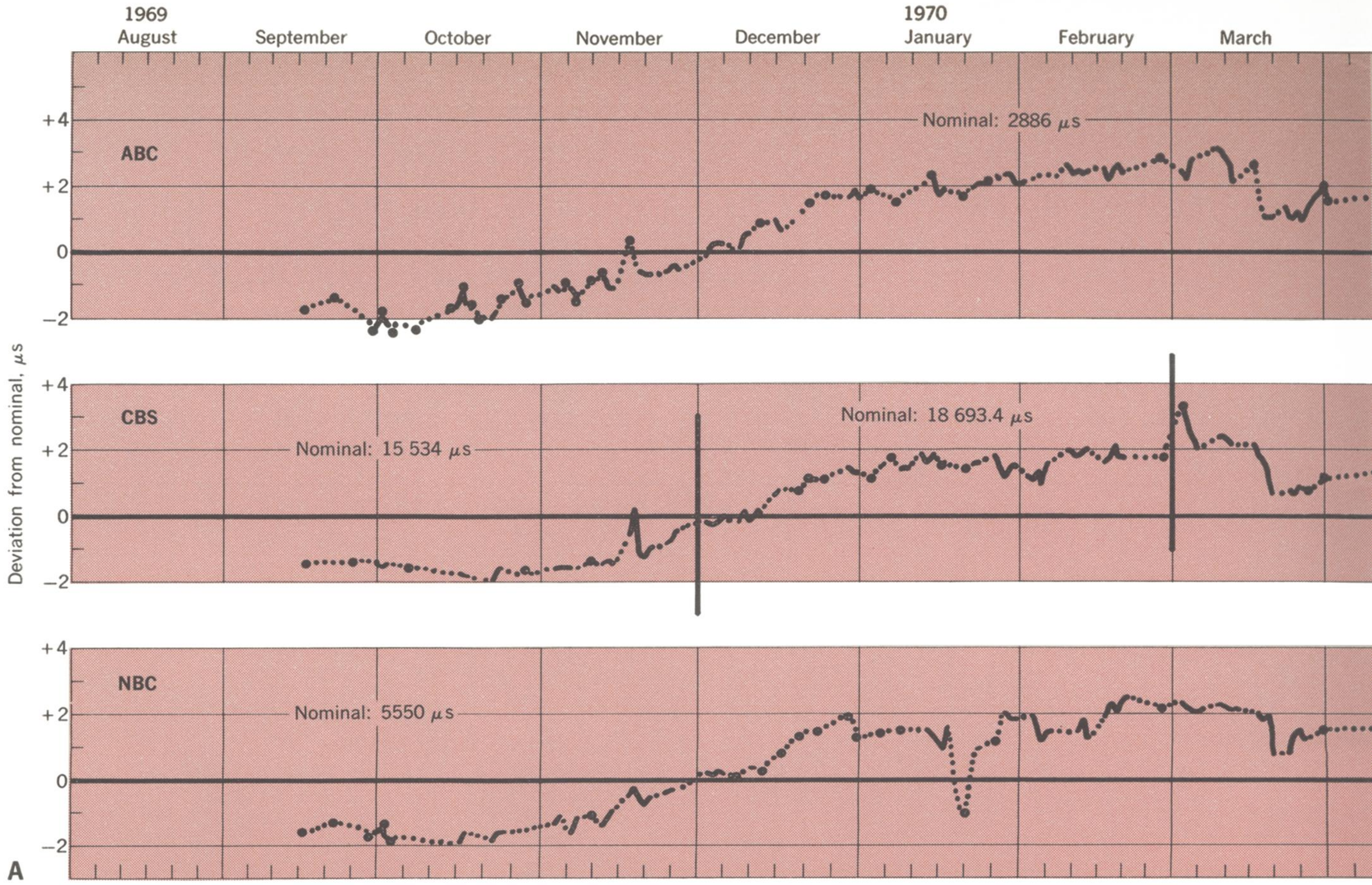
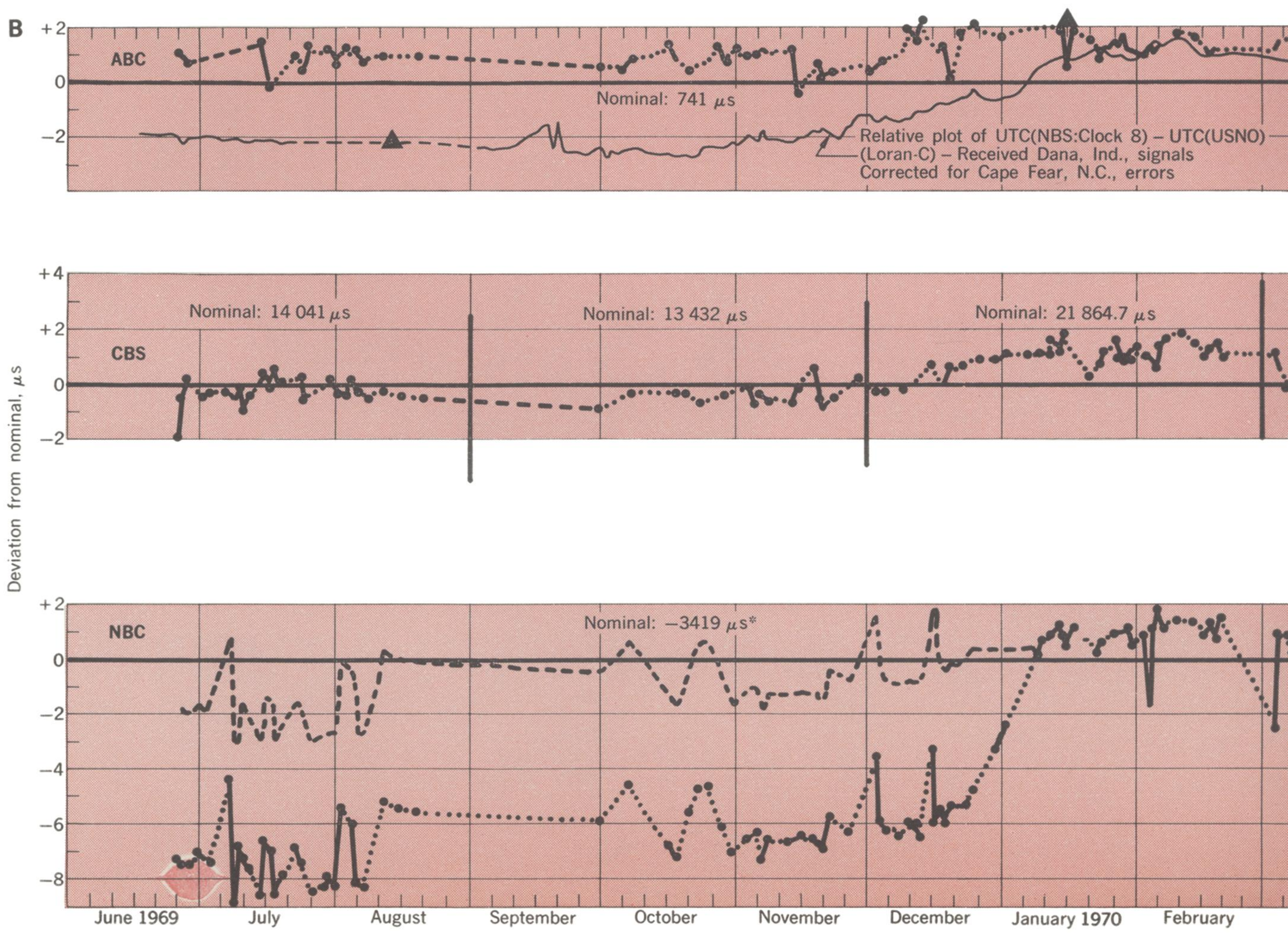
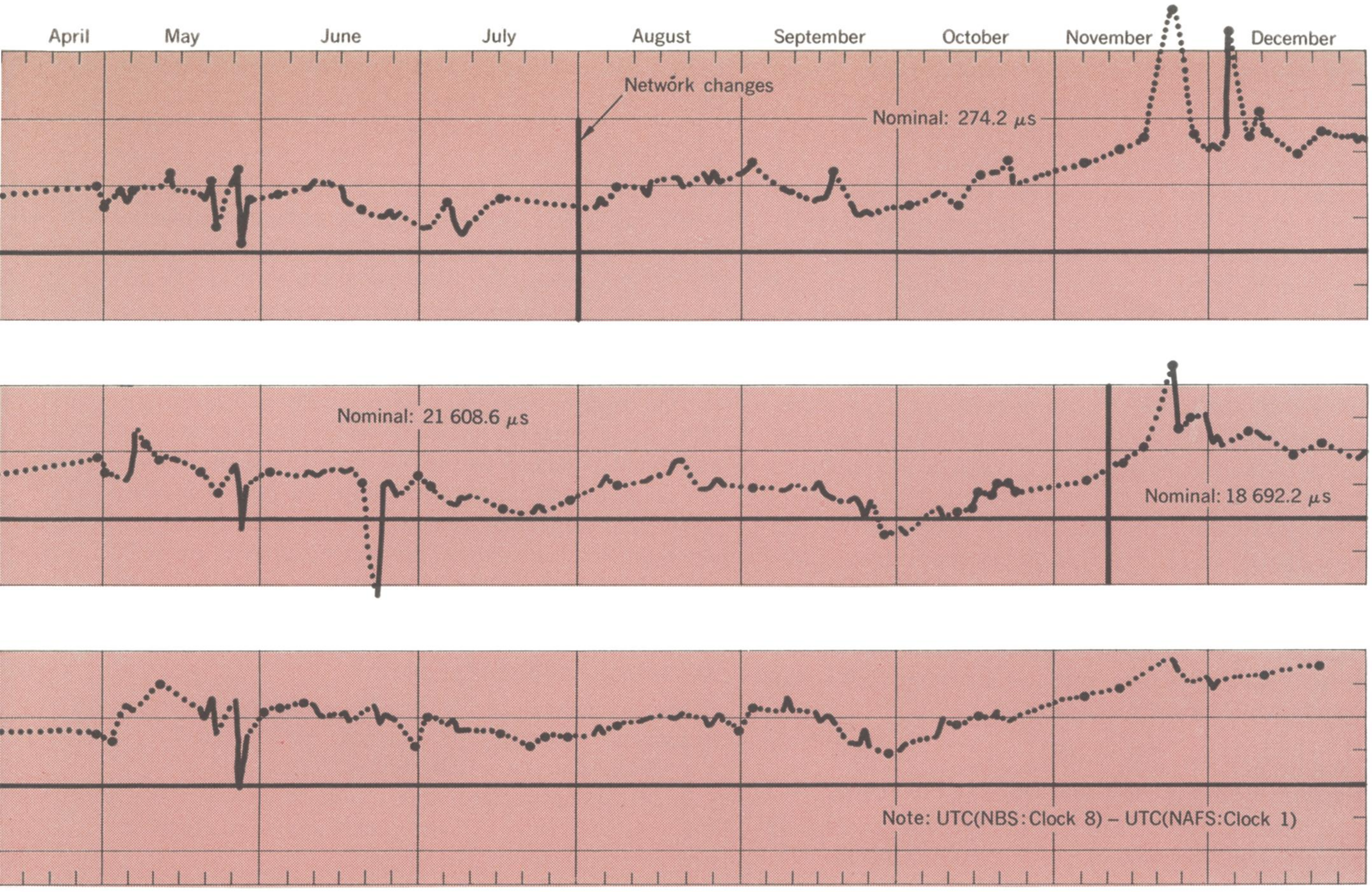
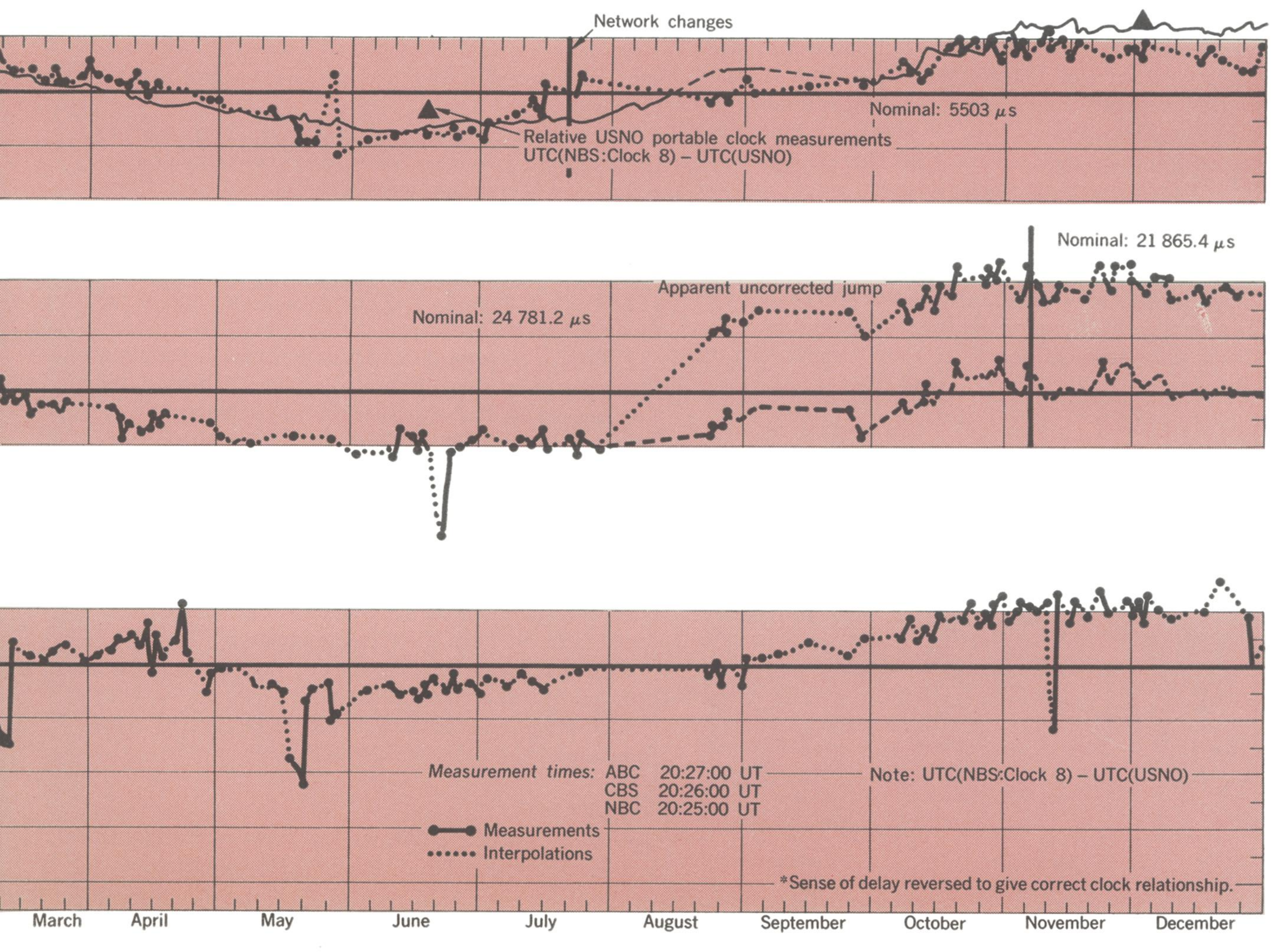


FIGURE 9. Differential path delays via the three commercial networks between (A) NBS, Boulder, Colo., and NAFS, Newark, Ohio, and between (B) NBS and USNO, Washington, D.C. Note that, as a result of some





equipment malfunctions, a lack of weekend measurements, and occasional local interference, gaps do appear in the data; even so, the differential delay curves for the three networks show strong correlation.



three networks. A graph of corrected Loran-C data (Dana) and USNO portable clock measurements has been superimposed (relatively) on the ABC data and quite close correspondence exists. For the last half of 1969, the Loran-C data and portable-clock check deviate about 3 μs from the TV line-10 curve. However, during 1970, the variations are about 1 μs. The reason for the 1969 variation is unknown except for possible equipment difficulties. (The Loran-C data consisted of signals received from Dana, Ind., at NBS in Boulder, Colo., and corrected for Cape Fear, N.C., [master] variations as reported by the USNO.[14]) The statistics of the relationships between remote time synchronizations via portable clocks, Loran-C, and television broadcasts are published elsewhere.[15]

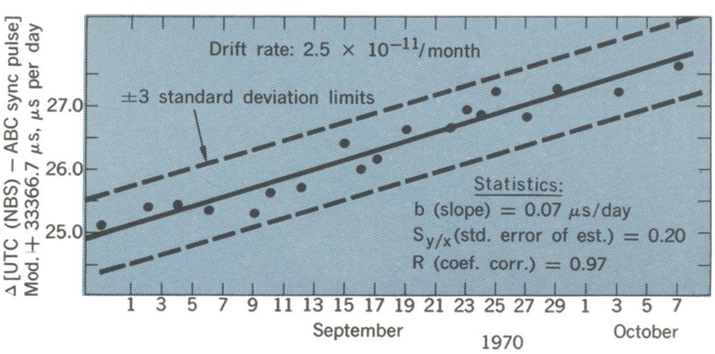
The NBC and CBS data for the NBS–USNO path show changes of 4 to 6 μs that do not appear real. (From December 1969 to January 1970, the NBC differential delay gains about 6 μs; from July to August 1970, the CBS data show a gain near 4 μs.) Without any adjustments, however, the data, with few exceptions, fall within a maximum excursion range of 10 μs.

Relation of TV line-10 measurements to NBS and USNO time scales

NBS issues to users on the basis of need the line-10 daily measurements in terms of UTC (NBS) in the monthly NBS Time and Frequency Services Bulletin.[16] A sample data sheet of NBS television measurements is shown for September 1970 in the box on page 47. The USNO distributes on the basis of need line-10 data in terms of UTC (USNO) in their weekly Series 4 time services bulletin.[14] These bulletins will publish future changes, modifications to the television system, or other factors that might affect a user in the field. Because of the periodic relationship of the television time interval with UTC, one usually can compute the value of a missing counter reading. In fact, the ABC data at Boulder show consistent continuity in counter readings between days for weeks at a time. For unknown reasons, the CBS and NBC data do not show such continuity over weekends; however, within respective weeks they are consistent. This may be due to a change of sync generators at the New York City originating stations.

Data such as shown in the sample box also enable one to study the stability of the network rubidium standards. The counter readings for UTC (NBS) minus line-10 (ABC) were adjusted by the daily modular frame rate to obtain the difference between the computed and actual readings. This difference is the daily divergence in microseconds between the NBS and ABC clocks. A plot of such results is given in Fig. 10 for the month of September 1970. This graph indicates that the rubidium standard at New York City (ABC) was drifting in terms of the UTC (NBS) clock at a rate of about 2.6 parts in 10^{11} per month with a standard error of estimate about the least square line fitting the data equal to about 0.2 μs. Rubidium standards, controlling television sync pulses over the microwave radio links, show nearly equivalent stability to laboratory specifications. This illustrates an additional potential of the TV line-10 system. With a known atomic frequency reference at the New York City originating studios and with the cooperation of the network distribution systems, counter readings in terms of UTC (NBS) or UTC (USNO) could be predicted, say a week in advance, within tenths of a microsecond.

FIGURE 10. Daily divergence between the UTC (NBS) clock and UTC (ABC) Rb clock in New York City via TV line-10 measurements.



Advantages and limitations

The advantages of TV line-10 synchronizations can be listed as follows:

1. Initial equipment is low in cost.
2. Measurements are simple.
3. The cost per clock synchronization is low compared with portable clock measurements.
4. Transmission of data has no effect on television network programs or viewing reception and is without cost to user.
5. Simultaneous clock comparisons can be made without error of a transfer portable clock.
6. The system shows a 10-μs reliability with the potential of a few microseconds.
7. Modular intervals are potentially predictable.
8. Three television networks with atomic clock references provide redundancy and enable cross synchronizations.
9. Simultaneous viewing of one television broadcast in the immediate area of several receivers can enable microsecond synchronization among clocks at these stations without regard to national "live" programming.

There are also limitations:

1. Microwave paths can be interrupted without notice.
2. There is limited simultaneous viewing time of nationwide network programs.
3. Present network distribution systems will not allow tie-in with West Coast transmission lines. However, the Los Angeles studios originate live programming several hours a day for the West Coast area; if line-10 measurements were made in terms of an NBS or USNO synchronized cesium clock and published, microsecond comparisons should be possible for this part of the United States also.
4. System will not work with tape delays—program must be "live" for all simultaneous measurements referred to the NBS and USNO television data.
5. Measurements currently are not made on weekends.
6. System ambiguity is 33 ms.
7. Propagation anomalies may limit the system's usefulness in some areas of the United States.

Conclusions

A 10-μs synchronization system now exists through the use of commercial television networks and inexpensive laboratory equipment. The television system shows potential for nearly an order-of-magnitude improvement with the cooperation of microwave radio equipment lessees (notice of reroute changes); redundant cesium frequency standards controlling originating broadcasts with known reference to UTC (NBS) or UTC (USNO); phase-continuous operation of such originating broadcast equipment as sync generators over weekends with backup battery power supplies; and improved digital counters at receiving laboratories with ns resolution. (See Parcelier.[5])

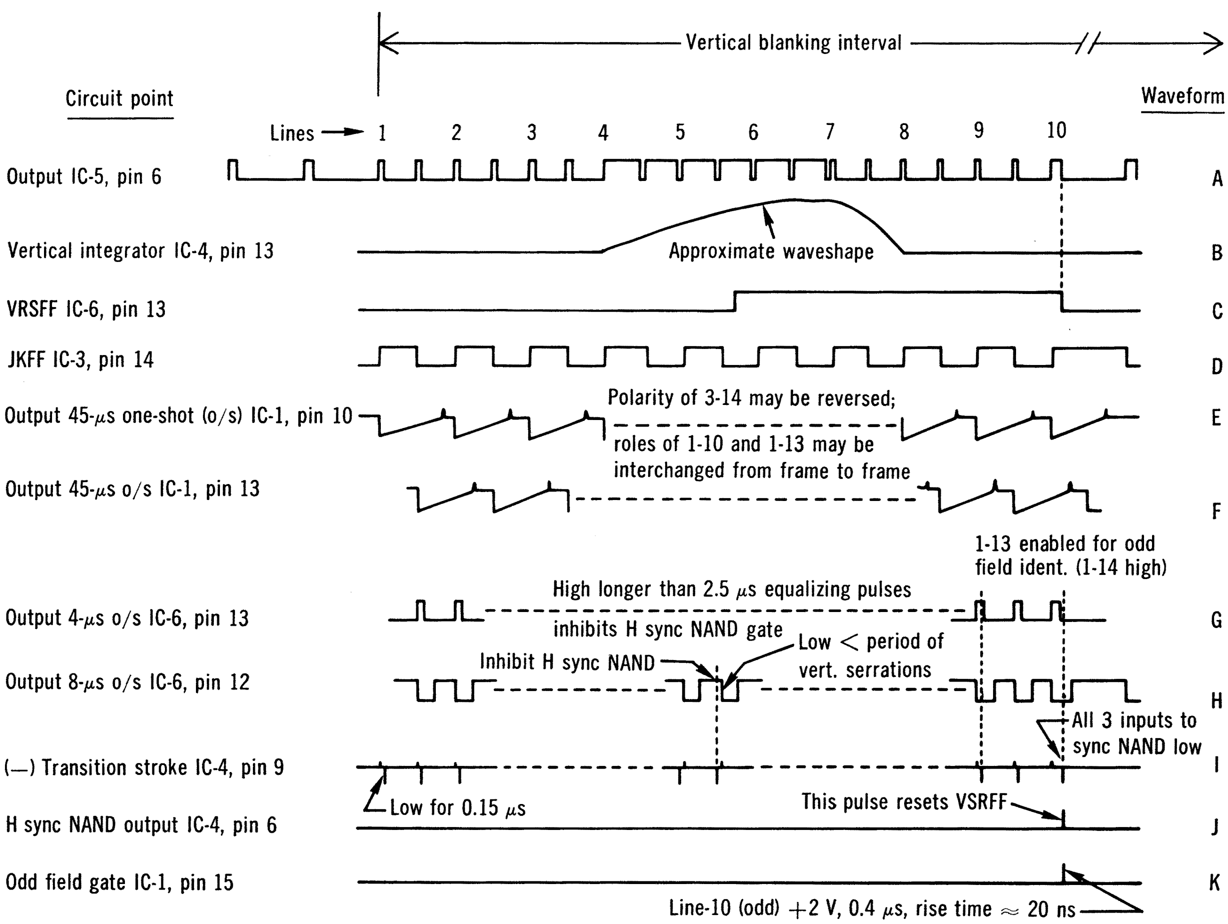
Additional and possibly more consistent data could be obtained if the line-10 system were automated to print out measurements on a daily basis. We encourage laboratories maintaining precise time, especially in southern Canada, southeastern United States, or any other intermediate points, to compare their clocks with the NBS or USNO time scales through TV line-10 synchronizations. (Since March 1, 1971, the USNO time service substation near Miami, Fla., has made TV line-10 measurements with good results.) The system conservatively covers about 70 percent of the continental United States, and it is hoped that some "live" television coverage can be extended to the West Coast distribution networks. The method is usable, however, for microsecond synchronization by simultaneous viewing of a common television broadcast; it should not be overlooked in coordinating many precise time centers, ships at sea, etc., within the broadcast field of a centrally located transmitter, such as on the West Coast or in Hawaii or Alaska.

As one looks to the future, the satellite-television links proposed for global communications show great potential for microsecond synchronization between clocks in different countries, provided basic differences in television system standards can be resolved.

Appendix. Details of TV line-10 pulse generator

As noted in this article, the input to the line-10 preamp is the positive video signal (negative-going sync) from the television set with a peak-to-peak amplitude of 0.6 to 1.0 volt. Refer to Fig. 7 for the following description of operation. The composite sync is amplified and inverted; 4 to 7 volts of composite video, with positive-going sync, is applied to the two-stage sync stripper to clean up the signal not reaching sync level. The output of the sync stripper at IC-5 (integrated circuit 5), pin 1 [sync at RTL (resistor-transistor logic) level], is connected to the input of the odd-field line-10 pulse generator. The output of IC-5, pin 6, is the composite sync waveform *A* shown in Fig. 11. The serrated vertical sync pulse, integrated by the vertical integrator, sets the VR-SFF (vertical reset–set flip-flop) at approximately the fourth serration (waveforms *B* and *C*, Fig. 11). The leading edge of every pulse will trigger the 4- and 8-μs one-shots and also toggle the dual JK flip-flop (IC-3) in the even–odd field identification circuitry. The waveform output of IC-3, pin 14, is shown as *D* in Fig. 11. If the time between leading edges is less than 45 μs, the output of IC-1, pin 3, will be low, enabling gate IC-1, pin 6. (See waveforms *E* and *F*, Fig. 11.)

FIGURE 11. Line-10 identification waveshapes at various parts of the circuit of Fig. 7.



The trailing edge of every pulse activates the horizontal sync NAND gate at IC-4, pin 9. If the time between leading and trailing edges is more than 4 μs but less than 8 μs, the horizontal sync NAND gate will generate a positive pulse that resets the VR-SFF (waveform *J*). This reset will drive IC-1, pin 7, and IC-6, pin 9, low for about 0.4 μs, resulting in a +0.4-μs output pulse for either L10 (line 10) odd or even, depending on the state of the even–odd identification. The output for L10 odd is therefore a +0.4-μs pulse coincident with the trailing edge of the L10 odd pulse (waveform *K*). The amplitude of this pulse is about 2 volts, with a rise time of ≈20 ns, and is sufficient to drive a time interval counter.

Component tolerances are such that no adjustments should be required after final assembly. The 45-μs one-shots should have a period between 40 and 55 μs. The range of the 8-μs one-shot period should be between 6 and 12 μs and that of the 4-μs one-shots between 3.7 and 4.3 μs.

The authors wish to thank George Kamas and James Barnes for substantive advice and helpful consultation in the preparation of this article. Wallace Hamilton and Glynetta Perrymore compiled the data and provided the data analysis. The U.S. Naval Observatory and the three television networks (ABC, CBS, and NBC) are acknowledged for their valuable help and cooperation in these tests.

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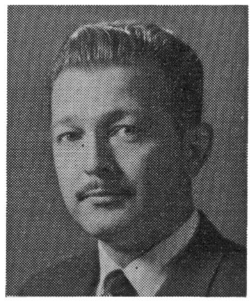

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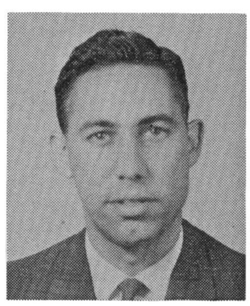

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