

Fig. 1. Waveforms of U. S. television format, vertical interval, and NBS experimental line-1 code (H = horizontal line period of $1/15\,750$ s, or $63.5\ \mu\text{s}$).

Results of Active Line-1 TV Timing

Abstract—Because of the increasing interest in time and frequency dissemination via television signals, NBS has sponsored an experiment using an active time and frequency code transmitted on a U. S. television network encompassing nationwide coverage. The code format is discussed and statistical results of system stability using the network path from New York City, N. Y., to Boulder, Colo., are presented through plots of phase with respect to time and plots of time domain stability using the Allan variance. Comparison is made of the frequency transfer capability of the line-1 method to the 3.57954 . . . MHz color subcarrier signal used for network colorcasts. The active line-1 TV time system offers distinct advantages over existing dissemination methods utilized within the continental U. S. of principal interest is the short measurement period required for a time or frequency calibration. The system typically permits calibration of a remote standard to 1 part in 10^{11} within one-half hour.

I. INTRODUCTION

The National Bureau of Standards (NBS) has for a long time been concerned with the public's need for accurate time-of-day and frequency information. Its WWV, WWVH, and WWVB time and frequency broadcasts are familiar to many people. Expanding technology in all facets has tested and found many times that these services were limited; it has become increasingly important that better methods be adopted.

If one measures the effectiveness of a time and frequency distribution method with weighted priorities given to accuracy, precision, ease of acquisition, cost, flexibility, reliability, etc., then the use of a network television time code is attractive compared to many other methods encompassing continental coverage. From television decoding equipment, the user could obtain the following signals:

1) Time-of-day as BCD logic which can interface directly with a digital clock.

2) 1-MHz Standard Frequency which exhibits good stability for use by broadcasters, industry, laboratories, or anyone wishing to obtain a frequency reference which is phase coherent with an NBS standard.

3) Time Tick, 1 pulse per second (pps) which is an on-time pulse once each second to be used in conjunction with a time interval counter and remotely originated time tick.

In order to implement the system on a nationwide scale, atomic frequency standards (primary and standby) along with a time code generator would be needed at the network originating studio. The complete package of encoding equipment could be installed at other originating studios for the same or another network in order to acquire greater coverage. The television affiliate would transmit the on-line code when telecasts originate from the network. This would require no additional equipment except in cases where processing amplifiers regenerate the vertical interval (the time code would be sent during the vertical interval [1]). In these instances a code bypassing device could be used in conjunction with the processing amplifier. The affiliate with a separate time code generator could choose to regenerate the time code so that it is broadcast at all times.

The cost is low for decoding equipment capable of an accuracy within 33 ms with a time-of-day demodulator, line-count, and control equipment developed by NBS (about 20 dollars for parts). If better precision is required, this may also be satisfied, but at higher costs; i.e., the present state of the art

yields a price tag of about 1000 dollars for a time and frequency decoder capable of precision to a few nanoseconds. With a precision decoder, time-of-day accuracy within $10\ \mu\text{s}$ is achievable after calibration of the particular network path joining the time code generator to the decoder [2].

II. THE ACTIVE TV TIME CODE

Line-1 of the vertical interval was chosen as the carrier for the experimental time and frequency code. Referring to Fig. 1, one sees that the added time and frequency signal has a level reaching approximately 50 percent of maximum white level. Therefore, the signal is visible on the screen as a series of small dots if one "rolls" the picture to observe the vertical interval. The first half of line-1 contains a 1-MHz sine wave which may be derived from a reference cesium atomic standard; the second half of line-1 is modulated by time-of-day and communications messages using a non-return-to-zero (NRZ) BCD, and ASCII alphanumeric code. The 1-MHz line-1 signal is used as the reference for a phase-locked oscillator, or PLL, at a receiver site. The available sampling time is short ($\sim 12\ \mu\text{s}$) and the sampling rate is equivalent to the television picture field rate (~ 60 Hz).

III. DATA

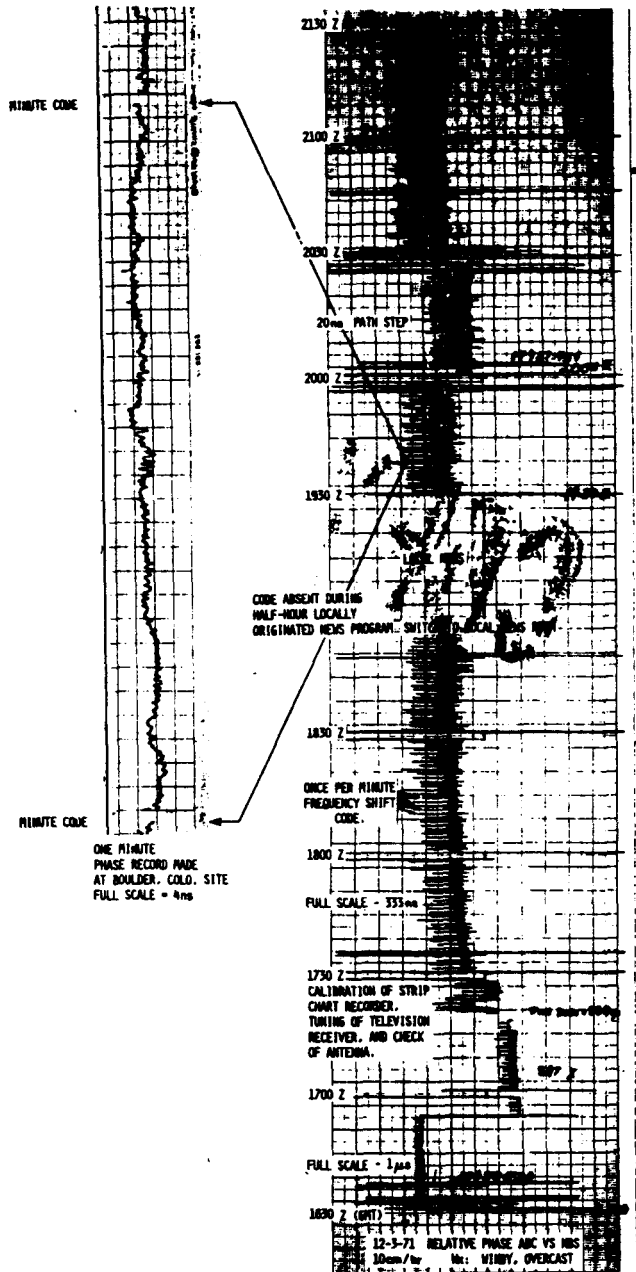
A cesium atomic frequency standard and time code generator were installed (October 23, 1971) at the originating studio for one of the U. S. television networks (New York City, N. Y.). At the Boulder, Colo., laboratory, a receiver decoder was interconnected to a

cesium standard, phase comparator, and strip chart recorder. Phase versus running time measurements were started each day at 1630 Greenwich Mean Time (GMT), the time at which the Denver area affiliate starts broadcasting network feeds, and they continued until 2130 GMT for the 5-day work week. The code was turned off at 2130 GMT (4:30 EST).

Fig. 2(a) shows a typical day-long record of relative phase of the decoder's 1-MHz PLL versus a cesium frequency reference at the Boulder receiver site. Typically the first network telecast was received at 1630 GMT. At the outset, chart full scale was equivalent to a 1- μ s phase shift. From about 1640 to 1655 GMT, we observed essentially a straight line phase record. (Perfect straight lines appearing at the center of the chart represent a "code absent" condition commonly due to local programs, commercials, and station identifications.) Shortly before 1700 GMT the local affiliate initiated a studio switch which appeared as a 400-ns path step. From 1700 to 1715 GMT our television receiver experienced interference from a nearby earth-to-satellite VHF transmission. The 1-MHz PLL still locked to the signal from New York, but with greater uncertainty. Prior to 1730 GMT the systems at the receiver site were checked, and the chart was calibrated and expanded to a full scale of 333 ns. From 1730 GMT until the end of the time signal transmission, the equipment remained untouched. Once each minute, the 1-MHz signal was turned off briefly to identify the beginning of the minute, and this portion of the format created a slight perturbation of the decoder's locked oscillator. Occasionally, a half-hour program required a path switch. One notes such a case from 2000 to 2030 GMT of Fig. 2(a). This type of switch occurred infrequently (about once each week); usually it was small as in this example.

The 1-min chart record [Fig. 2(a)] shows the phase noise as more or less random. Maximum short-term excursions of the 1-MHz PLL were about 5 ns with good reception of the local affiliate. Since the laboratory at Boulder is in a fringe area with respect to television reception from Denver, Colo., weather anomalies and aircraft caused variations in signal intensity and multipath. This most likely accounts for the apparent drift of the intensity of phase noise, i.e., the changing width during the day-long record. We have observed that short-term instabilities in the network path from New York City to Boulder are small enough that with a television signal of 500 μ V or more (typical for clear picture), a phase record for a 15-min interval permits calibration for a remotely located oscillator to 1 part in 10^{11} using the line-1 active system. In the example of Fig. 2(a) one sees a frequency offset of approximately 3×10^{-12} .

Fig. 3(a) is a graph of short-term stability of the 1-MHz PLL. This $\sigma_{\text{frequency}}$ versus τ analysis was performed using the Allan variance [3], [4]. Along with every color broadcast, the major TV networks transmit a short burst 3.57954... MHz signal at the start of each horizontal line to be used as a reference signal for demodulation of the color phase information. Each network derives its color burst signal from a rubidium-controlled oscillator/synthesizer whose output is usually stable to within 1 part in 10^{11} per day. By being phase-locked to this burst reference frequency, a color TV set's 3.57954... MHz oscillator displays good stability characteristics. I have



TYPICAL ONE DAY PHASE RECORD MADE AT BOULDER, COLO. SITE

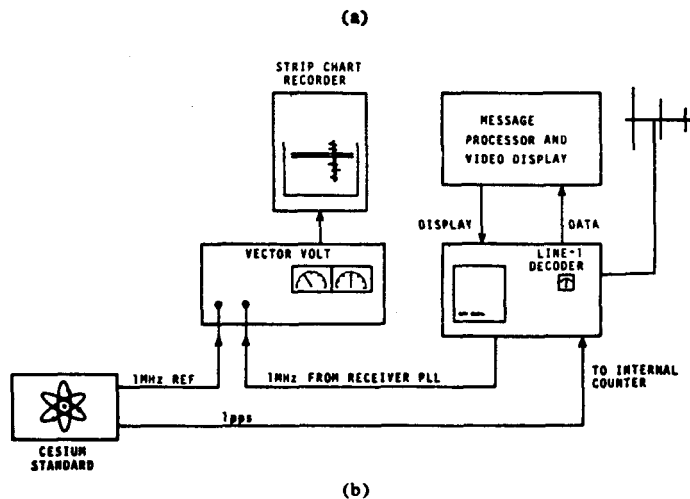


Fig. 2. (a) Typical phase versus time measurements for 1 min (full scale = 4 μ s) and 1 day (full scale = 333 ns). (b) Equipment layout for phase versus time measurements.

included data taken for color subcarrier stability for comparison to the line-1 active system; both deal with the transmission of frequency information via television. From data using the TV color subcarrier as a frequency reference for a remote location (Boulder, in this instance), statistical analyses done by Allan yield the following relations [5]:

$$\sigma_f(\tau) = \frac{10^{-8}}{\tau}, \quad \tau < 10 \text{ s}$$

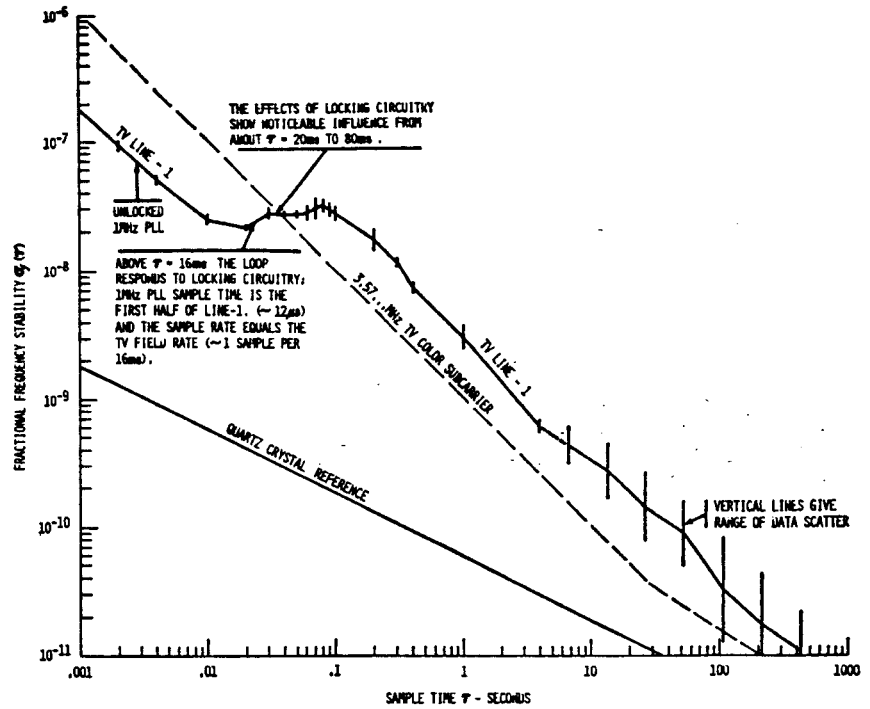
$$\sigma_f(\tau) = (3.5 \times 10^{-10} \text{ s}^{2/3})\tau^{-2/3}, \quad 10 \text{ s} \leq \tau \leq 1000 \text{ s}$$

where σ_f is a statistical measure of stability with respect to frequency averaged over a time τ in seconds. This function has been plotted on the graph of Fig. 3(a) for comparison. The color subcarrier stability for $\tau = 15$ min using this formula yields σ (15 min) = 4×10^{-12} . This is roughly a factor of two better than the active line-1 method.

Fig. 4 is a plot of relative cesium drift (network - NBS cesium clocks) for the path New York to Boulder from December 1, 1971 to January 27, 1972; path changes are evident in the plot. Although path switches from New York to Boulder seemed to occur often during the weekend (no data were taken during weekends, but time-of-arrival of the code on Monday mornings was frequently different from that observed the previous Friday), the network path was generally undisturbed for the duration of one work week. The most likely cause for weekend path changes stemmed from the large number of special television programs usually broadcast at this time. One might assume that when regular programming was resumed the path delay would return to its previous value. This was not always the case; however, the week-to-week data indicate that the network attempts to achieve very nearly the regular routing after the programming of special features.

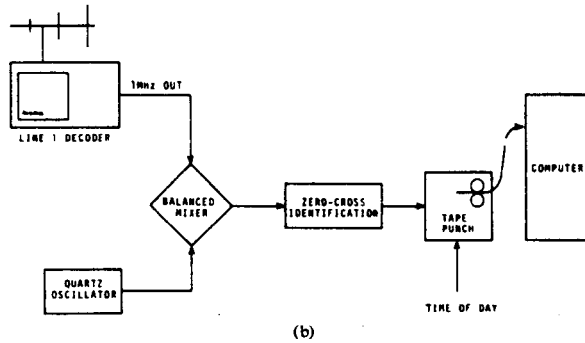
With respect to time-of-day synchronization, the passive line-10 identification technique has experienced great popularity since its inception in the late 1960's [2], [6]-[8]. It has been compared to the most sophisticated methods of time and frequency dissemination available today [5]. With this method, it is necessary that the remote site be time synchronized prior to measuring to within 33 ms, the ambiguity of the system. (The period of the recurrent line-10 is ~ 33 ms.) Also, the times of arrival of line-10 at a remote site must be coordinated with the same measurements taken at the master location equipped with an accurate standard. This can be done through joint communication or by relating measurements to published data from the NBS or USNO. Both initial calibration and reduction of data using the line-10 identification system represent time-consuming labors to many people; the chief advantage of the system lies in its low cost. At some TV stations cesium beams are used to control the line-10 rate, and time-of-coincidence (TOCs) are predicted in advance [9].

The active line-1 TV system transmits the time-of-day to the nearest microsecond. The active system's time-of-day synchronization should display the equivalent precision of the television line identification technique. Based on results using the passive line-10 system, time synchronization throughout most of the continental U.S.A. is possible to within 10 μ s at all times [2].



NOTE: 1. TEST RECEIVER BANDWIDTH ~ 30 Hz; LEAD TIME = 3ms
2. FROM $\tau = 1$ ms TO 6s, THE $\sigma_f(\tau)$ DATA WERE DERIVED FROM A COMPUTING COUNTER WITH A QUARTZ CRYSTAL REFERENCE ($\tau = 3$ ms-20s, $N = 2$; AVERAGING 10^4 - 10^5 SETS); FROM $\tau = 6$ TO 600s, $\sigma_f(\tau)$ MEASUREMENTS WERE TAKEN WITH THE INSTRUMENTATION SHOWN IN FIG. 3b; ($\tau = 6$ s-400s, $N = 2$, AVERAGING 6 SETS, THE MEASURING SYSTEM BANDWIDTH IS ~ 30 Hz)

(a)



(b)

Fig. 3. (a) σ_f frequency versus τ of active TV line-1 1-MHz PLL compared to 3.57954... MHz PLL derived from network color subcarrier (1 ms $< \tau < 15$ min). (b) Schematic for taking time domain stability data ($\tau = 6$ s to 400 s).

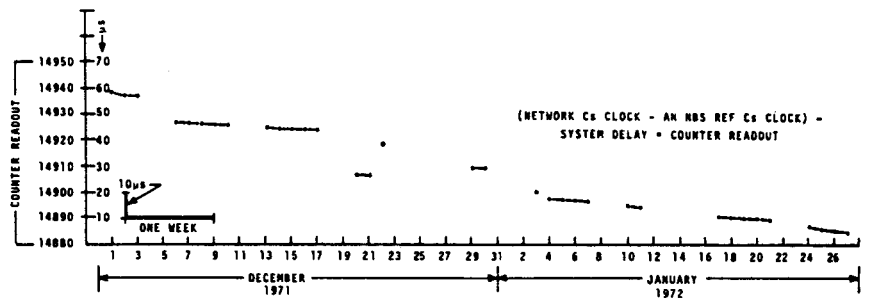


Fig. 4. A plot of clock differences between C_1 (New York network) and an NBS (Boulder, Colo.), C_2 standard illustrating long-term stability of active line-1 TV signals. (Offset between clocks is $\sim 13 \mu$ s/mo.)

IV. CONCLUSION

With time code generators installed at the television network centers in New York, N. Y., and Los Angeles, Calif., it is estimated that 70 percent of the United States' popula-

tion could be reached. Since the means of distribution already exists, implementation of the system appears to be relatively inexpensive.

In this letter the author has compared the line-1 frequency transfer capability with that

employed by the television network for color demodulation; i.e., 3.57954 . . . MHz colorburst reference. In the case of the active line-1 system, the stability of the locked 1-MHz PLL was only slightly less than that of a locked 3.57954 . . . MHz PLL. Additionally, it may be concluded that time-of-day synchronization is as good as passive systems employing a method of line identification. In summary, the advantages and limitations of an active television time and frequency distribution system are as follows:

A. Advantages

1) Measurements and reduction of data are fast and simple.

2) It combines the precision of line-10 time synchronization with subcarrier frequency transfer capability obtainable during network colorcasts.

3) User cost is proportional to degree of precision required.

4) For time-of-day information, the system is unambiguous to 24 h with reliability to 10 μ s and a potential of a few microseconds [2].

5) Since there are several dissimilar networks, atomic clock references for each provide redundancy and cross comparison of data.

6) Some network path changes are predictable; all are logged and accounted for and someday might be published afterwards.

B. Limitations

1) Microwave network paths can be interrupted without notice.

2) There is limited viewing time of nationwide network programs.

3) System will not work with tape delays without the use of special equipment; program, or at least line-1, must be "live" for measurements to be referred to the cesium atomic standard.

4) Propagation anomalies may limit the system's usefulness in some areas of the United States.

The study has shown that an active television code technique is feasible. The TV time system offers all of the precision of the passive line-10 identification and color subcarrier systems while allowing much greater ease of use from a data acquisition point of view. Furthermore, we believe its usefulness would extend to low, intermediate, and high accuracy users.

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DAVID A. HOWE
Time and Frequency Division
Nat. Bur. Stand.
Boulder, Colo. 80302

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