REAL TIME DISTRIBUTION VIA CONTROLLED TV TRANSMISSIONS

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ABSTRACT

Since first introduced as an experiment at the Third Annual PTTI Conference in Washington, DC (1971), this system has become operational at the television stations, WTTG (Channel 5), Washington, DC and KTTV (Channel 11), Los Angeles, CA. It permits independent and continuous transfers, without change in the broadcast format, with accuracies in the nanosecond region, as referenced to the U. S. Naval Observatory master clock.

This paper describes the present system with details of the equipment used in the control of transmissions and decoding, and shows the results of transfers made between some timing centers.

SUMMARY

A technique to distribute absolute time and frequency via controlled television transmissions was developed at the U. S. Naval Observatory (USNO) and successfully demonstrated in 1971 by an experiment performed between the Metromedia TV Station WTTG and the U. S. Naval Observatory (reference (1)).

This system is now operational from the TV stations WTTG (Channel 5) in Washington, DC, and KTTV (Channel 11) in Los Angeles, CA. It is used routinely by some laboratories around those areas to set their clocks to the U. S. Naval Observatory master clock (USNO MC) with accuracies and precision in the nanosecond region.

This paper describes the present system in detail, shows the results of transfers made routinely between some local timing facilities, and the USNO MC and describes some of its capabilities, limitations and applications.

INTRODUCTION

The technique consists of keeping TV transmissions synchronized to a reference clock within limits of the FCC broadcast specifications. These time coordinated transmissions are then used to set local clocks, or to measure their time and frequency differences with the USNO MC.

REVIEW OF NTSC TV FUNDAMENTALS

For those of you who are not familiar with the current NTSC color television standards, we would like to review them as they apply to precision time transfer.

In the USA, commercial TV broadcasts are generated at a rate of 30 pictures or frames per second. Each frame is composed of 525 lines and it takes about 33 milliseconds to transmit or to reproduce them. To minimize picture flicker, each frame has been divided into two groups of horizontal lines. Those groups, called odd and even fields, are transmitted so as to interlace each other. The process is called interlaced scanning. In this mode of operation the end of one field is separated from the start of the other by one half (1/2) a horizontal line (31.75 μs). The first nine lines of both fields contain equalizing and vertical pulses used to control the position and motion of the lines. The horizontal line 10 of the odd field was selected as a time marker because it is an easy line to identify.

At the transmitter, all of the recurrent waveforms and frequencies used in the modulation envelope are derived, or may be derived, from a single frequency. For example, let us start with 5 MHz. To derive the color subcarrier (SC):

$$SC = 5 \times \frac{63}{88} = 3.5795454\ldots\text{MHz} \rightarrow 279.36 \text{ ns.}$$

In case of the horizontal scan rate (H):

$$H = \frac{2SC}{455} = 5 \times 10^6 \times \frac{63}{88} \times \frac{2}{455} = 15734.266 \text{ Hz} \rightarrow 63.55\ldots\mu\text{s}$$

For the vertical (frame) rate (V):

$$V = \frac{H}{525} = 5 \times 10^6 \times \frac{63}{88} \times \frac{2}{455} \times \frac{1}{525} = 29.97...\text{Hz} \rightarrow 33.366...\text{ms}.$$

Since all pulse signals are derived from the subcarrier frequency, we can establish and maintain the pulses properly positioned in the time domain by phase shifting the subcarrier continuously until the desired pulse position is obtained. If we now consider the time period occupied by 30,000 frames:

$$33.36667 \times 10^{-3} \times 30{,}000 = 1001 \text{ seconds},$$

exactly. Thus, having caused an event which is periodic at the television vertical rate to coincide with a 1 pps pulse from the USNO MC, another coincidence must occur exactly 1001 seconds later.

By establishing an arbitrary time of coincidence, it is possible to calculate the dates (times) at which subsequent coincidences will occur between the one pulse per second time marks from the USNO MC and the emitted TV line 10 odd field pulse. These times of coincidence have been computed by assuming an initial coincidence at zero hours UT 1 January 1958. They are published by the USNO as TV TOC tables, Time Service Announcement Series 8.

These tables have the same format as those presently used for Loran-C. Table 1 gives the first TV TOC for each day in hours, minutes, and seconds. Table 2 gives all relative TOC's in a day. By adding the relative TOC's to the first TOC of any day, one obtains all absolute TOC's for that day. Table 3 gives the time differences for every second of the time interval between the TOC's.

For precise time application, the line 10 pulse must be precisely defined. We have defined this event as follows:

> "The Timing Mark shall be the 50% point on the leading edge of the first H synchronizing pulse following, by 1/2 line (31.78 μs), the last post-equalizing pulse in the vertical interval or, the H synchronizing pulse at the start of line 10 in fields 1 and 3 of the NTSC format in accordance with EIA RS 170A as emitted."

This Timing Mark is shown on Figure 1.

At this time we would like to call attention to the standard TV timing diagrams which appear in many publications including the FCC rules (Fig. 2&3). These timing diagrams invariably show the start of the odd fields and the start of the even field at the same T = 0 datum. The start of the field is defined as the leading edge of the first preequalizing pulse in the vertical interval (line 1). After the vertical interval which has a duration of 9 lines, the line 10 pulse appears. In the case of the fields 1 and 3, this pulse occurs 1/2 line or 31.75 µs after the start of the last post equalizing pulse; while in fields 2 and 4, the line 10 pulse occurs a full line (63.6 µs) after the last post equalizing pulse. Since the pulses start at the same datum (vertical rate), one could erroneously draw the conclusion that the horizontal pulses in alternate fields are not in phase. To accurately show the sequence of events in the extended horizontal time domain, the vertical interval should be displayed to the left in the case of fields 2 and 4. This would show that ALL pulse leading edges, even those of the equalizing pulses and the broad vertical serrations are synchronous and in phase at a period of 63.55 µs. During the vertical interval, extra pulses are inserted but synchronism is maintained by inserting these extra pulses at intervals of precisely twice the horizontal line rate.

By using circuitry which responds to all sync pulses and ignoring those occurring at a 1/2 line period, the extra pulses in the vertical interval, we obtain a uniform pulse train with a period of 63.55 µs (15734 Hz). Every 525 lines we obtain a pulse which coincides with the line 10 odd field pulse. This pulse train is processed by a phase locked tracking filter with a 500 ms loop time constant. A single pulse coincident with line 10 fields 1 and 3 is gated out of the system as the timing pulse.

For sync timing, a dedicated high stability NTSC sync generator is included in the transmitter control system. Additional signals are also available from the line 10 receiver for various display and calibration purposes.

REVIEW OF PAST WORK

The original system concept was evaluated on an experimental basis at station WTTG in Washington, DC, starting in July 1971. This system involved stabilizing the time base of the station sync generators to a cesium reference oscillator and adjusting the phase of the emitted pulse in the time domain (Figure 4). By monitoring the time of arrival of the line 10 pulses at the USNO, and correcting for propagation delays and equipment delays, error information was used to manually adjust the phase of the transmitted pulses in order to maintain correct emission time.

The frequency adjustments required at the transmitter were subsequently greatly reduced by the development of a controller, presently known as the TV time synchronizer, which compared emitted pulses with reference pulses generated internal to the system and issued phase-shift commands to the station sync generators in order to maintain on-time emission. Several safety devices were necessary to assure that the TV station would remain within FCC specifications and to inform users if the emission was controlled and on time.

Introduction of the servo loop at the transmitter did stablize the emission time of the transmitter and absolute times of emission were held to within a few hundred nanoseconds. Analysis of data taken before the installation of the servo loop showed considerably less scatter (phase instability) over short term observations with the absolute error removed. These observations prompted a study into the interaction of the TV station equipment, the receiving equipment, and the servo control system, with the object of attaining the short term (1 second) stability of the open loop system with the accuracy of the closed loop.

The study resulted in the following conclusions:

1. The period of the H pulses sampled at the vert. rate varied from frame to frame in excess of 150 ns.

2. The start and width of pulses were controlled by R-C mono-stable multivibrator. Only the start of blanking which preceeds sync by about 1.5 μs was controlled by the reference oscillator.

3. The sync separator in the consumer type TV receiver used to monitor the transmitter and feed back to the servo was deliberately made slow to improve noise immunity and also introduced about 100 ns additional jitter.

4. With the loop open, the short term stability of the sub-carrier phase was excellent (in the picosecond region).

5. Differential phase and gain in the receiver had to be improved and stabilized if pulse fidelity was to be maintained.

6. Differential phase and gain, as well as power supply regulation in the transmitter, influenced pulse stability, especially during changes in APL (average picture level). (Did we say that what happened between the pulses didn't concern us?)

The approach taken to system upgrading consisted of reducing jitter by speeding up the receiver sync separator, improving waveform fidelity, and reduction of sync generator jitter. If these measures would reduce jitter to below about 120 ns, the stable subcarrier (1/2 period 140 ns) could be used to clock control the timing pulses, thus removing the residual jitter.

A prototype receiver system was constructed, aligned for optimum phase and gain uniformity, and a very high speed comparator used for sync separation. In addition, the transmitter was equipped with a digital sync generator for the experiment. The result, as predicted, reduced jitter to the 100 ns range; low enough to warrant using the regenerated subcarrier to synchronize the timing pulse.

To evaluate this technique, the first zero crossing of the regenerated subcarrier following the 50% point on the leading edge of the line 10 (odd) pulse was selected as the timing point. The results of this experiment were encouraging. During some segments of program material, standard deviations well below ±1 ns were obtained consistently, while at other times, and during black and white programming, standard deviations increased to ±100-200 ns. The reason for the change during black and white transmission was, clearly, the loss of burst during monochrome transmissions. This condition was expected. The color transmission inconsistencies were traced to random phase relationship of H sync to subcarrier from one program segment to another. Since the film chains, tape machines, and studio cameras were phase matched at the studio switching point (within limits), the problem was isolated to the source material. No requirement existed in the specifications for consistence of phase between subcarrier and sync.

Discussions with TV network engineering officials confirmed our findings, but lent a note of encouragement. This aspect of the specification, while it was an expedient in the early days of color operations, was causing problems now since, without Subcarrier Horizontal phase Coherence (SCH), differentiation between fields one and three, as well as between fields two and four of the field NTSC color format, could not be readily accomplished. This fact causes many problems in tape editing. Several proposals are under consideration by the broadcast committee of the EIA. At this writing, a new specification has been proposed which specifies subcarrier phase to sync but is limited to studio operations and not yet applied to transmitted signals. Until the total television system establishes "SCH" the use of subcarrier sync will have to wait.

The subcarrier phase and its consistency with chrominance information in the picture is of great importance since it directly and obviously affects the color fidelity of the received picture. To maintain this quality, minor phase perturbations are reduced by a color lock loop. H sync, since it is less critical and at a much lower frequency, does have residual jitter. This jitter (approx. 100 ns) has negligible effect on picture quality for the viewer.

CURRENT SYSTEM CONFIGURATION

A. The system has been set up at the transmitter as shown by Figure

1. A cesium beam oscillator supplies a 5 Mhz frequency, via a phase microstepper, to a TV time synchronizer.

2. The TV time synchronizer performs the following main functions:

a) Synthesizes the 3.58 Mhz color subcarrier frequency for the TV transmitter.

b) Generates a reference time scale composed of line 10 odd field pulses which are set "on time" to the USNO MC via the TOC table.

c) Automatically corrects the phase of the generated 3.58 Mhz color subcarrier frequency, when necessary, to maintain synchronization between the emitted TV transmission and the USNO MC.

3. A TV receiver and line 10 discriminator continuously monitor the emitted TV transmissions. Any change in the time of emission of these transmissions (line 10 odd) is detected in the TV time synchronizer by comparing the received (or emitted) line 10 pulses output of the discriminator against the generated "on time" line 10 pulses reference.

If this difference is other than zero, but no more than ±10 μs, the time of emission of the TV transmissions is adjusted automatically by the TV time synchronizer by advancing or retarding the phase of the generated 3.58 Mhz color subcarrier frequency, until synchronization is again secured.

If this time difference exceeds ±5 μs, a slow modulation of ±0.5 μs is impressed on the 3.58 Mhz generated color subcarrier, and thus on the emitted TV program, to warn the PTTI user of a temporary large error in the time of emission of the TV transmissions.

NOTE: Changes in the time of emission of the TV transmissions occur when TV programs are switched from film library to video tape recording, to live programs, etc. Most of these changes are usually small.

The phase microstepper permits precise adjustment of the cesium output frequency to the USNO MC and thus maintains the generated line 10 odd reference on time.

B. The basic receiving or monitoring system used at the USNO, or at any of the local clock locations, is shown in Figures 7 and 8.

The TV receiver is tuned to the synchronized TV transmissions (KTTV or WTTG). Line 10 pulses are generated from the discriminator and their time of arrival, referenced to a local clock, are measured on a time interval counter.

When the measurement is made or reduced at a TOC (USNO Time Service Bulletin Series No. 8), the time difference obtained represents the time difference between the local clock and the TV clock (emitted signal) plus the propagation and system delay - or:

[(local clock - TV line 10 received) + C].

The propagation and system delay (C) can be computed or measured.

Since the USNO publishes the daily absolute time corrections to be applied to the WTTG and KTTV transmissions (USNO MC - TV emitted, USNO Time Service Bulletin Series No. 4), Table 4, the actual time difference between the USNO MC and the local clock can be obtained as follows:

(USNO MC - local clock) = [(USNO MC - TV emitted) - (local clock - TV received) - C].

Sophisticated TV transmitting, receiving and decoding equipment has been developed, and is available commercially, to implement this system and to display the absolute time difference between a local clock and the TV transmissions.

SYSTEM SYNCHRONIZATION AND CAPABILITIES

The USNO monitors continuously the transmissions from WTTG and KTTV (Fig.9&10) and maintains them synchronized with the USNO MC by changing, when necessary, the frequency output of the cesium oscillators installed at the TV transmitters. An arbitrary excursion limit of up to ±2.5 μs has been allowed in the TV transmissions before introducing a rate correction to the TV clock. This limit could be reduced, if desired.

Automatic time rate corrections as small as 0.86 nanosecond per day can be initiated from the phase microstepper. Figures 9 and 10 are plots of [USNO MC - WTTG] and of [USNO MC - KTTV]. They show how well this synchronization has been maintained in the last few months.

The daily time differences between the USNO MC and WTTG and KTTV are given as corrections on USNO Time Service Annoucements, Series 4 and 5, and by telephone announcements available by dialing (202) 254-4662 or AUTOVON 294-4662.

Various organizations and laboratories are presently utilizing this precise time distribution system to set or to compare the time of their own reference clock standard with that of the USNO MC. These TV time transfers are done routinely to real time accuracies of ±20 nanoseconds (ns) or better.

As an illustration, Figures 11 and 12 show how well two independent organizations, located approximately 25 km from WTTG measure the time difference between their reference clocks and the USNO MC.

Figure 11 shows the time relationship between the USNO MC and the USCG Washington Radio Station clock, located in Alexandria, VA, obtained by portable clock and by TV time measurement of WTTG transmissions. Neither statistical manipulation nor selection has been applied to the data used for this plot.

The measurements were obtained by utilizing a very simple system which consists of a TV receiver/line 10 discriminator and a time interval counter.

Figure 12 shows the time relationship between the USNO MC and the Applied Physics Laboratories (APL) clock, located in Laurel, MD, obtained by portable clock and by TV time measurements of WTTG transmissions with the slope removed.

The APL measurements were obtained by using an automatic TV monitor system.

The RMS deviation of these TV real time transfers, as verified by portable clock measurements, is within ±20 ns.

WTTG and KTTV transmissions are used routinely to distribute USNO MC time and frequency to locations as far away as Fort Detrick (MD) (60 km from WTTG), Dover, DE (130 km from WTTG), and Point Mugu, CA, approximately 95 km from KTTV.

Greater accuracies can be achieved by taking the TV measurements during periods when no phase corrections are made to the 3.58 MHz color subcarrier frequency at the TV transmitters (this can be ascertained easily by observing the stability of the received color subcarrier frequency or by looking at the received TV video), or by some statistical recognization or filtering of the data. Dr. Winkler of the USNO has recently experimented with an exponential weighted smoothing rejection technique to reduce the time differences between the USNO MC and WTTG transmissions measured at the USNO and found that a precision of 1 ns or better is obtainable from this TV system.

Tests on the receiving systems, performed by using RF generators of known stability, show that these receiving systems are capable of an absolute calibration accuracy of better than ±15 ns, and 1 sigma scatter consistently below 500 ps. The phase detector in the transmitter loop showed a dead band of ±2 ns and the digital phase shifter has a quantizing error of less than ±4 ns. The video processing in the TV plant inserts at least two slaved pulse generators before reaching the modulator, and finally, less than ideal regulation of the transmitter power supplies, especially during the vertical interval, cause changes in sync tip levels and leading edge slopes.

At the receiving site, antenna movement, transmission line propagation delay changes with temperature and humidity, and RF path propagation variations all contribute to limit system precision. All factors considered, this present line 10 time transfer system, as implemented, should be considered to have a precision capability of ±20 ns or better over path lengths of 100 μs or less and approaching ±50 ns at path lengths up to 350 μs. These figures are well confirmed by the time transfers reported above.

FUTURE PLANS AND APPLICATIONS

A problem encountered in installation of this system has been selection of a TV station which has mostly local program origination. Network affiliates were ruled out since they must operate off network feeds for a large percentage of the time. However, as reported and noted recently in the NBS Monthly Time and Frequency Bul. #238, some of the larger network outlets are installing Frame Synchronizers. These Frame Synchronizers destroy the usefulness of the station for relative time and frequency transfer using network observations. Simultaneous use of the same transmitters is unaffected, but they present an ideal situation for installation of the absolute time and frequency system discussed in this paper, since emission times may now be precisely controlled locally through the Frame Synchronizers.

The USNO presently has plans underway to implement this TV time distribution system in additional TV stations in the Washington/Baltimore Area in order to evaluate this technique as a means of providing an extremely accurate position/navigation system. Further applications in the fields of collision avoidance, geodesy and real time computer operations will be possible at low cost. Rapid navigation on the Capital Beltway, as mentioned by the Scientific Director of the U. S. Naval Observatory, may also be made possible.

There are approximayely 800 TV transmitters operating in the U.S. at this time and they offer tremendous potential for the distribution of real time, synchronized, transmissions at relatively little cost.

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REFERENCES

1. Lavanceau, J. D., and Carroll, D., "Real Time Synchronization via Passive Television Transmissions", Third Annual DoD Precise Time and Time Interval Strategic Planning Meeting, 16-18 November 1971, held at Naval Research Laboratory, Washington, DC.

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

TELEVISION LINE 10 ODD SYNC

33,366 MICROSECONDS/PERIOD

DATE 1977	TIME H	M	S	DATE 1977	TIME H	M	S	DATE 1977	TIME H	M	S
OCT 1	0	6	15	NOV 1	0	10	51	DEC 1	0	4	0
2	0	1	1	2	0	5	37	2	0	15	27
3	0	12	28	3	0	0	23	3	0	10	13
4	0	7	14	4	0	11	50	4	0	4	59
5	0	2	0	5	0	6	36	5	0	16	26
6	0	13	27	6	0	1	22	6	0	11	12
7	0	8	13	7	0	12	49	7	0	5	58
8	0	2	59	8	0	7	35	8	0	0	44
9	0	14	26	9	0	2	21	9	0	12	11
10	0	9	12	10	0	13	48	10	0	6	57
11	0	3	58	11	0	8	34	11	0	1	43
12	0	15	25	12	0	3	20	12	0	13	10
13	0	10	11	13	0	14	47	13	0	7	56
14	0	4	57	14	0	9	33	14	0	2	42
15	0	16	24	15	0	4	19	15	0	14	9
16	0	11	10	16	0	15	46	16	0	8	55
17	0	5	56	17	0	10	32	17	0	3	41
18	0	0	42	18	0	5	18	18	0	15	8
19	0	12	9	19	0	0	4	19	0	9	54
20	0	6	55	20	0	11	31	20	0	4	40
21	0	1	41	21	0	6	17	21	0	16	7
22	0	13	8	22	0	1	3	22	0	10	53
23	0	7	54	23	0	12	30	23	0	5	39
24	0	2	40	24	0	7	16	24	0	0	25
25	0	14	7	25	0	2	2	25	0	11	52
26	0	8	53	26	0	13	29	26	0	6	38
27	0	3	39	27	0	8	15	27	0	1	24
28	0	15	6	28	0	3	1	28	0	12	51
29	0	9	52	29	0	14	28	29	0	7	37
30	0	4	38	30	0	9	14	30	0	2	23
31	0	16	5					31	0	13	50

NOTES

TABLE 2
INTERPOLATIONS FOR ALL TOC'S IN A DAY
TIMES OF COINCIDENCE (NULL) EPHEMERIS
TELEVISION LINE 10 ODD SYNC

33,366 MICROSECONDS/PERIOD

H	M	S	H	M	S	H	M	S
0	0	0	11	7	20	22	14	40
0	16	41	11	24	1	22	31	21
0	33	22	11	40	42	22	48	2
0	50	3	11	57	23	23	4	43
1	6	44	12	14	4	23	21	24
1	23	25	12	30	45	23	38	5
1	40	6	12	47	26	23	54	46
1	56	47	13	4	7			
2	13	28	13	20	48			
2	30	9	13	37	29			
2	46	50	13	54	10			
3	3	31	14	10	51			
3	20	12	14	27	32			
3	36	53	14	44	13			
3	53	34	15	0	54			
4	10	15	15	17	35			
4	26	56	15	34	16			
4	43	37	15	50	57			
5	0	18	16	7	38			
5	16	59	16	24	19			
5	33	40	16	41	0			
5	50	21	16	57	41			
6	7	2	17	14	22			
6	23	43	17	31	3			
6	40	24	17	47	44			
6	57	5	18	4	25			
7	13	46	18	21	6			
7	30	27	18	37	47			
7	47	8	18	54	28			
8	3	49	19	11	9			
8	20	30	19	27	50			
8	37	11	19	44	31			
8	53	52	20	1	12			
9	10	33	20	17	53			
9	27	14	20	34	34			
9	43	55	20	51	15			
10	0	36	21	7	56			
10	17	17	21	24	37			
10	33	58	21	41	18			
10	50	39	21	57	59			

NOTES

TABLE 3
INTERPOLATIONS FOR ALL SECONDS BETWEEN TOC'S

TELEVISION LINE 10 ODD SYNC
33,366 MICROSECONDS/PERIOD

M	S	(µS)	M	S	(µS)	M	S	(µS)	M	S	(µS)
0	1	1000.000	0	51	17633.333	1	41	900.000	2	31	17533.333
0	2	2000.000	0	52	18633.333	1	42	1900.000	2	32	18533.333
0	3	3000.000	0	53	19633.333	1	43	2900.000	2	33	19533.333
0	4	4000.000	0	54	20633.333	1	44	3900.000	2	34	20533.333
0	5	5000.000	0	55	21633.333	1	45	4900.000	2	35	21533.333
0	6	6000.000	0	56	22633.333	1	46	5900.000	2	36	22533.333
0	7	7000.000	0	57	23633.333	1	47	6900.000	2	37	23533.333
0	8	8000.000	0	58	24633.333	1	48	7900.000	2	38	24533.333
0	9	9000.000	0	59	25633.333	1	49	8900.000	2	39	25533.333
0	10	10000.000	1	0	26633.333	1	50	9900.000	2	40	26533.333
0	11	11000.000	1	1	27633.333	1	51	10900.000	2	41	27533.333
0	12	12000.000	1	2	28633.333	1	52	11900.000	2	42	28533.333
0	13	13000.000	1	3	29633.333	1	53	12900.000	2	43	29533.333
0	14	14000.000	1	4	30633.333	1	54	13900.000	2	44	30533.333
0	15	15000.000	1	5	31633.333	1	55	14900.000	2	45	31533.333
0	16	16000.000	1	6	32633.333	1	56	15900.000	2	46	32533.333
0	17	17000.000	1	7	266.667	1	57	16900.000	2	47	166.667
0	18	18000.000	1	8	1266.667	1	58	17900.000	2	48	1166.667
0	19	19000.000	1	9	2266.667	1	59	18900.000	2	49	2166.667
0	20	20000.000	1	10	3266.667	2	0	19900.000	2	50	3166.667
0	21	21000.000	1	11	4266.667	2	1	20900.000	2	51	4166.667
0	22	22000.000	1	12	5266.667	2	2	21900.000	2	52	5166.667
0	23	23000.000	1	13	6266.667	2	3	22900.000	2	53	6166.667
0	24	24000.000	1	14	7266.667	2	4	23900.000	2	54	7166.667
0	25	25000.000	1	15	8266.667	2	5	24900.000	2	55	8166.667
0	26	26000.000	1	16	9266.667	2	6	25900.000	2	56	9166.667
0	27	27000.000	1	17	10266.667	2	7	26900.000	2	57	10166.667
0	28	28000.000	1	18	11266.667	2	8	27900.000	2	58	11166.667
0	29	29000.000	1	19	12266.667	2	9	28900.000	2	59	12166.667
0	30	30000.000	1	20	13266.667	2	10	29900.000	3	0	13166.667
0	31	31000.000	1	21	14266.667	2	11	30900.000	3	1	14166.667
0	32	32000.000	1	22	15266.667	2	12	31900.000	3	2	15166.667
0	33	33000.000	1	23	16266.667	2	13	32900.000	3	3	16166.667
0	34	633.333	1	24	17266.667	2	14	533.333	3	4	17166.667
0	35	1633.333	1	25	18266.667	2	15	1533.333	3	5	18166.667
0	36	2633.333	1	26	19266.667	2	16	2533.333	3	6	19166.667
0	37	3633.333	1	27	20266.667	2	17	3533.333	3	7	20166.667
0	38	4633.333	1	28	21266.667	2	18	4533.333	3	8	21166.667
0	39	5633.333	1	29	22266.667	2	19	5533.333	3	9	22166.667
0	40	6633.333	1	30	23266.667	2	20	6533.333	3	10	23166.667
0	41	7633.333	1	31	24266.667	2	21	7533.333	3	11	24166.667
0	42	8633.333	1	32	25266.667	2	22	8533.333	3	12	25166.667
0	43	9633.333	1	33	26266.667	2	23	9533.333	3	13	26166.667
0	44	10633.333	1	34	27266.667	2	24	10533.333	3	14	27166.667
0	45	11633.333	1	35	28266.667	2	25	11533.333	3	15	28166.667
0	46	12633.333	1	36	29266.667	2	26	12533.333	3	16	29166.667
0	47	13633.333	1	37	30266.667	2	27	13533.333	3	17	30166.667
0	48	14633.333	1	38	31266.667	2	28	14533.333	3	18	31166.667
0	49	15633.333	1	39	32266.667	2	29	15533.333	3	19	32166.667
0	50	16633.333	1	40	33266.667	2	30	16533.333	3	20	33166.667

NOTES

U. S. NAVAL OBSERVATORY
WASHINGTON, D.C. 20390

3 NOVEMBER 1977

DAILY PHASE VALUES AND TIME DIFFERENCES SERIES 4

NO. 561

THE TABLE GIVES: UTC(USNO MC) - TRANSMITTING STATION

UNIT = ONE MICROSECOND

	WASH. DC WTTG EMITTED	L.A. CA KTTV EMITTED	NBC 1925 UT	NATIONAL TELEVISION NETWORKS NBC 1931 UT	CBS 1926 UT	CBS 1932 UT	ABC 1927 UT	ABC 1933 UT
OCT. 27	-2.17	0.2	21,530.9	14,509.7	12,120.6	5,098.0	9,194.1	2,171.6
28	-2.21	0.2	4,451.4	30,795.6	11,708.0	4,675.4	25,485.8	18,463.4
29	-2.25	-	20,753.0	13,730.7	13,711.0	6,691.3	431.7	26,776.0
30+	-2.29	-	188.2	26,532.5	10,347.3	13,696.9	32,499.4	25,315.4
31+	-2.36	0.2	16,465.6	9,443.1	7,075.2	42.6	4,135.9	30,480.0
NOV. 1+	-2.39	0.3	32,756.0	25,733.5	6,643.5	16,336.1	20,428.6	13,406.1
2+	-2.42	0.4	15,681.7	8,659.2	6,286.4	15,913.4	3,353.9	29,698.0

+ VALUES FOR THESE DAYS WERE OBTAINED DURING THE 2000 UT HOUR FOR NBC, CBS, AND ABC.

REFERENCES: (A) TIME SERVICE INFORMATION LETTER OF 15 AUGUST 1973
(B) TIME SERVICE ANNOUNCEMENT, SERIES 9, NO. 125 (LORAN-C)
(C) DAILY PHASE VALUES AND TIME DIFFERENCES, SERIES 4, NO. 195 (TV)

NOTES:

(1) PROPAGATION DISTURBANCES WERE OBSERVED NEAR THE FOLLOWING TIMES:
28 OCT. 1900/4
29 OCT. 1240/4, 1645/4, 2005/3
30 OCT. 1505/4.

(2) NAVY STATION OFF-AIR TIME:
NWC 31 OCT. 0250 TO 0301 UT

Table 4. USNO Series No. 4

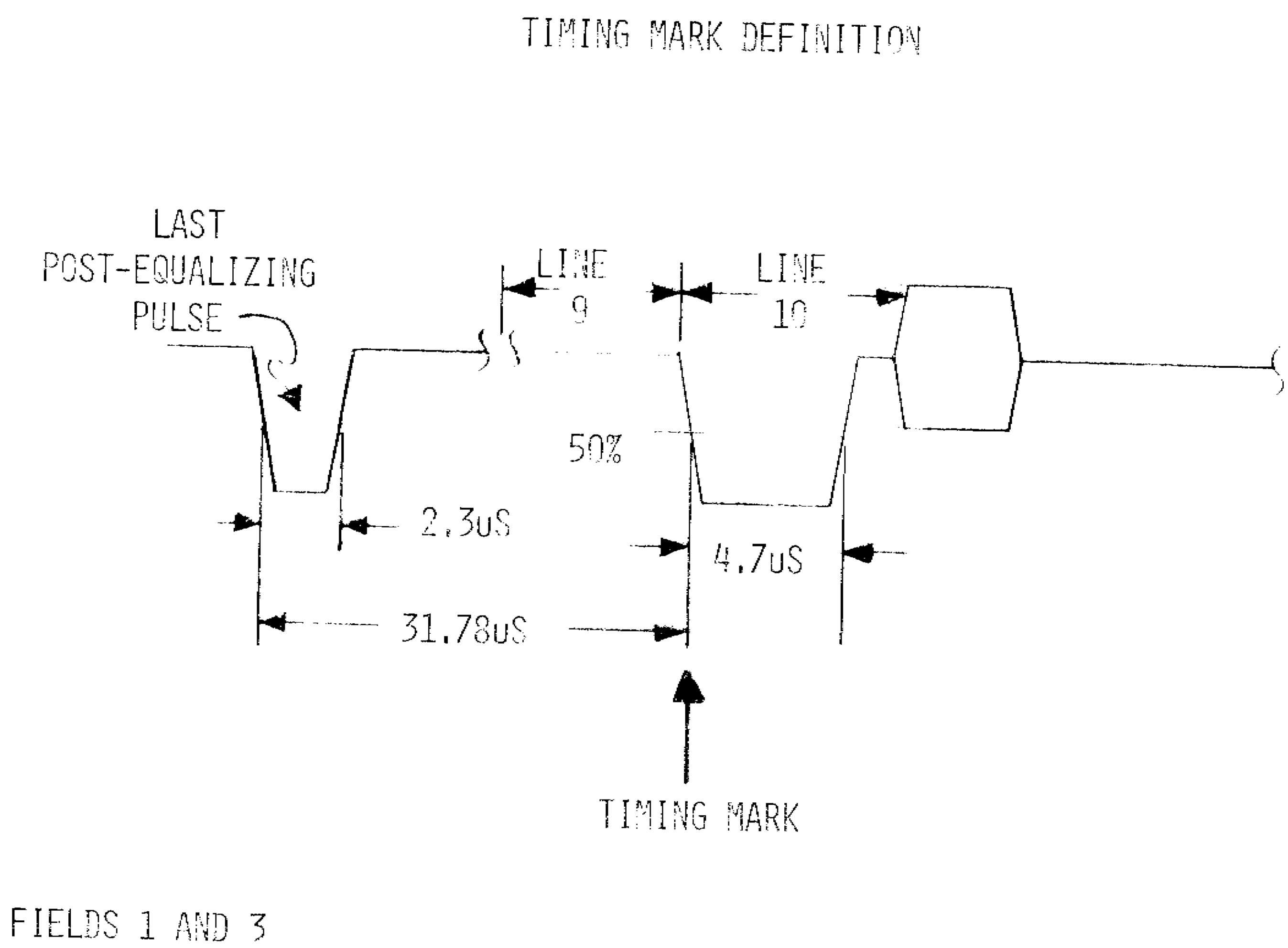


Fig. 1. Timing Mark Definition

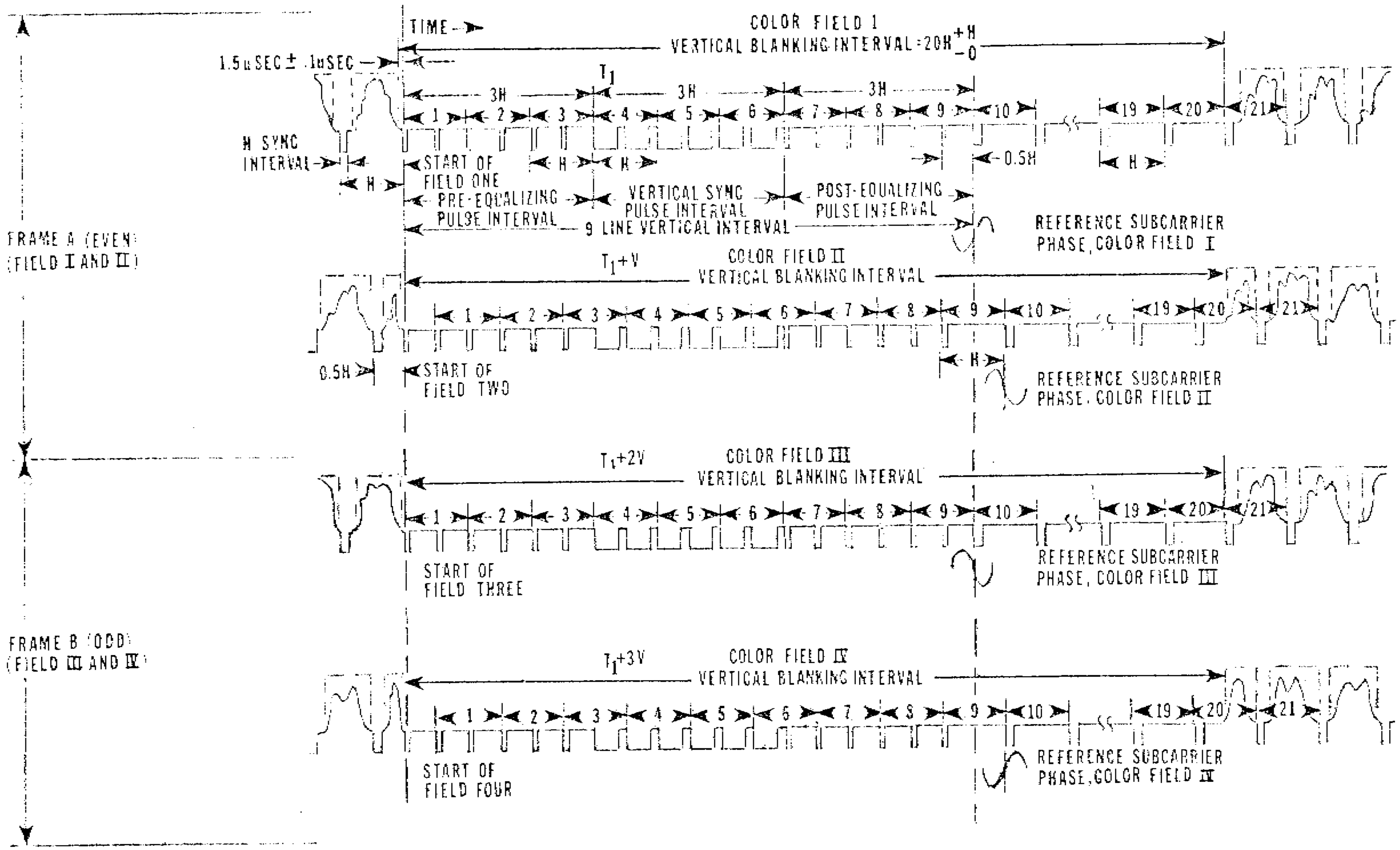


Fig. 2. Standard TV Diagrams

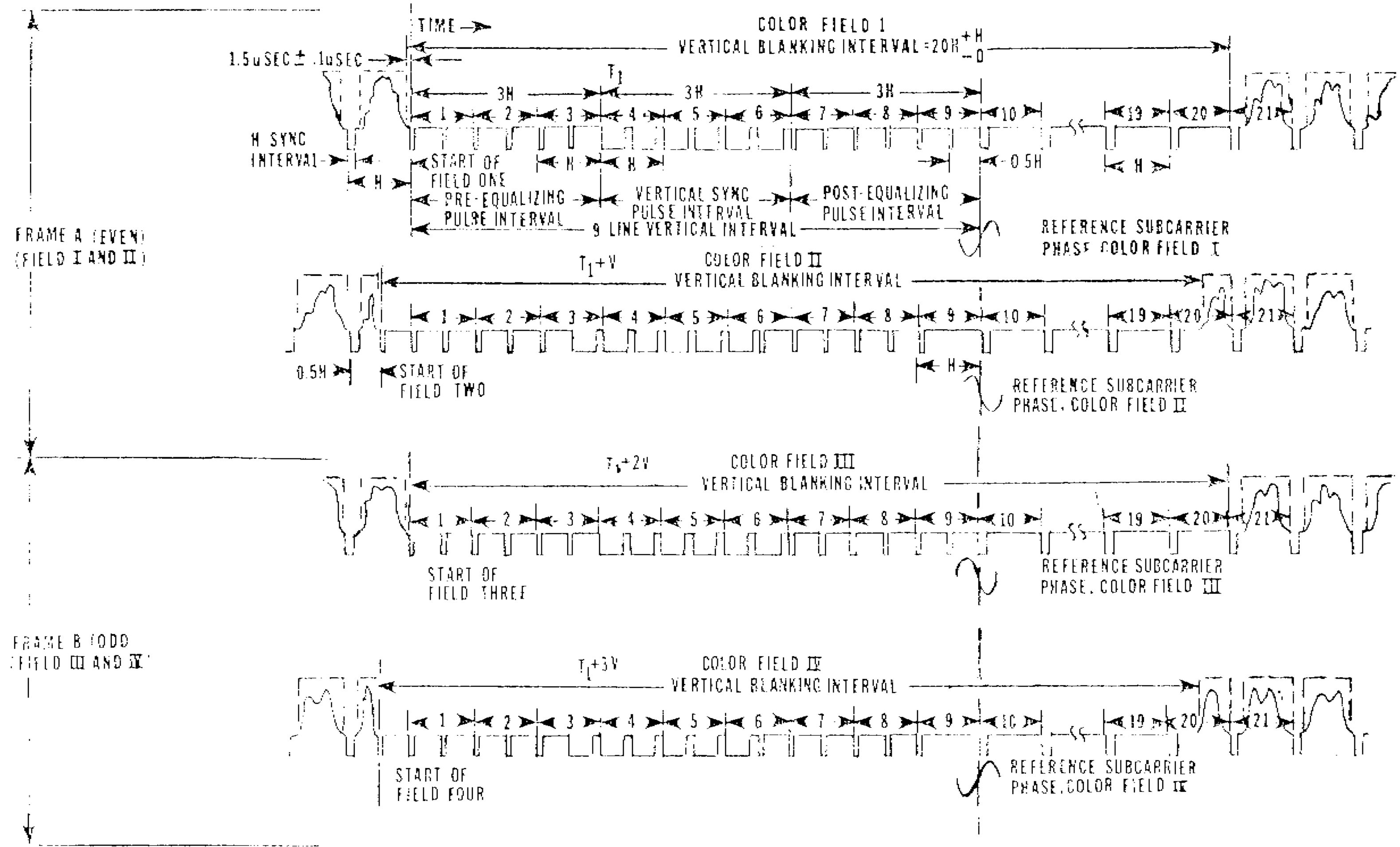
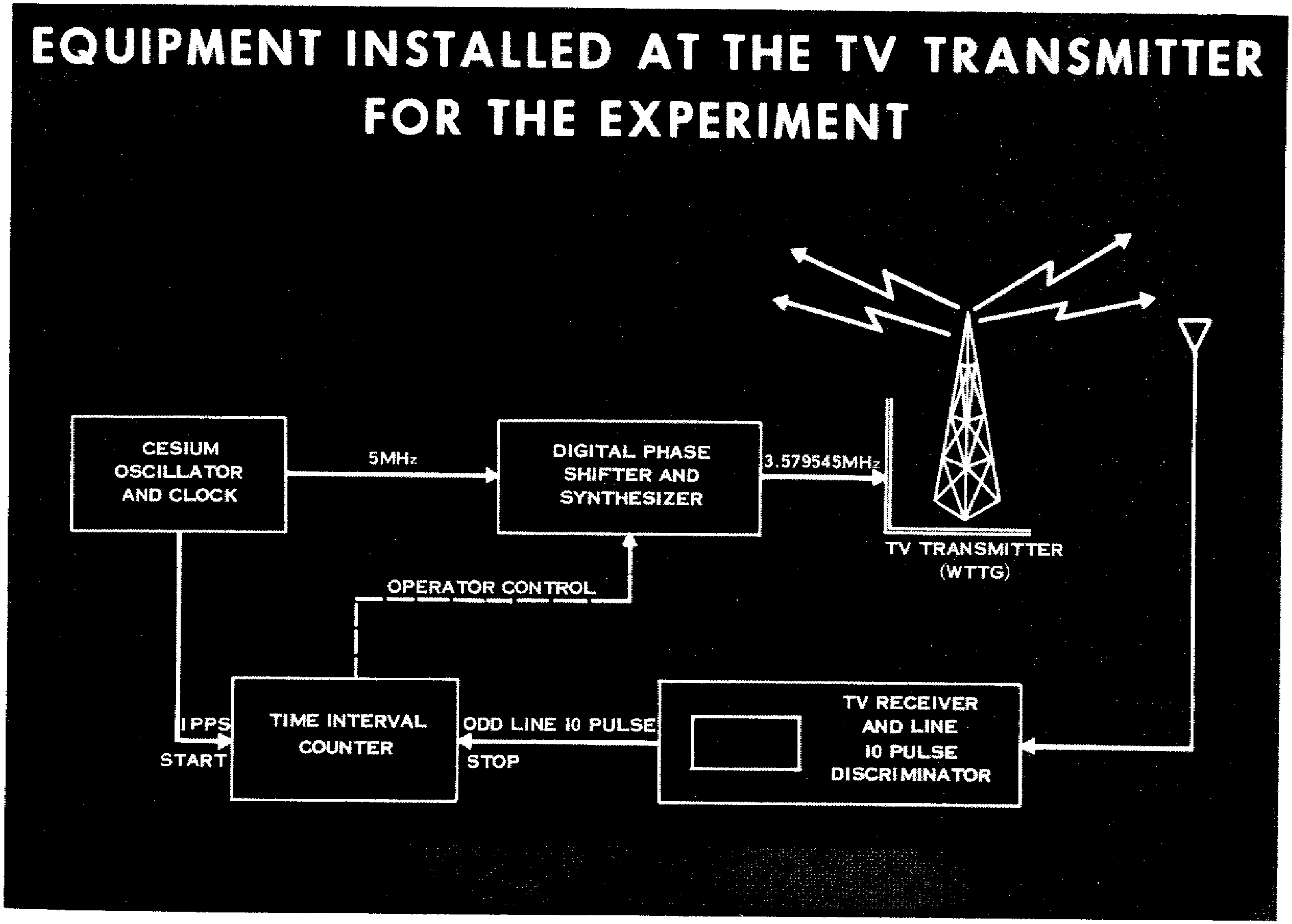


Fig. 3. Standard TV Diagrams with Fields 2 & 4 Displaced


EQUIPMENT INSTALLED AT THE TV TRANSMITTER
FOR THE EXPERIMENT
CESIUM OSCILLATOR AND CLOCK
5MHz
DIGITAL PHASE SHIFTER AND SYNTHESIZER
3.579545MHz
TV TRANSMITTER (WTTG)
OPERATOR CONTROL
1 PPS
START
TIME INTERVAL COUNTER
ODD LINE 10 PULSE
STOP
TV RECEIVER AND LINE 10 PULSE DISCRIMINATOR

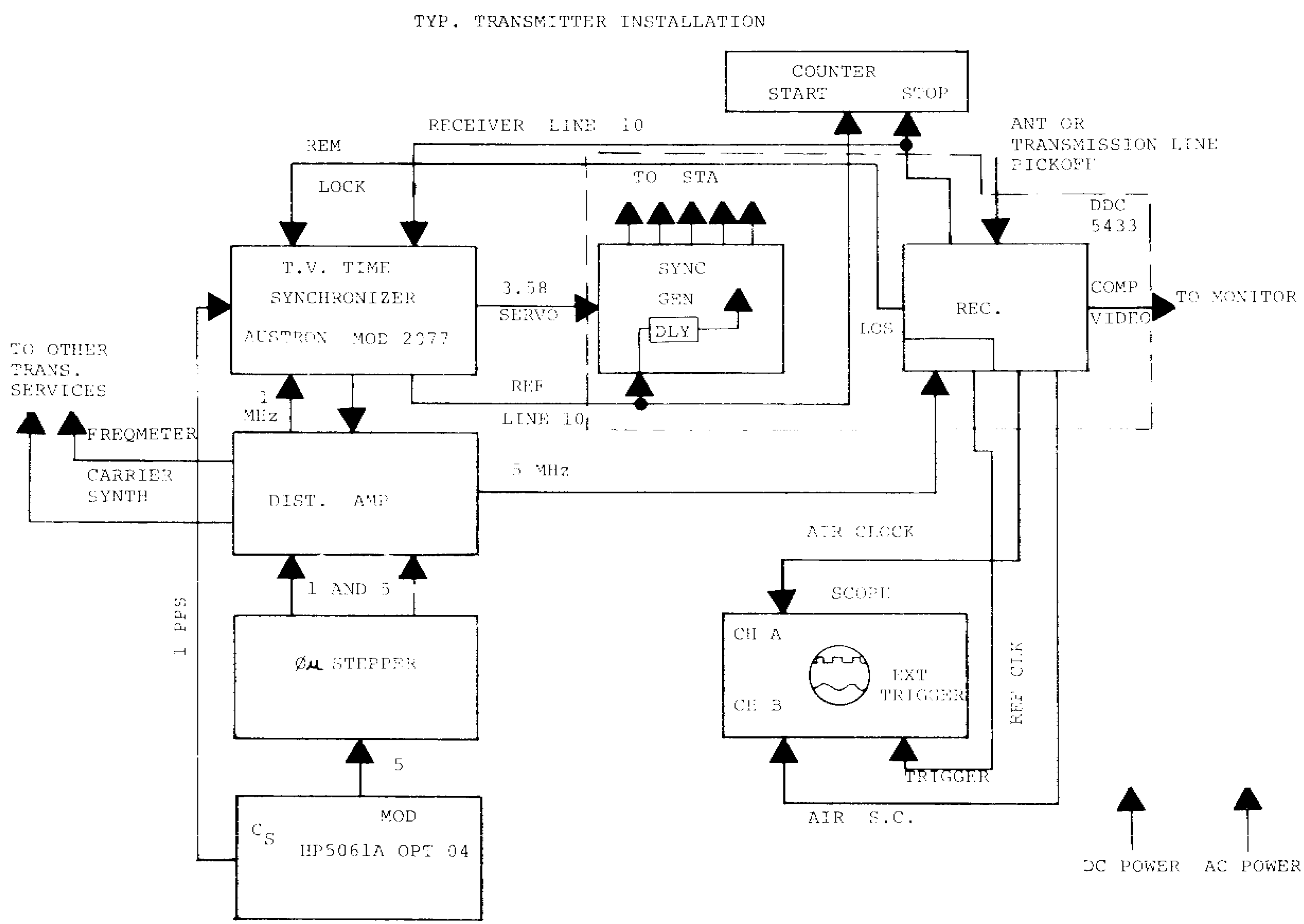
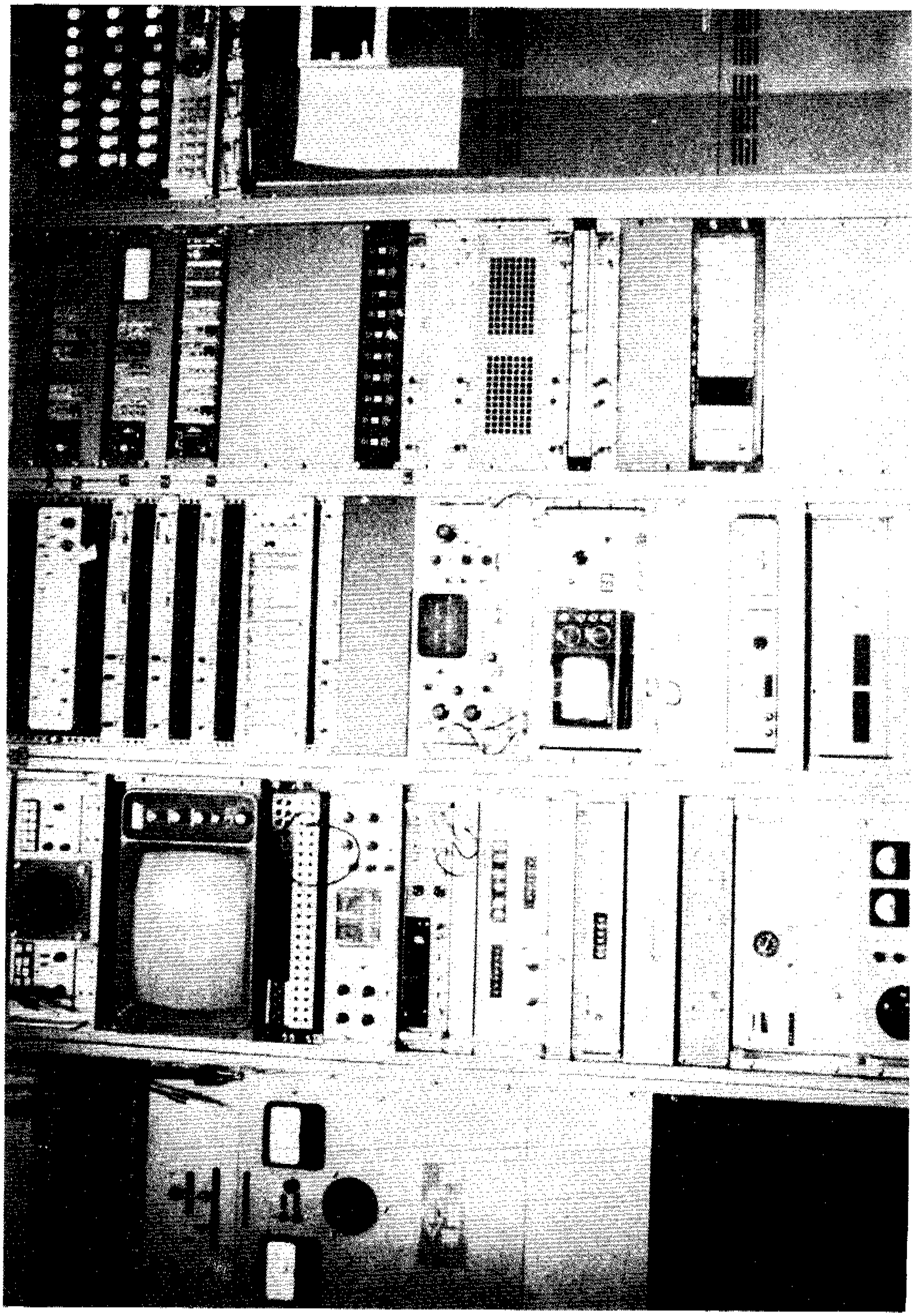


Fig. 5. Transmitter Control System



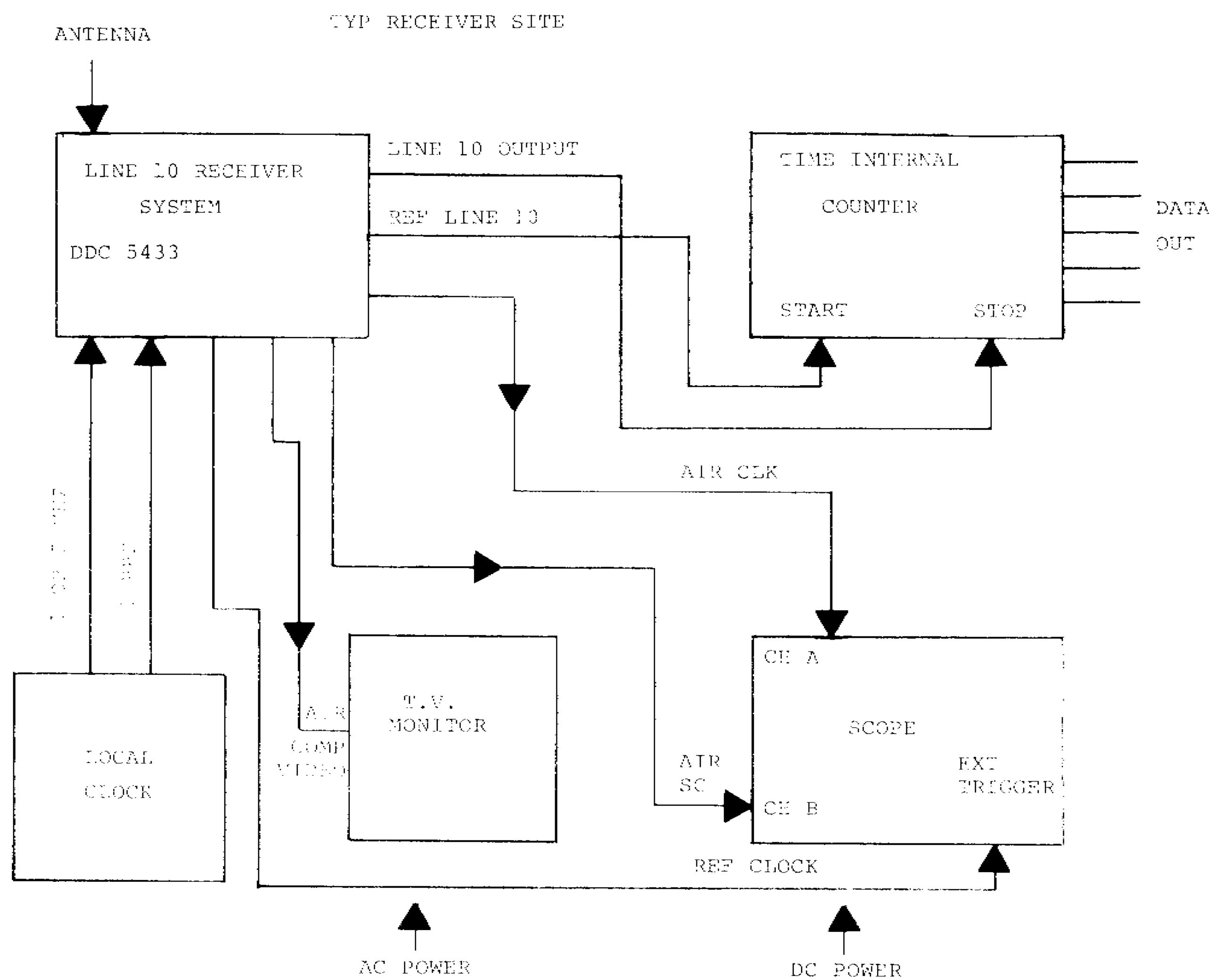
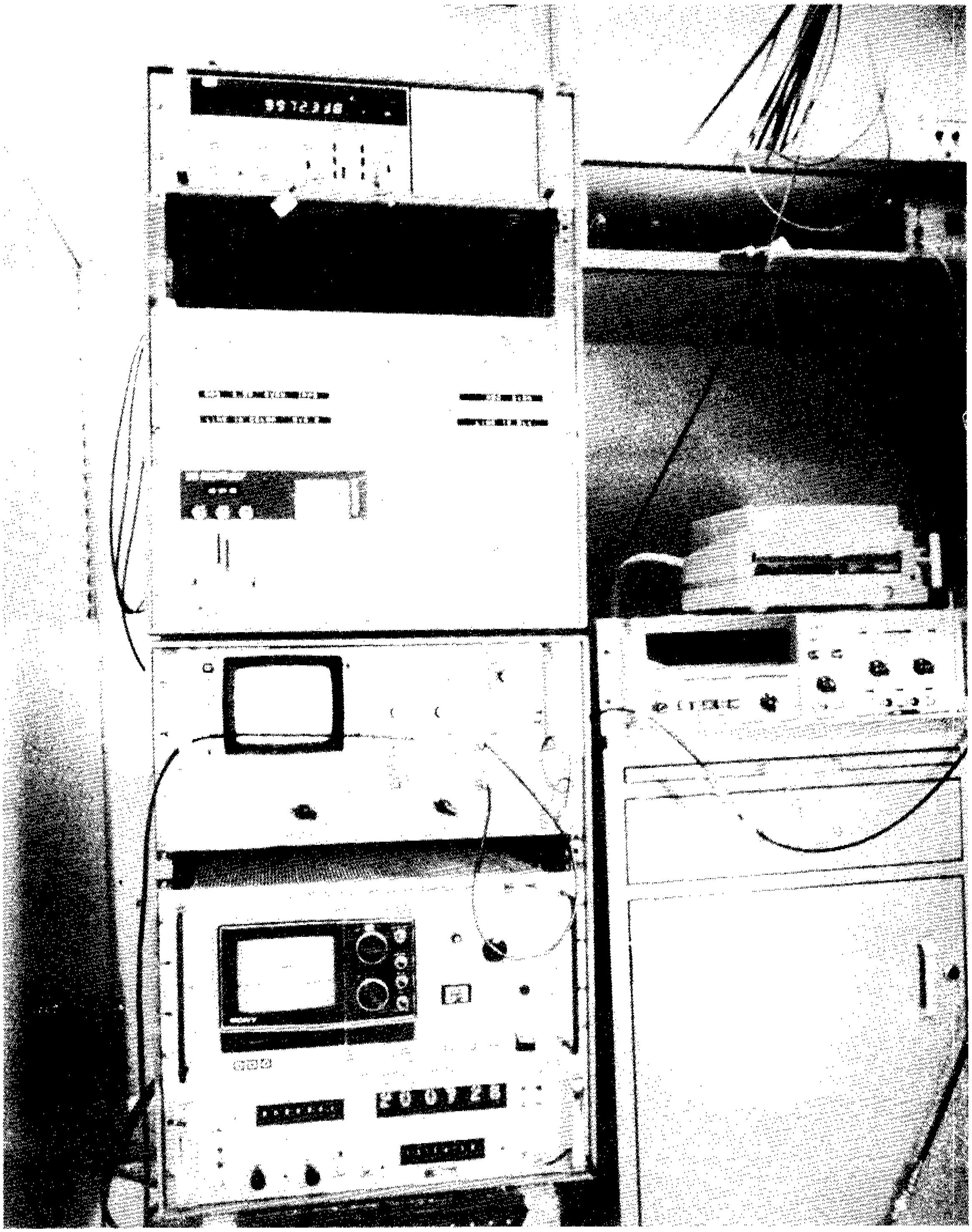


Fig. 7. Receiving Decoding System



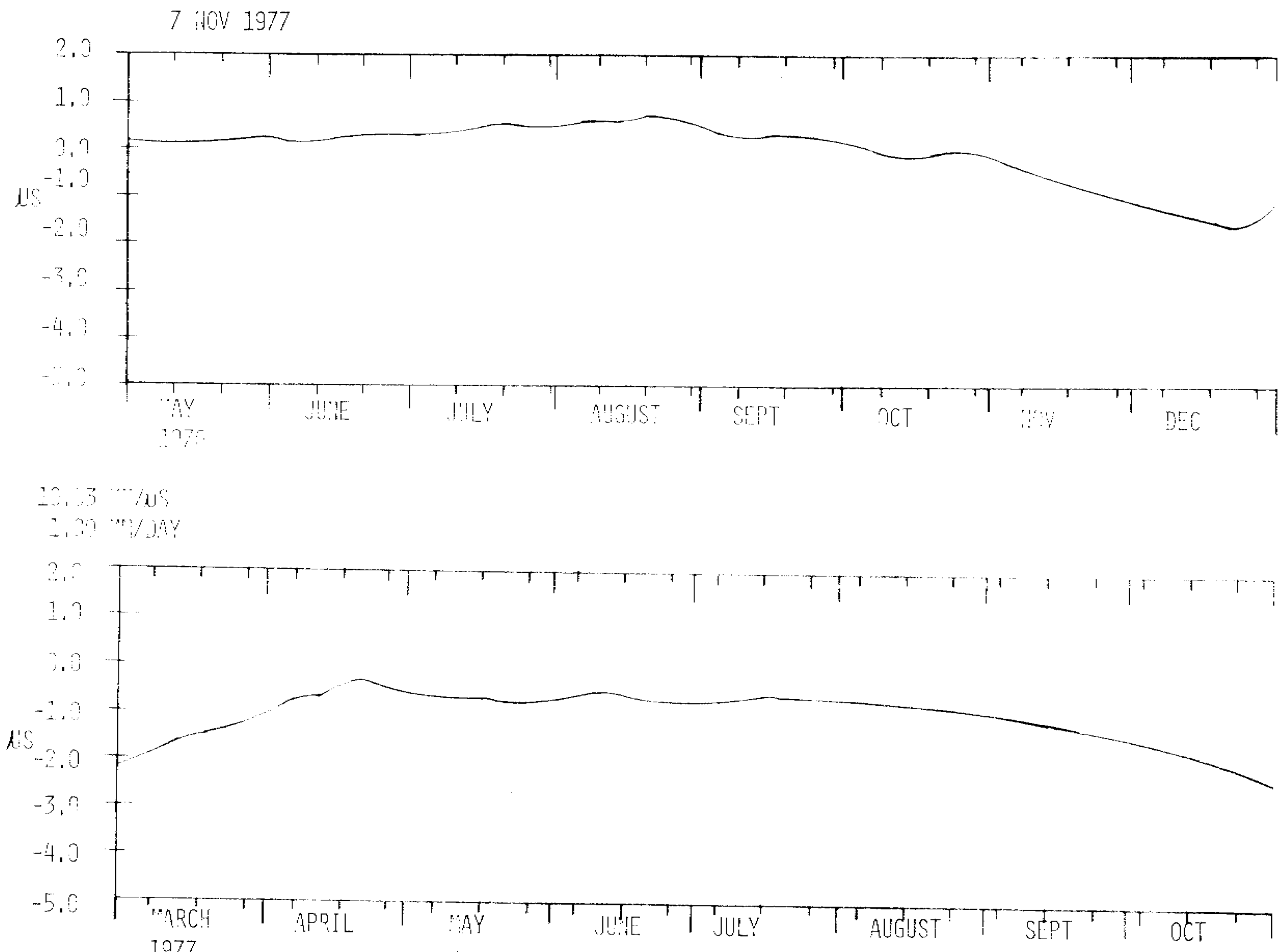


Fig. 9. Time Differences Between USNO and WTTG

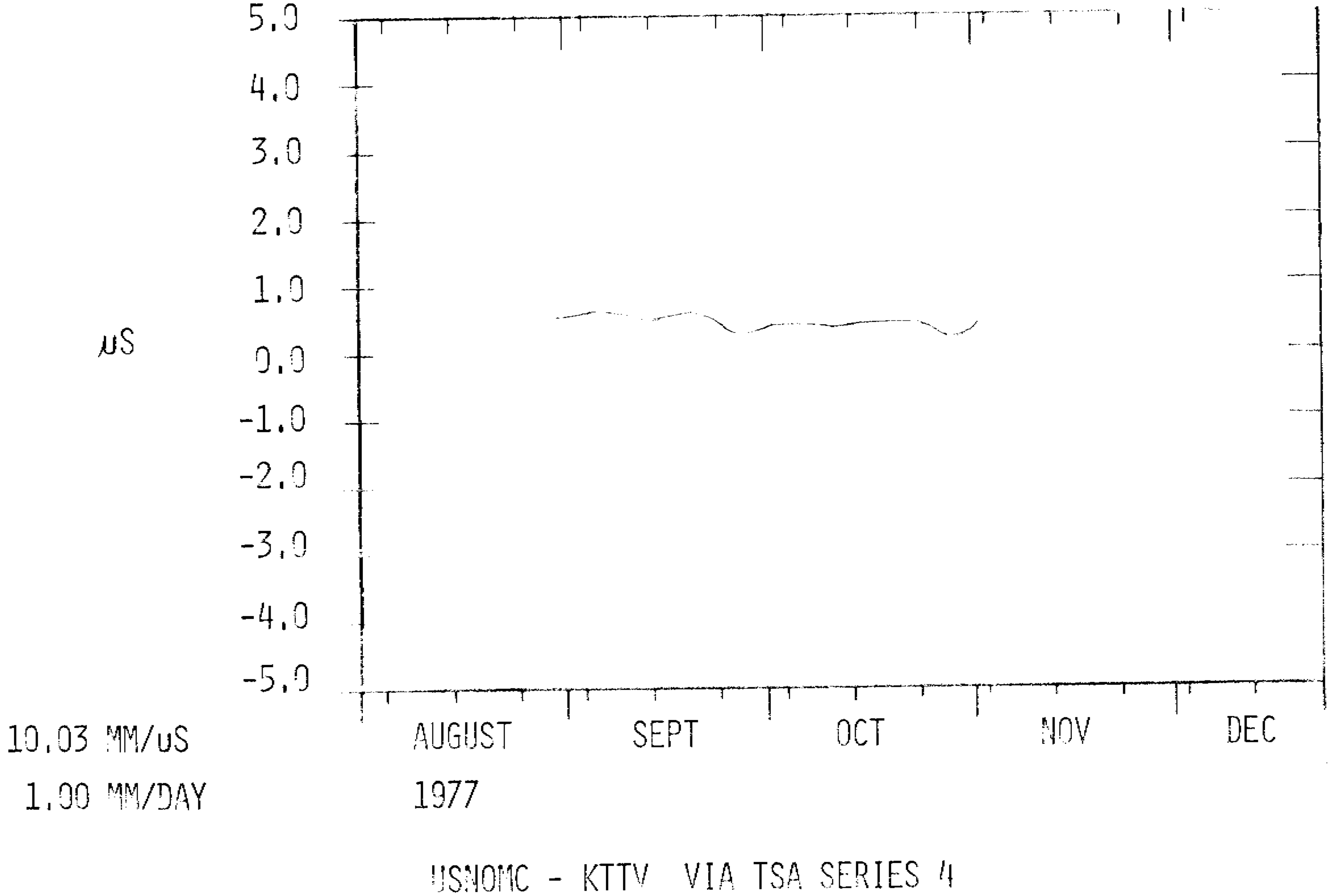


Fig. 10. Time Differences Between USNO and KTTV

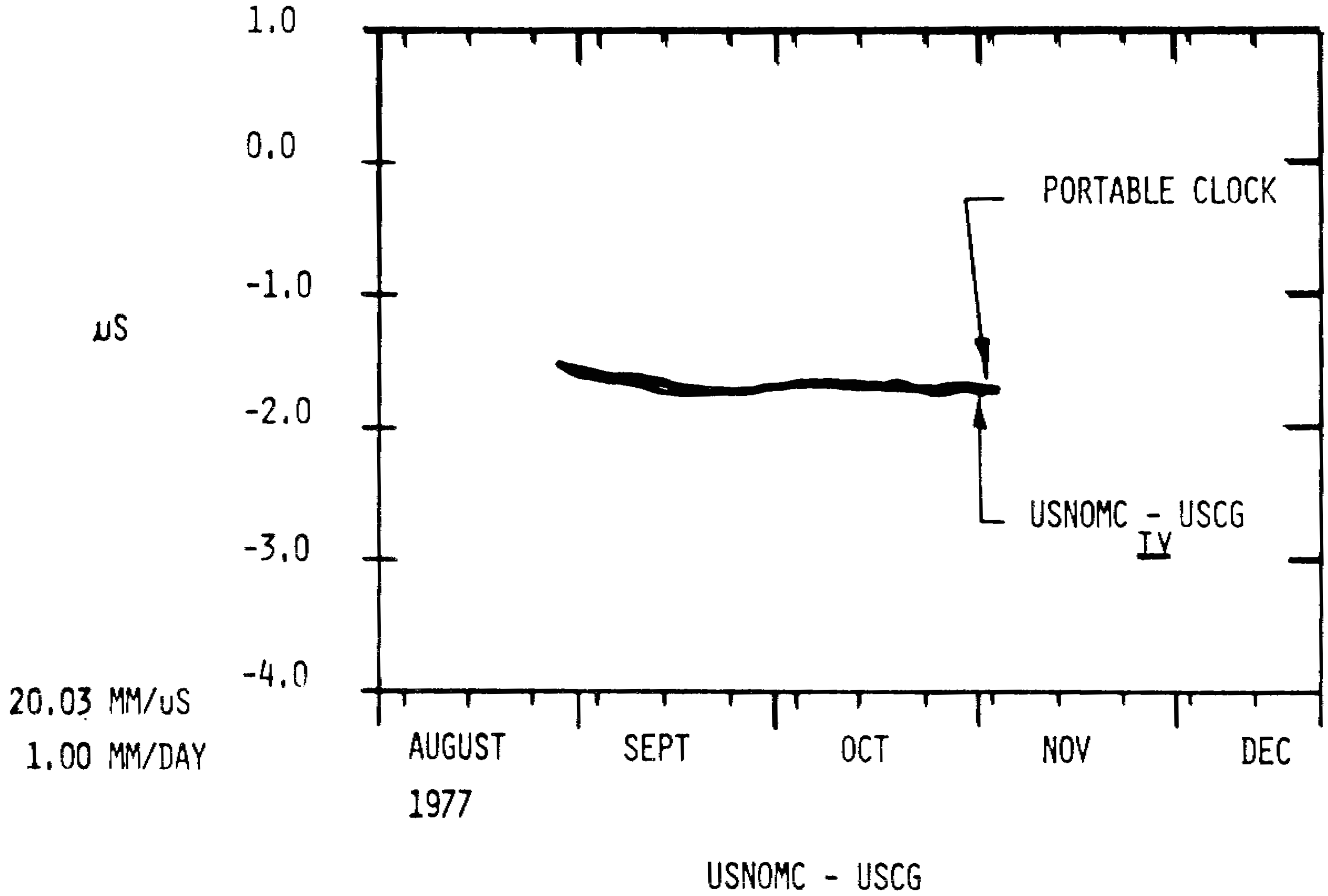


Fig. 11. Time Differences Between the USNO MC and USCG

Fig. 12. Time Differences Between the USNO MC and APL With Slope Removed