X66-10861

SP 4-49
Revised September 1, 1965
Supersedes SP 4-49
Dated March 13, 1964

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TIMING AND COUNTDOWN SYSTEMS HANDBOOK

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Government contractors only.

Prepared by
TIMING AND COUNTDOWN SYSTEMS BRANCH
MEASUREMENTS SYSTEMS DIVISION

SP 4-49

TIMING
AND
COUNTDOWN SYSTEMS
HANDBOOK

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September 1, 1965

LIST OF EFFECTIVE PAGES

Total number of pages in this publication is 78, consisting of the following:

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INTRODUCTION

PURPOSE

The purposes of this handbook are to present the John F. Kennedy Space Center (KSC) Timing and Countdown Systems Operations Plan, to provide a description of the systems in use, to familiarize personnel engaged in space vehicle checkout and launch operations with available KSC timing and countdown services and to show how these services may be obtained.

SCOPE

To fulfill the purposes stated above, this handbook explains:

a. Timing and countdown systems in use at KSC.

b. Responsibilities and functions of the Timing and Countdown Systems Branch.

c. Procedures for obtaining support services.

d. Timing and frequency standards.

e. Location of timing equipment.

RESPONSIBILITIES

The Timing and Countdown Systems Branch is responsible for the development, installation, operation, and maintenance of the correlation time base at KSC. The Timing and Countdown Systems Branch is directly responsible to the Chief, Measurements Systems Division for technical planning and mission performance. The Division Chief reports to the Assistant Director for Information Systems for mission assignment.

FUNCTIONS

The functions of the Timing and Countdown Systems Branch are to provide for the generation, verification, and distribution of timing and countdown signals, related events, and reference standard frequencies. Distribution is in formats consistent with the demands of KSC instrumentation, monitor, display, control, and analysis requirements. The Timing and Countdown Systems Branch provides the requisite functions of control, direction, and coordination necessary for mission fulfillment. All Government and contractor activities refer their timing requirements to the Timing and Countdown Systems Branch for integration into the KSC system.

REQUESTS FOR SERVICES

Organizations requiring KSC timing and countdown support should direct their requests to the Timing and Countdown Systems Branch (INS-23). As much advance notice as possible is required for planning purposes, procurement, installation, etc. Requirements should be submitted on KSC Form 22-19; sample shown on page vii/viii.

CHANGES AND REVISIONS

The information in this handbook is compatible with the latest information concerning KSC timing and countdown systems. However, technological advances may make this handbook subject to change. As new information develops, this handbook will be revised to incorporate it. A change will consist of one or more new pages containing updated material. A new title page for the handbook will be included with each change showing the latest effective date. The changes will be distributed by the Timing and Countdown Systems Branch (INS-23) to all persons issued a copy of the basic handbook. When a change is received, insert the new pages in the handbook and remove and destroy any superseded pages. Each person holding a copy of the basic handbook is responsible for keeping his copy up to date.

Each page containing changed material will have the word "Changed," followed by the change date, at the bottom of the page opposite the page number. A change in the technical content of a text page will be indicated by a vertical black line in the outer margin of the page, extending the full depth of the changed text.

A List of Effective Pages at the front of each handbook lists all the pages in the handbook. A new List of Effective Pages will be issued with every change, listing every page in the handbook, with the date of the last change, and indicating the pages included in the current change. A cross-check on the status of the handbook can be made by referring to the latest List of Effective Pages.

When the pages affected by previous changes and the current change total over 60 percent of the handbook, a revision will be issued. A revision is a complete reissue with all change dates and symbols deleted; and all modified page, figure, paragraph, and table numbers renumbered in sequence. When a revision is distributed, holders of copies of the handbook should remove from the binders all previous pages, insert the revision pages, and destroy the old pages.

COMMENTS AND RECOMMENDATIONS FOR IMPROVEMENT

Comments and recommendations to change, correct, and improve this handbook are invited. Correspondence about this handbook should be submitted to the Chief, Timing and Countdown Systems Branch (INS-23), John F. Kennedy Space Center, NASA, Kennedy Space Center, Florida 32899.

TIMING REQUIREMENTS

KSC TIMING SYSTEM

OFFICE SYMBOL INS-23

DESCRIPTION	SAMPLE	1	2	3	4	5
Timing Signal	2PPS SERIAL PULSE WIDTH CODE					
AMPLITUDE	28 VDC					
CURRENT and/or IMPEDANCE	50 ohms or 5 MA					
DESCRIPTION OF LOAD	Relay					
ADDITIONAL DESCRIPTIVE INFORMATION	Correlation Accuracy 5 Micr Sec.					
LOCATION (RACK NO., BLDG) ROOM NO.	Rack #199 Row B, Area X LCC-2nd Fl. ROOM No. -2pg					

INFORMATION BY: ____________________ SECTION: ____________________ DATE: ____________________

KSC FORM 22-19 (3/64)

SECTION I

TIMING SYSTEMS OPERATIONS PLAN

1-1. GENERAL

Precise timing and frequency correlation signals are essential to every launch, checkout, research, and development area. Timing signals are recorded with all data during checkout, countdown, and flight to provide an accurate reference for correlating data during the mission and during data reduction and analysis.

The KSC timing systems are designed to perform the following specific tasks:

a. Provide an extremely accurate and stable source of timing signals at rates and in formats consistent with the needs of area instrumentation, monitor, control, display, and analysis.

b. Maintain time synchronization with universal primary standards and the Air Force Eastern Test Range (AFETR).

c. Provide precision discrete frequency signals referenced to universal primary standards.

d. Distribute timing and frequency signals to all NASA and AFETR activities at Merritt Island and at other KSC locations.

e. Generate, distribute, and display countdown timing signals from launch or checkout computer-controlled tests.

Accurate timing depends on the generation of precise frequency signals. Precision pulse trains and sine waves of exceptionally high spectral purity are required as standards for laboratory calibrations and a source of clock pulses in electronic computers. To provide the accuracy needed at KSC, locally generated signals are continuously compared with standard radio transmissions and synchronized with AFETR timing. Inputs are compared and then generated as a signal coded for distribution consistent with the user's instrumentation requirements. Accuracy is further increased by distributing the signals on high-quality transmission cables, whereby propagation uncertainties due to atmospheric conditions remain nominal and greater mechanical integrity is provided to the system.

Correlated timing signals are distributed to all instrumentation facilities and launch activities. These facilities include, but are not restricted to, KSC tracking, telemetry, measuring, checkout, data handling, and instrumentation sites. Signals are provided at rates, and in formats, for the particular requirements of each using organization. Formats used at KSC range in frequency from 1 pulse per minute (ppm) to 1,000 pulses per second (pps). All formats are compatible with the requirements for both manual and automatic data reduction. They are also suitable for recording on magnetic tape, recording oscillographs, strip charts, and film.

The Central Timing Station maintains two identical sets of equipment for accumulating and generating accurate time and frequency signals. Each set consists of a standard reference oscillator, a time-base generator, and a timing signal transmitter. The duplication of equipment serves two purposes: it provides a standby, and ensures high accuracy by comparing the outputs of two sets of equipment. Because of the large size of Merritt Island, subcentral satellite stations provide remote areas with signals of central timing accuracy.

The timing system supplies terminal timing units to all areas that have instrumentation. Signals from these units activate the individual instrumentation media. Modular design is used to facilitate expected expansion and respond in a timely manner to users needs.

1-2. OBJECTIVES

The present KSC timing concept was adopted because it met all timing requirements and incorporated the maximum desirable features to provide the following basic services:

a. Provide a timing synchronization capacity for local and interrange accuracies of ± 10 microseconds predicted for the global and deep-space requirements on the UT2 time scale (reference Interrange Instrumentation Group (IRIG) Document 106-62).

b. Serve approximately 150 measurement, instrumentation, checkout, monitor, control, and display activities with coded time-of-day, countdown clock, sequence control, and asynchronous event signals.

c. Correlate times and frequencies of all NASA launch and flight activities at KSC with stability of ± 1 part in 10^{10}.

1-3. SYSTEM DESCRIPTION

The KSC timing systems consist of equipment installed at the Central Timing Station located in the Central Instrumentation Facility (CIF) and remote sites. These sites include the Launch Control Center (LCC), Vehicle Assembly Building (VAB), Pad Terminal Connection Room (PTCR), Mobile Launcher (ML), Manned Spacecraft Operations Building, (MSOB) Fluid Test Complex; Ordnance Field Test Laboratory Building, Flight Crew Training Building (FCTB), etc. Figures 1-1, 1-2, and 1-3 show the equipment and the distribution layout of the timing system.

The Central Timing Station contains the equipment required to accumulate, synchronize, and generate accurate time and frequency signals, Timing signal distribution is by high-quality transmission cables between major locations at KSC.

Each of the two identical sets of equipment at the Central Timing Station consists of a reference oscillator, time base generator, and a timing signal line driver. This duplication provides a standby unit in case of failure, and insures a high degree of accuracy by comparing the output of the two sets of equipment. At using activities, timing terminal units are housed in rack-mounted equipment areas; individual instrumentation media are energized. Modular design is used to facilitate expansion and provide a program quick reaction capability.

Accuracy of KSC timing and frequency signals is continuously compared with incoming signals from standard radio transmissions. KSC timing signals must be synchronized with present and future AFETR-operated timing distribution systems. This is accomplished by cable interface at the Banana River repeater building and by reception of the AFETR ultra high frequency (UHF) range time transmission. The AFETR UHF transmission is the source of timing signals for all instrumentation activities located off Merritt Island.

1-4. STANDARD TIMING AND FREQUENCY GENERATION

1-5. TIMING SYNCHRONIZATION

The KSC Central Timing Station generates all required time codes and formats for local distribution and establishes a precise timing data source for remote locations. Synchronized signals are compared for verification and transmitted to using activities where the timing information is then transformed into proper codes and formats for distribution to remote user instruments.

The Central Timing Station time base generator provides the basic coded time-of-day, as well as all pulse and timing outputs required for timing operation. The rate dividers in the time base generator may be advanced or retarded to allow for synchronization with the external synchronization sources. The basic accumulation of time is binary coded decimal (BCD). Translational techniques convert BCD to straight binary hours, minutes, and seconds. Each code is then scanned to provide inputs for signal transmission.

The timing signal transmitter serializes these data into a pulsewidth code modulating a coherent 1kc carrier and transmits these data together with synchronizing information to remote timing distribution locations.

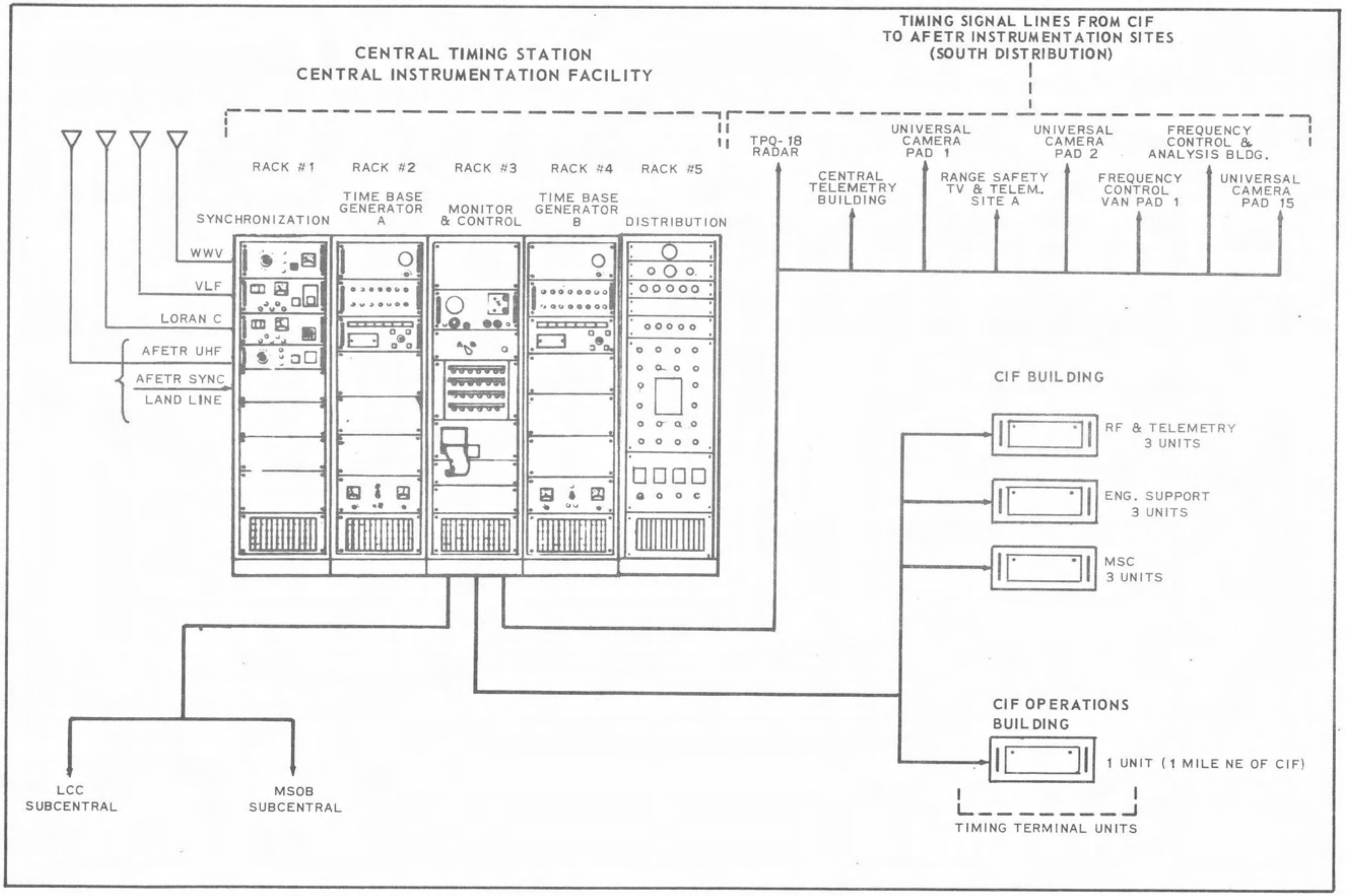


Figure 1-1. Central Timing Station Distribution

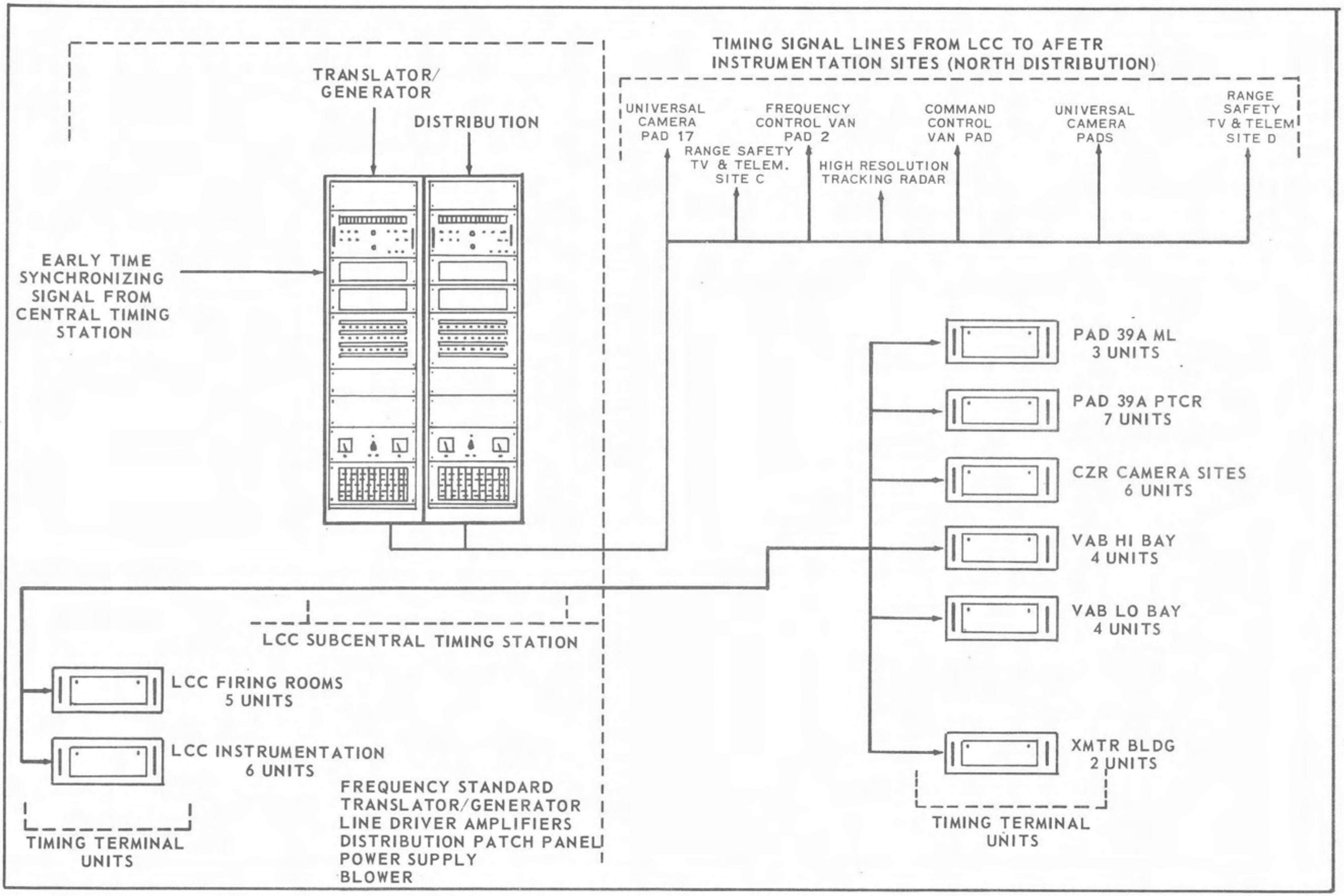


Figure 1-2. LCC Subcentral Timing Station Distribution

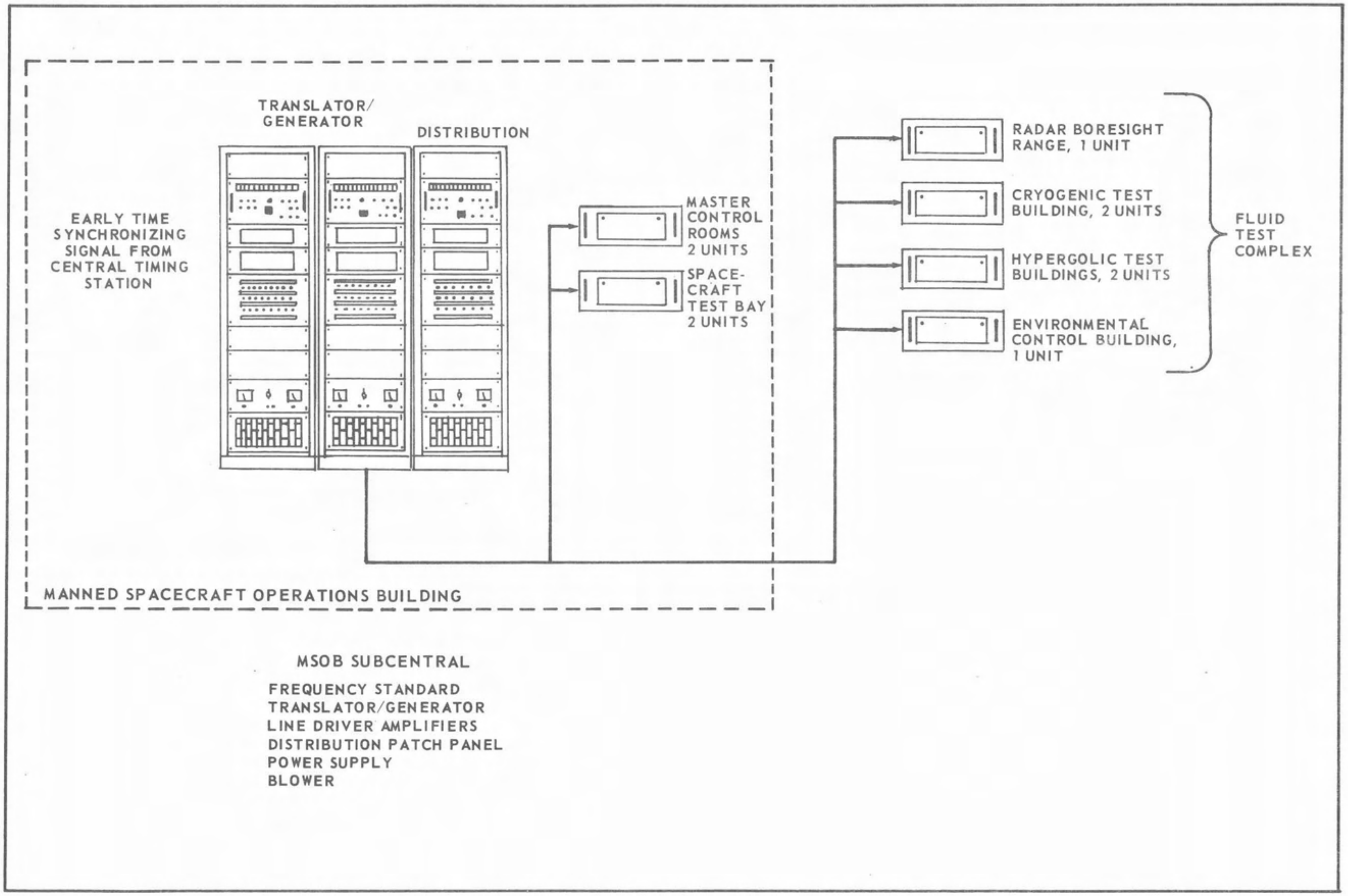


Figure 1-3. MSOB Subcentral Timing Station Distribution

Independent timing channels provide the high reliability necessary for KSC operations. A timing signal comparator/selector monitors the output of each independent timing channel and selects (on the basis of operational status compared with AFETR synchronizing signals) the timing channel to be transmitted.

1-6. Station WWV. Synchronization with WWV is accomplished by receiving a standard WWV time broadcast. Assuming the propagation delay is known, the timing systems can be synchronized within 100 microseconds. A 1pps signal generated at the Central Timing Station is delayed to conform to the propagation delay of the received WWV time signal to allow precise comparision of the relative phase of the two signals. The locally generated 1 pps signal is used to trigger the horizontal sweep in the oscilloscope while the received signal is observed visually on the oscilloscope display. The locally generated 1 pps delayed signal is varied in time to align the leading edges of the two signals for precise time synchronization with WWV.

Since the transmitted frequency of WWV is the high frequency radio spectrum, the ground wave coverage is limited and the signal in Florida is received by ionospheric reflection. The variable doppler shifts caused by ionosphere variations introduce in the received frequency an uncertainty of several standard parts in 10^7; consequently, direct comparison of this signal with the local frequency standard to an accuracy greater than a few parts in 10^7 is not feasible.

1-7. Very Low Frequency (VLF). To obtain and maintain accuracies of from one part in 10^9 to a few parts in 10^{10}, very low frequency (VLF) standard broadcasts have been initiated. In the VLF range, extremely low attenuation and excellent phase shift stability permits comparison to a few parts in 10^{10} by observing the phase relationship between the carrier and local frequency standards.

VLF synchronization provides long-term and short-term accuracy significantly greater than that obtained by WWV reception. A number of VLF stations now transmit on precision control carrier frequencies with accuracies of a few parts in 10^{11}. A VLF receiver at the Central Timing Station measures the relative phase difference between the standard broadcast VLF carrier and the locally generated reference frequency. Again the locally generated pulse rate is used to trigger an oscilloscope, and the received carrier is fed to the vertical deflection plates of the scope. Amount and direction of drift over a period of time indicates when the reference frequency deviates from standard. The locally generated signal can be manually adjusted to compensate for any frequency difference.

1-8. Loran C Radio. Loran C radio transmissions for time synchronization offer microsecond accuracies which are several orders of magnitude better than those of station WWV or VLF. A Loran C receiver is provided at the Central Timing Station to allow relative phase measurements between the Loran C carrier and the locally generated reference.

1-9. Air Force Eastern Test Range (AFETR).

Timing is also synchronized with AFETR timing by comparison with the received AFETR master time signal. The time synchronization technique is identical to the station WWV technique. The timing signal is obtained from the modulated timing signals transmitted by a UHF communication link from Cape Kennedy Air Force Station (CKAFS). The signal is demodulated in the receiving equipment at the Central Timing Station. Synchronization by cable through the Banana River repeater building is used for backup.

1-10. FREQUENCY CALIBRATION

The incoming VLF and low frequency (LF) signals are amplified and their phases, relative to that of the locally generated reference generator in the Central Timing Station, are measured in phase comparators. The output of the phase comparator, representing a phase error signal, controls a servomotor which drives a phase shifter to maintain a phase null. The input to the frequency synthesizer is thus a phase-shifted signal at 100kc that is coherent with respect to the incoming signal.

If the timing reference signal is in complete agreement with the VLF and LF carriers, the phase shifter will cancel the difference between them. If there is a slight frequency offset, the phase shifter will cancel the gross phase difference and provide a rate proportional to the offset. A counter dial indicates this frequency offset, and adjustment to the reference oscillator is made manually. This provides the means for rating and adjusting the reference oscillator. The stability of the VLF receiver relative to the incoming carrier is better than ± 1 microsecond. The resulting frequency determination will be accurate within one part in 10^{10} per day. A continuous permanent record is made of this phenomenon.

1-11. TIME CALIBRATION

The inverse of frequency is time; therefore, a precision frequency standard may become a time standard of the same accuracy.

Available for time-of-day synchronization are the WWV high frequency transmissions and the VLF broadcasts. These standard transmissions allow synchronization to approximately 1 millisecond after extended observation periods. The VLF transmissions for time setting provide greater synchronization accuracy. The oscillator output is divided down to 1 pps through a divider network which allows adjustment of time to within 20 microseconds of universal time on a 24-hour basis. The VLF frequency standard output and the reference oscillator output phase drift are kept as a permanent record.

The 100kc Loran C transmissions considerably improve time transfer uncertainties. The crossover point of the third cycle of the received pulse is usually the reference point. This point may be determined to a precision of 0.5 microsecond. Loran C transmission is used to meet the required interrange synchronization accuracy.

1-12. DISTRIBUTION

1-13. CABLES

Major distribution of timing signals to KSC-supported activities on Merritt Island is via wideband video pair (PEVL or PSVL per Military Specification MIL-C 9660). A velocity of propagation factor of 0.7 will cause a delay of approximately 35 microseconds from the CIF to the LCC and approximately 4 microseconds from the CIF to the MSOB. Compensation is made by generating an early time code and subcentral delay within ± 2 microseconds. Distributions from subcentral locations maintain this correlation using 19-gauge telephone pairs or 20-gauge twisted shielded pairs, and coaxial cable for intra-site distribution.

1-14. TIMING TERMINAL UNIT

The point of electrical connection where timing signals are made available is the timing terminal unit. The modular unit is in a 19-inch rack panel, 7 inches high, with internal cooling. Military Specifications 1-6181D and 1-26600 are used as a guide for radio frequency interference (RFI) considerations.

Outputs for recording pen and oscillograph galvanometer actuation, camera neon driving, magnetic tape recording, signal loss alarm, etc., are available. Virtually any signal may be accommodated by the terminal unit for any format.

Appendix A describes in detail the equipment used in distributing timing signals by cable (wire).

1-15. TIMING SIGNAL FORMAT

Present and proposed missile, satellite, and space research programs require standardized time formats for the efficient interchange of test data among interested activities. These formats must meet the requirements of both manual and automatic data reduction and be suitable for recording on magnetic tape, recording oscillographs, strip charts, and film, and be suitable for real-time transmission.

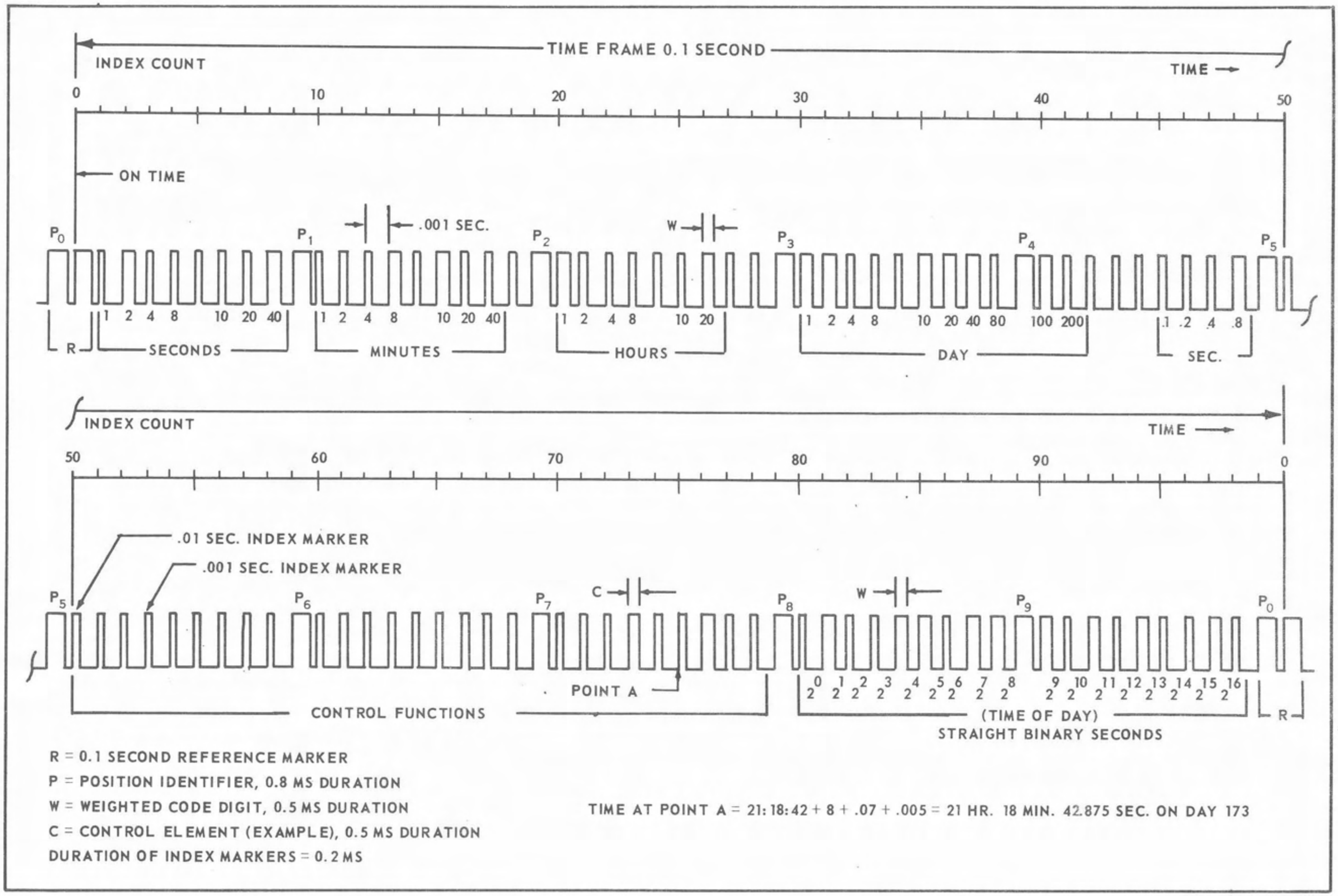
The task of standardizing instrumentation timing systems was assigned to the Tele-Communications Working Group (TCWG) of the IRIG by a steering committee in October 1956. The standards were accepted by the committee at Boulder, Colorado on July 20, 1960. NASA concurred with the standards.

Five code formats (IRIG formats A, B, C, D, and E; figures 1-4 through 1-8) form the basis of timing signal distribution at KSC. Provisions for two additional codes have been made.

1-16. ULTRA HIGH FREQUENCY (UHF)

The UHF multiplexed timing transmission, slaved to the AFETR central timing generator, is radiated from a location near the Cape Kennedy Central Control. This UHF transmission is the sole source of timing signals for tracking sites located off the Kennedy Space Center.

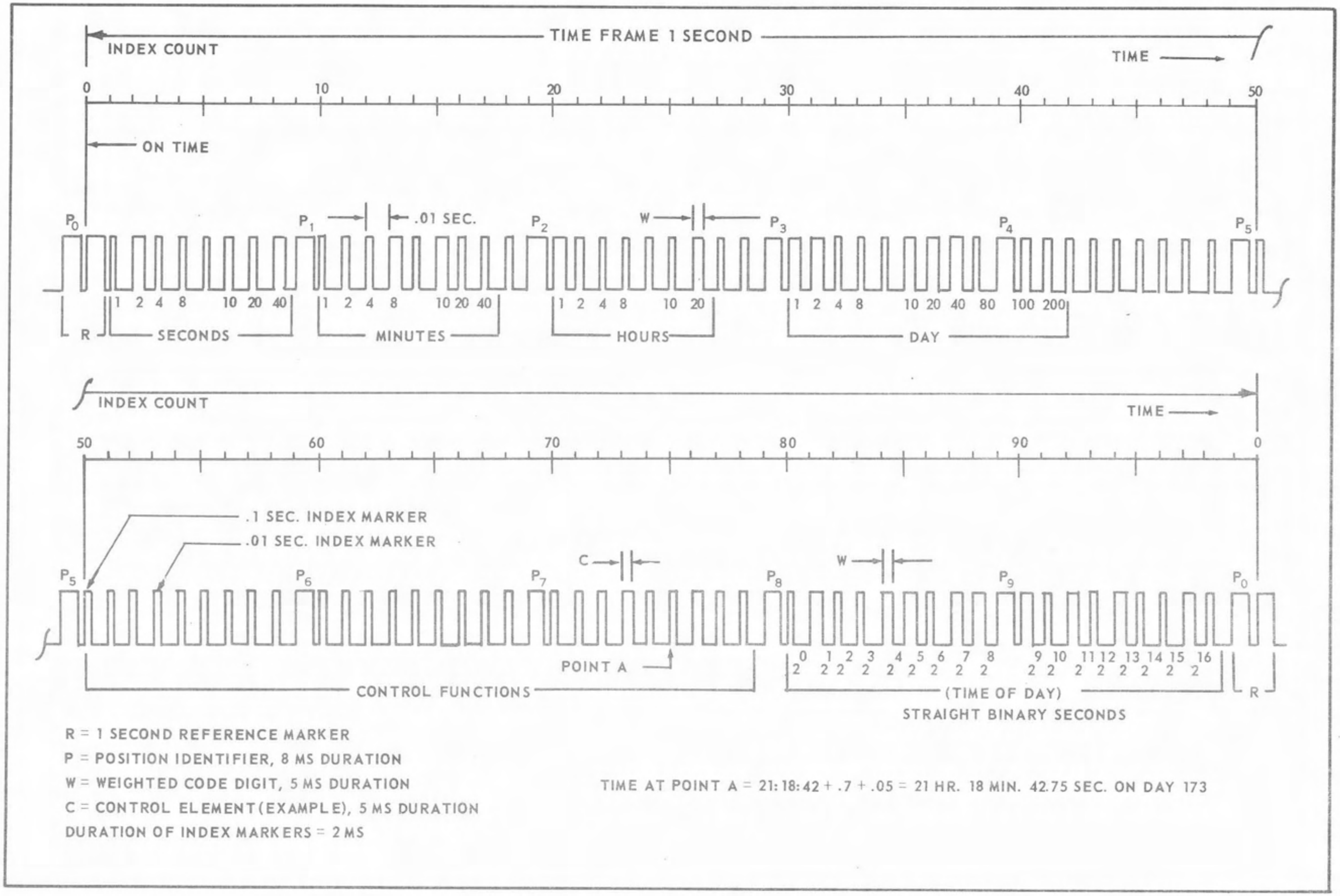
Reception at remote receiver activities is through directional UHF receiving antennas. Coaxial transmission lines connect the receiving antenna to a UHF receiver for the transfer of RF signals. Reception is limited to line-of-sight transmission (approximately 65 kilometers). Appendix B describes in detail the UHF timing distribution system.



R = 0.1 SECOND REFERENCE MARKER
P = POSITION IDENTIFIER, 0.8 MS DURATION
W = WEIGHTED CODE DIGIT, 0.5 MS DURATION
C = CONTROL ELEMENT (EXAMPLE), 0.5 MS DURATION
DURATION OF INDEX MARKERS = 0.2 MS

TIME AT POINT A = 21: 18: 42 + 8 + .07 + .005 = 21 HR. 18 MIN. 42.875 SEC. ON DAY 173

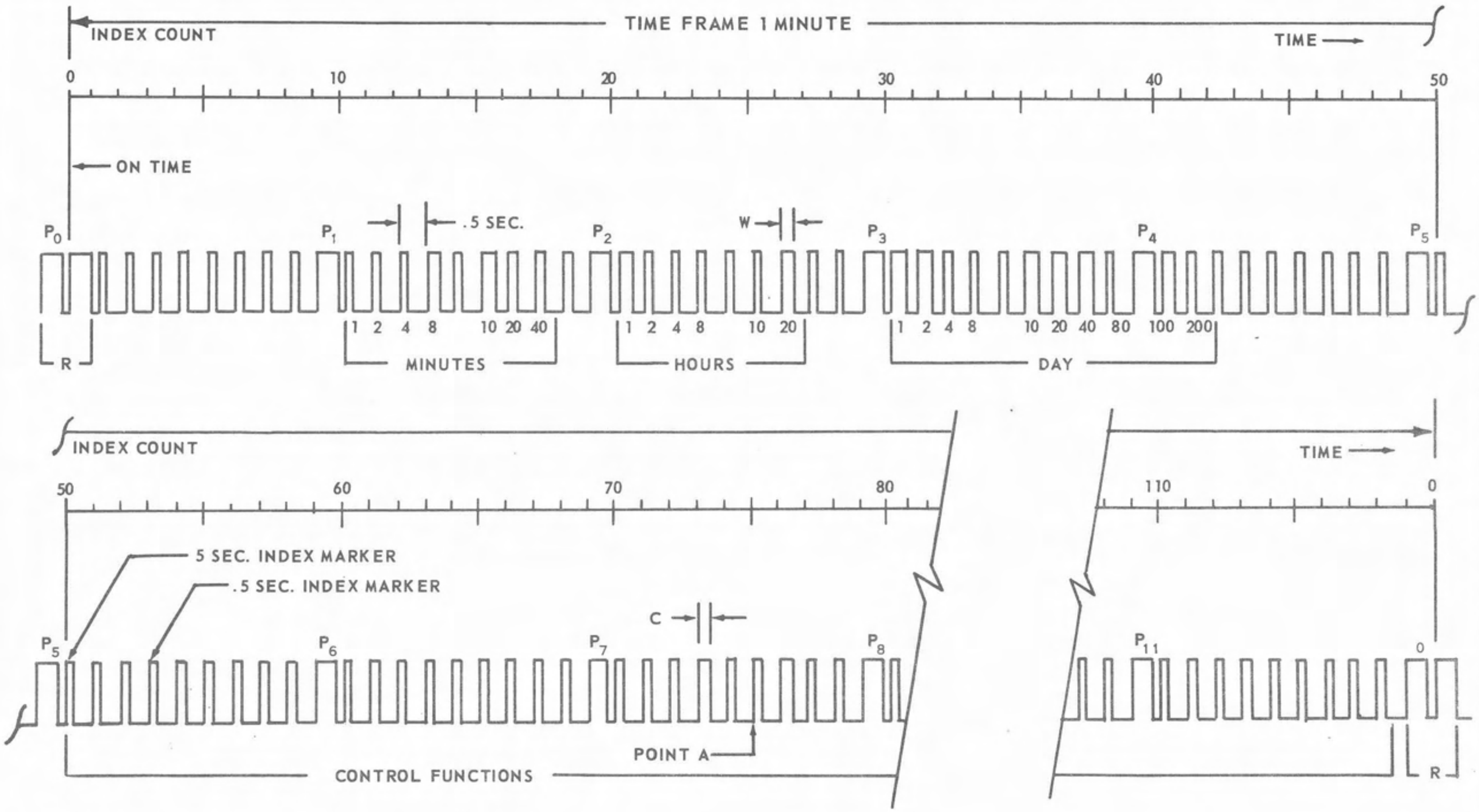
Figure 1-4. IRIG Standard Format A (1000 pps code)



R = 1 SECOND REFERENCE MARKER
P = POSITION IDENTIFIER, 8 MS DURATION
W = WEIGHTED CODE DIGIT, 5 MS DURATION
C = CONTROL ELEMENT (EXAMPLE), 5 MS DURATION
DURATION OF INDEX MARKERS = 2 MS

TIME AT POINT A = 21:18:42 + .7 + .05 = 21 HR. 18 MIN. 42.75 SEC. ON DAY 173

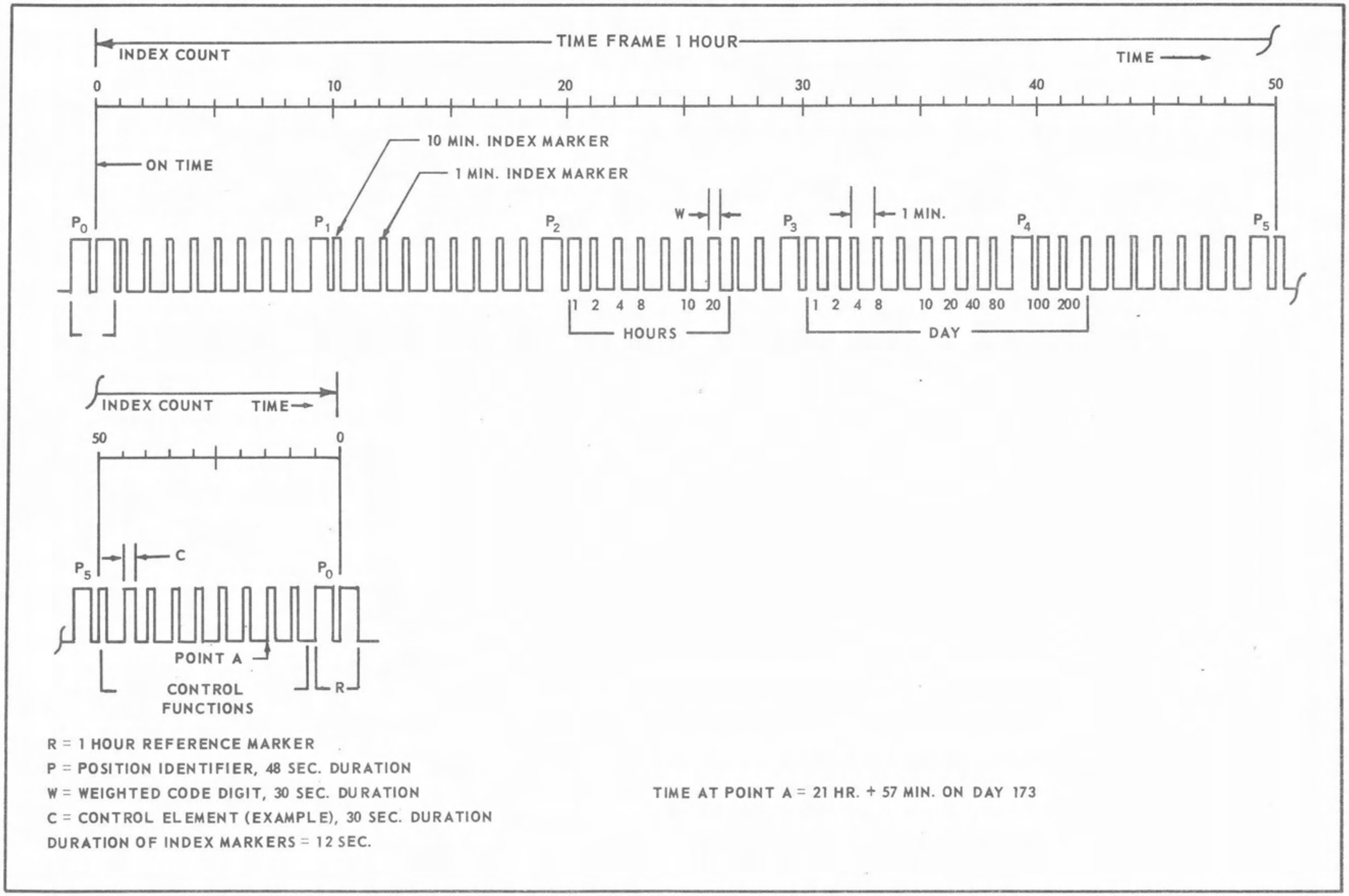
Figure 1-5. IRIG Standard Format B (100 pps code)



R = 1 MINUTE REFERENCE MARKER
P = POSITION IDENTIFIER, 0.4 SEC. DURATION
W = WEIGHTED CODE DIGIT, 0.25 SEC. DURATION
C = CONTROL ELEMENT (EXAMPLE), 0.25 SEC. DURATION
DURATION OF INDEX MARKERS = 0.1 SEC.

TIME AT POINT A = 21:18 + 37.5 SEC. = 21 HRS. 18 MIN. 37.5 SEC. ON DAY 173

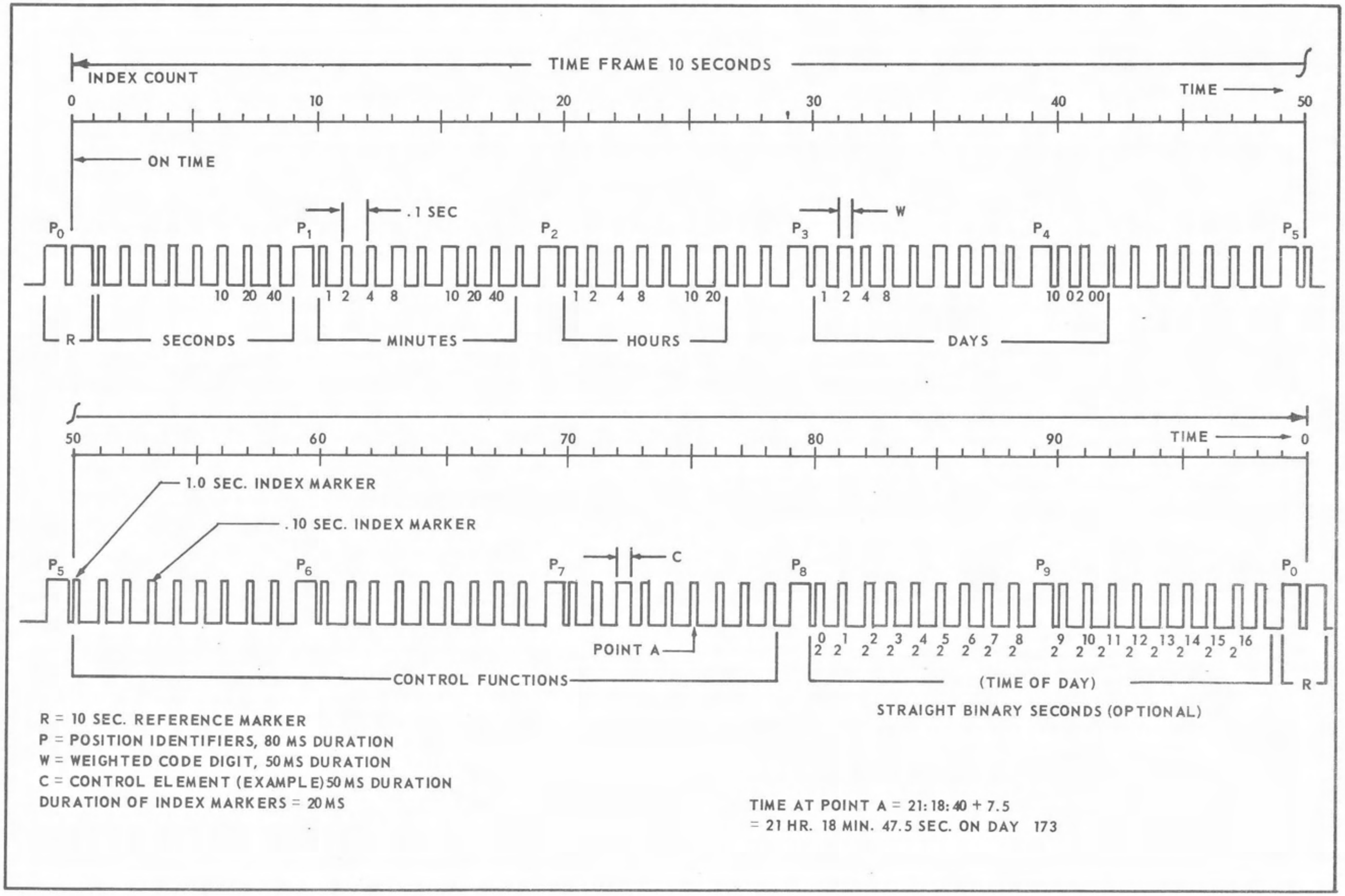
Figure 1-6. IRIG Standard Format C (2 pps code)



R = 1 HOUR REFERENCE MARKER
P = POSITION IDENTIFIER, 48 SEC. DURATION
W = WEIGHTED CODE DIGIT, 30 SEC. DURATION
C = CONTROL ELEMENT (EXAMPLE), 30 SEC. DURATION
DURATION OF INDEX MARKERS = 12 SEC.

TIME AT POINT A = 21 HR. + 57 MIN. ON DAY 173

Figure 1-7. IRIG Standard Format D (1 ppm code)



R = 10 SEC. REFERENCE MARKER
P = POSITION IDENTIFIERS, 80 MS DURATION
W = WEIGHTED CODE DIGIT, 50 MS DURATION
C = CONTROL ELEMENT (EXAMPLE) 50 MS DURATION
DURATION OF INDEX MARKERS = 20 MS

TIME AT POINT A = 21:18:40 + 7.5
= 21 HR. 18 MIN. 47.5 SEC. ON DAY 173

Figure 1-8. IRIG Standard Format E (10 pps code)

SECTION II

TIMING AND FREQUENCY STANDARDS CONSIDERATIONS

2-1. QUALITIES OF VLF TRANSMISSION

Stabilized frequency broadcasts in the VLF range have made possible a worldwide system of precision time and frequency calibration. VLF transmissions, unlike high frequency broadcasts, follow an extremely stable propagational path. Under normal conditions, the day-to-day variation of propagation time, even at great distances, amounts to no more than a few microseconds. Consequently, an accurately controlled frequency transmission or carrier wave, from some master frequency site, may be received at nearly any point on the globe, with practically no loss of accuracy.

Without supplementary equipment, a high-quality VLF phase-tracking receiver may be used to calibrate a local frequency standard to an accuracy of 1 part in 10^9 within a few minutes. A 24-hour reading will determine frequency to a few parts in 10^{11}. Furthermore, since a VLF receiver provides a locked reference to the incoming signal, a VLF system is the potential basis of an extremely precise permanent timekeeping installation. The useful accuracy of such an installation is limited, substantially, only by its initial synchronization with a master standard. Synchronization in the range of 1 millisecond can be achieved through time-pulse broadcasts; a portable time standard can yield synchronization to a few microseconds.

VLF offers the opportunity for a complete time and frequency system whose accuracy approaches that presently obtainable in many national observatories and primary standards laboratories. VLF combines this virtue with two others of equal importance: it is practical, and it is dependable. Instrumentation requirements are modest; calibration procedures are simple and routine.

2-2. VLF BROADCASTS

2-3. UNITED STATES FREQUENCY STANDARD

The United States Frequency Standard (USFS), maintained at the U.S. Bureau of Standards Laboratories, Boulder, Colorado, is the averaged frequency of several very precise crystal oscillators and atomic resonators. At present, its value is held constant to within 5 parts in 10^{11} of its nominal frequency. Comparison with other atomic standards, internationally located, allows an even more exact determination of its frequencies within this range.

One of the primary functions of the USFS is to transmit stabilized VLF frequency broadcasts over Station WWVL. A phase-locked transmission control system keeps the transmitted frequencies stable relative to the USFS. A weekly Bureau of Standards Bulletin reports daily frequency variations to 1 part in 10^{11}. This figure represents the final usable accuracy of the broadcasts and the present accuracy of the USFS. (Further information may be obtained from the Radio Broadcast Service Section, National Bureau of Standards Laboratories, Boulder, Colorado. Information on Naval VLF stations may be obtained from the U.S. Naval Observatory, Washington 25, D.C.)

Basic USFS frequencies are, with respect to the A.1 (atomic) scale, nominally equivalent to the Ephemeris Time (ET) scale. No presently known adjustments can bring A.1 time in closer agreement with ET; however, as more precise determinations become available, they will result in an altered definition of the A.1 scale.

Before the ET scale was adopted in 1956, the UT2 scale (based on the average length of the day) was the primary standard. The UT2 scale is still used for most purposes though it is considered not invariant and is defined at the beginning of each year as being off the A.1 scale by a certain amount. Currently, UT2 time is considered slower than A.1 time by 150 parts in 10^{10}. This means that the UT2 second is slightly longer than the A.1 second, and the frequency of a signal expressed with reference to the UT2 scale will be slightly higher than its expression with respect to the A.1 scale.

All standard frequency broadcasts are offset to correspond to the current value of the UT2 scale. The basic A.1 frequency is altered by -150 parts in 10^{10} so that, for example, a broadcast signal announced as 20kc represents 20,000 cycles per UT second.

2-4. VLF STABILIZED FREQUENCY TRANSMISSION PROPAGATION MODE

High frequency radio broadcasts follow an optical ray mode of propagation, and propagation time often varies suddenly and unpredictably with changes in the ionospheric condition. Thus, at intermediate or long ranges, though high frequency is still perfectly usable for transmitting messages, it is severely limited as a source of time or frequency information. VLF transmissions, on the other hand, follow a long range path that can be characterized as a type of wave guide propagation. Propagation is pictured as occurring between two sharp concentric boundaries, the surface of the earth and the ionospheric D-layer. It is the hardness of the D-layer for VLF propagation that is primarily responsible for the extreme stability of propagation time, and consequently accounts for the stability of frequency transmissions. Details of the waveguide analysis may be found elsewhere. Following are two general consequences of immediate importance:

a. Quantitative calculations of the time delay involved in propagation may differ for different frequencies. First, the height of the D-layer as seen by various VLF-range frequencies is not constant. For example, in summer, the average daytime height above the U.S. is 70km for a 14kc signal. It is slightly higher for higher frequencies and lower for lower frequencies.

Second, there is a substantial dispersion. The 14.2kc velocity has been measured to be 0.1 percent greater than the 18.2kc velocity.

Finally, there is a seasonal change in the D-layer height of about 7km.

Though the daily stability of a given signal's propagation time may be very high, actual calculation of that time is complex. Fortunately, these calculations are irrelevant in considering the accuracy of frequency transfer. Day-to-day propagation stability is of first importance, but not total propagational delay.

b. There is a regular daily change (diurnal effect) of about 15km between the daytime and nighttime signals. This is more directly related to frequency calibrations, and results in the trapezoidal shape of tracking records. Since the change occurs fairly sharply around sunrise and sunset, there will be only a brief period of transition for stations along a north-south axis. For stations along an east-west axis, the transition is longer, occupying the time during which the twilight line crosses the intervening distance. Characteristically, the change in east-west axis propagation time will take the pattern of several incremental stairsteps. The diurnal period is thus not suitable for highly accurate frequency transfer. Also, daytime calibrations seem slightly more stable and accurate than nighttime calibrations.

2-5. PROPAGATION DISTURBANCES

Besides normal propagational variations, VLF signals may be influenced by two further anomalous factors:

a. Magnetic disturbances. Magnetic storms, especially at night, may result in phase uncertainties of approximately 5 microseconds. Such variations are unimportant though, if frequency determinations are made over periods of several hours.

b. Sudden ionospheric disturbances. Solar eruptions or very high altitude explosions may cause sudden depressions in the ionospheric D-layer. These may be recognized by a rapid increase of phase over an interval up to 8 minutes, and a subsequent exponential decay of the accumulated increase over a period up to 1-1/2 hours. VLF is also characterized by a generally high noise level caused by thunderstorms and other atmospheric disturbances. With a narrow-band receiver that has a blanking circuit, a 20db improvement in the signal-to-noise ratio is possible with only about 1db loss in carrier level; this virtually eliminates interference without affecting tracking performance. It is thus possible to maintain uninterrupted tracking under noise conditions that would make reception of time or message signals completely impossible.

2-6. ACCURACY

In a 1960 transatlantic experiment, VLF signals transmitted from station GBR in Rugby, England, were received in Cambridge, Massachusetts, with an indicated propagational variation of only 2 parts in 10^{11} over 24-hour averaging periods. Barring unusual propagational conditions, which are easy to recognize, this figure is a fair estimate of the accuracy of which VLF is generally capable. This establishes a potential means of transferring a frequency with the accuracy that can be achieved by the best laboratory standards.

2-7. PRESENT VLF TRANSMITTING FACILITIES

VLF wavelengths range from 10 to 100km, and large antenna facilities are required at transmitting sites. Even though the number of VLF stations is relatively small, the antipodal range of VLF signals allows reception at all points on the globe. Present stations range from Hawaii to Panama to England, and permit uninterrupted tracking anywhere, even under severe conditions. Table 2-1 lists available VLF transmitting stations.

Table 2-1. VLF Stations Transmitting On Stabilized Carrier Frequency

Station	Carrier Freq. (kc)	Location	Latitude - Longitude	
NAA	18.6	Cutler, Me.	44°40'N	47°14'W
NBA	18.0	Balboa, Canal Zone	09°04'N	79°39'W
NPG	24.0	Jim Creek, Wash.	48°05'N	121°35'W
NPM	19.8	Lualualei, Hawaii	21°24'N	158°10'W
NSS	22.3	Annapolis, Md.	38°59'N	76°30'W
WWVL	20.0	Boulder, Colo.	39°59'N	105°16'W
GBR	16.0	Rugby, England	52°22'N	01°11'W

2-8. TIME SCALES

Frequency measurements are the practical basis of time measurements; but the frequency must be defined in terms of some time scale. Until recently there has been no way to construct a frequency device--a mechanical clock, tuning fork, or electronic oscillator--whose long-term invariance could be depended on or whose frequency characteristics could be confidently reproduced in other devices. Consequently, time scales have been defined from astronomical motions, and astronomical observations have been used to check and correct the frequency standards on which practical time determinations depend. A brief discussion of the various time scales follows.

2-9. SOLAR TIME

According to the basic astronomical model first formulated by Kepler, the earth moves in an elliptical orbit with the sun at one of two foci. The angular speed of the motion is governed by Kepler's Law: that the earth moves so as to sweep out equal areas of the ellipse in equal times. Thus, in figure 2-1, if the shaded portion 1 is equal in area to shaded portion 2, the earth will move from A to B and from A' to B' in equal times. This means that its angular speed between A' and B' will be greater than between A and B. In observational terms, the sun will move across the sky, relative to the fixed stars, at a variable rate; and consequently, the time between two subsequent passages of the sun across the meridian will vary. Noon on a sundial will fall ahead of noon on a wristwatch for half the year, and behind for half the year. The maximum difference, occurring in early November, is about 16 minutes.

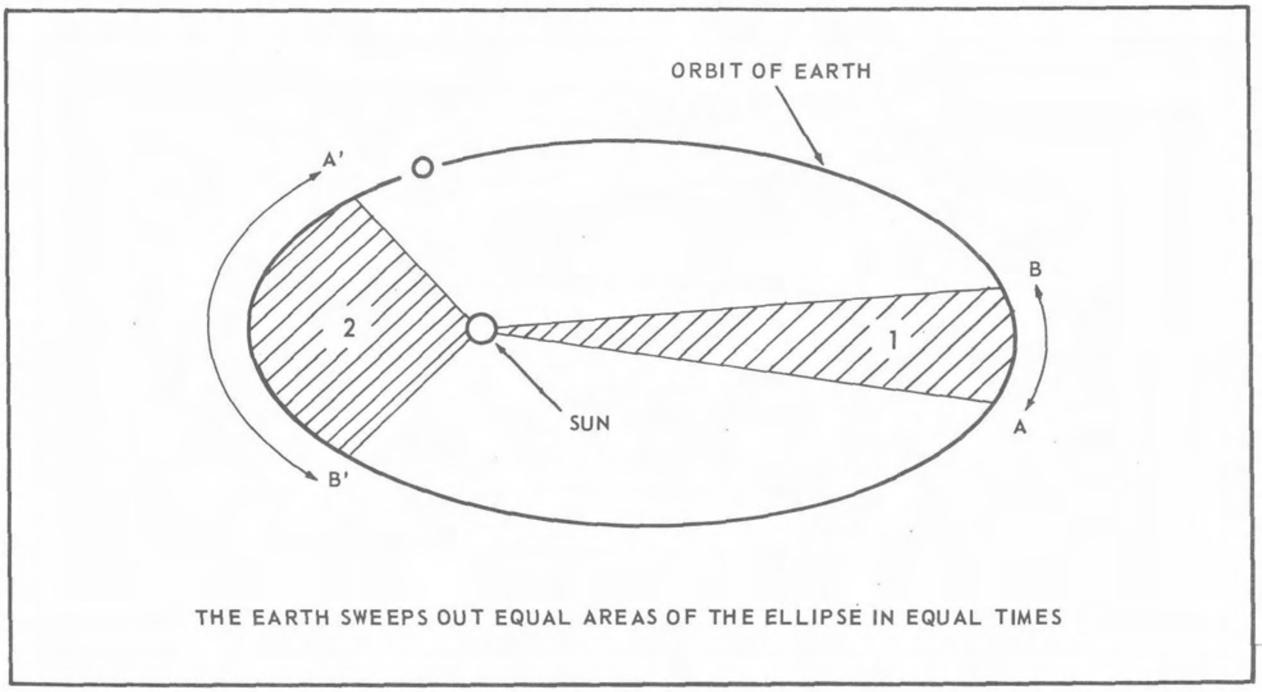


Figure 2-1. Kepler's Law

Since it would be impractical to continually adjust watches to the varying length solar day (or apparent solar time) a basic time scale is derived from the average length of the solar day throughout the year, or mean solar time. This time scale, designated Universal Time (UT), is employed for almost all conventional timekeeping.

As initially defined, UT assumes that the earth's rotation on its axis is uniform. Two corrections to this initial time scale (identified as UT0) are necessary. First, the earth's axis nods slightly, and this nutation leads to an error in rotational observations not corrected for. Second, seasonal changes on the earth's surface (such as the varying mass of ice in the polar regions) apparently change the earth's moment of inertia enough to cause corresponding slight variations in its rotational speed. Observations corrected for the first factor (nutation) give the UT1 time scale; and this scale in turn, corrected for seasonal variations, gives the UT2 scale. It is the UT2 scale that is expressed in Greenwich Mean Time (GMT), to which we normally refer when we set our watches; or speak of hours, minutes, and seconds.

But even with corrections, the UT2 scale is not invariant. The average length of the solar day changes from year to year, both through a long term slowing, and unpredictable changes in the earth's inner constitution. Even a perfect and invariant clock would need occasional readjustment if it were not gradually to lose all relation to solar time. Since it is just such a clock that is desired, no version of UT time is a sufficient definition of an invariant unit of time.

2-10. EPHEMERIS TIME

The above considerations led to the international adoption of a new time scale, Ephemeris Time in 1956. An ET second is defined as "the fraction 1/31,556,925.9747 of the tropical year for 12^hET, January 0, 1900," The ET scale thus ignores the rotation of the earth, and is based directly on the orbit of the earth around the sun. It is assumed that there are no unaccountable variations in the earth's orbit, and that the ET scale corresponds exactly to astronomical relationships that can be repeatedly observed. One consequence of the adoption of this invariant unit is that absolute ET time (which may be represented as a clock running on the ET scale since 1900) would now be off with respect to the mean time of solar noon. This is of little consequence, however, since the primary purpose of the ET scale is merely to establish an invariant and permanently available reference. In practice, measurements of the motion of the moon are the basis of ET determinations; but these are precisely relatable to the earth's orbital motion.

2-11. ATOMIC TIME

In close relation to the ET scale is the atomic time scale (AT). Atomic resonators will in theory produce an invariant frequency, even though design and production techniques may change, and even though there are inevitable slight differences in the construction of any two oscillators. They overcome, through direct dependence on basic physical constants, the factors immemorially responsible for the undependability of manmade timing devices.

At present, an AT second has been defined on a provisional scale (A.1 time) as 9,192,631,770 cycles of a cesium beam atomic standard. However, the stability of an atomic standard is significantly greater than our existing determination of the relation between A.1 and ET time. The cesium beam standard varies less than 1cps from its nominal frequency, but comparisons with astronomical observations indicate that this value represents the ET second only within a margin of 20cps. An A.1 second might differ from an ET second by as much as two parts in 10^9. Improvement of this equivalence must wait until long term observations make available a more precise determination of the relation between the two scales. When these observations are realized, there will be a redefinition of the atomic scale; for example, the A.2 scale might employ a second equal to 9,192,631,763.5 cycles of a cesium beam standard, known to be within a half cycle of an ET second, or some similar new scale.

Finally, stabilized VLF frequency broadcasts are offset to approximate the current value of UT2 time. From January 1, 1960 to January 1, 1962, all broadcasts were offset by -150 parts in 10^{10} and, since January 1, 1962, have been offset -130 parts in 10^{10}.

Thus the nominal value of the broadcasts, for example 20kc, is unchanged and is the practical standard for UT2 time. But with respect to the A.1 or ET scales, the broadcast frequency is altered through the years, and is currently 19.999999740kc on the A.1 scale.

2-12. FREQUENCY AND TIME TRANSMISSION

The National Bureau of Standards raised 400-foot antennas and built transmitters to substantially increase the coverage of the standard frequency and time transmissions of NBS stations WWVB (60kc) and WWVL (20kc). The new facilities are near Fort Collins, Colorado.

The wide-scale distribution of the USFS and of time signals is needed to coordinate the operations of the global network of missile and satellite stations, to improve the uniformity of frequency measurement on a national and international basis, and to provide a more accurate yardstick of frequency (easily available to many users) for electronic research and development.

The importance of higher accuracy and wider distribution in the transmission of the USFS, is indicated by the strong support this program has received from the National Aeronautics and Space Administration. NASA provided financial assistance for construction of both the initial 20kc station (WWVL) and the transmitters and the large antenna for the new 20kc station.

WWVB and WWVL have been transmitting for several years from sites near the Boulder, Colorado, Laboratories of the Bureau of Standards. The existing stations are quite small and electrically inefficient but they have served to substantiate the basic concepts of using the lower frequencies to obtain more stable signals and wider coverage for standard frequency and time signal broadcasts. Although WWVL, in the mountains near Boulder, radiates less power than a 15-watt light bulb, its signal has been received in New Zealand. Even under present conditions the reliability and accuracy of signals from the two stations have enabled some organizations to cancel plans for installing expensive atomic frequency standards within their own laboratories.

With the new antennas and transmitters, the radiated power of WWVL increased to 1 kilowatt; WWVB increased to 7 kilowatts. Signals from both stations are compared continuously with the USFS, which is provided by two cesium beam atomic clocks maintained by the NBS Radio Standards Laboratory.

The 60kc transmission of WWVB is particularly designed to serve users in the continental United States, since signals at this frequency propagate with more stability than those at 20kc for distances to 2,000 miles.

Time signals at 60kc offer a precision ranging from a hundred-thousandth to a millionth of a second (depending on distance from transmitter). This is 100 to 1,000 times more stable than the shortwave signals from NBS station WWV, Beltsville, Maryland. WWVB time signals, emitted once per second, consist of modulation by five cycles of a 1,000-c/s sine wave.

The WWVL 20kc transmission is designed to extend the experimental studies required to provide accurate time signals, clock synchronization, and frequency transmission over most of the world, with very narrow band signals.

The National Bureau of Standards considered using VLF for their standard frequency transmission as early as 1930. The principal reason for adopting an HF system at station WWV and station WWVH, Maui, Hawaii, however, was that few users at that time had low frequency receivers. Two other reasons for not using low frequencies were the high cost of the antenna and the possibility of interference from natural noise.

Since 1930, the problem of natural noise has been overcome by reducing the bandwidth and by using integration type measuring techniques. Also, VLF and HF receivers now cost about the same. The high stability and long range coverage of the lower frequencies have been thoroughly established by both theory and experiment.

The basic reason for the different characteristics of the higher and lower frequency ranges is the difference in the way these signals travel around the globe. The high frequency transmissions of WWV and WWVH bounce between the earth and the ionosphere and depend upon the mirrorlike qualities of the ionosphere to reflect them to distant points. However, the reflective quality of the ionosphere varies because of changes in the atmosphere and in radiation from the sun. (During a large solar storm the ionosphere can become so disrupted that it does not reflect the high frequency signals at all.) These variations cause the time, for a high frequency signal to travel between two points, to change continuously and sometimes cause the signal to be entirely lost in outer space.

LF and VLF transmissions follow the curvature of the earth since the ionosphere and the ground act as upper and lower limits of a gigantic duct to guide the signals over the globe. In such cases the ionosphere serves only as boundary, not a direct reflector, and has little effect on the speed of the waves. The lower frequencies travel a more direct route between points on the surface of the earth.

The instabilities of high frequency propagation necessitate the averaging of signals from WWV for a period up to 30 days, to achieve a precision of 1 part in 10^{10}; the usual attainable precision is only about 1 part in 10^6. Reliable reception is limited to a few thousand miles. The 20kc transmission will offer a precision of 1 part in 10^{10} or better, on a global basis, within an observing period of 1 day. Within the same 1-day observing period, the 60kc transmission will offer a precision of 5 parts in 10^{11} within the continental United States.

Besides having more powerful transmitters and more effective antennas, the new stations are more effective because of the characteristics of the new 380-acre site. Its primary assets are high soil conductivity, the availability of electric power, relative freedom from violent weather extremes, manmade noise, and easy access. The diamond-shaped antenna for each station is approximately 1,900 feet long and 750 feet wide. Each antenna is supported by four 400-foot guyed steel masts.

WWVB and WWVL do not replace the shortwave transmission of WWV or WWVH. The high frequency signals require only simple receivers and their accuracy is sufficient to meet the current needs of television and radio stations, electric power companies, amateurs, smaller businesses, and the general public.

SECTION III

COUNTDOWN TIMING SYSTEM

3-1. GENERAL

This section describes the countdown timing system in use at KSC for Saturn V launch and prelaunch activities. The KSC countdown timing system is designed and equipped to:

a. Generate countdown timing signals under automated and/or human control at 27 KSC locations and KSC complexes at Cape Kennedy.

b. Encode these signals in serial form for transmission over voice-quality telephone lines.

c. Distribute the signals through central switching stations to all activities concerned.

d. Decode and translate the signals into parallel lines for energizing countdown readout displays at all KSC locations and KSC complexes at Cape Kennedy.

The countdown, a carefully followed operational procedure, is associated with the launch of a missile or space vehicle, the controlled test, or the checkout of any such vehicle or space system component. The countdown may continue for the total period preparatory to launch and total vehicle flight time, or a portion of such a period or time span. All events are correlated with an independent reference called countdown time, generated and controlled by countdown timing system components.

The advancement of time within the countdown system depends on the relative success and the completion of each step in the preparatory phase of the procedure. The processes of counting, holding, and recycling the system can be controlled by either automated or human responses.

A study of the character of retransmission required to link the countdown system components, showed that possibly 70 receiver/decoders can be visualized in the final system, while the sources of countdown generation would probably remain about the present number. A prime design objective, therefore, was economy in the receiver/decoder circuitry. Figures 3-1 and 3-2 show the KSC Countdown distribution.

3.2 SYSTEM DESCRIPTION

In the systems concept, two sources of countdown timing are considered: those originating at the launch complex and those originating at local test and checkout positions. Both consist of a countdown generator/decoder combination. The entry of count

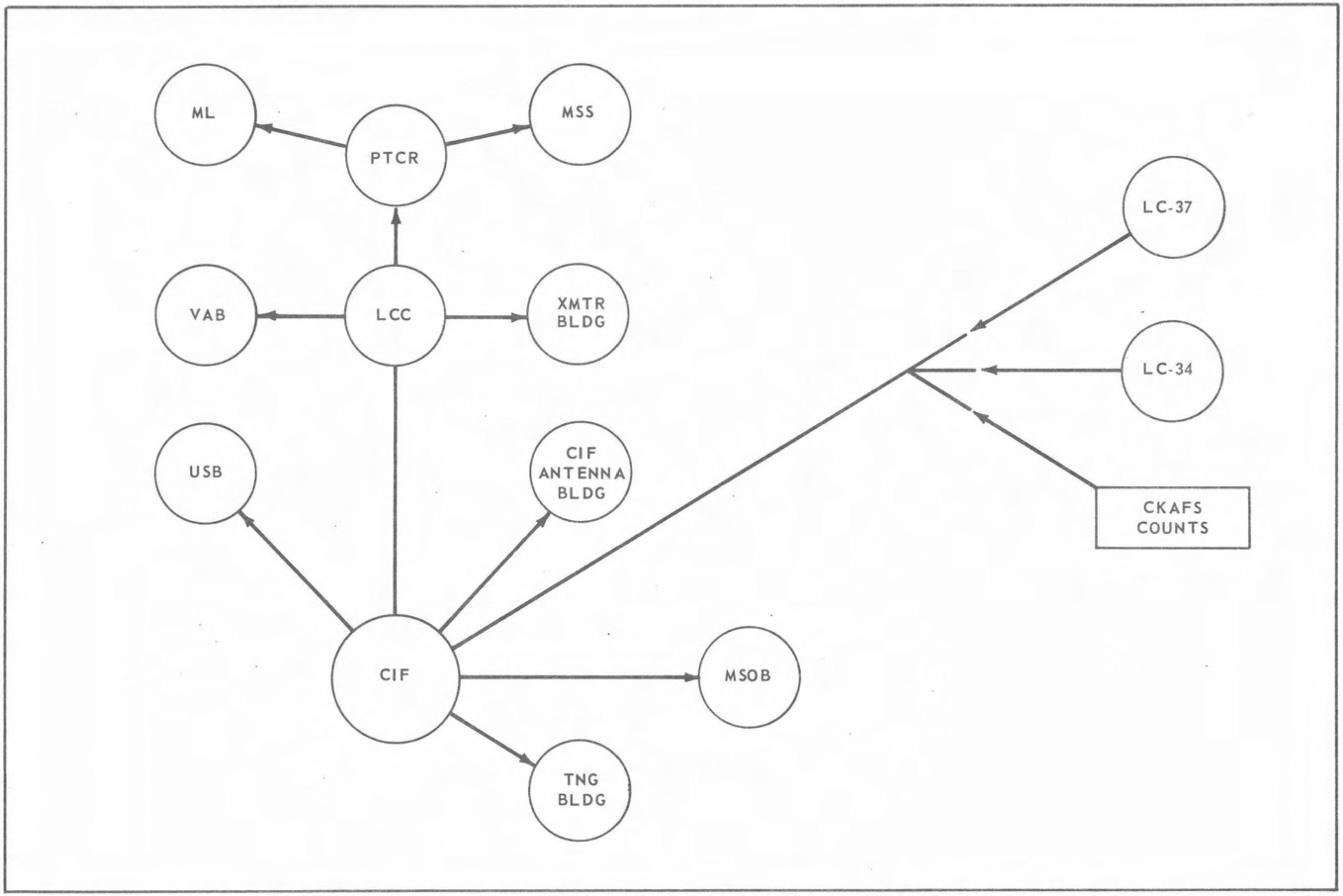


Figure 3-1. Launch Vehicle Countdown Distribution

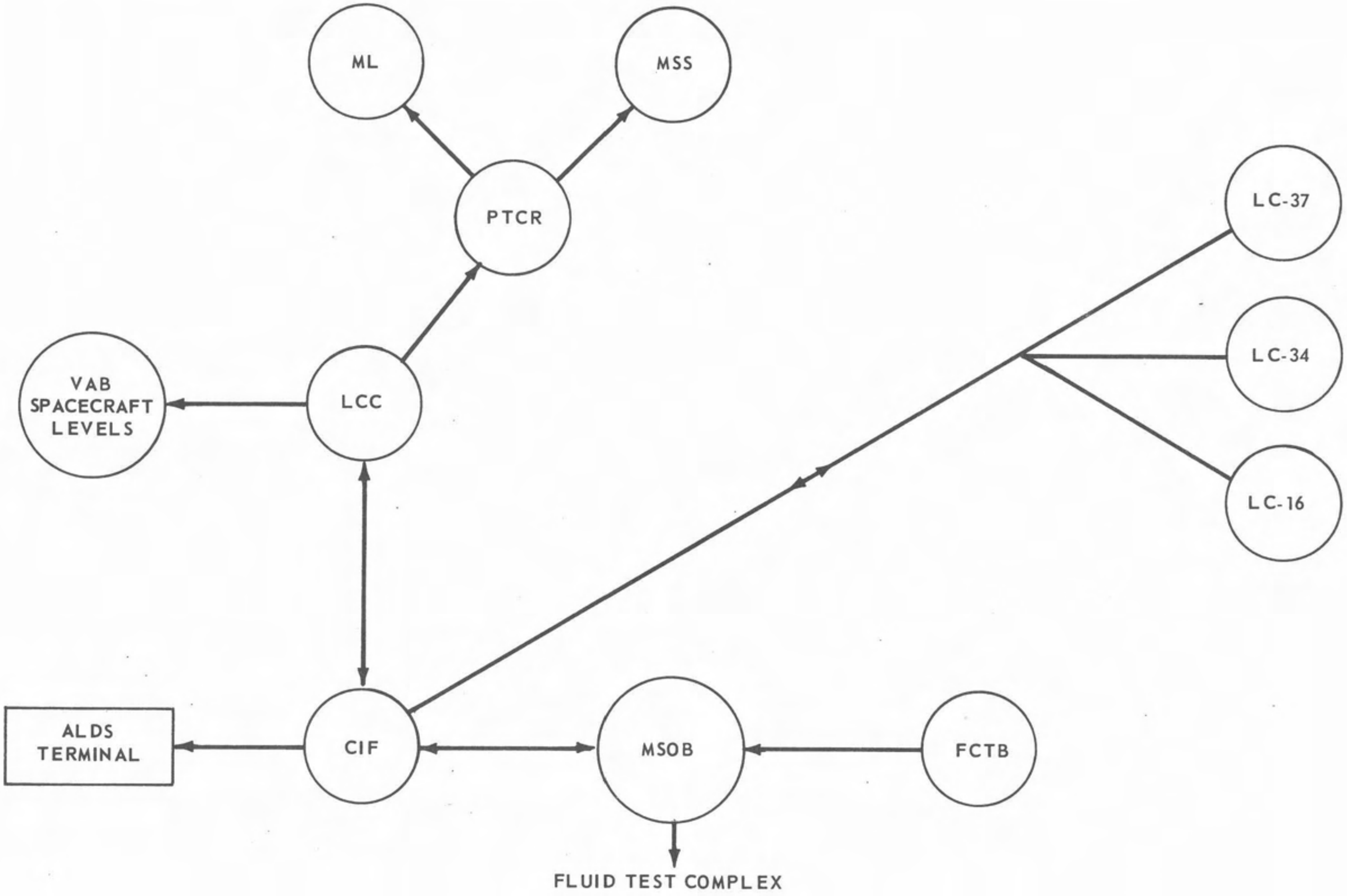


Figure 3-2. Spacecraft Countdown Distribution

data at the launch complex is automated (parallel binary coded decimal input is accepted). The test and checkout positions include a remote control panel for the entry of count data by a test conductor. Each system is of modular construction. The systems can count down from a present time, and count up from the point of liftoff. The count is in seconds, minutes, hours, and days with a sign digit to indicate whether the displayed time is a countdown or a countup.

System parameters are:

a. The transmission medium is 19-gauge wire in pairs, nominally 600-ohm impedance, unshielded common telephone wire.

b. The total length of the wire within the network may approach 500,000 feet.

c. The signal would be transmitted at a nominal zero (0) dbm level.

For this type of transmission, a tone burst approach is definitely preferred. Experience shows that any tone frequency between 1 and 3kc is optimum. The transmission of a residual tone signal is sometimes advisable. Inclusion of the residual tone capability is a no-effort-no-expense feature and it has been made an encoder requirement.

Modulation ratios of 3 to 1 (burst-to-residual) appear optimum. To allow for anticipated crosstalk and noise signals along the transmission path by neighboring signals within the bundle of pairs, and from electric and magnetic fields external to the cable, the moduation ratio set at the encoder is made continuously adjustable to a 4 to 1 maximum ratio.

3-3. DISTRIBUTION

3-4. GENERATOR/ENCODER

The generator portion of the generator/encoder is made up of the digital time accumulator. The accumulator accepts a signal at 1pps appropriately divided to accumulate a count in terms of seconds, minutes, hours, and days. It can count down from a present time, or count up and accumulate time after liftoff. The accumulator can be preset; can be stopped and hold the count; started on command; and jump set-to-zero time while continuing the count.

The encoder portion of the generator/encoder consists of the digital circuitry for developing the serialized pulse output. The encoder output is retransmittable over voice-quality telephone lines. The serial line outputs are binary encoded countdown time values with appropriate frame synchronization pulses (included to contain all required information for the transmission of the sign plus eight digit data). Impedance and signal output levels are consistent with local telephone and AT & T long lines.

Both tone burst and level shifts outputs are available. (See figure 3-3.)

3-5. RECEIVER/DECODER

The receiver portion of the receiver/decoder demodulates the tone burst input signal or conditions the dc shift input signal in preparation for decoding.

The decoder portion of the receiver/decoder detects the serial input bit rate, stores time data in a shift register, translates this data into the seven-level display format, and provides driving power for ten readout displays.

3-6. CONTROL PANEL

The control panel contains all operational controls for conducting a test countdown. The countdown from an automated source is encoded for retransmission by replacing the control panel input to the countdown generator by the parallel data entry lines from the external source. The test conductor has access to only those controls that are absolutely necessary to countdown data entry. The panel occupies minimum rack space and is capable of remoting to a desk-top housing. These factors have resulted in the design indicated in figure 3-4.

The KSC countdown timing system control panel includes the following operational controls:

a. Digit Wheel Controls. These controls preset seconds, minutes, hours, days, and the plus or minus sign. A parallel line control allows the unit seconds, tens of seconds, unit minutes, tens of minutes, unit hours, tens of hours, unit days, and tens of days to be set in each accumulator stage. The sign preset determines the direction of the count by signalling the accumulator to count down from the preset time when the sign is minus, or count up from the preset time when the sign is plus.

b. Reset Control. This control enters preset time and sign control signals on the displays.

c. Count Control. The count control initiates counting in the accumulator in the direction predetermined by the sign preset control.

d. Hold Control. This control stops the accumulation of time, at which point the time display retains its last count time.

e. Liftoff Controls. These controls determine the mode of achieving liftoff time. The three switch positions are AUTO, OFF, and SIMULATE. In the AUTO position, liftoff time is zero count time (a value arrived at by counting down from a preset time, continuing through zero into plus time). When the liftoff switch if OFF, the countdown generator counts down to zero and stops. When the liftoff switch is placed in the momentary SIMULATE position, the count will immediately go to zero

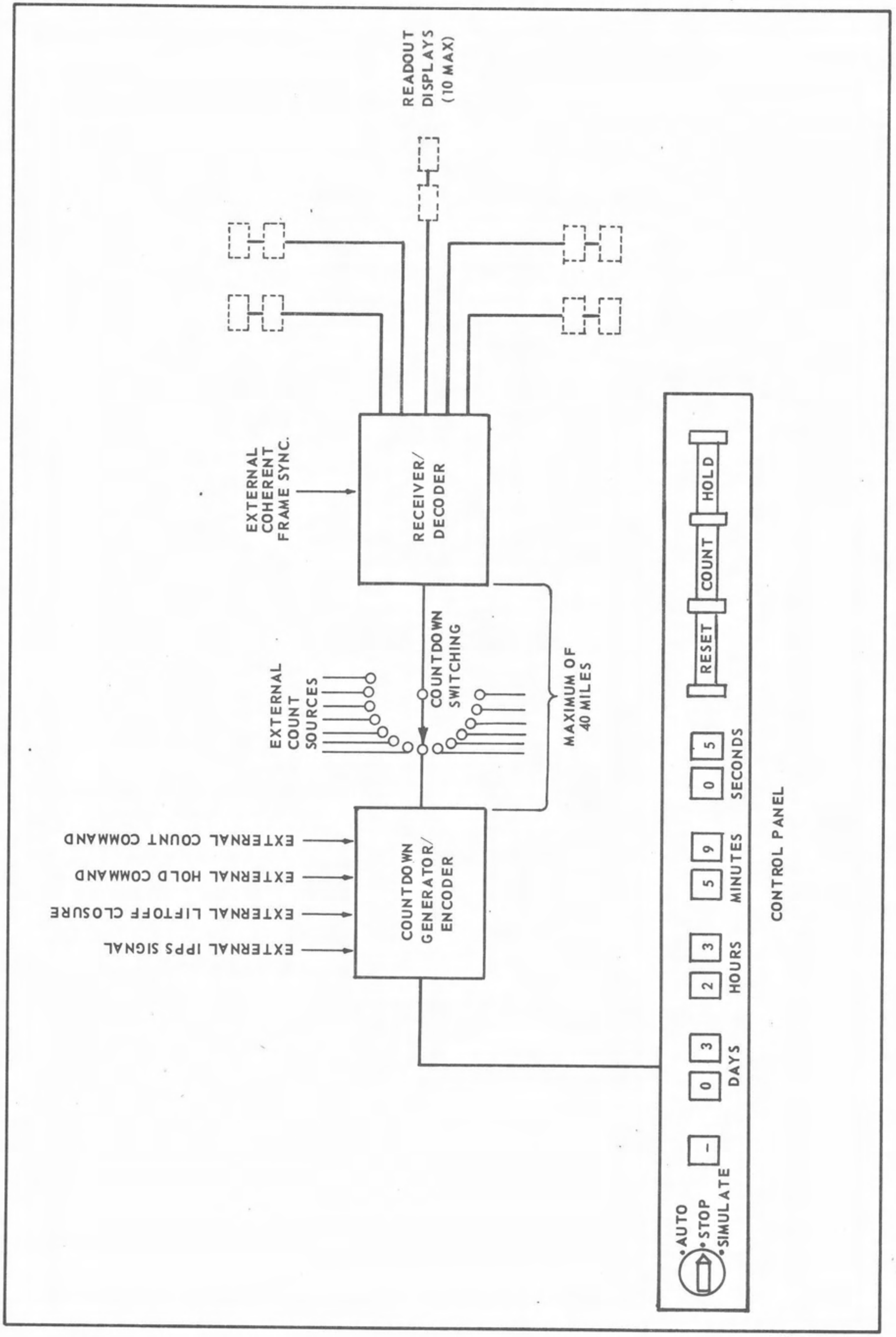


Figure 3-3. Encoder/Decoder

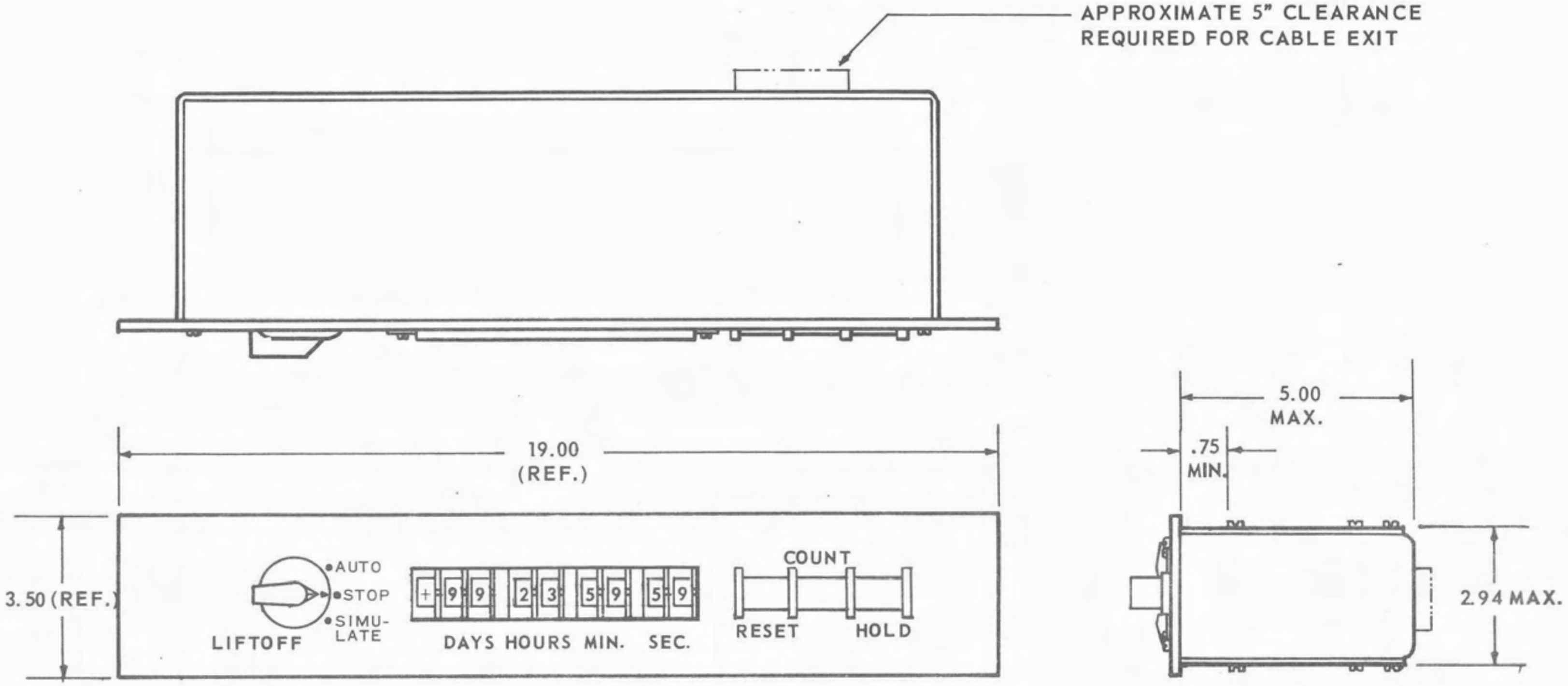


Figure 3-4. Control Panel, Dual Countdown System

time and commence counting in the positive direction.

f. Readout Test Pushbutton Switch. This switch energizes all readout characters to display 8. The 8 digit requires energizing all readout lamps in the seven-segment bar-type display and provides an immediate functional check of display continuity.

3-7. FORMAT

To provide for a distribution format that will permit translating input data into commonly used computer language (if the countdown should be required for other than display reasons), a straight binary coded decimal format was selected. The number of bits (binary digits) was held to an absolute minimum to keep the decoder shift register as inexpensive as possible. The countdown transmission format is shown in figure 3-5.

3-8. DISPLAY

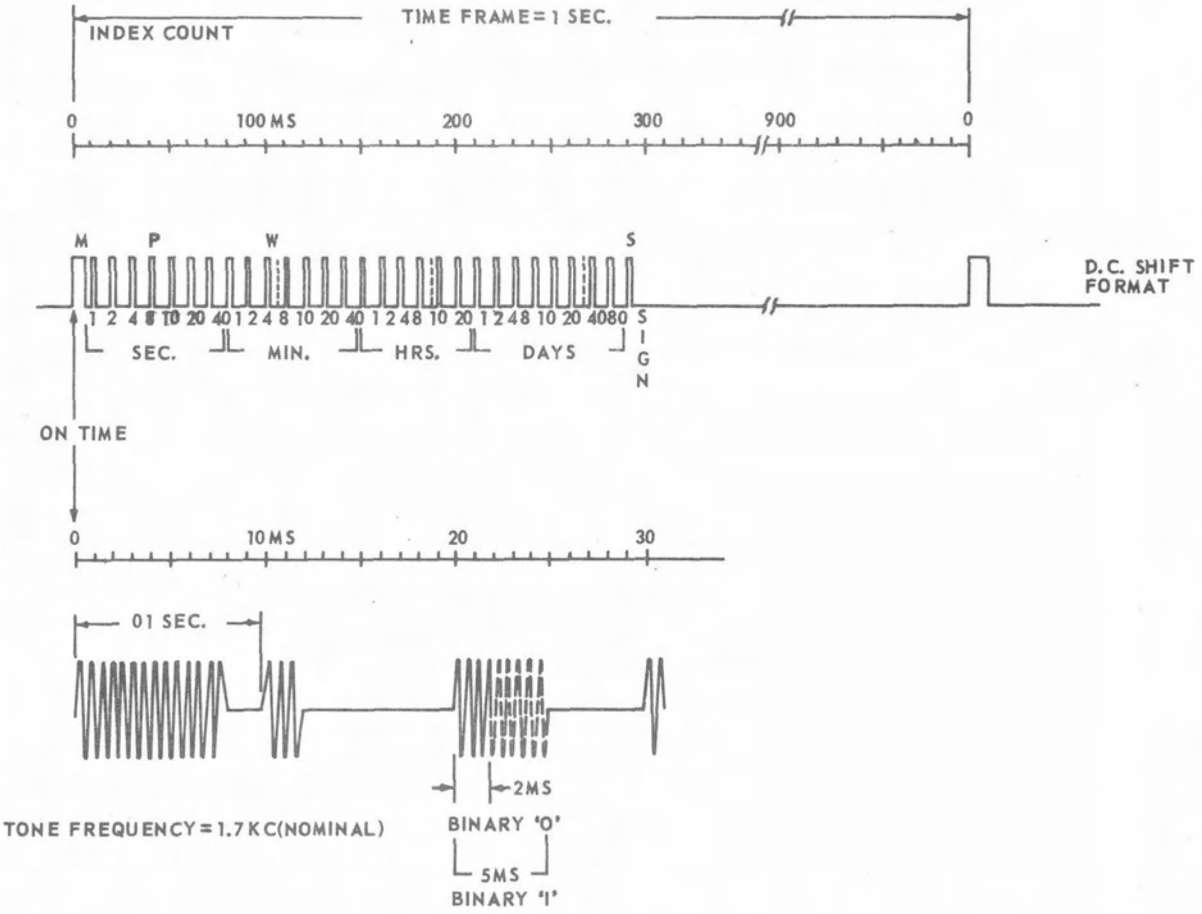
The countdown display presents a decimal in-line numeral indication of an arbitrary time period in days, hours, minutes, and seconds. An additional indication presents a plus, minus, or H figure (for hold condition).

Each numeral and the symbols are composed of bar segments illuminated from the rear by incandescent lamps. Lighting the appropriate lamps forms the figures 0 to 9 and either a plus sign, minus sign, or the letter H.

Numeral blocks are arranged in groups of two to present a two-digit indication of time in days, hours, minutes, and seconds. Thus, prelaunch or postlaunch time can be simultaneously displayed. Figures 3-6 and 3-7 show the countdown readout display units.

3-9. JOINT COUNT

Two counts will be prevalent during a Saturn/Apollo launch: the launch vehicle and the spacecraft countdowns. At some time, determined by operational considerations, all displays will present the launch vehicle countdown to zero and countup from liftoff.



TONE BURST FORMAT

TRANSMISSION LEVEL = 0dbM INTO 600Z

ALTERNATE RESIDUAL CARRIER LEVEL = -10dbM NOMINAL

M = 1 SEC. REFERENCE MARKER
8 MILLISECOND
P = CODE DIGIT BINARY '0'
2 MILLISECOND
W = WEIGHTED CODE DIGIT BINARY '1'
3 MILLISECOND

S = SIGN BIT CODE
5MS = MINUS SIGN
2MS = PLUS SIGN

Figure 3-5. Countdown Transmission Format

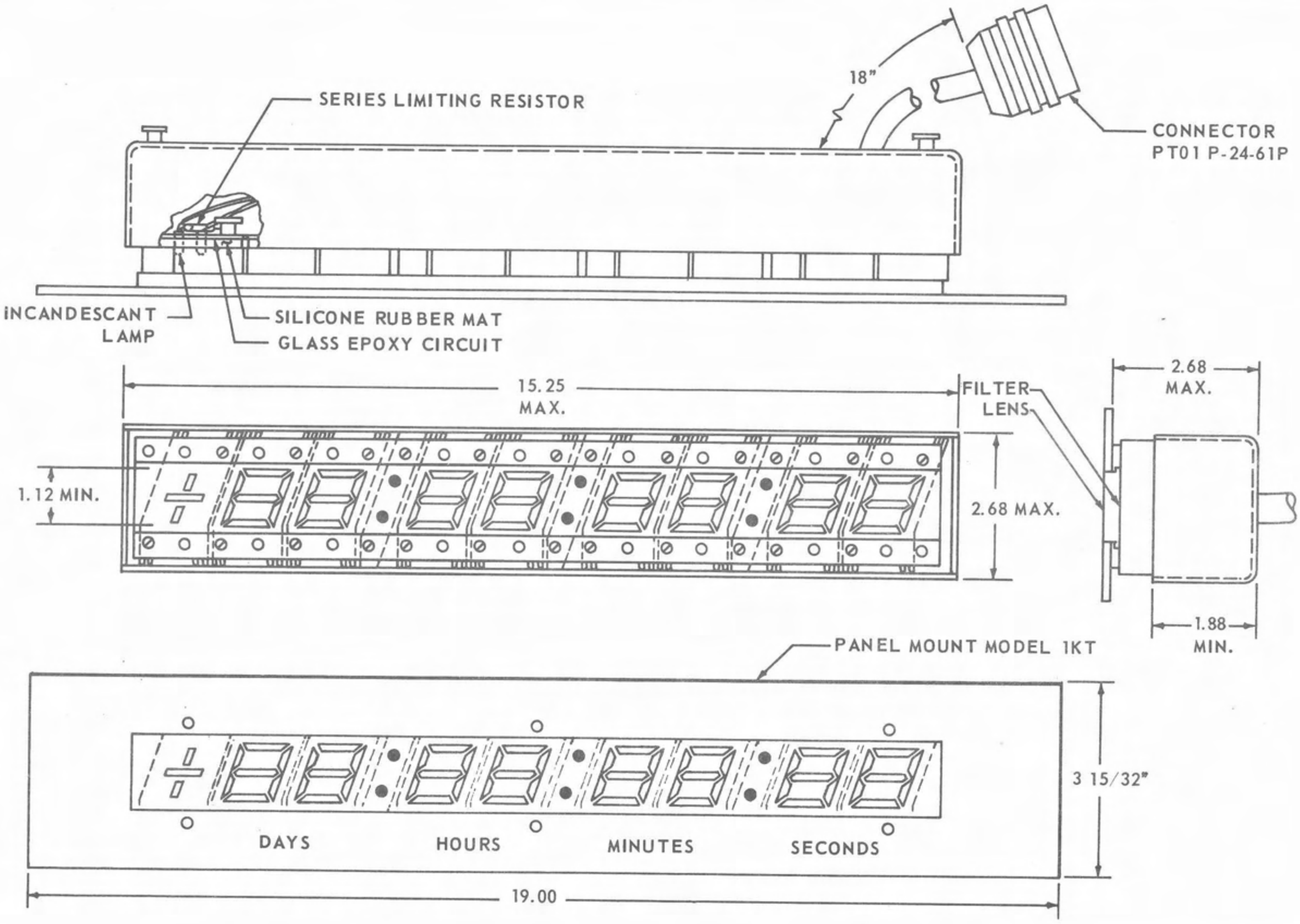
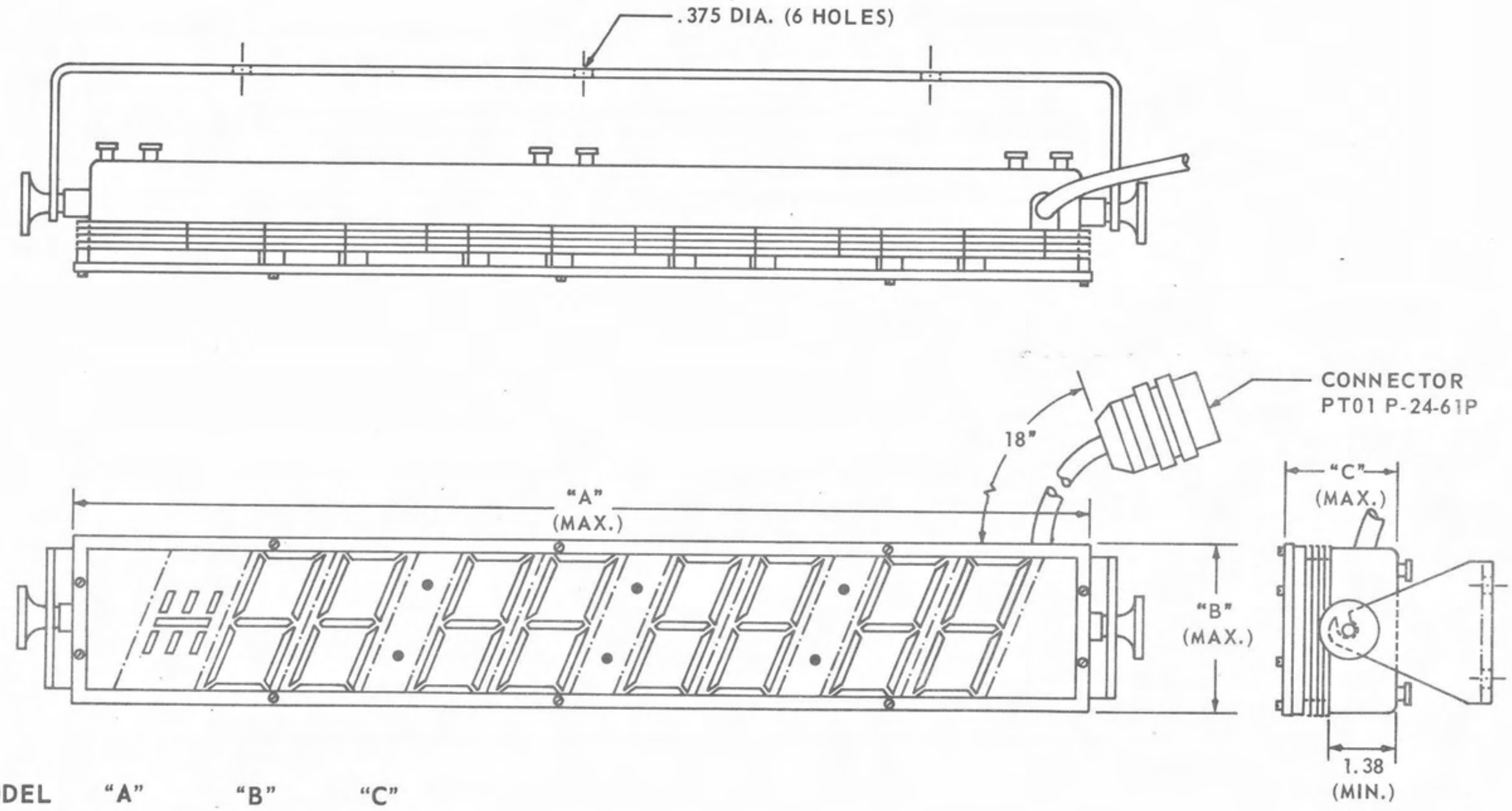


Figure 3-6. Countdown Readout Display Unit (Model IKT)



MODEL	"A"	"B"	"C"
2KT	21.75	3.62	2.44
5KT	45.25	7.12	2.44

Figure 3-7. Countdown Readout Display Unit (Models 2KT and 5KT)

APPENDIX A

USER LOCATION TIMING EQUIPMENT

This appendix explains the operation and functions of the equipment used in the KSC timing system.

A-1. TIMING TERMINAL UNIT MODEL 2220

The Timing Terminal Unit accepts low level pulse and sine wave signals from land lines, reshapes these signals to dc conditions, modulates signals or generates higher levels as required, and delivers them at specific voltage and impedance levels to local data collection equipment. Terminal units in single or multiple quantities are located at every instrumentation site which requires central timing. The exact functional operations contained in a timing terminal unit may be varied to suit the requirements of the timing site by insertion of appropriate plug-in circuit modules. These modules are essentially interchangeable and may be used in any desired arrangement within the particular terminal unit. The Timing Terminal Unit frame contains the power supply for all plug-in modules, all necessary interconnecting wiring between modules, and all wiring for input signals and output signals to and from the modules. The modules provided are:

a. DC Regenerator Model 2221

b. Relay Driver Model 2222

c. Positive Line Driver Model 2223

d. Negative Line Driver Model 2224

e. High Frequency Sine Wave Driver Model 2226

f. Modulator Amplifier Model 2227

g. Low Frequency Sine Wave Driver Model 2228

The Timing Terminal Unit frame is mainly a structural support and contains a power supply for ten plug-in slots. The power supply is standard in all respects, employing a conventional transformer-rectifier-filter combination followed by a multiple shunt regulator system of breakdown diodes driven by a constant current transistor source. All eight breakdown diodes are 6-volt units to simplify thermal design problems. The center tap of this diode string is connected to the chassis with a hash filter from each supply potential to the neutral potential. Output voltages from the regulator are ±24 volts dc, ±12 volts; and 6 volts dc separate a 3-volt breakdown diode with a keep-alive resistor, and a hash-filter provides a -3 volt logic clamp potential. A transistor provides constant current to the regulator circuits (independent of 115-volt line fluctuations) by maintaining a constant voltage drop between the base and the negative terminal of the supply potential by using a breakdown diode and a current source resistor. When no circuit modules are inserted in the Timing Terminal Unit, the current through the transistor is determined solely by a 300-milliampere resistor. Each individual circuit module contains a resistor between the connector pins to increase the total current flow by an amount equal to the current drawn by that circuit module. This keeps the current flowing through the breakdown diode string at approximately 300 milliamperes for any number of circuit modules plugged into the Timing Terminal Unit. Each circuit module also contains necessary resistors to balance the current between the various breakdown diodes of the regulating string so the current through each individual diode is maintained at approximately 300 milliamperes. With this arrangement, the power dissipated by each diode of the regulating string is held at a constant value thereby maintaining stable temperature conditions and uniform output impedance over the entire range of line and load variations.

A-2. DC REGENERATOR MODEL 2221

The DC Regenerator accepts a bipolar repetition rate or conditioned pulse train from the distribution amplifier and regenerates the positive and negative spikes into the same type of level shift which controls the spikes at the central facility. The level shifts are not transmitted over the land lines because the transformers necessary for optimum transmission over land lines are unable to handle the dc conditions. An input transformer is employed with a floating primary winding and a balanced secondary winding. Each half of the winding is connected to a triggering diode with a variable voltage divider in the center tap of the winding to provide adjustable back bias on the diodes; this controls the threshold level of the triggering. Each threshold diode triggers a monostable binary unit for approximately 100 microseconds; because of the balanced secondary winding, the first one-shot is triggered on the leading edge of the pulse and the second one-shot is triggered on the trailing edge. The function of these one-shots is to sharpen the risetime of the trigger pulse to ensure satisfactory operation of the following flip flop consisting of transistor and associated circuitry. The logic level output signal from the collector is coupled by complementary symmetry emitter followers to the arm of the selector switch. The phasing of the DC Regenerator is such that this output terminal will become a logic level 1 when a positive pulse appears at the pin of the transformer.

The DC Regenerator is an essential part of any configuration of the Timing Terminal Unit in which dc outputs such as voltage levels, relay contact closures, or modulation envelopes may be desired. Since several dc output signals may be required from a single Timing Terminal Unit, several DC Regenerators are required; several sets of interconnecting wiring between the corresponding DC Regenerator and its ensuing amplifier are also required. This flexibility is accomplished by the use of an output selector switch and the wiring within the timing terminal unit. Pins of 10 module slots in the Timing Terminal Unit are connected so that five possible separate logic level dc shift signals may be accommodated in one Timing Terminal Unit. No more than five can be employed because there would be more DC Regenerators than output amplifiers and the logic level signals would have no destination.

A resistor connected between connector pins corrects the current capability of the power supply by approximately 18 milliamperes (the current drawn by the DC Regenerator). Resistors balance the current distribution within the shunt regulator diode string.

A-3. RELAY DRIVER MODEL 2222

This circuit module accepts a logic level signal from the DC Regenerator and energizes a high speed mercury contact relay in response to the controlling input. The input selector switch is connected to the same pin as the corresponding DC Regenerator. With the input signal at logic level 0 (-3 volts), an amplifier transistor is saturated and the relay driver resistor is completely cut off; the relay is then deenergized. When the input signal becomes logic level 1, the amplifier transistor cuts off and base current through the coupling diode forces the transistor into full conduction, thereby energizing the relay. This relay has a coil which must operate the contacts at 6.4 volts so the initial voltage of 24 volts across the relay ensures a rapid pull-in. When the input signal becomes -3 volts, and the transistor drops out of conduction, the negative volt spike is damped at the 82-volt level by a breakdown diode. Since the 82-volt level is lower than the transistor voltage rating, it protects the transistor against breakdown.

The mercury relay is a Form C contact; the normally closed contact breaks the normally opened contact which makes contact and vice versa. A resistor serves to increase the current capability of the power supply when the relay driver is plugged-in, and balancing resistors equalize the power dissipation of the shunt regulator diode string. Both the pull-in and dropout times of the relay are less than 2 milliseconds, and all closures are essentially bounce free. The relay has a life expectancy of at least one billion cycles and may be operated satisfactorily at 100 pps. The relay contacts are rated at 2 amperes maximum, with a maximum of 500 volts across open contacts. The power rating is 100 volt amperes maximum and contact protection is required unless the load is particularly resistive.

A-4. POSITIVE LINE DRIVER MODEL 2223

This circuit module amplifies the logic level output from a DC Regenerator to an output switch of 0 to +6 volts or 0 to +12 volts. The Input Selector Switch must be connected to the same signal bus as the corresponding DC Regenerator output. When the input signal rests at logic level 0, the amplifying transistor is cut off and another amplifier transistor is fully conducting in saturation. The collector potential is 0 volts, and this voltage is protected by complementary symmetry emitter followers. When the input signal becomes logic level 1, the first amplifying transistor becomes fully conductive and cuts off any current flow in the other transistor. The collector of this transistor rises to a point where it is clamped by a diode. Since the potential on the cathode is determined by the setting of the front panel switch at either +6 volts or +12 volts, the collector swing of the transistor is the corresponding voltage. The emitter followers pass the same voltage to the output terminal at low impedance.

To reduce power dissipation in the transistor, the collector potential is clamped at a voltage higher than the base. The differential voltage is perhaps 0.5 volt. Accidental short circuits are prevented by limiting the output current by bypassing the resistors. When the nominal load of 1,000 ohms is connected to the output terminal, a full 12-volt swing can be produced across that impedance. If a short circuit to ground is connected to the output terminal, then the transistor goes into saturation conditions with the collector dropping to approximately 0 volts. This arrangement protects against excessive dissipation either in the transistor or in any other internal circuit components. The use of complementary symmetry emitter followers provides a low impedance signal in both transient conditions.

A metering resistor provides increased current capability for the power supply when a positive line driver is plugged into a module receptacle. Current balancing resistors are connected to the negative end of the shunt regulator diode string to compensate for any additional load.

A-5. NEGATIVE LINE DRIVER MODEL 2224

This circuit is basically identical to the Positive Line Driver in performance characteristics because the output signal ranges from 0 to -12 or 0 to -6. The exception is the differences in polarity. Fewer stages of amplification (polarity inversion) are required between the input signal and output terminal.

A-6. HIGH FREQUENCY SINE WAVE DRIVER MODEL 2226

This circuit module is independent of any other circuit module in the Timing Terminal Unit. Its purpose is to accept a balanced line sine wave input in the frequency range of 100,000 cycles to 1 megacycle and to deliver a single-ended output signal of at least 1 volt rms amplitude into a 100-ohm load. An input transformer couples the signal from a floating winding to a single-ended winding on the secondary to drive the gain control. The arm of the gain control is coupled through an operating resistor to the base of the differential amplifier pair. The inverted signal to the transistor collector is coupled by a compensated voltage divider to the base of the output transistor. The signal at the transistor collector is coupled through voltage dividers back to the opposite base of the differential pair to complete a feedback loop. A bypass capacitor provides a low impedance path to ground so the net ac gain of the amplifier from the base of the transistor to the collector is 11. On a dc basis,the value comes into the feedback loop and the net gain of the amplifier is approximately 1.3. Since all transistors are the triple-diffused planar silicon type, this large amount of dc feedback guarantees operation of the amplifier in the linear region without any noticeable drift. The output coupling capacitor breaks the relatively low dc potential (+4 volts) from the output terminal while passing all of the ac components. A resistor provides a dc path for charging the capacitor in the event that there is no external path. The bandwidth of this amplifier, independent of the input transformer, is approximately 3 megacycles.

The metering resistor increases the capacity of the power supply by approximately 27 milliamperes which is approximately the current drain by the High Frequency Sine Wave Driver. A current balancing resistor equalizes the load current between the -12 and -24 volt supplies to preserve uniformity of power dissipation in the shunt regulator diode string.

A-7. MODULATOR AMPLIFIER MODEL 2227

This module card accepts an input subcarrier of 1,000 cycles and an amplitude module with correct phase characteristics. This carrier is in response to a level shift input from a DC Regenerator. The subcarrier input is coupled by a line isolating a transformer from the floating primary winding to a single-ended secondary winding driving output level control. The arm of this potentiometer is connected to a phase-shifting network consisting of a series resistor and a shunt-resonant network. Amplifier transistors form an amplifier exactly like that described in the High Frequency Sine Wave Driver.

A signal level of about 4 volts to the transistor collector is coupled by a blocking capacitor to the input end of a modulator circuit consisting of a ratio resistor and a modulating switch. The modulating input is coupled from a DC Regenerator through the input selector switch to a noninverting amplifier, then to the transistor base in such a fashion that when the input is at logic level 0, both transistors are in saturation. The 1,000-cycle signal is attenuated by the ratio setting of a resistor and passes through a blocking capacitor and attenuator to an adjustable attenuator. When the modulating input signal rests at logic level 1, then neither transistor is in conduction and the full 4-volt peak-to-peak-signal passing through the capacitor appears at the arm of the resistor essentially unattenuated. The adjustable resistor is set to produce an output signal of desired amplitude (10 volts peak-to-peak or less) when the signal at the test point is 4 volts peak-to-peak. The output amplifier is identical to the previous amplifier.

Phase control and filtering of the input 1,000-cycle subcarrier are accomplished by the tuned circuit. The inductance is adjustable to compensate for delays in transmission of either the subcarrier frequency or the modulating signal. The inductor should be adjusted so that changes in the observed modulation level are coincident with the zero axis crossing of the 1,000-cycle carrier.

The metering resistor increases the load capacity of the power supply required by the modulator amplifier by approximately 50 milliamperes. There is a current balancing resistor to equalize power in the shunt regulator diode string.

A-8. LOW FREQUENCY SINE WAVE DRIVER MODEL 2228

This module card is identical to the High Frequency Sine Wave Driver Model 2226, except for the frequency range; 100 to 100,000 cycles.

A-9. SPECIAL SIGNAL TERMINAL MODULES

Terminal modules are available for distribution of special signals such as camera instrumentation neon drivers, oscillographic galvanometer drivers, event conditioning drivers, etc. (See figures A-l and A-2).

A-10. RFI CONSIDERATIONS

The terminal unit is dimensioned so it may be enclosed in a secondary housing to meet the RFI considerations of MIL-I-26600, and be fitted in a 19-inch equipment rack.

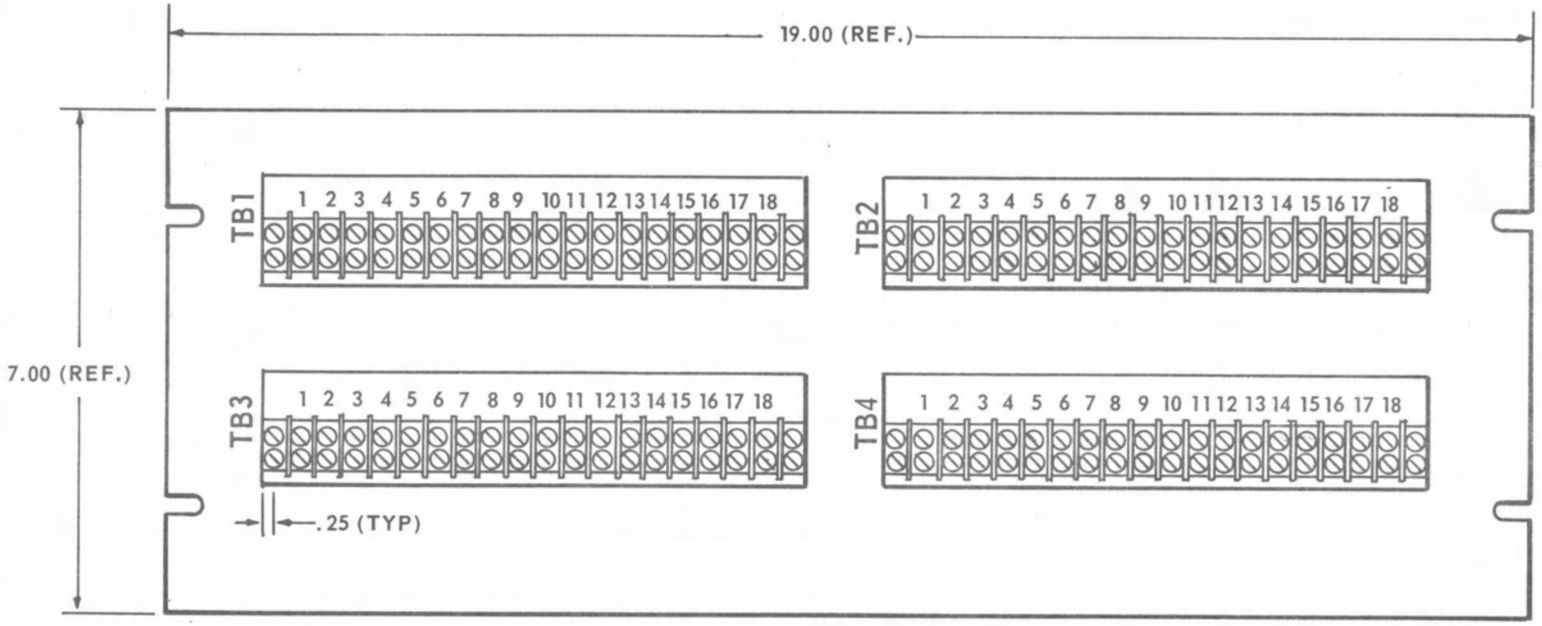


Figure A-1. Timing System Interface Panel

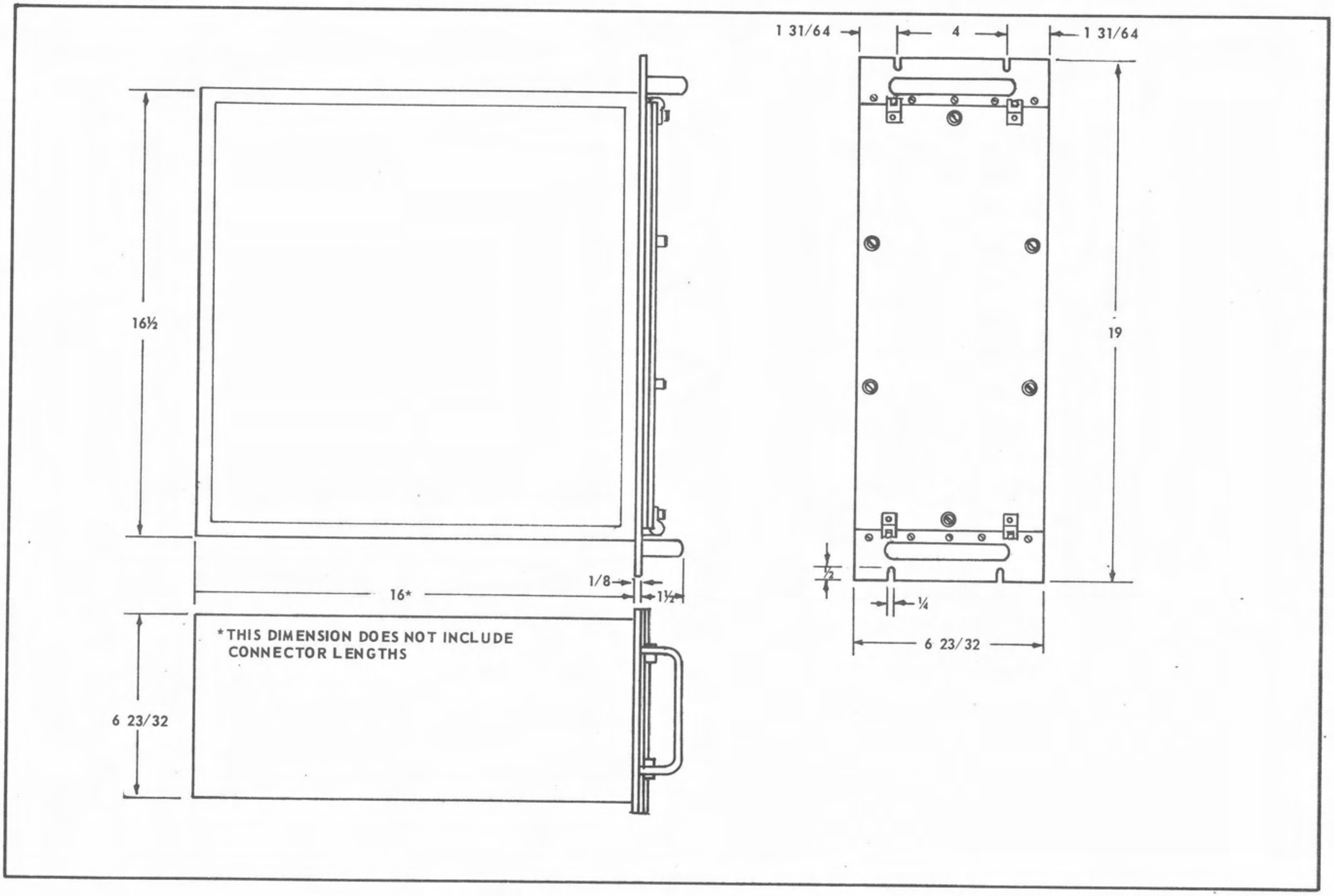


Figure A-2. Terminal Module Dimensions

APPENDIX B

UHF TIMING DISTRIBUTION SYSTEM

This appendix describes the AFETR UHF timing distribution system which is used as a source of KSC correlation timing signals. This distribution system is also used by remote tracking sites as the source of timing signals. The following components are described in detail:

a. UHF Pulse Transmitter

b. UHF Transmitter

c. Decoder

d. Auxiliary Omnidirectional UHF Transmitting Antenna

e. Coaxial Transmission Line

B-1. FUNCTIONS

The UHF timing distribution system performs the following functions:

a. Accepts up to 80 time code and repetition rates from an existing time code generator and multiplexes these codes and repetition rates for transmission on a single channel.

b. Transmits this multiplexed information over a UHF link to receiver sites whose antennas are within the line of sight of the UHF transmitter (up to 65 kilometers).

c. Receives and amplifies the transmitted information to a level suitable for a decoder operation.

d. Decodes the various repetition rates and time codes into separate channels with signal characteristics capable of operating Timing Terminal Units.

B-2. UHF PULSE TRANSMITTER

The UHF transmitter, modulated by pulsed data code groups from the encoder, has the following characteristics and meets the following requirements:

a. Tunable from 1,725 through 1,775 megacycles.

b. Video input impedances are 75 ohms unbalanced; 124 ohms balanced.

c. Transmitter RF output impedance matches the impedance of the associated transmission line and of the omnidirectional antenna.

d. The transmitter provides sufficient radiated peak-pulse RF power or average RF power at the antenna to meet or exceed the following signal strength requirements, with all equipment installed at the end location as specified in procurement specification GEEIA-R-7516:

1. The pulsed data code groups transmitted and received have the capability of being received within a 40-mile radius of the transmitter.

2. Minimum acceptable signal-to-noise ratio is 20 decibels (db).

e. The radiated pulse width is 1.8 microseconds ± 10 percent at half amplitude; maximum 2.0 microseconds at the base.

f. The radiated pulse droop is not to exceed 5 percent of the peak value with 20 pulses per 1 millisecond time interval.

g. The maximum duty cycle is 20 percent; average duty cycle is 3 to 5 percent.

h. A change of frequency with variations in the duty cycle, power supply voltage, RF load, and ambient temperatures, is not to affect the frequency deviation by more than 0.01 percent of center frequency.

i. The maximum VSWR (voltage-to-standing-wave ratio)is 1:2.

j. The transmitter is capable of handling the following signals:

1. A time division multiplex signal from the encoder consisting of a train of not more than 100 pulses, occuring at a 100,000pps bit rate, per 1 millisecond time frame. The delay of each bit, with respect to the beginning of the time frame, will be unique for each group or repetition rate provided.

2. Random spaced pulses.

3. Output pulses from the encoder with the following characteristics:

Pulse width: 2 microseconds maximum
Pulse rise time: 0.5 microsecond maximum
Pulse decay time: 0.8 microsecond maximum
Amplitude: +8.0 (± 0.5) volts
Base line: 0 (± 0.5) volt

B-3. UHF TIMING RECEIVER

The UHF Timing Receiver (figure B-1) utilizes a crystal mixer and a local cavity oscillator which operates continuously. The intermediate-frequency (IF) strip provides the required gain. The detected output of the IF is fed directly to the input of the decoder.

The pulse modulated receiver has the following characteristics.

a. Preferred frequency range of 1,700 to 1,800 megacycles; a required range of 1,725 to 1,775 megacycles.

b. RF input impedance of the receiver matches the impedance of the RF coaxial transmission line, and of the directional UHF receiving antenna.

c. Output impedance of the receiver is 75 ohms, unbalanced; 124 ohms, balanced. Noise figure is 10 db.

d. Tunable cavity local oscillator.

e. The change of frequency in the receiver with variations in duty cycles, power supply voltage and ambient temperatures does not affect frequency deviation by more than 0.01 percent of center frequency.

f. IF amplifier plug-in capability for ease of maintenance and repair. IF plug-in amplifier for each receiver has:

1. Continuously adjustable IF gain of 60 db.

2. Preferred IF of 60 megacycles.

3. IF bandwidth of 8, 6, 4, 2, 1, and 0.5 megacycles.

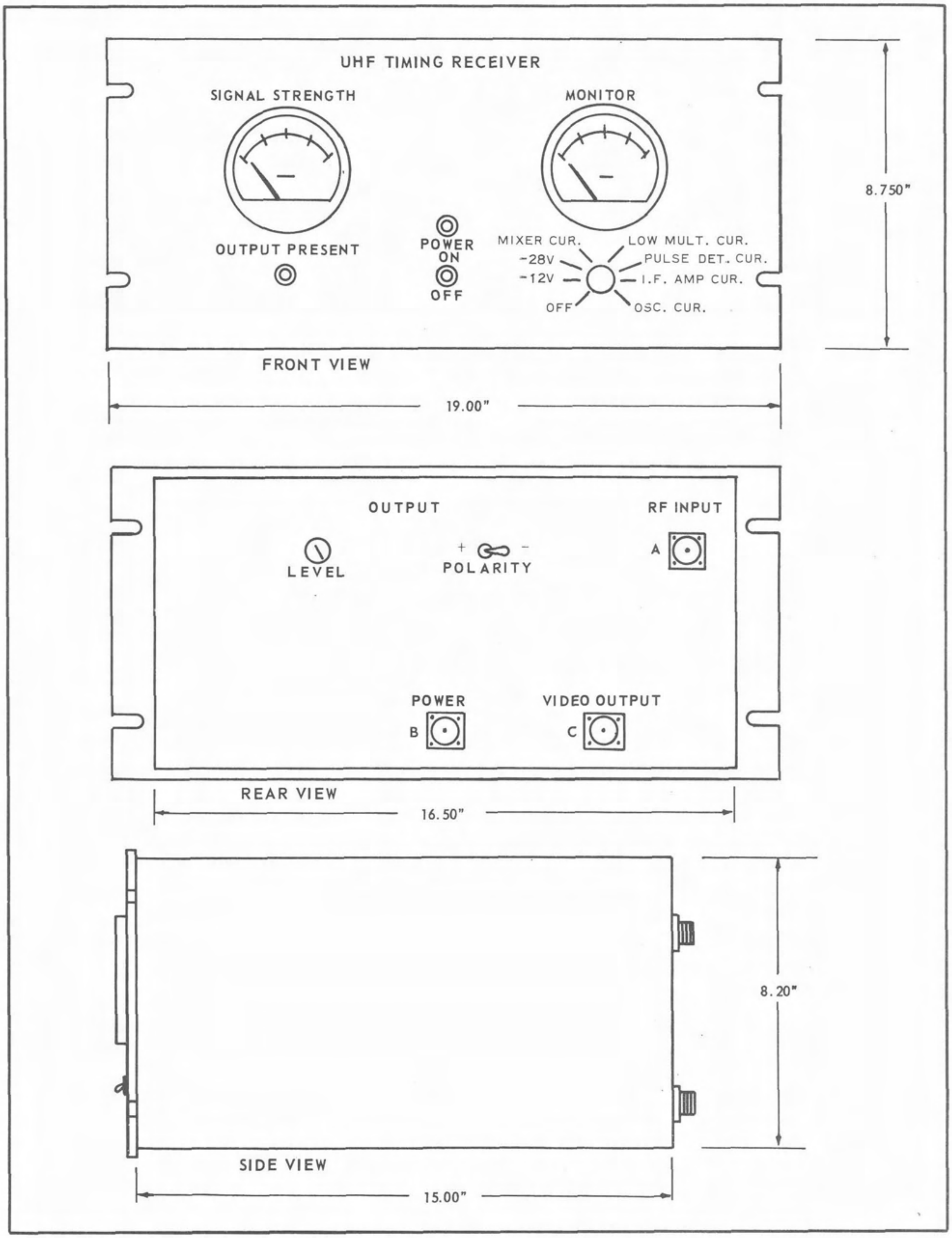


Figure B-1. UHF Timing Receiver

4. Capability of handling and converting the received signal back to its original shape at the time the signal was fed into the UHF Pulse Transmitter. Receiver output signals have:

Maximum pulse width of 2 microseconds
Maximum pulse rise time of 0.5 microsecond
Maximum pulse decay time of 0.8 microsecond
Minimum adjustable amplitude of 0 to ± .05 volt
Base line of 0 (± 0.5) volt
Polarity with positive and negative pulses

5. A gain control mechanism, to make the required output voltage available for the decoder input.

6. Panel lamps to indicate whether the primary power is ON, a signal is being received, and a signal is being provided for the encoder.

7. Its own internal power supply operating on 177 volts ± 10 percent, at 60 cycles ± 5 percent. It provides the voltage to operate the receiver. Silicon diode rectifiers reduce the heat generated by the power supply.

B-4. UHF DECODER

The maximum repetition rate (code bit rate) to be transmitted is 1,000pps (the frame rate for the distribution system). Since the next slower signal transmitted would be 500pps, each alternate 1,000-microsecond frame is empty. In addition, the last 600 microseconds of each frame is empty. This information can be used to synchronize the decoder.

A digital technique is used in the decoder for reliability. In addition to the propagation delay, the decoder is provided with signal delay means variable from 0 to 200 microseconds, with a maximum of 1 microsecond as the smallest increment of delay adjustment.

B-5. CAPABILITIES

The UHF Decoder has the following capabilities:

a. Synchronize automatically to the incoming frame rate.

b. Compensate for total time delay of the signal which has been transmitted early in time.

c. Accept 80 serial signal bits plus a 1,000pps frame marker at a frame rate of 1,000cps; examine each received signal bit for its delay with respect to the beginning of the 1-millisecond time frame; and (from this information) route each signal bit to the correct signal output circuit card. The UHF Decoder thus converts the 80-bit serial input to 80 output signals.

d. Clock the 80 output signals to ± 1 microsecond of the required phase relationship.

B-6. INPUT SIGNAL

The UHF Decoder has the following input signal tolerances:

a. Maximum pulse width of 2 microseconds

b. Maximum pulse rise time of 0.5 microsecond

c. Maximum pulse decay time of 0.8 microsecond

d. Amplitude of +4 (± 2.0) volts

e. Base line of 0 (± 0.5) volt

f. Input impedances of 75 ohms, nominal, single-ended; and 125 ohms nominal, balanced. Both are selectable.

B-7. OUTPUT SIGNALS

The decoder has two types of output circuits. One type employs a bistable unit and is used for decoding the pulse position code channels. The other type uses a monostable unit for providing an output from repetition rate channels. In either case, the capability of the output circuits is limited to two channels per subassembly.

The output signals of any one channel take the following two forms:

a. Output Signal No. 1. In demodulation, the signals are shaped in accordance with AFETR Document A-600101 into the following shapes:

B1
C2
D1
D3
D4
E1
E2
E3
E4
PR1
PR2
PR4
PR8
PR12
PR14
PR22
PR24
PR27
PR28
PR37
IRIG - A, B, C, D, E

b. Output Signal No. 2. These signals are transformed into the following shapes by differentiating circuits, in accordance with AFETR Document A-600102:

DS-B-1
DS-C-2
DS-D-1
DS-D-2
DS-D-3
DS-G-1
DS-G-3
DS-H-1
DS-H-3
DS-R-1
DS-R-2
DS-R-4
DS-R-8
DS-H-12
DS-R-14
DS-R-22
DS-R-24
DS-R-27
DS-R-28
DS-R-37
DS - IRIG - A, B, C, D, E

B-8 Signal Characteristics. The decoder has the following output signal characteristics:

a. Output Signal No. 1:

1. Voltage: Continuously adjustable from 0 (± 0.5) volt to + 10 volts minimum into a 600-ohm load.

2. Duration:

(a) Code Outputs: Duration of the pulses from the code output circuit is equal to the time interval between the repetition rate and the corresponding pulse position code bit in the code channel in question, within ± 1 microsecond.

(b) Pulse Outputs: Duration of the pulses from the pulse output circuit is 400 (± 50) microseconds. This duration may be increased to 50 milliseconds + 5 percent minimum by adding capacitors.

3. Rise Time: Will not exceed 5 microseconds.

4. Decay Time: Will not exceed 1 microsecond.

5. Source Impedance: 600 ohms maximum for both card types.

b. Output Signal No. 2:

1. Voltage: Continuously adjustable from 0 (± 0.5) volt to plus and minus 10 volts, baseline to peak, into a 600-ohm load.

2. Duration: The pulses will be triangular, and shall have a duration of 400 (±50) microseconds.

3. Rise Time: 0.5 microsecond maximum.

4. Decay Time: (Emax. to 0.05 Emax.) 400 (±50) microseconds.

5. Source Impedance: 600 ohms maximum (both positive and negative going signals) referenced to system ground.

B-9 Output Signal Accuracy. The leading edge of all outputs of the decoder is timephased to 1 on time at the central timing generator to within 1 microsecond. Pulse-to-pulse spacing (leading-edge-to-leading-edge) will be accurate to within 0.1 microsecond for any code or repetition rate transmitted. All output codes and rates will be clocked to within 1 microsecond of each other.

B-10 Output Channel Requirements. Space for 40 output channels is provided as part of the decoder. The unit is wired to accept either a code output circuit or a pulse output circuit with no wiring changes. Each output slot receptacle contains a minumum of ten signal pins. The decoder provides up to 40 code output or 40 pulse outputs or any combination of the two types to yield a total of 40 output channels, with the insertion of the respective output circuits.

The decoder is designed so that output circuits may be removed without affecting the desired reception and decoding with the following exception: an output card must be plugged into the DS-R-4 and/or DS-R-19 channel if reception of pulse position codes is desired.

Forty additional output channels may be added, using the outputs from the remaining 40 matrixed channels available from the decoder and a separate rack-mounted subchassis. The subchassis will contain only output circuits, receptacles and wiring as described. Power and input signals are taken from the decoder. Power and matrixed channel signals for operation of the 40-channel subchassis are provided through connectors on the rear of the decoder chassis.

B-11 SIGNAL AND POWER TERMINATIONS

The decoder input signal from the receiver and the 40 output channel signals will be terminated at the right rear of the decoder chassis through series 53 taper pin devices. These signal terminations are colorcoded and marked as to receiver signal and channel output number. Signal outputs from the remaining 40 matrixed channels, which will be routed to the subchassis, are terminated at right rear of the decoder chassis through a multiple pin connector.

B-12 DIRECTIONAL UHF RECEIVING ANTENNA

B-13 ANTENNA

This antenna (figure B-2) is used to receive the transmitted pulsed data code groups.It has the following characteristics:

a. The antenna is parabolic and unidirectional with an operating frequency of from 1,725 megacycles to 1,775 megacycles.

b. It is vertically polarized with a narrow beam width of not more than 10 degrees.

c. It has a gain of 22 db for a 5-foot reflector, and 27 db for a 6-foot reflector, over an isotropic antenna.

d. The impedance of this antenna matches the impedance of the UHF receiver and the impedance of the associated transmission line.

e. Since environment and atmosphere would expose the antenna to salt air,precautions have been taken to prevent corrosion, rust and destruction.

B-14 TOWER

To support the antenna, a guyed tower with the following characteristics is employed:

a. Height of the tower is 60 feet; including antenna, 70 feet

b. The tower can withstand 125-mile-per-hour (true) wind velocity.

c. For access to the top of the tower, an outside galvanized ladder is provided.

d. The tower, ladder, and guy cables are properly grounded. These

Figure B-2. Directional UHF Receiving Antenna and Tower and associated installed items also are galvanized and treated to prevent corrosion and rust.

B-15 RF COAXIAL TRANSMISSION LINE

The RF coaxial transmission line connects the UHF directional receiving antenna to the UHF receiver for the transfer of RF signals. Characteristics of the transmission line are as follows:

a. It has an operating frequency of 1,725 to 1,775 megacycles. Signal loss from the antenna to the receiver will not exceed 40 percent for a 200-foot transmission line.

b. The impedance is that of the UHF directional receiving antenna and of the UHF receiver.

c. The transmission line is protected against the same atmospheric conditions as the antenna.

d. The cable is approximately 200 feet long and flexible.

APPENDIX C

GLOSSARY OF TERMS AND ABBREVIATIONS

Definition of Terms

BINARY NUMBER SYSTEM - A number system which uses two symbols, usually denoted by "0" and "1", and has two (2) as its base. (Not to be confused with CODE DIGIT WEIGHTING.)

CODE DIGIT - One of a definite set of ELEMENTS, the set comprising a CODE WORD. Each CODE DIGIT is weighted individually and numerically.

CODE DIGIT WEIGHTING - The numerical value assigned to a particular CODE DIGIT position.

CODE WORD - A definite series of ELEMENTS which collectively convey information defining an instant of time.

ELEMENT - One of the parts of which any time signal is composed.

INDEX COUNT - A number which identifies a specific INDEX MARKER position with respect to a specific REFERENCE MARKER.

INDEX MARKERS - Uncoded periodic interpolating ELEMENTS.

POSITION IDENTIFIER - An ELEMENT or combination of ELEMENTS which denote the position of a portion or all of a CODE WORD.

REFERENCE MARKER - The basic periodic ELEMENT which establishes that instant of time defined by the CODE WORD.

TIME FRAME - All information between corresponding points of two successive REFERENCE MARKERS.

Abbreviations

AC	Alternating Current
AFETR	Air Force Eastern Test Range
AT	Atomic Time
AT&T	American Telephone and Telegraph Company
BCD	Binary Coded Decimal
BIT	Binary Digit
CIF	Central Instrumentation Facility
CKAFS	Cape Kennedy Air Force Station
DB	Decibel
DC	Direct Current
ET	Ephemeris Time
FCTB	Flight Crew Training Building
GMT	Greenwich Mean Time
IRIG	Interrange Instrumentation Group
KSC	John F. Kennedy Space Center
LCC	Launch Control Center
LF	Low Frequency
LSB	Least Significant Bit
MILA	Merritt Island Launch Area
ML	Mobile Launcher
MSB	Most Significant Bit
MSOB	Manned Spacecraft Operations Building
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NRZ	Non-Return-to-Zero
PAM	Pulse Amplitude Modulation
PDM	Pulse Duration Modulation

Abbreviations (continued)

PPM	Pulse Per Minute
PPS	Pulse Per Second
PTCR	Pad Terminal Connection Room
PWC	Pulse Width Coded
PWM	Pulse Width Modulation
RF	Radio Frequency
RFI	Radio Frequency Interference
SBS	Straight Binary Seconds
TCW	Time Code Word
TCWG	Tele-Communications Working Group
TOD	Time of Day
VAB	Vehicle Assembly Building
VLF	Very Low Frequency
VSWR	Voltage-to-Standing-Wave Ratio
UHF	Ultra High Frequency
USFS	United States Frequency Standard
UT	Universal Time

APPROVAL

SP 4-49

KSC
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