DATUM INC

Handbook of Time Code Formats

THE COMPANY

From its inception in 1968, Datum has been involved in the highly specialized field of precision timing instrumentation. Today, the company designs and manufactures the most comprehensive array of time and frequency products in the industry. Our customers include most agencies of the U.S. Government as well as commercial and governmental entities throughout the western world. Ranging from miniature displays to complete range timing systems, Datum's products include off-the-shelf equipment as well as customized instrumentation tailored to specific customer requirements. Applications are as diverse as deep space exploration programs, medical research and vehicle test operations.

Datum's technical management staff is committed to ongoing product development. As new technologies evolve, our designs are evaluated and, when appropriate, upgraded to reflect the newest innovations.

Cover photo: Great Nebula in Orion

Inside photo: Trifid Nebula in Sagittarius

FOREWORD

The Handbook of Time Code Formats is provided as a reference for timing instrumentation users. It contains a compilation of the time code formats most commonly employed by industry and U.S. Government agencies at the time of printing. In addition, the handbook contains brief discussions of time definitions, standard time broadcasts, methods of time determination and time error vs. accuracy reference material.

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INTRODUCTION

The use of coded timing signals to assist in the correlation of data began to take on widespread importance in the early 1950's. Timing signals were used for the correlation of data recorded on oscillographs, strip charts, printers, magnetic tapes and film.

The instrumentation requirements of the nation's missile and space programs were the forces behind the development of Timing Instrumentation and Time Code Formats. In the mad ICBM-weapon-systems rush and in the stampede into space, the development of systematic, efficient timing techniques was neglected. The use, definition and application of Time Code Formats was completely arbitrary and left to the individual ingenuity of each agency and each design engineer.

The evolution of the hundreds of Time Code Formats in use in the early 60's has resulted in more general usage of standardized formats, some of which are described on the following pages. Other formats have been abandoned as programs were completed or have died due to non-use. The Inter-Range Instrumentation Group (IRIG) was responsible for standardization of Time Code Formats and timing techniques. This standardization has resulted in more widespread use of Timing equipment and Timing techniques in such commercial activities as air traffic control, medical instrumentation, law enforcement, public utility, etc.

Information contained in this book has been gathered from IRIG, Hewlett-Packard and NBS standard publications.

SELECTION AND USE OF TIME CODE FORMATS

Coded time signals, commonly called "Time Code Formats", some of which are contained in this Handbook, are primarily used to provide correlation of multiple data sources and multiple data points during the monitoring or recording of various types of data. Precise time, related to world-wide time scales, is of critical importance in monitoring spaceship launching and tracking activities. Time intervals, rather than world-wide time, are important in monitoring processes: recording measurements and performance for weapon systems testing, flight testing, medical research, etc. Time, when recorded with data, serves as a convenient means of correlating various types of data recorded on different medias. Time also becomes a convenient reference for data retrieval should analysis of a recording be desired in the future.

Selecting a Time Code Format involves evaluation of the accuracy and data resolution being recorded, as well as an evaluation of the specific recording media. The bandwidth of the recording device governs the rate of the Time Code Format and, therefore, its resolution. The accuracy of the time and the Time Code Format depends primarily on the source of the Format and its relationship to world-wide time or on the accuracy of its individual frequency sources (refer to Appendix). Thus, various time codes are defined at different rates and different resolutions.

Referring to the IRIG standards, the Time Code Formats defined are established to support such high-speed data acquisition as camera instrumentation, as well as such very slow-speed data acquisition required for oscillographs or strip chart recorders.

When the Time Code Format is to be transmitted or when the specific recording device requires signal conditioning, additional characteristics are usually incorporated. Most common is the addition of a sine wave carrier, amplitude-modulated by the Time Code Format. This permits the signal to be conveniently transmitted by means of telephone communications or perhaps by means of being recorded on lower-bandwidth magnetic tape recorders.

ABBREVIATIONS

PDM	PULSE DURATION MODULATION
PWM	PULSE WIDTH MODULATION
TCW	TIME CODE WORD
TOD	TIME OF DAY
Hz	An abbreviation for HERTZ. The derived unit of frequency (cycles per second).
kHz	KILOHERTZ (1000 HERTZ)
ppm	PULSES PER MINUTE
pps	PULSES PER SECOND
ms	MILLISECOND (0.001 second)
μs	MICROSECOND (0.000001 second)
fph	FRAMES PER HOUR
fpm	FRAMES PER MINUTE
fps	FRAMES PER SECOND
UTC	UNIVERSAL TIME COORDINATED. (The U.S. Naval Observatory is responsible for maintaining the reference for time and time interval for the Department of Defense per DOD Directive 5160.51, 1 Feb. 1965.)
BCD	BINARY CODED DECIMAL
CF	CONTROL FUNCTION
SBS	STRAIGHT BINARY SECONDS
STOD	SECONDS TIME OF DAY
BIT	BINARY DIGIT
LSB	LEAST SIGNIFICANT BIT
MSB	MOST SIGNIFICANT BIT
PAM	PULSE AMPLITUDE MODULATION
PWC	PULSE WIDTH CODED

GLOSSARY OF TERMS

ACCURACY (CODE)	The correctness of CODE DIGIT WEIGHTING
BINARY NUMBER SYSTEM	A number system which uses two symbols, usually denoted by "0" and "1", and has two 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 individually and numerically weighted
CODE DIGIT WEIGHTING	The numerical value assigned to a particular CODE DIGIT position
CODE WORD (TIME)	A definite set of ELEMENTS which collectively convey information defining an instant of time
ELEMENT	One of the parts of which any time signal is composed
FORMAT	The arrangement of ELEMENTS within a group
INDEX COUNT	The number which identifies a specific ELEMENT position with respect to a REFERENCE MARKER
INSTRUMENTATION TIMING	A parameter serving as the fundamental independent variable in terms of which data may be correlated
INDEX MARKERS	Uncoded periodic interpolating ELEMENTS
ON TIME	The state of any ELEMENT being coincident with the STANDARD REFERENCE TIME
POSITION IDENTIFIER	An ELEMENT denoting the position of a portion or all of a CODE WORD
PULSE	A variation of a quantity whose value is normally constant; the variation is characterized by a "rise" and a "decay" and has a finite "duration"
REFERENCE MARKER	A periodic combination of ELEMENTS which establishes that instant of time defined by the CODE WORD
SECOND	The basic unit of TIME
TIME INTERVAL	Time interval indicates the duration of a segment of time without reference to when the time interval begins and ends
STANDARD REFERENCE TIME	The basic repetition rate chosen as the common time reference for all other INSTRUMENTATION TIMING. (usually 1 pps)
TIME	Time signifies epoch; that is, the designation of an instant on a selected time scale and is used in the sense of TIME of day
TIME CODE ZERO (Tco)	The instant of time defined by all CODE WORDS as zero. It is derived from and coincident with an ELEMENT of the STANDARD REFERENCE TIME
TIME FRAME	The TIME INTERVAL between consecutive REFERENCE MARKERS containing all ELEMENTS of a time FORMAT.

INTER-RANGE INSTRUMENTATION GROUP
STANDARD INSTRUMENTATION TIMING FORMATS

General

In the early 1950s it became apparent that efficient interchange of test data between the various test ranges and contractor, university and Government laboratories would require time code standardization. This task of standardization was assigned to the Tele-Communications Working Group (TCWG) of the IRIG in October of 1956. The original IRIG standards were accepted by the Steering Committee in 1960. IRIG publication No 104-60 defined the original IRIG Formats. This document was later revised and then reprinted in August, 1970 as Document No. 104-70. The current Document is No. 200-70 (it differs from No. 104-70 in title page only). More information regarding the efforts of IRIG and the availability of IRIG standards can be gained by contacting the Secretariat, Range Commander's Council, White Sands Missile Range, New Mexico 88002. More detail concerning the individual range synchronization and instrumentation timing can be obtained by referring to IRIG Document 103-59, "Instrumentation Timing Systems" brochure.

Description of Formats

In the IRIG family, individual Time Code Formats are alphabetically designated 'A', 'B', 'D', 'E', 'G', and 'H'. These are defined in IRIG Document No. 104-70. IRIG 'C', originally defined in IRIG Document No. 104-60, has been eliminated and effectively replaced by IRIG 'H'. Various signal forms are described in the IRIG Document. Identification numbers have been developed in accordance with the following procedure.

Rate Designation:
A) 1000 pps
B) 100 pps
D) 1 ppm
E) 10 pps
G) 10000 pps
H) 1 pps

Form Designation:
0) Pulse, width-coded
1) Sine wave, amplitude-modulated

Carrier/Resolution:
0) No carrier/index count interval
1) 100 Hz/10 ms
2) 1000 Hz/1 ms
3) 10000 Hz/0.1 ms
4) 100000 Hz/0.01 ms

Coded Expressions:
0) BCD, CF, SBS
1) BCD, CF
2) BCD
3) BCD, SBS

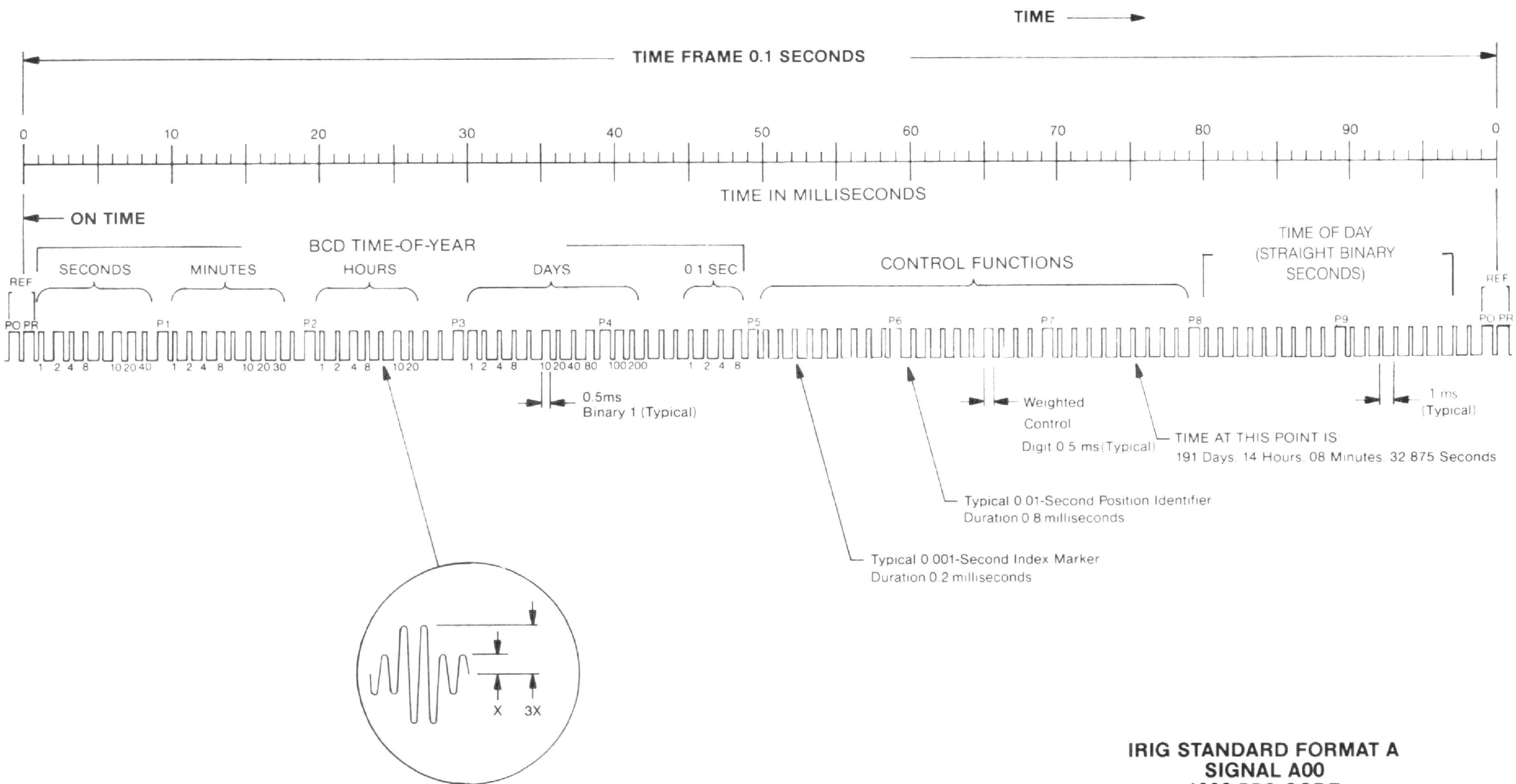
Only the following signals are recognized to be standard forms in accordance with the IRIG standard:

Format A	Format B	Format D	Format E	Format G	Format H
A000	B000	D001	E001	G001	H001
A003	B003	D002	E002	G002	H002
A130	B120	D111	E111	G141	H111
A133	B123	D112	E112	G142	H112
		D121	E121		H121
		D122	E122		H122

IRIG FORMAT 'A'—GENERAL

1. **TIME FRAME:** 0.1 second
2. **CODE DIGIT WEIGHTING OPTIONS:** BCD, SB or both:
   a. Binary Coded Decimal Time-of-Year CODE WORD — 34 binary digits.
      (1) Seconds, minutes, hours, days and 0.1 seconds. Recycles yearly.
   b. Straight Binary Time-of-Day CODE WORD — 17 binary digits.
      (1) Seconds only.
      Recycles each 24 hours. (86399)
3. **CODE WORD STRUCTURE:**
   a. **BCD.** Word begins at INDEX COUNT 1. Binary-coded elements occur between POSITION IDENTIFIER ELEMENTS (seven for seconds; seven for minutes; six for hours; ten for days; four for 0.1 seconds) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
   b. **SB.** Word begins at INDEX COUNT 80. Seventeen binary-coded elements occur, with a POSITION IDENTIFIER between the 9th and 10th binary-coded elements.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first, except for fractional seconds information, which occurs following the day-of-year information.
5. **ELEMENT RATES AVAILABLE:**
   a. 1000 per second (basic Element rate)
   b. 100 per second (POSITION IDENTIFIER rate)
   c. 10 per second (Frame rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: 0.2 milliseconds (Binary Zero or uncoded Element)
   c. CODE DIGIT duration: 0.5 milliseconds (Binary one)
   d. POSITION IDENTIFIER: 0.8 milliseconds
   e. REFERENCE MARKER: Two consecutive POSITION IDENTIFIERS.

      (The "on-time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 1 millisecond (unmodulated); 0.1 millisecond (modulated).
8. **CARRIER FREQUENCY:** 10 kHz when modulated.



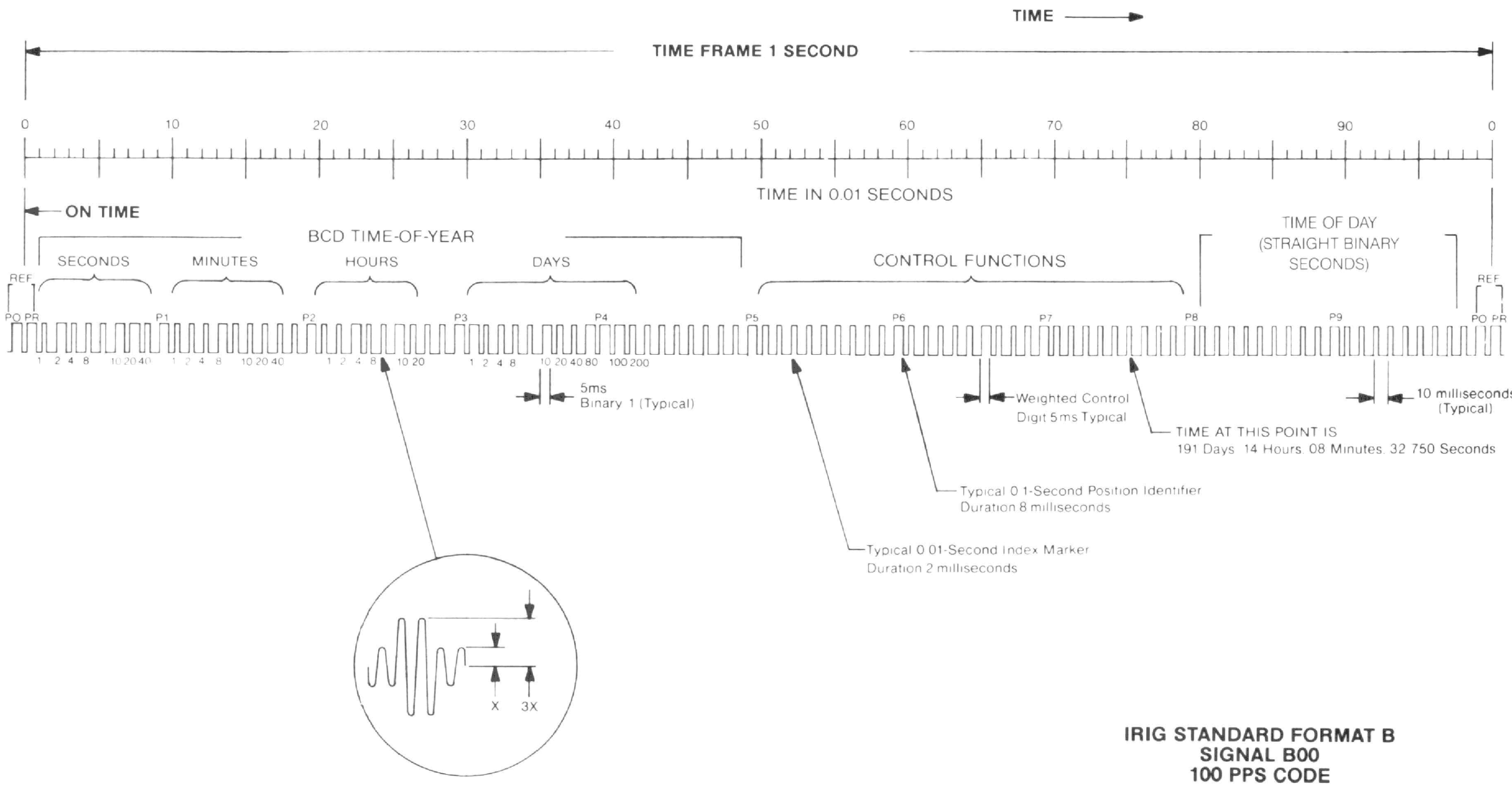
TYPICAL MODULATED CARRIER (10000 Hz)

IRIG STANDARD FORMAT A
SIGNAL A00
1000 PPS CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'B' — GENERAL

1. **TIME FRAME:** 1.0 second.
2. **CODE DIGIT WEIGHTING OPTIONS:** BCD, SB or both:
   a. Binary Coded Decimal Time-of-Year CODE WORD — 30 binary digits.
      (1) Seconds, minutes, hours and days. Recycles yearly.
   b. Straight Binary Time-of-Day CODE WORD — 17 binary digits.
      (1) Seconds only. Recycles each 24 hours. (86399)
3. **CODE WORD STRUCTURE:**
   a. **BCD:** Word begins at INDEX COUNT 1. Binary-coded elements occur between POSITION IDENTIFIER ELEMENTS (seven for seconds, seven for minutes; six for hours; ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
   b. **SB:** Word begins at INDEX COUNT 80. Seventeen binary-coded elements occur with a POSITION IDENTIFIER between the 9th and 10th binary-coded elements.
4. **LEAST SIGNIFICANT DIGIT:** occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 100 per second (basic Element rate)
   b. 10 per second (POSITIVE IDENTIFIER Rate)
   c. 1 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: 2 milliseconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 5 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 8 milliseconds
   e. REFERENCE MARKER — one per second: Two consecutive POSITION IDENTIFIERS.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 10 milliseconds (unmodulated); 1 millisecond (modulated).
8. **CARRIER FREQUENCY:** 1 kHz when modulated.



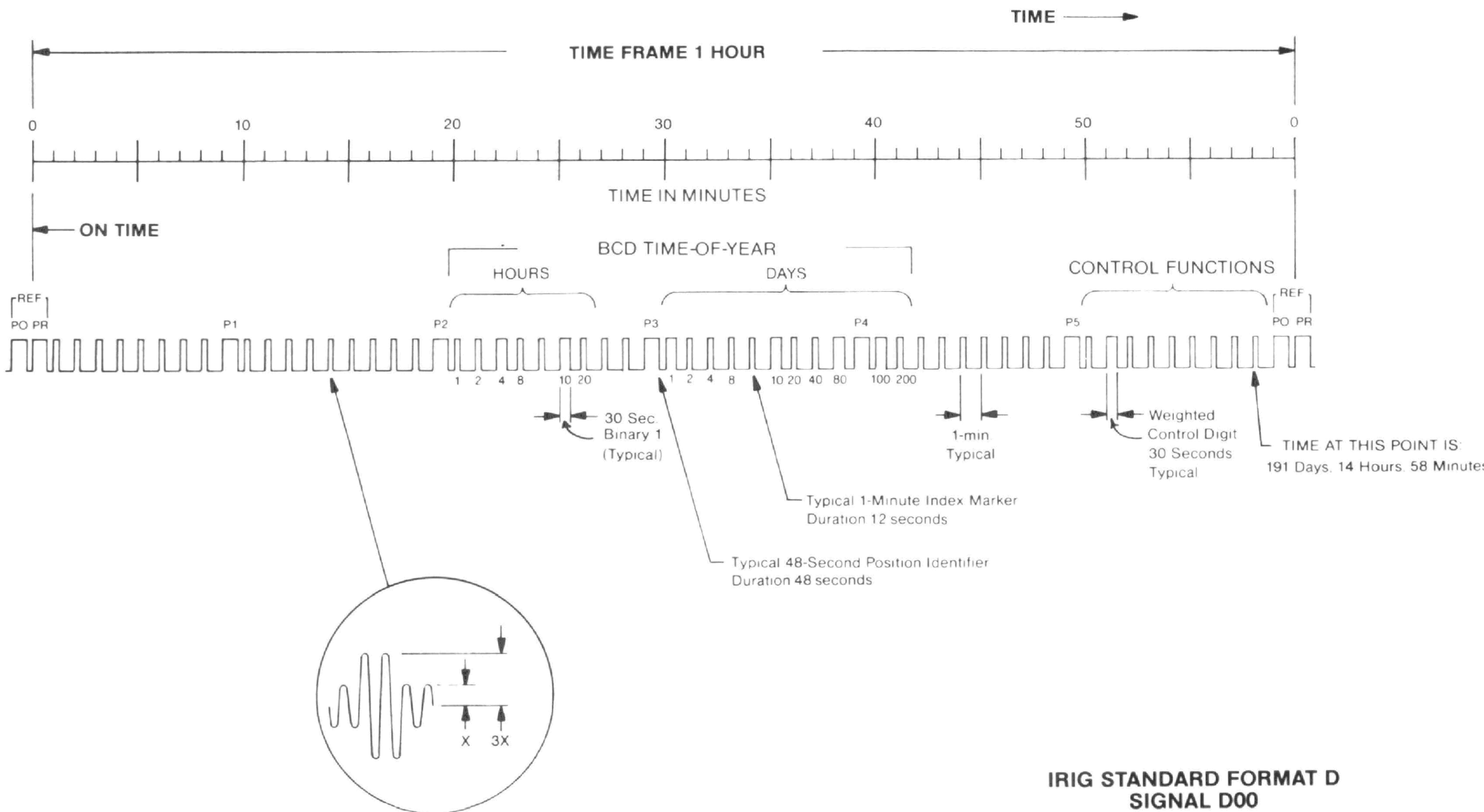
TYPICAL MODULATED CARRIER (1000 Hz)

IRIG STANDARD FORMAT B
SIGNAL B00
100 PPS CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'D' — GENERAL

1. **TIME FRAME:** 1 hour
2. **CODE DIGIT WEIGHTING OPTIONS:** Binary Coded Decimal Time-of-Year CODE WORD only — 16 binary digits.
   a. Hours and days. Recycles yearly.
3. **CODE WORD STRUCTURE:**
   a. **BCD:** Word begins at INDEX COUNT 20. Binary-coded elements occur between POSITION IDENTIFIER ELEMENTS (six for hours; ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per minute (basic Element rate)
   b. 1 per 10 minutes (POSITION IDENTIFIER Rate)
   c. 1 per hour (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: 12 seconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 30 seconds (Binary one)
   d. POSITION IDENTIFIER (one per 10 minutes) duration: 48 seconds (Refers to the leading edge of the succeeding Element).
   e. REFERENCE MARKER (one per hour): Two consecutive POSITION IDENTIFIERS.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 1 minute (unmodulated); 0.01 seconds (modulated 100 Hz); 0.001 seconds (modulated 1000 Hz)
8. **CARRIER FREQUENCY:** 100 or 1000 Hz when modulated.



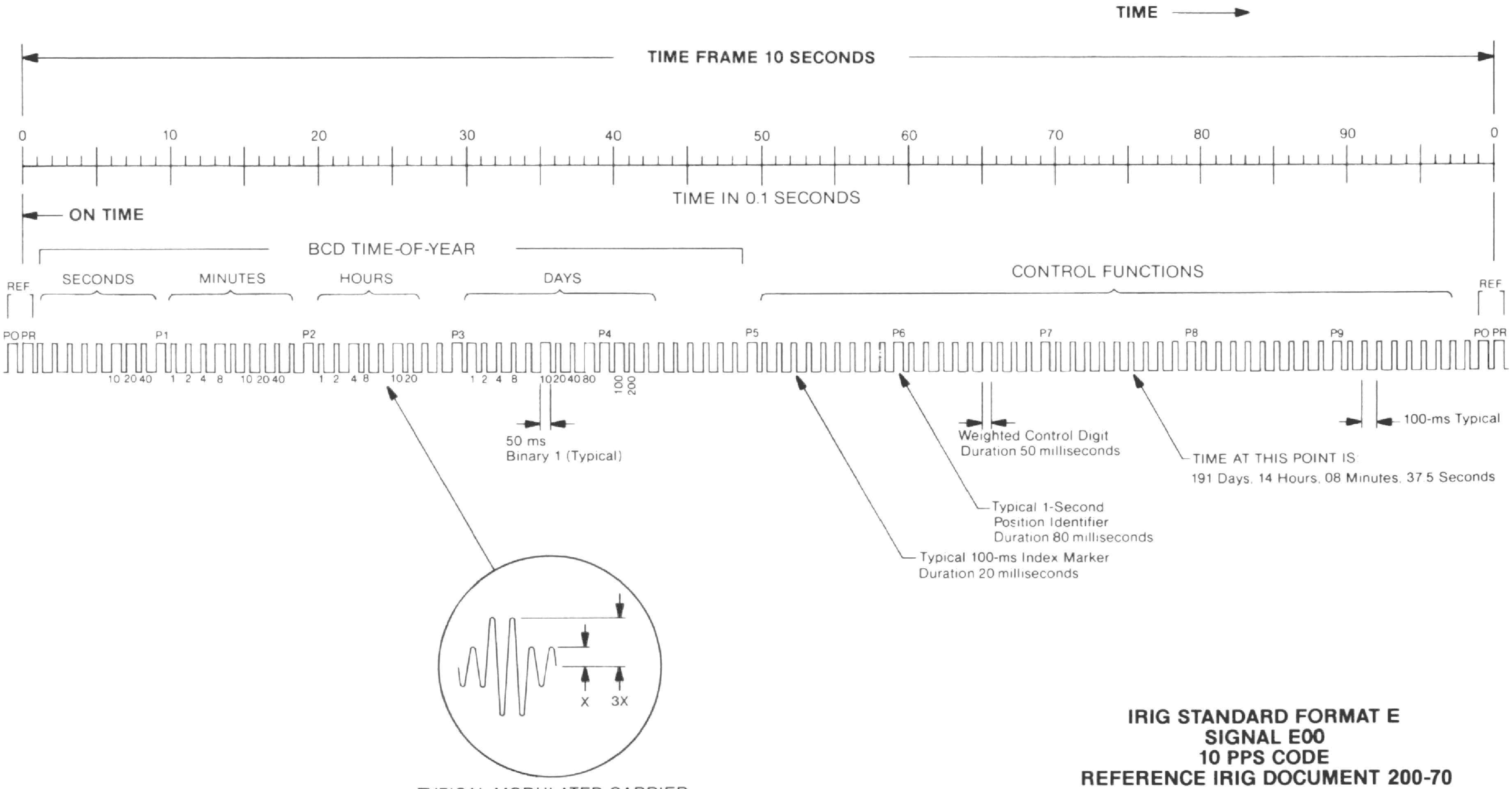
TYPICAL MODULATED CARRIER
RECOMMENDED FREQUENCY, 100 Hz or 1000 Hz

IRIG STANDARD FORMAT D
SIGNAL D00
1 PPM CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'E' — GENERAL

1. **TIME FRAME:** 10 seconds
2. **CODE DIGIT WEIGHTING:** BCD: Time-of-Year CODE WORD — 26 Binary Digits. Seconds, minutes, hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:**
   BCD: Word begins at INDEX COUNT 6. Binary-coded Elements occur between POSITION IDENTIFIER ELEMENTS (three for seconds, seven for minutes; six for hours, ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 10 per second (basic Element rate)
   b. 1 per second (POSITION IDENTIFIER Rate)
   c. 0.1 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: 20 milliseconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 50 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 80 milliseconds (Refers to the leading edge of the succeeding Element).
   e. REFERENCE MARKER (one per 10 seconds): Two consecutive POSITION IDENTIFIERS.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 100 milliseconds (unmodulated).
   0.01 seconds (modulated 100 Hz);
   0.001 seconds (modulated 1 kHz).
8. **CARRIER FREQUENCY:** 1 kHz or 100 Hz when modulated.



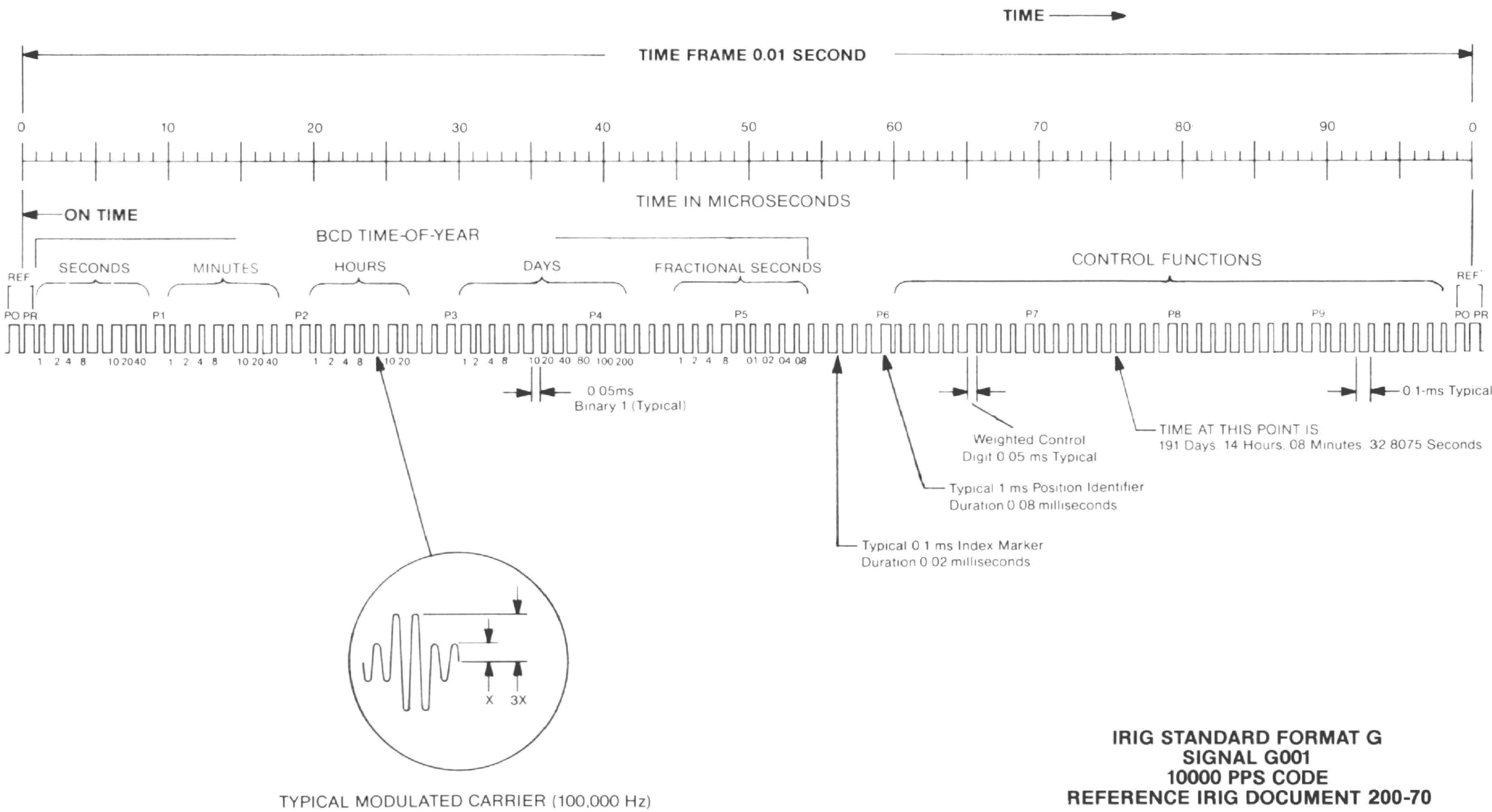
TYPICAL MODULATED CARRIER

RECOMMENDED FREQUENCY, 100 Hz or 1000 Hz

IRIG STANDARD FORMAT E
SIGNAL E00
10 PPS CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'G' — GENERAL

1. **TIME FRAME:** 0.01 second.
2. **CODE DIGIT WEIGHTING:** BCD Time-of-Year CODE WORD — 38 binary digits.
   a. Seconds, minutes, hours, days, 0.1 seconds and 0.01 seconds; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD Word begins at INDEX COUNT 1. Binary Coded Elements occur between POSITION IDENTIFIER ELEMENTS (seven for seconds; seven for minutes; six for hours; ten for days; four for 0.1 seconds; four for 0.01 seconds) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first, except for fractional seconds information, which occurs following the Day-of-Year information.
5. **ELEMENT RATES AVAILABLE:**
   a. 10000 per second (basic Element Rate)
   b. 1000 per second (POSITION IDENTIFIER Rate)
   c. 100 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.02 milliseconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 0.05 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.08 milliseconds
   e. REFERENCE MARKER: Two consecutive POSITION IDENTIFIERS.
      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 0.10 milliseconds (unmodulated); 0.01 milliseconds (modulated).
8. **CARRIER FREQUENCY:** 100 kHz when modulated.

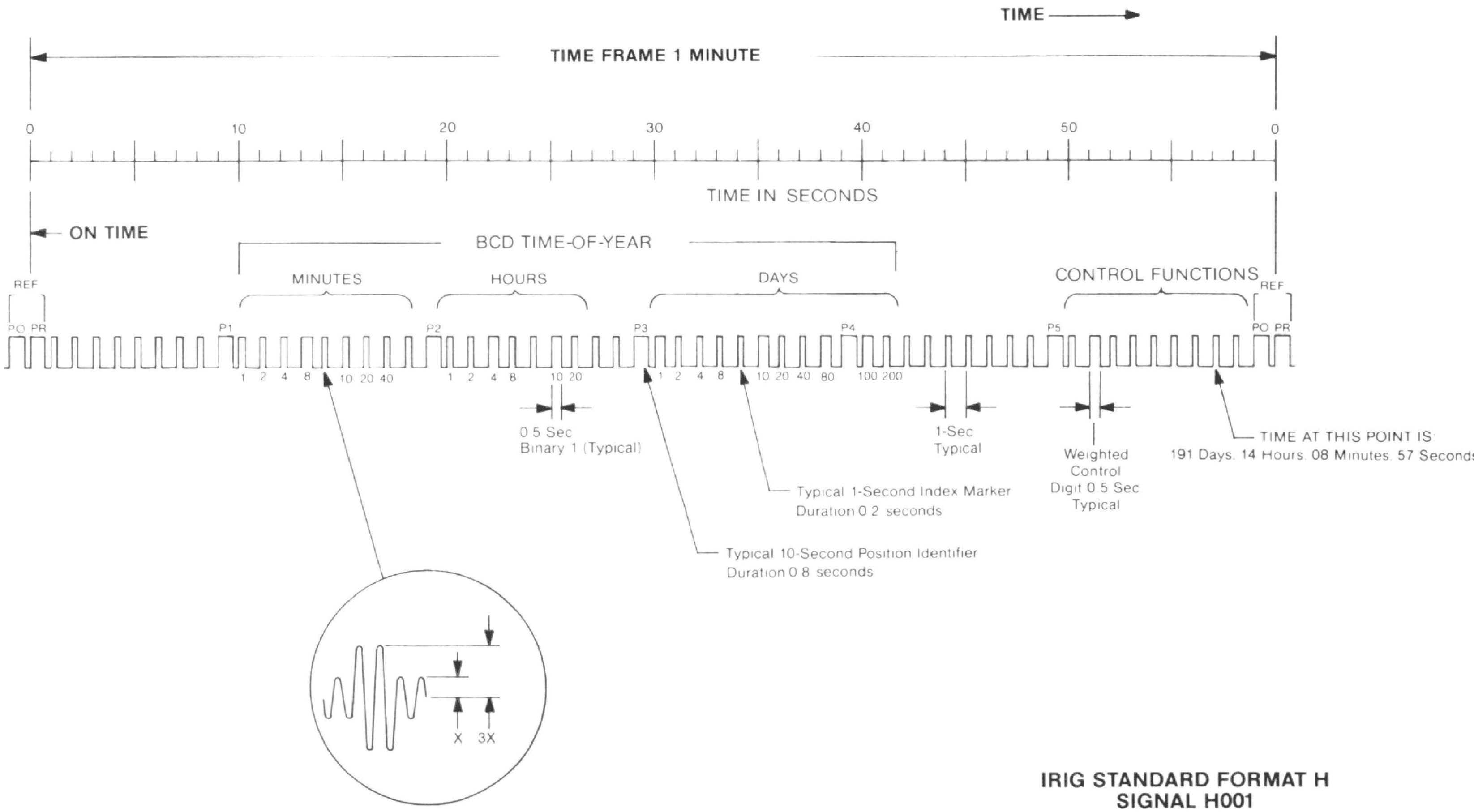


IRIG STANDARD FORMAT G
SIGNAL G001
10000 PPS CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'H' – GENERAL

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING:** BCD Time-of-Year CODE WORD — 23 binary digits. Minutes, hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD word begins at INDEX COUNT 10. Binary-Coded Elements occur between POSITION IDENTIFIER ELEMENTS (seven for minutes; six for hours; ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per second (basic Element Rate)
   b. 1 per ten seconds (POSITION IDENTIFIER Rate)
   c. 1 per minute (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.2 seconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 0.5 seconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.8 seconds
   e. REFERENCE MARKER: 1 per minute. Two consecutive POSITION IDENTIFIERS.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 1 second (unmodulated); 0.01 seconds (modulated 100 Hz); 0.001 seconds (modulated 1 kHz).
8. **CARRIER FREQUENCY:** 1 kHz or 100 Hz when modulated.



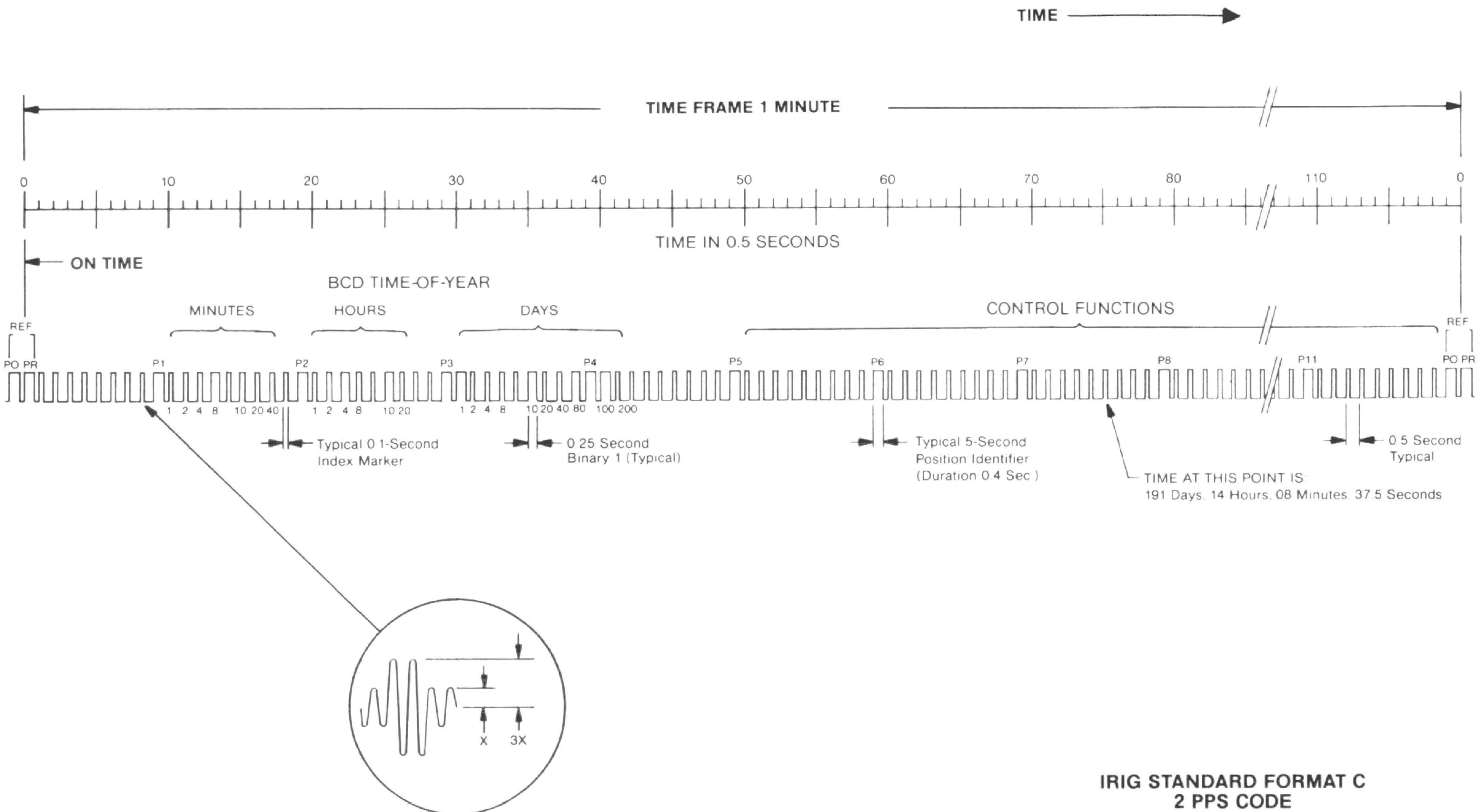
TYPICAL MODULATED CARRIER (100 Hz)

IRIG STANDARD FORMAT H
SIGNAL H001
1 PPS CODE
REFERENCE IRIG DOCUMENT 200-70

IRIG FORMAT 'C' — GENERAL (OBSOLETE) HISTORICAL

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING OPTIONS:** Binary Coded Decimal Time-of-Year CODE WORD only — 23 binary digits. Minutes, hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 10. Binary-coded Elements occur between POSITION IDENTIFIER Elements (seven for minutes; six for hours; ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 2 per second (basic Element rate)
   b. 1 per 5 seconds (POSITION IDENTIFIER Rate)
   c. 1 per minute (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: 0.1 seconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 0.25 seconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.4 seconds (Refers to the leading edge of the succeeding Element)
   e. REFERENCE MARKER: Two consecutive POSITION IDENTIFIERS.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 0.5 seconds (unmodulated); 0.01 seconds (modulated 100 Hz); 0.001 seconds (modulated 1000 Hz).
8. **CARRIER FREQUENCY:** 100 or 1000 Hz when modulated.



TYPICAL MODULATED CARRIER
(RECOMMENDED FREQUENCY 1000 Hz or 100 Hz)

IRIG STANDARD FORMAT C
2 PPS CODE
(DISCONTINUED)
REFERENCE IRIG DOCUMENT 104-60

NOTES

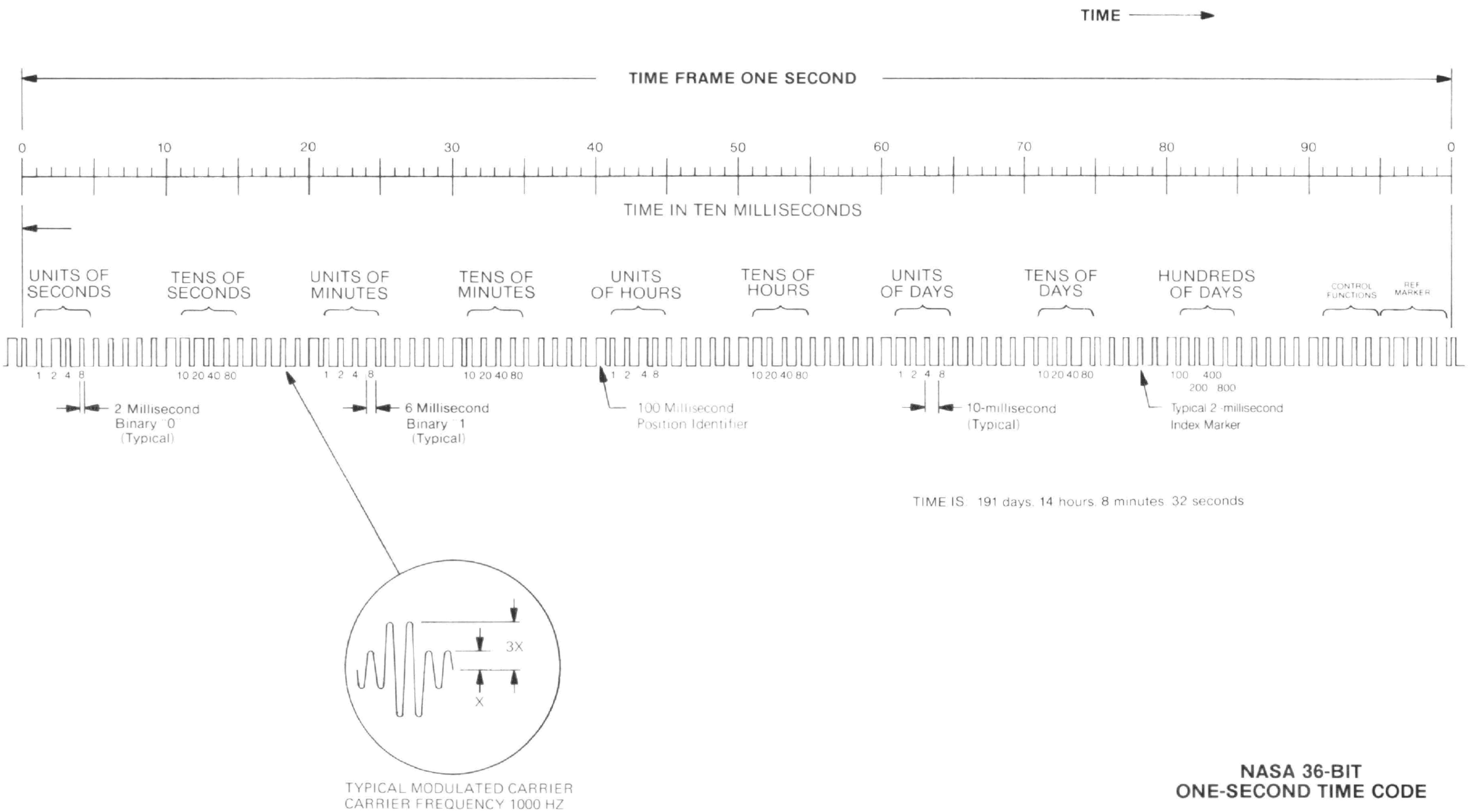
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TIME CODE FORMATS

NASA 36-BIT TIME CODE (GENERAL)
(NASA 1 SECOND BCD TIME CODE)

1. **TIME FRAME:** 1 second
2. **CODE DIGIT WEIGHTING:** Binary Coded Decimal Time-of-Year CODE WORD — 30 binary digits. Seconds, minutes, hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 1. Binary-Coded Elements occur between POSITION IDENTIFIER ELEMENTS in 4-digit groups until the CODE WORD is complete. A CODE DIGIT occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 100 per second (basic Element Rate)
   b. 1 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 2 milliseconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 6 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 6 milliseconds
   e. REFERENCE MARKER: Five consecutive POSITION IDENTIFIERS followed by an INDEX MARKER.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the INDEX MARKER following the four POSITION IDENTIFIERS.)
7. **RESOLUTION:** 10 milliseconds (unmodulated); 1 millisecond (modulated).
8. **CARRIER FREQUENCY:** 1 kHz when modulated.

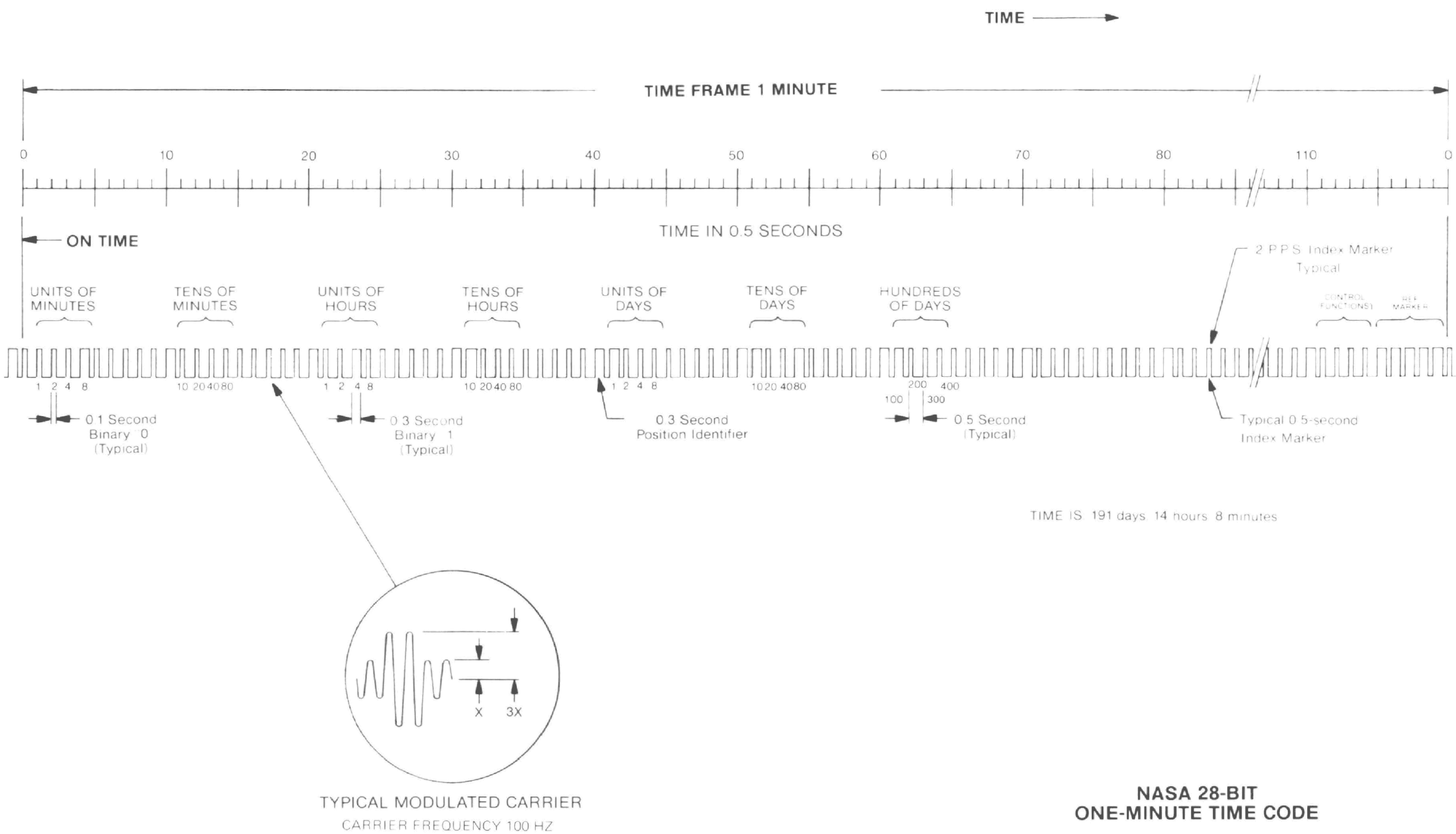


NASA 36-BIT ONE-SECOND TIME CODE

NASA 28-BIT TIME CODE (GENERAL)
(NASA 1 MINUTE BCD TIME CODE)

1. **TIME FRAME:** 1 minute.
2. **CODE DIGIT WEIGHTING:** Binary Coded Decimal Time-of-Year CODE WORD — 23 binary digits. Minutes, hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 1. Binary Coded Elements occur between POSITION IDENTIFIER ELEMENTS in four-digit groups until the CODE WORD is complete. A CODE DIGIT occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 2 per second (basic Element Rate)
   b. 1 per minute (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.1 second (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 0.3 second (Binary one)
   d. POSITION IDENTIFIER duration: 0.3 second
   e. REFERENCE MARKER: Five consecutive POSITION IDENTIFIERS followed by an INDEX MARKER.

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the INDEX MARKER following the four POSITION IDENTIFIERS.)
7. **RESOLUTION:** 0.5 second (unmodulated); 0.01 second (modulated 100 Hz); 0.001 second (modulated 1000 Hz).
8. **CARRIER FREQUENCY:** 100 Hz or 1000 Hz when modulated.

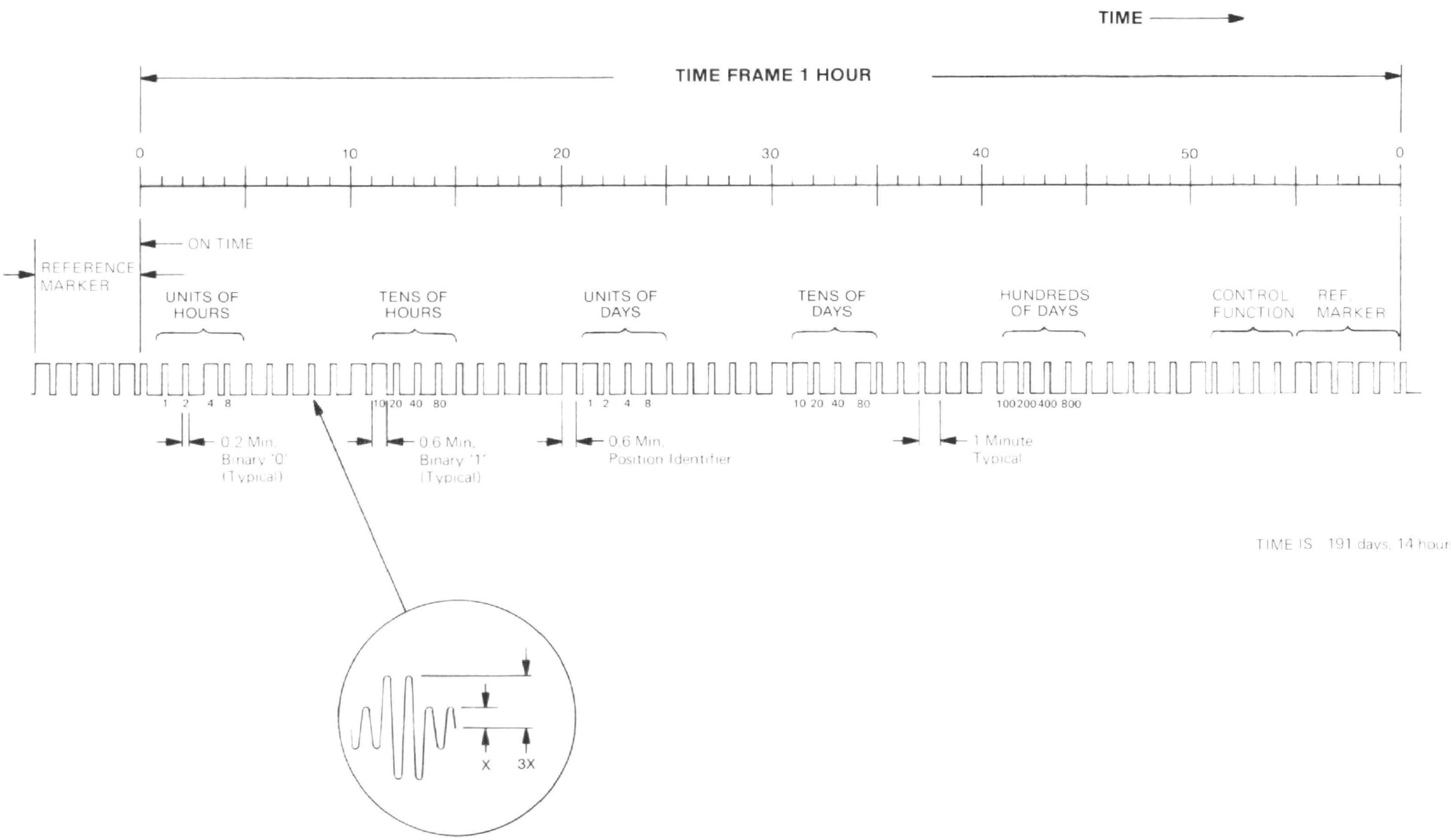


NASA 28-BIT
ONE-MINUTE TIME CODE

NASA 20-BIT TIME CODE (GENERAL)
(NASA 1-HOUR BCD TIME CODE)

1. **TIME FRAME:** 1 hour.
2. **CODE DIGIT WEIGHTING:** Binary Coded Decimal Time-of-Year CODE WORD — 16 binary digits. Hours and days; recycles yearly.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 1. Binary-coded elements occur between POSITION IDENTIFIER ELEMENTS in four-digit groups until the CODE WORD is complete. A CODE DIGIT occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per minute (basic Element Rate)
   b. 1 per hour (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.2 minutes (binary zero or uncoded Element).
   c. CODE DIGIT duration: 0.6 minutes (Binary One)
   d. POSITION IDENTIFIER duration: 0.6 minutes
   e. REFERENCE MARKER: Five consecutive POSITION IDENTIFIERS followed by an INDEX MARKER

   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the INDEX MARKER following the four POSITION IDENTIFIERS).
7. **RESOLUTION:** 1 minute (unmodulated); 10 milliseconds (modulated 100 Hz); 1 millisecond (modulated 1 kHz)
8. **CARRIER:** 100 Hz or 1 kHz when modulated.

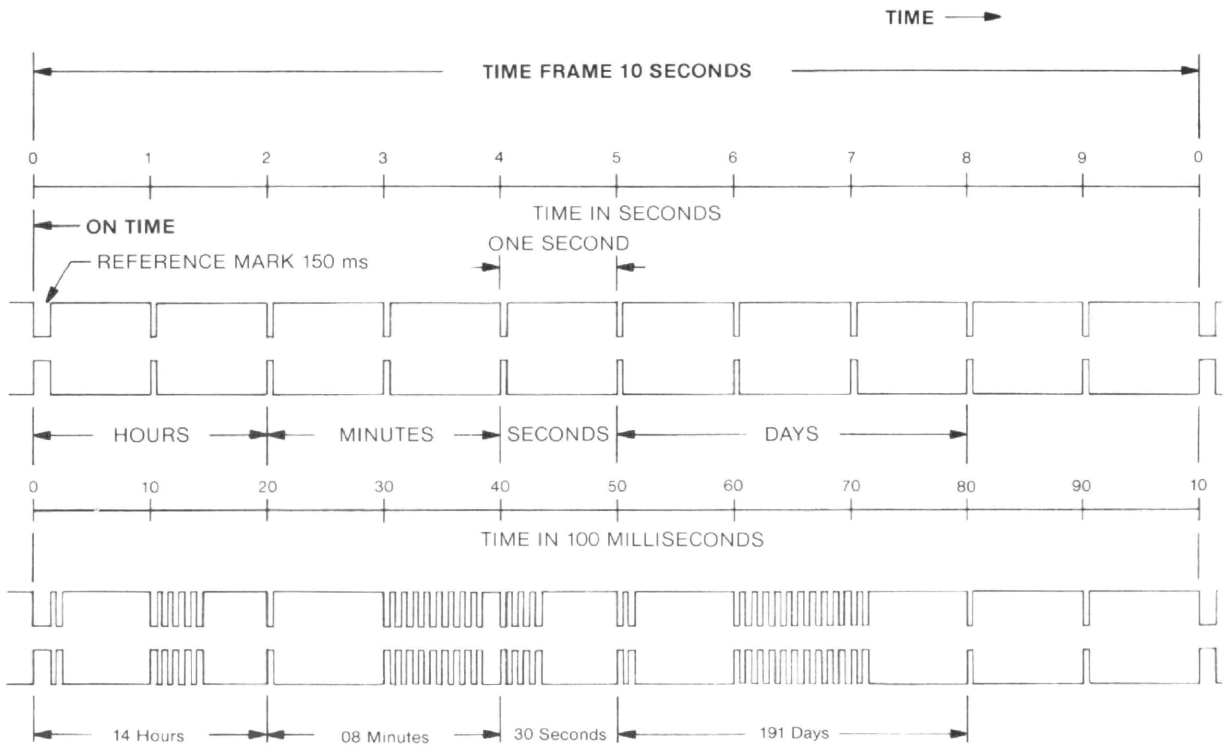


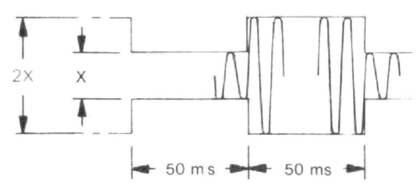
TYPICAL MODULATED CARRIER
(RECOMMENDED FREQUENCY: 100 Hz)

NASA 20-BIT
ONE-HOUR TIME CODE

NASA SERIAL DECIMAL — SUPPRESSED CARRIER (GEMINI)

1. **TIME FRAME:** 10 seconds
2. **CODE DIGIT WEIGHTING:** Decimal Time-of-Year CODE WORD. Decimal pulse-coded.
   a. Seconds, minutes, hours and days. A coded pulse is designated by 50 milliseconds of suppressed carrier.
3. **CODE WORD STRUCTURE:**
   a. DECIMAL: Word begins at INDEX COUNT 2. Decimal elements occur between POSITION IDENTIFIER ELEMENTS in nine-digit groups until CODE WORD is complete. A Code Digit (50 milliseconds of suppressed carrier) represents one decimal count and is added to accumulate the value of each CODE WORD. An INDEX MARKER occurs between code groups to provide separation for visual resolution.
4. **HOURS CODE WORD:** Occurs first, followed by minutes, seconds and days.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per second (POSITION IDENTIFIER Rate)
   b. 1 per 10 seconds (Frame Rate)
   All other rates are variable depending on code content.
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. CODE DIGIT duration: 50 milliseconds (decimal count of one)
   c. POSITION IDENTIFIER duration: 50 milliseconds
   d. REFERENCE MARKER duration: 150 milliseconds
   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the 150-millisecond reference occurring at 1 per 10 seconds).
7. **RESOLUTION:** 1 second (POSITION IDENTIFIER); 10 second (Frame Rate); 1 millisecond (Modulated).
8. **CARRIER:** 1 kHz



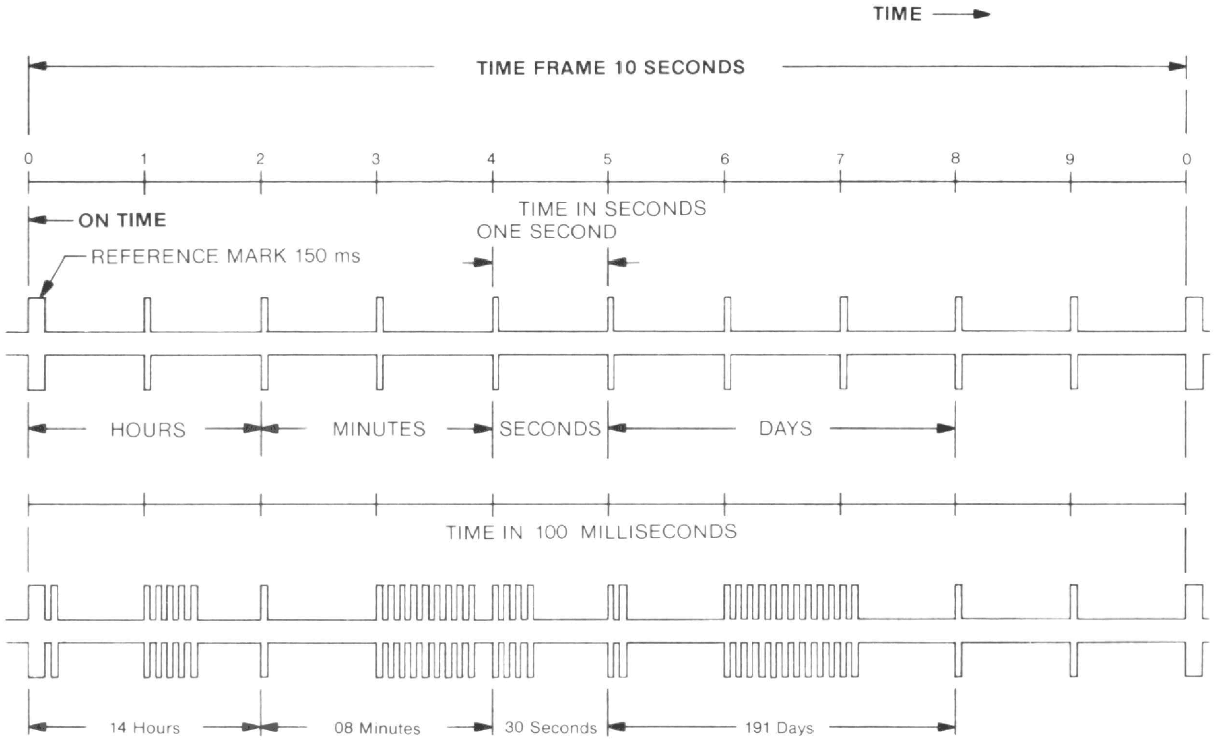


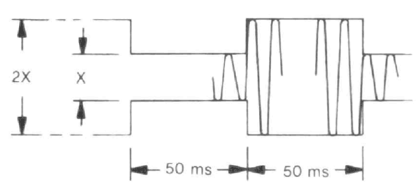
TYPICAL MODULATED CARRIER 1000 HZ

NASA SERIAL DECIMAL CODE
— SUPPRESSED CARRIER —
(Gemini)

NASA SERIAL DECIMAL — EXALTED CARRIER (APOLLO)

The Exalted Carrier form of NASA serial decimal Time Code is exactly equal to the Suppressed Carrier format. The only difference lies in the method of modulating the 1000 Hz sinewave.





TYPICAL MODULATED CARRIER (1000 Hz)

NASA SERIAL DECIMAL CODE
– EXALTED CARRIER –
(Apollo)

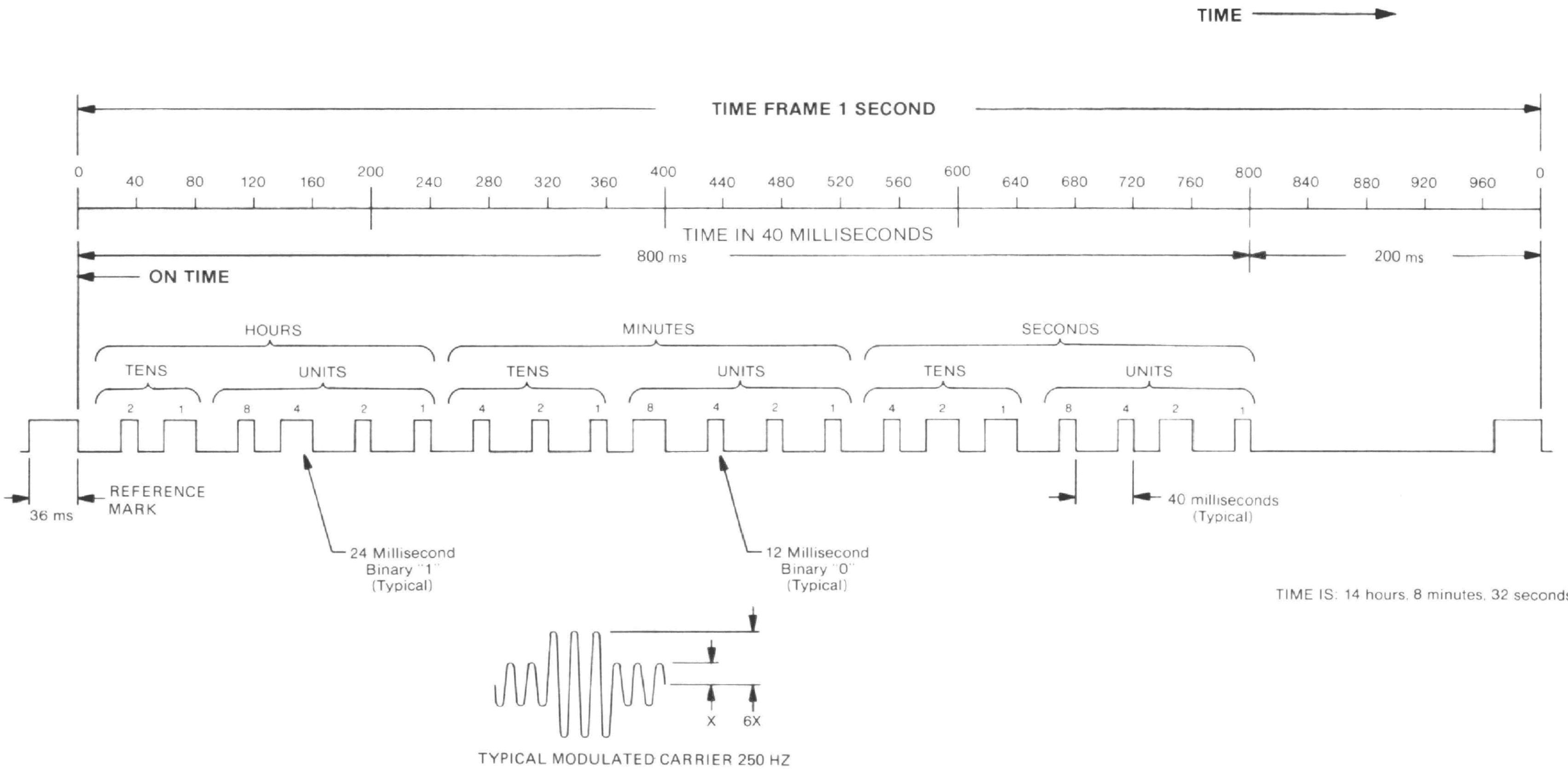
NOTES

OTHER COMMONLY USED TIME CODE FORMATS

25 PPS — ONE SECOND — 250 Hz
XR3 FORMAT

1. **TIME FRAME:** 1 second
2. **CODE DIGIT WEIGHTING:** BCD: Time-of-Day CODE WORD — 20 binary digits.
   a. Hours, minutes, seconds. Recycles every 24 hours.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 1. Binary-coded Elements occur consecutively (six for hours, seven for minutes, seven for seconds) until the CODE WORD is complete.
4. **MOST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 25 per second (basic Element rate). (Four consecutive pulses missing at end of frame)
   b. 1 per second (Frame rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its trailing edge.
   b. Binary zero duration: 12 milliseconds
   c. CODE DIGIT duration: 24 milliseconds (Binary one)
   d. REFERENCE MARKER — 1 per second Duration: 36 milliseconds

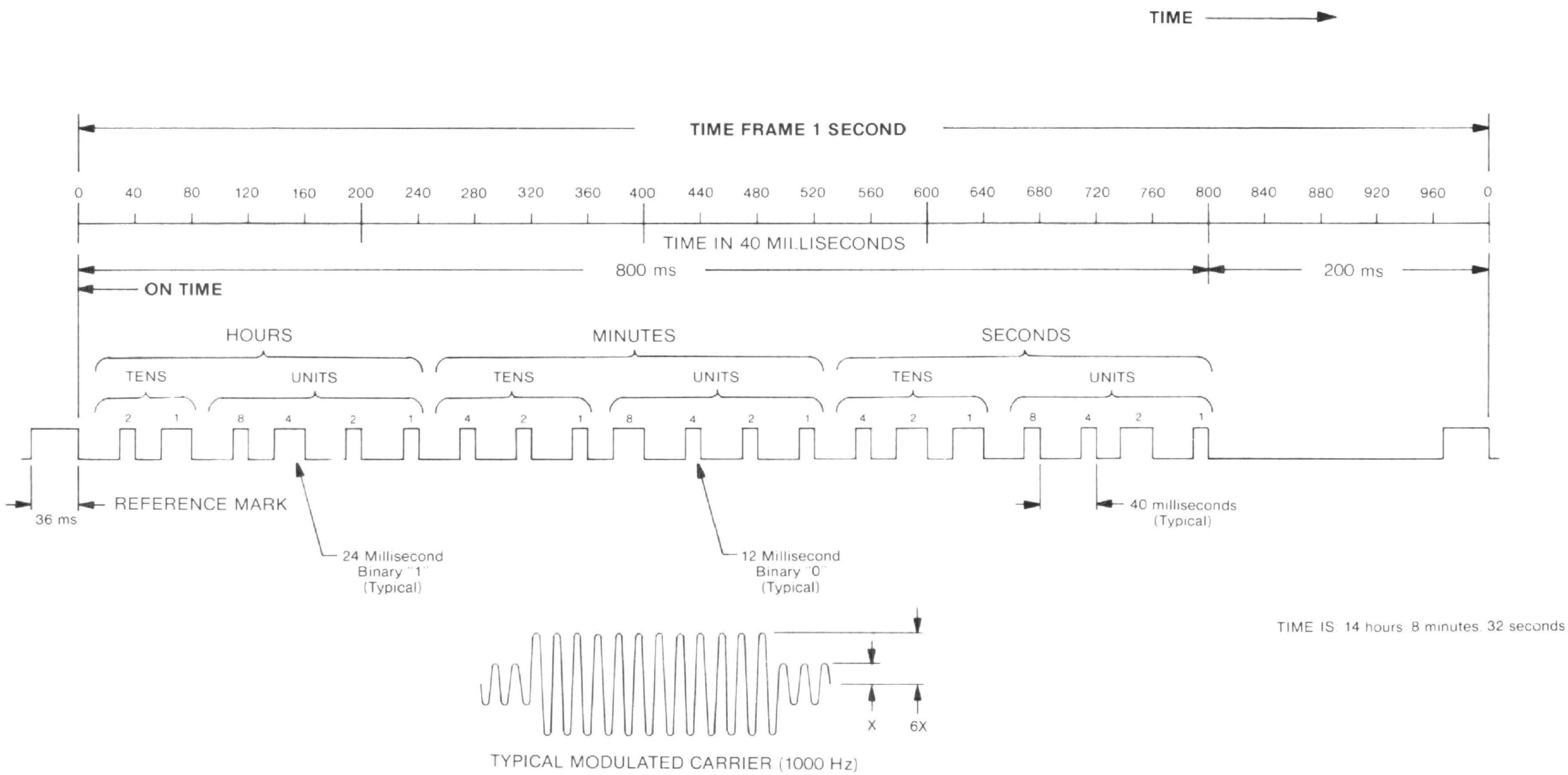
   (The "On-Time" point, to which the CODE WORD refers, is the trailing edge of the REFERENCE MARKER).
7. **RESOLUTION:** 1 second (Frame Rate) (unmodulated). 40 milliseconds during CODE WORD only. 4 milliseconds (modulated).
8. **CARRIER FREQUENCY:** 250 Hz.



25 PPS — ONE SECOND TIME CODE (250 Hz - XR3)

2137 FORMAT

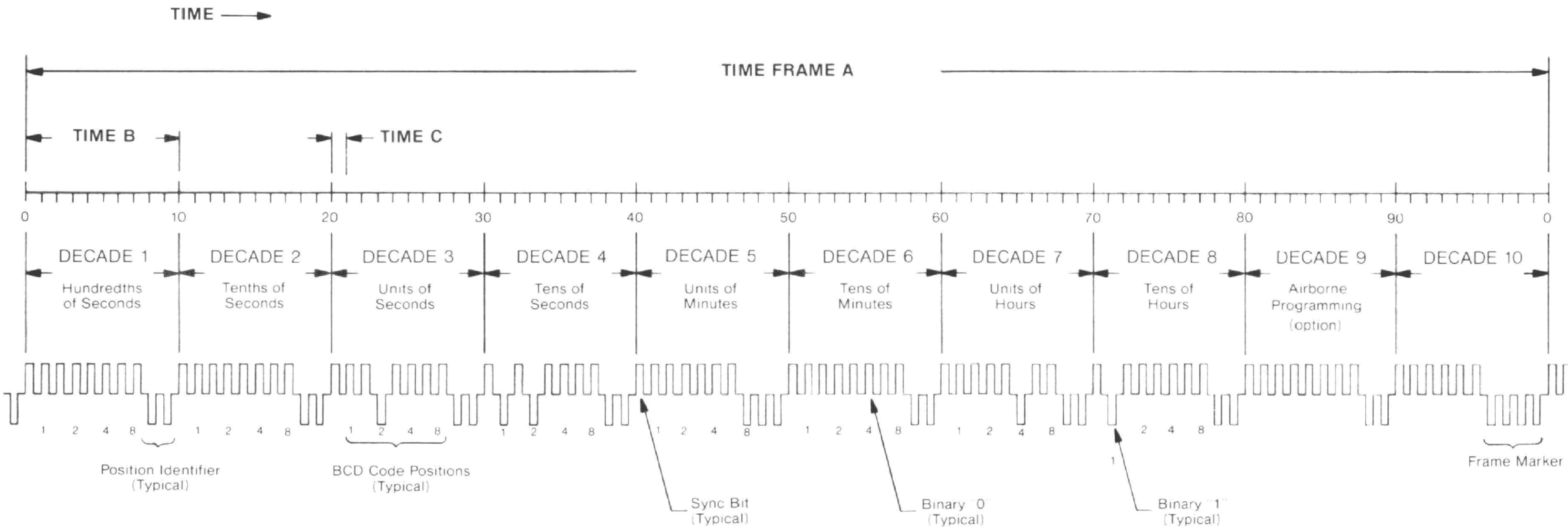
The 2137 Format is exactly the same as the XR3 Format. The 2137 Format modulates a 1000 Hz carrier, thus provides a 1 millisecond resolution.



25 PPS — ONE SECOND TIME CODE (1000 Hz - 2137)

FEDERAL AVIATION ADMINISTRATION — NAFEC TIME CODES

1. **TIME FRAME:** Any of five from 10 seconds to 50 milliseconds.
2. **CODE DIGIT WEIGHTING:** Binary Coded Decimal Time-of-Day CODE WORD: from 30 binary digits (50-ms TF) to 18 binary digits (10-second TF).
   a. 0.01 seconds, 0.1 seconds, seconds, minutes and hours; recycles every 24 hours.
3. **CODE WORD STRUCTURE:**
   a. BCD word begins at INDEX COUNT 1. Binary-coded elements occur between POSITION IDENTIFIER ELEMENTS until the CODE WORD is complete. An INDEX MARKER occurs between each BCD digit and between each Decimal Group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   Variable from 10 per second (10-second Frame Rate) to 2000 per second (50-ms Frame Rate).
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: Variable from 50 milliseconds (10-second Frame) to 250 microseconds (50 ms Frame).
      INDEX MARKER is always positive amplitude (binary zero uncoded Element or Sync Mark).
   c. CODE DIGIT duration: Variable from 50 ms (10-second Frame) to 250 microseconds (50 ms Frame).
      CODE DIGIT is always negative amplitude (binary one).
   d. POSITION IDENTIFIER — same duration as INDEX MARKER — Position Identifier is always two Index Markers and negative in amplitude.
   e. REFERENCE MARKER — four consecutive binary ones followed by an INDEX MARKER (binary zero).
      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the INDEX MARKER following the four consecutive ones).
7. **RESOLUTION:** From 100 milliseconds (10 second Frame) to 500 microseconds (50 millisecond Frame).
8. **CARRIER:** Normally not Carrier modulated.



Time Code Frame Rate	TIME		
	A	B	C
1F/10 SEC	10 SEC	1 SEC	100 MS
1F/SEC	1 SEC	100 MS	10 MS
5F/SEC	200 MS	20 MS	2 MS
10F/SEC	100 MS	10 MS	1 MS
20F/SEC	50 MS	5 MS	500 μs

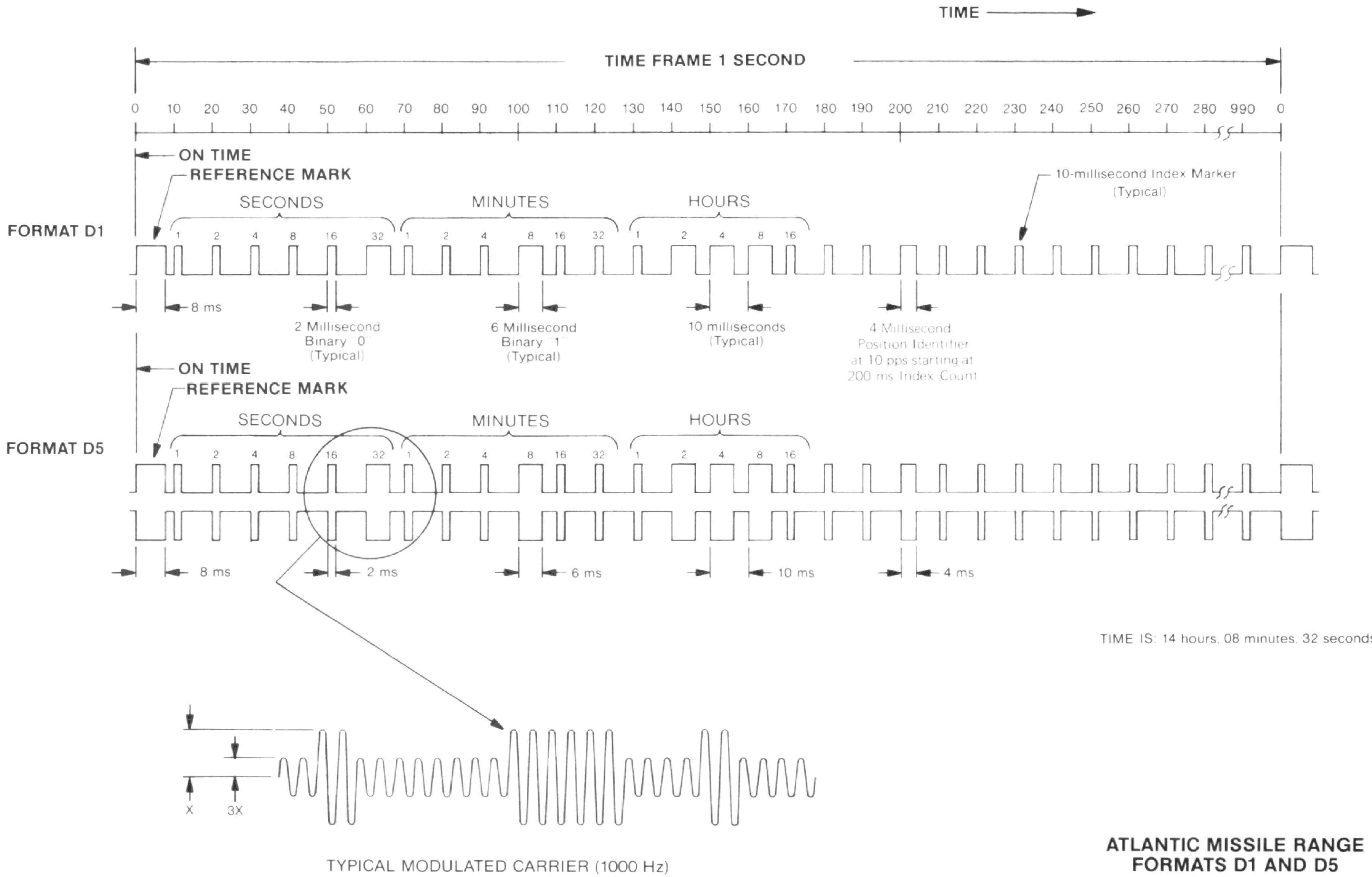
TIME IS: 14 hours, 08 minutes, 32.00 seconds

FEDERAL AVIATION AGENCY
NAFEC TIME CODE

ATLANTIC MISSILE RANGE
FORMAT D1/D5

1. **TIME FRAME:** 1 second
2. **CODE DIGIT WEIGHTING:** Grouped Binary Time-of-Day CODE WORD — 17 binary digits.
   a. Seconds, minutes and hours. Recycles every 24 hours.
3. **CODE WORD STRUCTURE:**
   a. Binary word begins at INDEX COUNT 1. Grouped binary elements occur (six for seconds, six for minutes, five for hours) until the CODE WORD is complete.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 100 per second (basic Element rate)
   b. 10 per second (INDEX MARKER)
   c. 1 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration: (100 PPS); 2 milliseconds (Binary zero or uncoded Element)
   c. INDEX MARKER duration: (10 PPS); 4 milliseconds
   d. CODE DIGIT duration: 6 milliseconds (Binary one)
   e. REFERENCE MARKER duration: 8 milliseconds

   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the REFERENCE MARKER).
7. **RESOLUTION:** 10 milliseconds (unmodulated); 1 millisecond (modulated 1 kHz); D5 code
8. **CARRIER FREQUENCY:** 1 kHz — Code designation changed to D5.



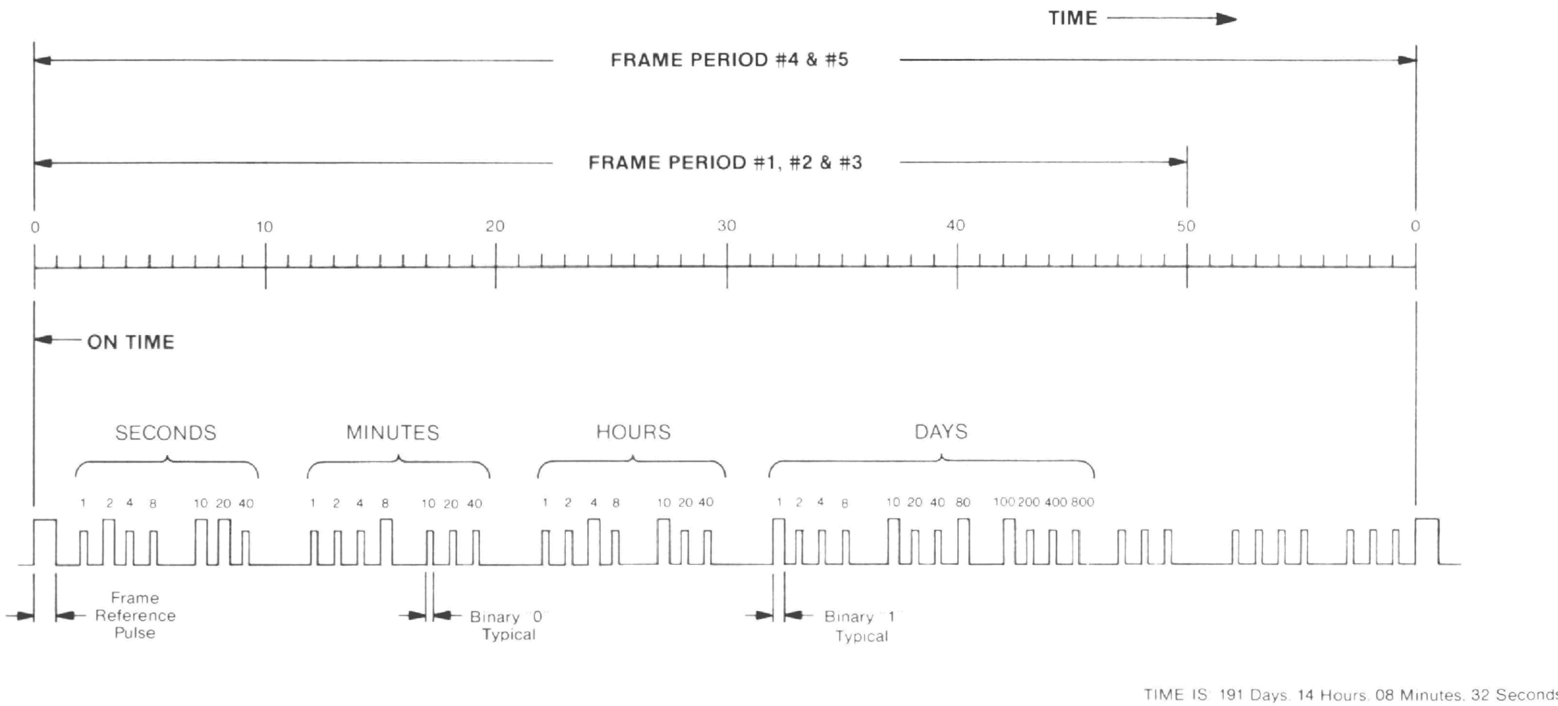
ATLANTIC MISSILE RANGE FORMATS D1 AND D5

DATUM BI-LEVEL SLOW-CODE (5-Rate Selectable)

The DATUM special Bi-Level Slow-Code is designed to provide a convenient and efficient TIME REFERENCE for strip charts and oscillograph records. Five different and unique codes are provided to enable selection of the desired resolution consistent with the paper speed.

The CODE is width modulated, BCD Format. Amplitude modulation is also added to aid in the separation of the coded information.

Each Code Group is separated by a space to aid in fast recognition of the coded data without loss of resolution or inclusion of extraneous pulses. Coded information represents Time-of-Year in seconds, minutes, hours and days.



CODE	Pulse Rate	Frame Period	Binary Zero	Binary One	Frame Ref Pulse
1	50 pps	1 Sec.	4 ms	10 ms	20 ms
2	10 pps	5 Sec.	20 ms	50 ms	100 ms
3	5 pps	10 Sec.	40 ms	100 ms	200 ms
4	1 pps	60 Sec.	200 ms	500 ms	1000 ms
5	1 p/10s	10 Min.	2 sec	5 sec	10 sec

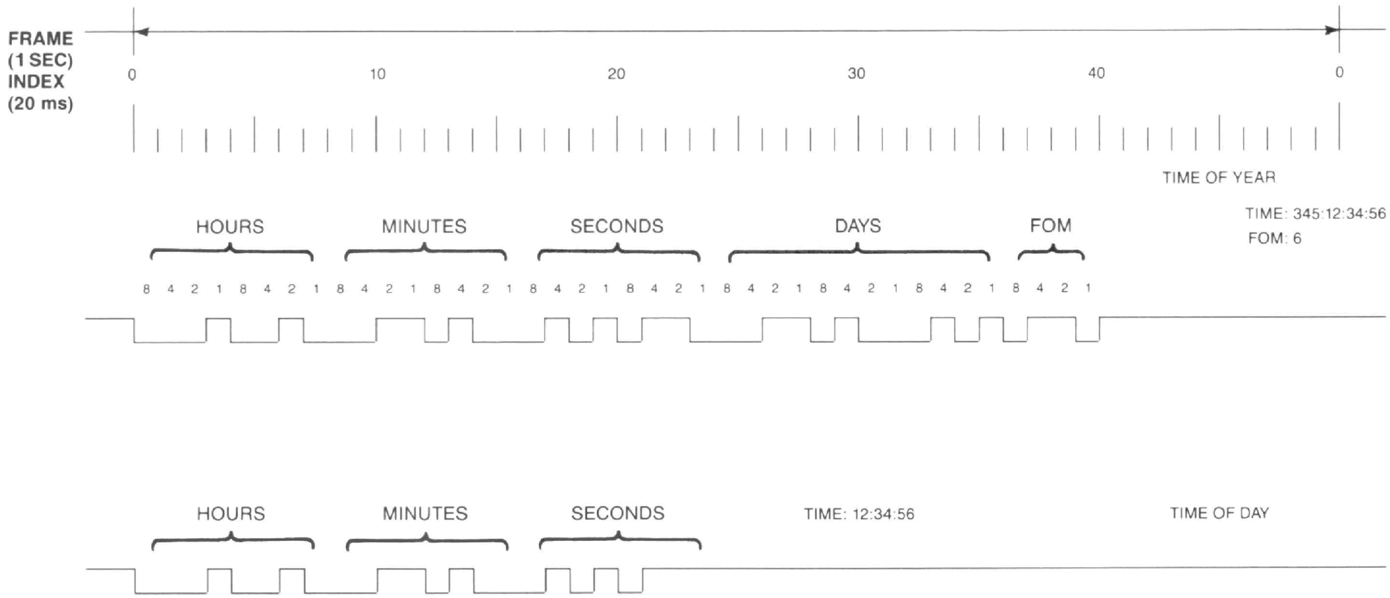
DATUM INC.
BI-LEVEL — 5-RATE
SLOW CODE

48-BIT TIME OF YEAR
BINARY CODED DECIMAL (BCD) CODE

1. TIME FRAME: 1 second
2. CODE DIGIT WEIGHTING: Binary coded decimal time-of-year code word - 48 binary digits. Days, hours, minutes and seconds, FOM; recycles annually.
3. CODE WORD STRUCTURE: BCD. Word begins at index 0. Binary coded elements occur in four-digit groups until the code word is complete.
4. MOST SIGNIFICANT DIGIT: Occurs first
5. INDEX PERIOD: 20 milliseconds

24-BIT TIME OF DAY
BINARY CODED DECIMAL (BCD) CODE

1. TIME FRAME: 1 second
2. CODE DIGIT WEIGHTING: Binary coded decimal time-of-day code word - 24 binary digits. Hours, minutes and seconds; recycles daily.
3. CODE WORD STRUCTURE: BCD. Word begins at index 0. Binary coded elements occur in four-digit groups until the code word is complete.
4. MOST SIGNIFICANT DIGIT: Occurs first
5. INDEX PERIOD: 20 milliseconds



Signal in accordance with MIL-STD-188-100
Balanced Low Level Digital Interface Requirements

Binary Coded Decimal Formats
40 Bit Time of Year
24 Bit Time of Day

NOTES

U.S. STANDARD TIME BROADCAST FORMATS

UNITED STATES STANDARD BROADCAST

GENERAL

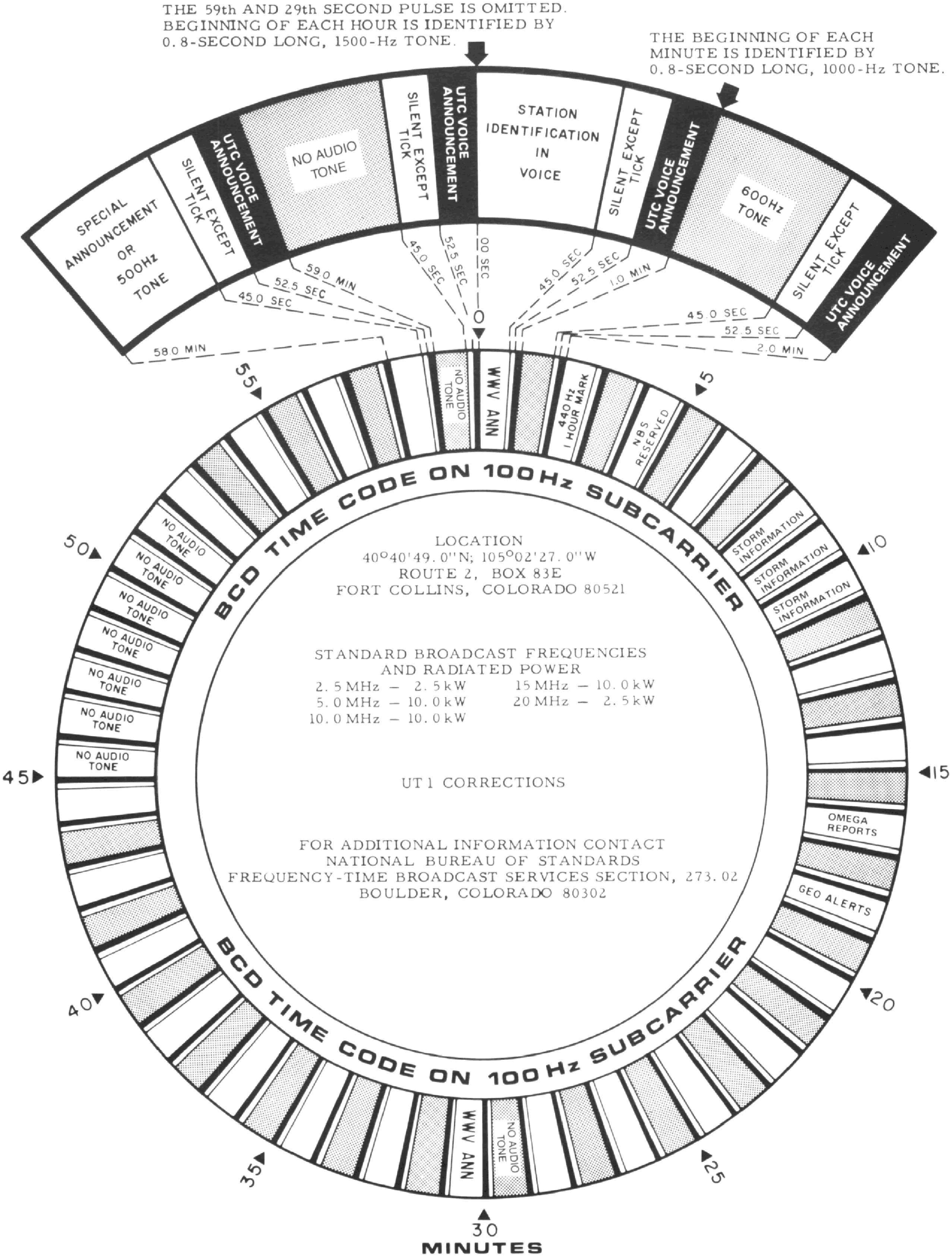
The National Bureau of Standards maintains three radio stations whose function it is to transmit standard time broadcasts for laboratories and individual users throughout the world. Radio stations WWV and WWVH are high frequency broadcast stations on carrier frequencies of: 2.5 MHz, 5 MHz, 10 MHz and 20 MHz. WWV additionally broadcasts on 25 MHz (see Appendix 'A'). In addition to the two high-frequency radio stations, Radio Station WWVB broadcasts serial time codes at a 60 kHz transmission carrier for accurate frequency measurements within the continental United States.

Radio Stations WWV and WWVH have, in addition to serial Time Codes, voice time announcements and special voice announcements as required, as well as various tone signals. A precise one-second "tick" is also broadcast by both WWV and WWVH for audio determination of Epoch and period time synchronization.

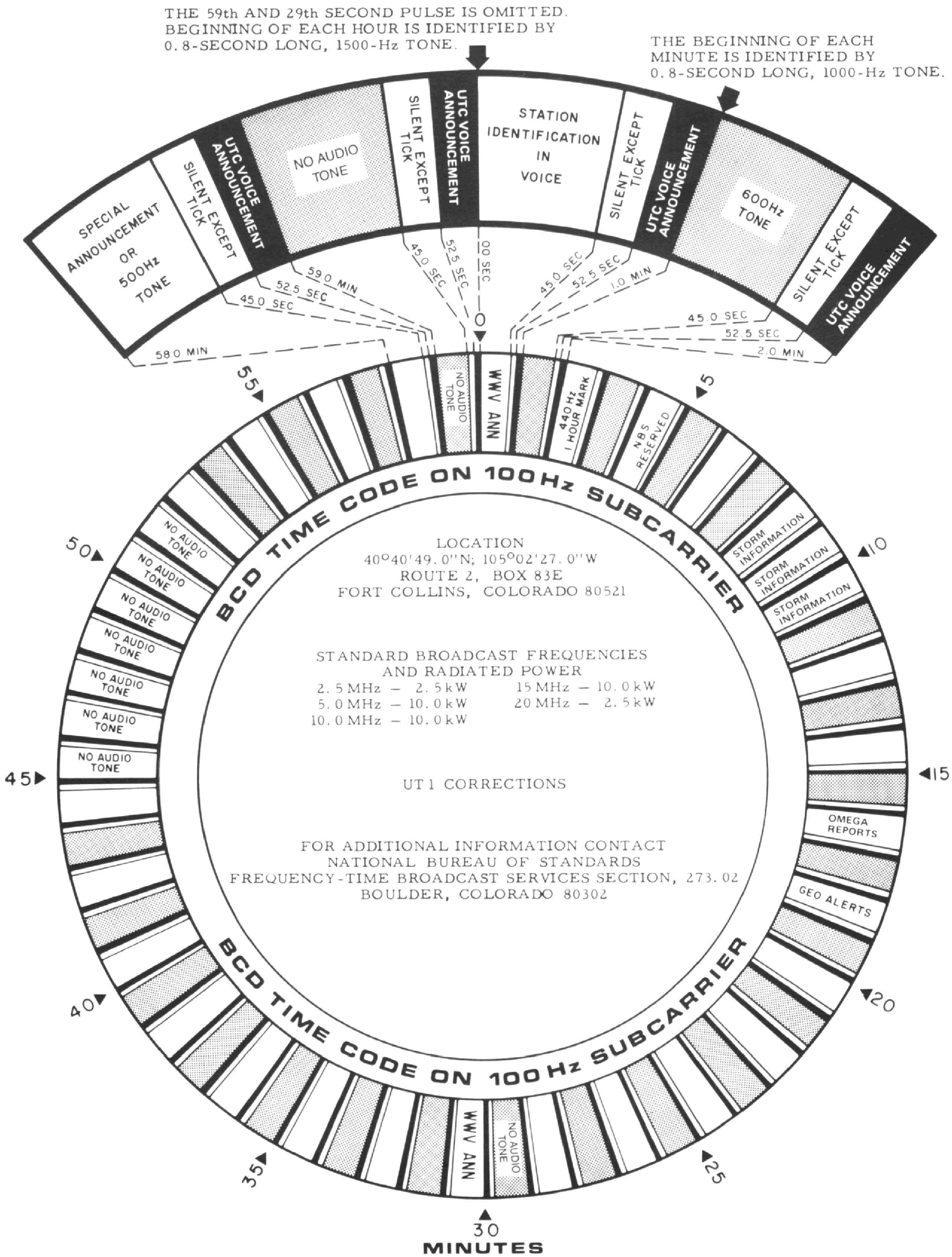
The time being broadcast by WWV, WWVH and WWVB is Universal Time Coordinated (see Appendix 'B') and is maintained to the internationally-agreed time by one-second corrections. Further, the code formats provided by each station provide coded information to enable determination of Universal Time (UTI).

The serial time codes (as part of the radio transmissions) are shown and described on the following pages. Additional information regarding the broadcasts, as well as definitions and user data, is available in Appendix 'B' of this Handbook and available from the National Bureau of Standards, Frequency-Broadcast Services Station 273.02, Boulder, Colorado 80302.

WWV BROADCAST FORMAT (TYPICAL)



WWV BROADCAST FORMAT (TYPICAL)

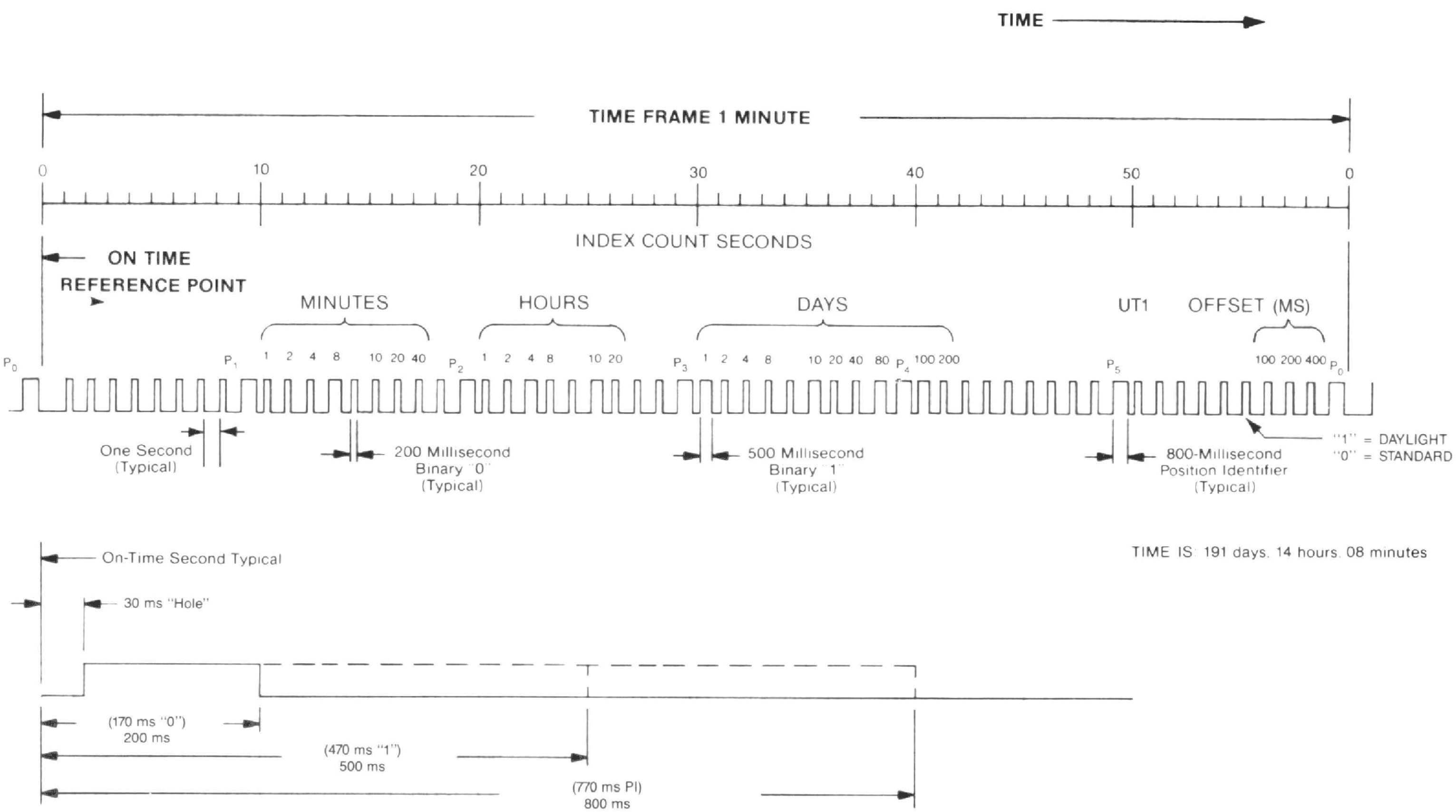


datum inc

WWV/WWVH TIME FORMAT

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING:** BCD Time-of-Year CODE WORD — 30 binary digits.
   a. Minutes, hours, days and UT correction. 0.01 seconds, 0.1 seconds.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 10 + 30 milliseconds. Binary-coded Elements occur between POSITION IDENTIFIER ELEMENTS (seven for minutes, six for hours, ten for days, seven for UT correction) until the CODE WORD is complete. POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** (Minutes) occurs first — UT correction occurs after days.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per second (basic ELEMENT rate)
   b. 1 per 10 seconds (POSITION IDENTIFIER Rate)
   c. 1 per minute (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is 30 milliseconds before the element.
   b. INDEX MARKER duration: 170 milliseconds (Binary zero or uncoded element)
   c. CODE DIGIT duration: 470 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 770 milliseconds
   e. REFERENCE MARKER — 1 per minute. One POSITION IDENTIFIER followed by a missing digit position.

   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of an imaginary (missing) POSITION IDENTIFIER following a POSITION IDENTIFIER).
7. **RESOLUTION:** 1 second (unmodulated); 0.01 second (modulated 100 Hz) (theoretical)
8. **CARRIER:** 100 Hz — 100% modulation
9. **TIME SCALE:** Universal Time Coordinated with coded correction to UT1.



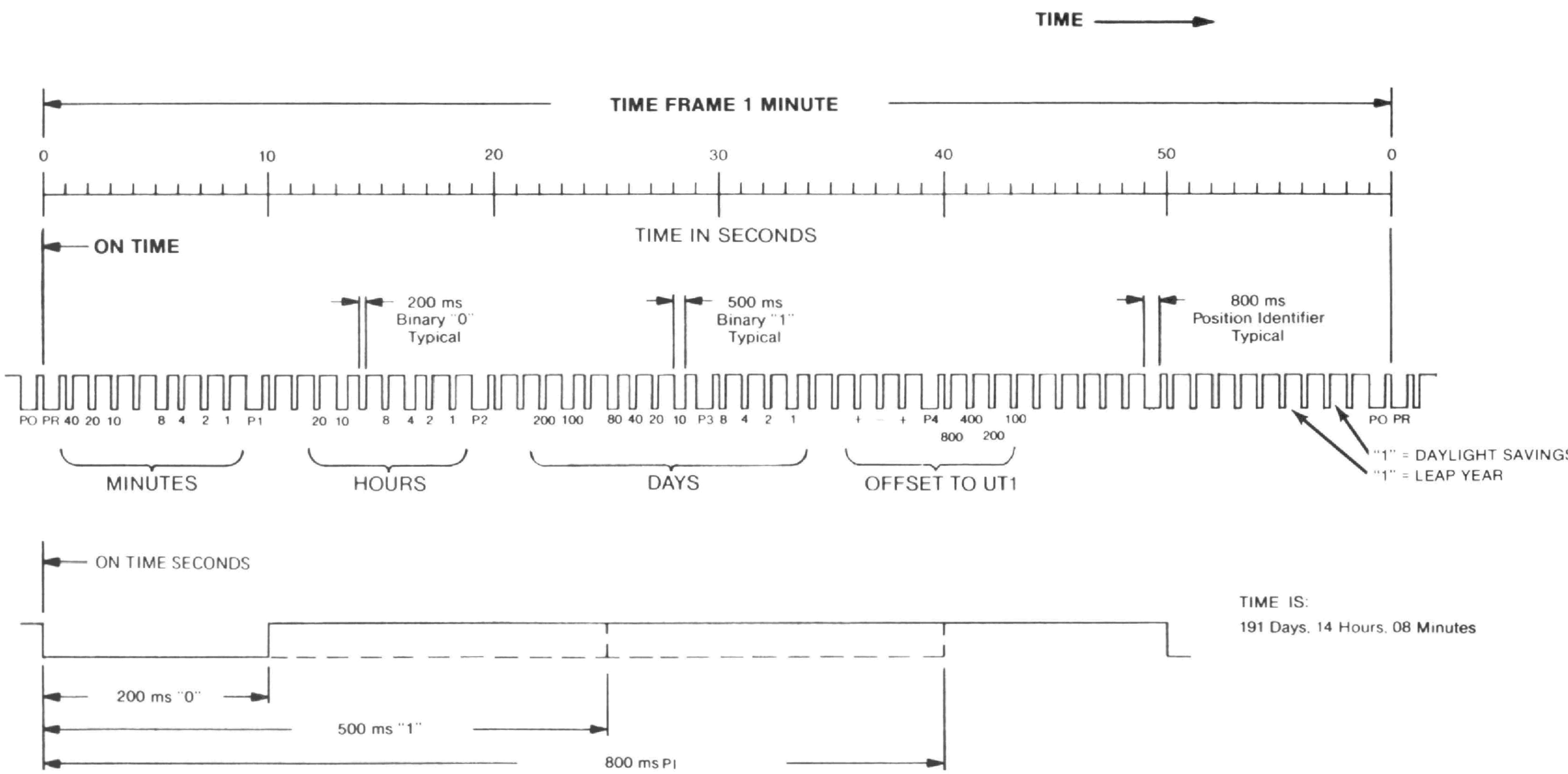
MODULATION: 100 Hz AT 100% MODULATION

NATIONAL BUREAU OF STANDARDS
WWV/WWVH
Standard Time Code Envelope

WWVB TIME FORMAT

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING:** BCD Time-of-Year CODE WORD — 35 binary digits.
   a. Minutes, hours, days, UT correction 0.1 seconds, 0.01 seconds, 0.001 seconds.
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 1. Binary coded elements occur between POSITION IDENTIFIER ELEMENTS (seven for minutes, six for hours, ten for days, 4 for UT corrected) till the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** (Minutes) occurs first — UT correction occurs after days.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per second (Basic Element Rate)
   b. 1 per 10 seconds (POSITION IDENTIFIER Rate)
   c. 1 per minute (Frame rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.2 seconds (Binary zero or uncoded element)
   c. CODE DIGIT duration: 0.5 seconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.8 seconds
   e. REFERENCE MARKER — 1 per minute. Two consecutive POSITION IDENTIFIERS

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER).
7. **RESOLUTION:** 1 second (unmodulated)
8. **CARRIER:** 60 kH_Z (1:10 modulation ratio) suppressed carrier.
9. **TIME SCALE:** Universal Time Coordinated with coded correction to UT1.



LEAP YEAR SET 1 JAN – 28 FEB
DAYLIGHT SET DURING DAY PRIOR TO GMT-5HR OF CHANGE.

NATIONAL BUREAU OF STANDARDS
WWVB TIME CODE
ONE-PPS CODE ENVELOPE

NOTES

APPENDICES

NOTES

APPENDIX 'A'
TIME DETERMINATION

1.0 INTRODUCTION

With the exception of the carrier and format coherency and the pulse-to-pulse precision of the individual format involved, the various Time Code Formats referenced and described in this Handbook are independent of the time scale or of accuracy. Achieving the desired results from the timing device depends upon the precision of the clock providing the timing signals and upon its maintenance.

Much has been written on the theoretical and practical requirements and limitations of synchronizing widely separated clocks.

2.0 ELEMENTS OF TIME PRECISION

Three basic elements are required to set and maintain time precision. First, "epoch" time is the time of year in seconds, minutes, hours and days to be presented by the timing device. Next, a consistent time interval, usually one second, must be determined in order to place the timing device in synchronism with the Master System. Thirdly, the rate of time generation, e.g., frequency, must be compared and correlated to ensure that the timing-device time-scale will remain in correspondence, within the precision requirements of the system, to master time.

3.0 METHODS OF SYNCHRONIZATION

There are many ways of synchronizing widely separated clocks to one another. However, two basic approaches provide the fundamental methods of synchronizing to world or universal time. The greatest precision is obtained by transporting a portable clock to each station requiring synchronization. This allows the determination of epoch and period and calibration of time scales. The precision, of course, depends upon the complexity and sophistication of the portable clock and the distance between the timing stations to be synchronized.

A less complex and less accurate method uses the standard time broadcast maintained by the National Bureau of Standards: WWV, WWVH or WWVB. In actuality to perform all three determinations, both high-frequency and very low frequency transmission, or an equivalent means, must be established. In practice, the high frequency broadcasts give sufficient precision to determine epoch and calibration but do not provide sufficient precision for determination of period. This is due to uncertainties of the high frequency broadcast brought about by variation in atmospheric conditions, climate, distance, etc. The use of VLF transmissions provide a more accurate means of frequency comparison. since the same variables are either non-existent or have minimum effect on the reception and determination of the calibrating frequency.

An excellent and considerably more detailed source for synchronization techniques and equipment can be found in the Hewlett-Packard publication, Application Note No. 52. Research into IEEE papers and time and frequency publications available from the National Bureau of Standards will give further information.

4.0 CALIBRATION AND MAINTENANCE OF FREQUENCY SOURCE

The use of high frequency broadcast or local Master Station provides a ready means of determining period and epoch for synchronization of the timing device. A more complex problem, however, exists in calibrating and maintaining the frequency source that is used to develop the basic time-scale used for the timing device.

First, a determination as to the desired scale must be made, be it universal time, atomic time, stepped atomic time, or universal time coordinated (refer to Appendix 'B').

The basic frequency source of the timing device must be calibrated to the desired time-scale, which will then determine the quantitative development of the epoch value of time over the desired period of operation. Typical frequency sources for timing devices are derived by Quartz oscillators. The configuration of these Quartz oscillators determines their precision and accuracy per unit time. The variation of these frequency sources results in an offset from the absolute time scale selected, which is termed "time error." The time scale or frequency source must then be periodically recalibrated and the timing device reset to maintain the desired minimum time error with respect to the master synchronizing source.

The equation for total time error is:

$$E = E_o + \left(\frac{f_o}{f_r} - 1\right) t + \frac{at^2}{2}$$

This indicates that the total time error at any time t depends upon four variables. Where E_O is the initial time error, f_O is the initial frequency setting; f_r is the reference frequency setting; a is the oscillator aging rate and t is elapsed time. Figure 1 shows a plot of this equation whereby the time error results in a parabola. It should be noted that the frequency change of the oscillator is assumed to be linear in an ever increasing value. A negative slope of the frequency change would invert the parabola. Figure 2 shows the effect of various frequency variations on the time error.

It can be seen then that the time error of a timing device increases exponentially as the frequency of the oscillator drifts. If an oscillator is set precisely to coincide with the Master oscillator, offset is zero and the total time error will be a result only of the aging of the oscillator. The offset of the oscillator will vary the time error on a linear basis as shown in Figure 2.

The Nomograph on the following page can be used as an aid to estimate the time error accumulated over a period of time due to aging and due to offset. In accordance with the equation, these two values should be added to determine the total error of any individual condition. By examining Figure 2 it can be seen that by setting the oscillator consistent with the direction of drift, one can extend the operating period for any given maximum error desired.

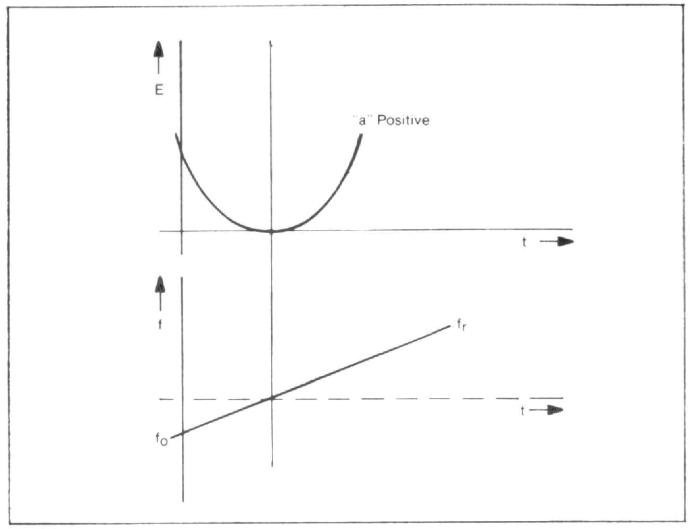


FIGURE 1

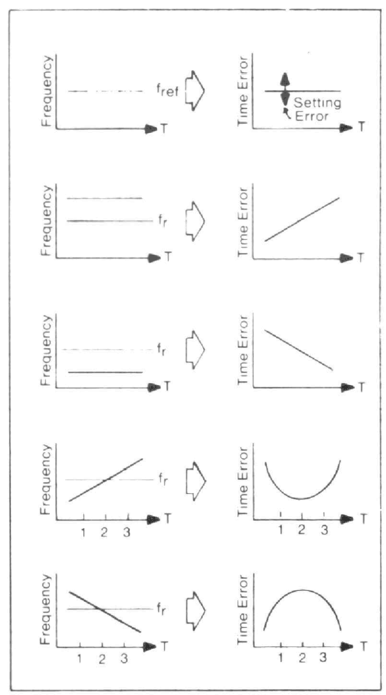
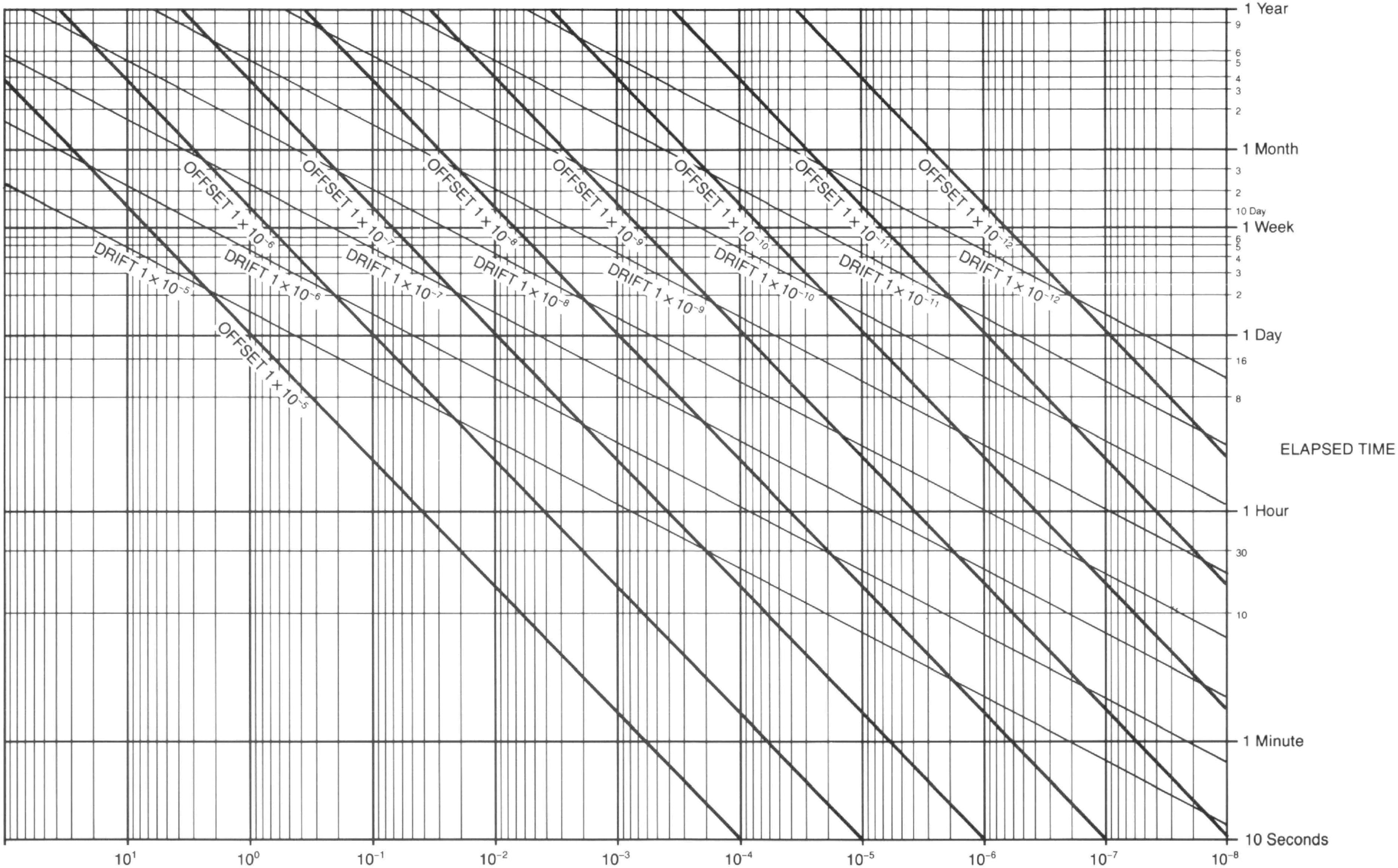


FIGURE 2

ACCUMULATED TIME ERROR VERSUS ELAPSED TIME



ACCUMULATED TIME ERROR—SECONDS

NOTES

APPENDIX 'B'
TIME

1.0 INTRODUCTION

The Time Code Formats provided by the particular timing device are independent of the time scale and of the precision of any particular device or system. Over the years there have been many time scales utilized and defined; some have been revised and discarded as more accurate methods of time determination have been conceived. Others have been redefined and consolidated in order to reduce the confusion and, hopefully, make the determination of time, e.g., the second and its accumulation, a more useable and understandable quantity.

Presently the majority of the time scales are either derived from or related to the atomic second. The atomic second is defined specifically by a hyperfine transition of the atom of cesium-133. This is defined as the duration of 9,192,631,770 oscillations.

With respect to human endeavors, the most logical and most widespread definition of time comes from the relationship of the earth to the sun, to the moon and to the stars. This relates to man's desire to eat lunch at 12 noon, go to sleep at night and arise in the morning. More complicated, however, are the requirements for accurate astronomical experiments and, therefore, the need for an invariant reference so that meaningful predictions can be made of celestial happenings related to measurable time on earth.

The purpose of this Appendix is to list and briefly define the various time scales; a more comprehensive discussion can be obtained from the Hewlett-Packard publication, Application Note No. 52, as well as other technical and historical publications.

2.0 SOLAR TIME

Solar Time represents the early efforts of man to establish a time scale related to the position of the earth with respect to the sun at uniform intervals. This served the needs of mankind until increased precision of astronomical observations indicated that the earth's rotation was not uniform; that its speed was not constant. Therefore, the relationship of the earth to the sun caused a continuous variation of the second and thus the accumulation of time.

3.0 AVERAGE SOLAR TIME

An attempt was made to develop a coherent non-variable second by averaging the variations due to the orbital uncertainty of the earth's axis. A mean solar second was thus determined to be a mean solar day divided by 86,400. This was still not adequate due to the non-uniformity of the earth's rotation and required an adjustment of approximately one day every four years.

4.0 UNIVERSAL TIME

Because of the need for a uniform time scale throughout the world, Universal Time was defined and based on the rotation of the earth about its axis as with mean Solar Time. Universal Time was developed on the assumption that the earth's rotation was constant and it was chosen so that local noon would occur when the sun was on the local meridian. Basic Universal Time is equivalent to mean Solar Time and is identified as UT0. UT1 and UT2 provide corrections to basic Universal Time to compensate for the rotational uncertainties of the earth and to accommodate seasonal changes. Until recent years, the most widely-used scale was UT2. This time scale was in use at the majority of the nation's missile ranges and tracking facilities. UT2 was maintained and defined by the U.S. Naval Observatory and broadcast worldwide on NBS radio stations WWV and WWVH. In January of 1972, both standard broadcasts converted to the UTC time scale which may be corrected to UT1.

5.0 SIDEREAL TIME

The Sidereal second is determined from the Sidereal day which is strictly defined by observation of the earth with respect to the stars. A Sidereal day is approximately 23 hours, 56 minutes and 4.09 seconds referenced to a mean Solar day. A Solar Year will contain 366.24 Sidereal days. Sidereal time is used by some astronomy researchers for celestial experiments.

6.0 MEAN SIDEREAL TIME

As in the case of mean Solar Time, mean Sidereal Time is an adjustment of Sidereal Time to compensate for the nodding or nutation of the earth's axis.

7.0 EPHEMERIS TIME

The uncertainty of the rotation of the earth on its axis, even when all possible corrections have been made, does not provide an invariable standard. The need for uniform time has lead astronomers to define the Ephemeris second. Ephemeris time is based on the motion of the earth about the sun and is obtained from observations of the motion of the moon about the earth. The International Committee of Weights and Measures defines the Ephemeris second for January 0, 1900 at 12 hours Ephemeris time. The accumulation of time due to the Ephemeris second would result if the sun continued in its apparent instantaneous rate, but corrected for orbital eccentricity and nutation of the earth's axis. It thus appears to be an invariable unit of time for astronomical purposes.

Obviously, the difficulty of making precise measurements of the position of the moon, except over extremely long periods of time, causes the ultimate delay in determination of the Ephemeris second and its degree of accuracy.

8.0 ATOMIC TIME

As discussed earlier, Atomic Time is based on the hyperfine oscillations of the cesium atom. Atomic Time appears to be gaining popularity as the Universal Time interval to be used for the majority of timing requirements. The frequency used to transmit WWVB is derived from the atomic frequency standard, as is the time broadcast by Radio Stations WWV and WWVH. At the present time these time scales are corrected on an internationally-agreed-upon basis, but there appears to be serious discussion suggesting the abandonment of the Universal Time and a move to maintain total compliance to the atomic second.

9.0 UNIVERSAL TIME COORDINATED (UTC)

Universal Time Coordinated is an internationally-agreed-upon time scale as defined by the International Time Bureau (BIH).

Prior to January 1972, the UTC time scale was offset, minus 300 parts in 10^{-10}, from the internationally-defined atomic frequency. This gave rise then to the term "stepped atomic time," which related to time developed by the Atomic Frequency Standard but which was corrected on a periodic basis to agree with Universal Time.

Time presently being broadcast by WWV, WWVH and WWVB is UTC stepped in one-second increments as necessary to agree with UTC as determined by the International Time Bureau (BIH). The frequency used to accumulate UTC is the atomic scale.

Historically, the National Bureau of Standards has been charged with defining and regulating the atomic frequency standard. The U.S. Naval Observatory has been charged with maintaining Universal Time (UT2). In 1968, it was mutually agreed that UTC (USNO) and UTC (NBS) would be coordinated starting at OOUT on 1 October 1968. At that time the frequency standard at USNO was adjusted to coordinate with the UTC time scale.

10.0 U S TIME STANDARD

The U S Time Standard differs from nominal Universal Time (Greenwich Mean Time) by an integral number of hours. This time is kept by the United States Naval Observatory Master Clock and is now coordinated with the Universal Time Coordinated of the National Bureau of Standards.

11.0 TIME ZONES

The United States is divided into four standard time zones separated by an integral number of hours earlier than Greenwich Mean Time. Greenwich Mean Time is defined as Universal Time. Eastern Standard Time is 5 hours earlier, Central Standard Time is 6 hours earlier, Mountain Standard Time is 7 hours earlier and Pacific Standard Time is 8 hours earlier. There are 24 world time zones, each based on longitude. By international agreement, Greenwich, England is the site of the prime meridian at zero degrees longitude.

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