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UNIFIED S-BAND DATA HANDLING SYSTEM

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SUMMARY

The data handling portion of the Unified S-Band tracking system consists of three readily separable subsystems. These are: a) the Timing System, b) the Antenna Position Programmer, and c) the Tracking Data Processor. Each of these subsystems is briefly described below.

Apollo Timing Subsystem

The Apollo Timing Subsystem accepts inputs from a standard frequency oscillator employing an atomic reference standard and derives from the frequency standard all the time signals required at an S-Band tracking facility. The subsystem employs two identical time standards plus common time conversion and signal distribution circuitry; also included is a time calibration facility employing a WWV receiver and a VLF receiver.

Each time standard accepts two identical and redundant one mc input signals and divides the frequency down to one pulse per second using BCD dividers. Provisions are provided at 100KPPS to adjust the pulse timing to within 0.1 μsec of a desired value, and all frequencies generated below 100 kc are phase coherent.

The one pulse per second signal is then divided, to make BCD time available for a period of up to one year. The BCD time of year out of this portion of the time standard is then used to drive visual displays and to provide time of year information for time code generators. The outputs of either of the two time standards can be selected by means of a simple switch driving many logic gates to provide the switch over function.

The circuitry, fed redundantly by the two time standards, includes a BCD to binary converter, a status clock, a special frequency generator, propagation delay generator, and miscellaneous circuitry for signal distribution.

The BCD to binary converter accepts BCD time of year information from a time standard and generates the binary second, hundreds of milliseconds, and millisecond of the year on six different sets of outputs.

The status clock provides outputs to visual displays that present count-down information before beginning a mission program and elapsed time information after beginning a mission program. The duration of any "holds" that occur during the count down are also provided by displays driven from the Status Clock.

The special frequency generator is used to develop all special pulse trains not normally available from the time standard's divider chains. For example, a number of special square waves with frequencies from 600 PPS to 2400 PPS are required as a time base synchronizing signal for the data transmission equipment used in conjunction with the Tracking Data Processor.

The propagation delay generator provides a means for simulating the propagation time required for a WWV signal to traverse the path from the transmitter to local receiver. It provides delays adjustable over the range of ten microseconds through one second in ten microsecond increments.

Special circuits are provided to enable a standard to be calibrated from the 1 kc tone bursts available on WWV carrier frequency. Other related circuits are provided to enable the two time standards to be synchronized with each other after one of them has been calibrated with WWV. Complete facilities are included in the subsystem for self-calibration and maintenance.

Antenna Position Programmer

The Antenna Position Programmer provides antenna steering signals for an X-Y type antenna by comparing the actual antenna position with a predetermined (command) input, and providing an analog output proportional to their difference.

Actual antenna position is determined through the use of 17 bit + sign shaft position encoders, for both the X and Y angles. Command angles are obtained from three sources: tape, computer, and manual. The tape mode utilizes the precomputed orbital parameters transmitted to the tracking site. Real time from the Timing System and the tape time are compared and the tape is controlled so as to maintain time synchronism. Computer input is provided by an on-site computer and is formatted identically with the tape data input.

Both the computer and the tape data are incremented by dividing successive command samples by ten (in the 1 sample/second mode) or by 100 (in the 1 sample/10 second mode), and adding via an accumulator the command increment each 100 ms to the command angle used during the previous 100 ms. Additionally, the command data may be modified by the use of the manual entry digit switches. These switches may be used in an "offset" mode whereby the value set into the switches is added to the tape or computer data. Alternately, the digit switches may be used exclusively as the command data source. This mode of operation is defined as manual.

A cycle of system operation includes:

1. Sampling the real angles.
2. Converting the real angles from binary to 8421 BCD.
3. Sampling the command angle and adding the command increment.
4. Modifying the command angle with offset and "stored error" data.
5. Computing the difference between the command and real angles and providing an analog output signal whose magnitude is 1 volt per degree error.

The "stored error" data mentioned in (4) above is obtained while the system is in the auto-track mode (that is, control of the antenna by the tracking receivers). In this mode the command data is compared with the actual antenna position and any difference (i.e., discrepancy) stored for use during the next period of program mode operation. The stored error may be selected at any time during auto-track by the system operator or it is automatically selected as the last sample when the system switches from Auto to Program.

Tracking Data Processor

The Tracking Data Processor (TDP) accepts data from the ranging system, the shaft angle encoding system and the timing system. It processes this data, adds station identification and status information and arranges it a High Speed Data

Format and a Low Speed Data Format. The High Speed data is a serial output provided to a modem (at a selectable rate of 600, 1200, 2000 or 2400 bits per second) and a magnetic tape recorder. The Low Speed data is converted from binary or Binary Coded Decimal to serial Baudot and provided to a teletype communication link, a page printer, and a computer.

The TDP is classified as either a Single System or a Dual System. The Single System displays and transmits range and the range rate (Doppler) information from only one vehicle. The Dual System displays and transmits range and range rate information from two vehicles in the high speed and low speed data outputs by alternately transmitting the data from each vehicle.

Various other features of the TDP include the following:

1. It processes the range rate information at a selectable rate in a selectable count destruct or non-destruct mode.
2. The TDP generates an error detection code (consisting of 12 bits) using polynomial division techniques and inserts the code at the end of each frame of high speed data.
3. It provides the capability of rearranging and manually controlling the high speed data format.
4. The TDP provides the capability to recover the data stored on magnetic tape for post "real-time" transmission to the modem.
5. It provides a test mode of operation to check out its major internal functions.

INTRODUCTION

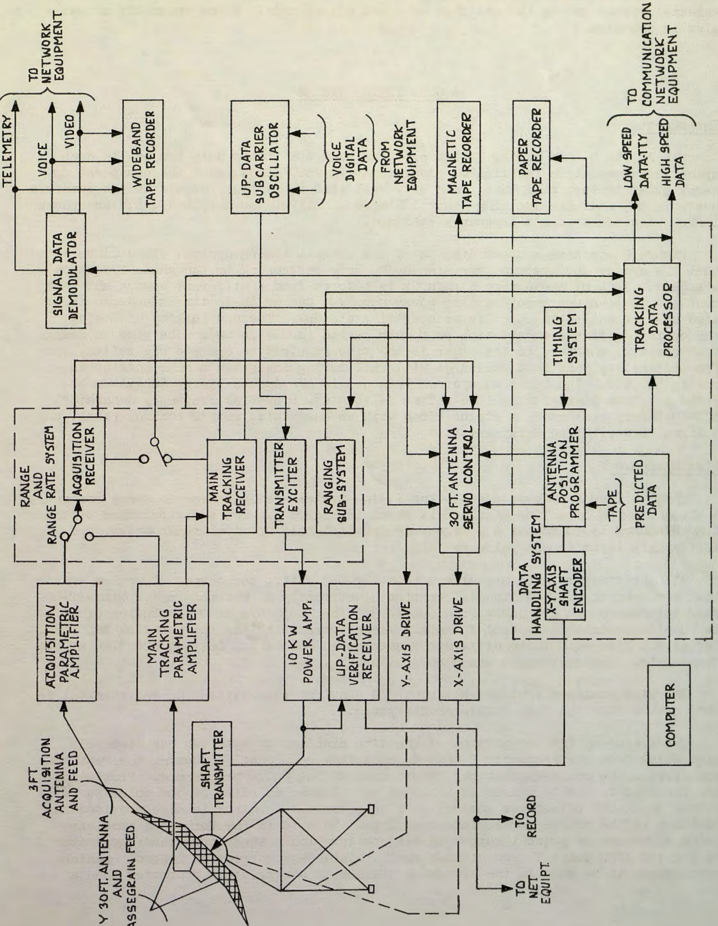
The Unified S-Band System, sponsored by Goddard Space Flight Center, is planned to provide tracking and communications for the lunar phase of the Apollo missions. This will require the use of three (3) 85-foot antenna facilities. Several additional facilities (using 30-foot antennas) will be required for system evaluation and to support other phases of the mission. In addition to the range, range rate, and angle measurements, the Unified S-Band System also provides for the transmission of voice and data to and from the spacecraft. The Range and Range Rate Receiver Subsystems were provided by the Jet Propulsion Laboratory.

A Unified S-Band ground station (Figure 1) consists of a 30- foot antenna, Cassegrain feeds, diplexer, acquisition system, parametric amplifier, receiver, transmitter, ranging equipment, subcarrier oscillators, data demodulator, a Timing System, Antenna Programmer and Tracking Data Processor. The last three items comprise the subject of this paper and are grouped together as the Unified S-Band Data Handling System. The system concept and detailed performance specifications were prepared by the Goddard Space Flight Center.

The Timing System provides the real time data required by the various subsystems throughout the station. Time information is supplied in parallel binary and BCD time-of-year form, in various time codes, and as a variety of timing pulse trains. This system is driven by an atomic frequency standard (GFE) with a stability of two parts in 10^{11}.

The Antenna Position Programmer provides positioning signals to the tracking antenna by comparing desired (command) and actual positions and generating an error signal proportional to the difference. Provision is included for several sources of command data and a variety of control modes.

The Tracking Data Processor assembles and pre-processes all pertinent tracking



BASIC UNIFIED S-BAND STATION

data prior to transmission to the central processing facility. Data is prepared for transmission at various data rates up to 2400 bits per second by assembly in a selected format and by the addition of a polynomial code. A low speed TTY output also is provided.

APOLLO TIMING SYSTEM

Introduction

The Apollo S-Band Timing System provides accurate timing data for use in deep space instrumentation facilities. Approximately 2500 lines leave the equipment to carry pulse trains, sine waves, and universal time in various formats to the numerous users in and near the Tracking Control Station. All of the output signals are phase locked with the system's frequency standard.

Figure 2 contains a block diagram of the overall timing system. It will be noted that the system employs two time standards, both referenced to the basic frequency standard. Each of these time standards is powered from a different source and each contains its own emergency battery power supply. One of these time standards is used on-line while the other is an operating standby. The possibility of losing the operating time standard with an 8 hour period is one in 667. The time to change from one time standard to the other is the time required to operate one switch, and the probability that both standards will fail during any given 8 hour mission is one in 500,000. The basic subsystems included in the Apollo Timing Subsystem besides the Time Standards include a Time Calibrator, a Special Frequency Generator, BCD-to-Binary Converter, a Status Clock with an associated remote control panel, and a Signal Distribution Subsystem.

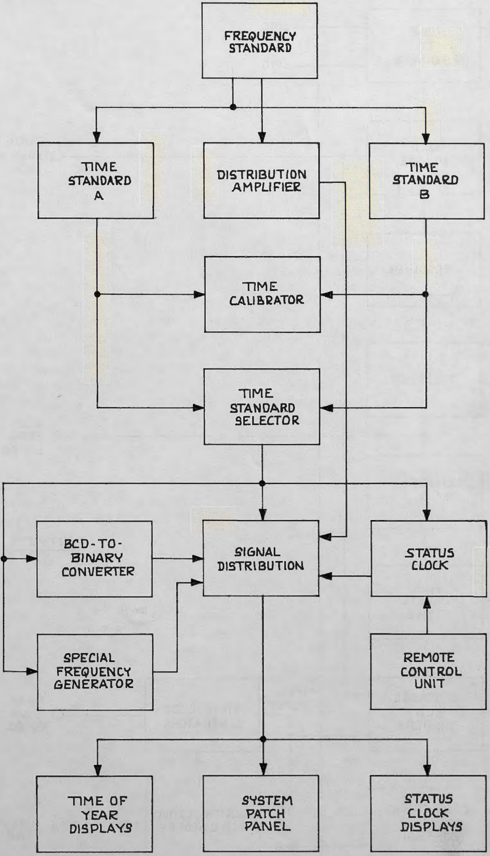
Time Standard

The two Time Standards used in the Timing System are identical in every respect. A block diagram of a Time Standard is shown in Figure 3. The basic function of the Time Standard is to accept a 1 megacycle input signal, provided redundantly, and divide this input to one pulse per day.

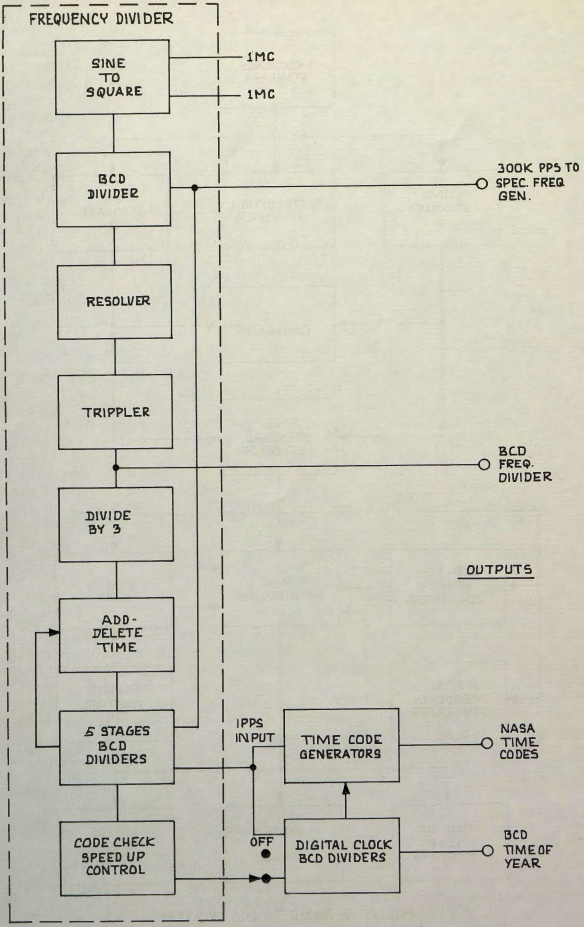
All the dividers used are direct counting 0-9 units, and output BCD pulse trains that are used to provide time information concurrently in several ways. Time-of-year information is available from one to 365 (or 366) days at a resolution of up to 10 microseconds in several formats. These formats include the parallel BCD Time, Serial BCD Time with three different frame rates, and Serial Decimal BCD Time at one frame rate. Binary formats are also provided.

The Time Standard includes all controls required for calibration and checkout in conjunction with the Time Calibrator Subsystem.

The frequency divider portion of the Time Standard accepts two one megacycle sine waves from the Frequency Standard, adds them redundantly, squares the result, and divides the one megapulse per second down to one pulse per second. Provisions are included to enable pulses to be added and deleted at rates of one pulse per second to 10,000 pulses per second. A fine correction control is also provided in addition to the coarse correction capability. This is in the form of a resolver using sine-co-sine potentiometers in conjunction with a quadrature phase generator at the 100 KPPS point in the divider chain. This fine correction control enables corrections to be made to the frequency divider to a resolution of better than a



APOLLO S-BAND TIMING SYSTEM



TIME STANDARD BLOCK DIAGRAM

tenth of a microsecond. A digital accumulator is geared to this control so that time shifts can be periodically observed to determine the overall system accuracy.

Frequency accuracy is continuously checked against VLF standard transmissions, and the on-time accuracy of the system is checked by comparison with WWV transmissions. Propagation delay is automatically compensated for at each site.

Status Clock

The Status Clock is used to drive remote displays indicating the countdown, elapsed time, and hold time status. All operating controls for this unit are located at the Servo Control Console. The clock is capable of being preset to any time from 0 to 999 hours in either a countup or countdown mode. Internal provisions will cause the clock to automatically switch from the dountdown to the elapsed time mode of operation at time 0. Time 0 corresponds to the time a mission program is begun. Whenever the countdown is stopped for any reason, a hold time display will indicate the elapsed time since the hold was initiated. The hold time automatically resets to 0 when the countdown is resumed. An additional feature of the Status Clock is the capability for setting it so that it will automatically start in any preset state, at any preset time of year.

BCD-To-Binary Converter

The BCD-to-Binary Converter employs the Couleur[1] system of conversion. The technique essentially involves parallel loading the BCD time-of-year information into a shift register which is divided into the corresponding number of decades. Conversion is accomplished by alternately shifting and operating on the time-of-year data. The arithmetic operation following the shift involves subtracting a 3 or 5 depending on the decade if a "1" is detected in the most significant bit. The entire operation is clocked by a 500 KC pulse train and the conversion process requires 70 microseconds. The output time-of-year is provided in three word lengths. The output of the converter register is fed into two other registers as well as being fed back into itself in order to store the binary time-of-year in milliseconds, tenths of seconds, and seconds. Serial outputs are also provided. The serial outputs are coincident with the outputs of the converter portion of the unit and are accompanied by appropriate clock pulses.

Special Frequency Generator

The Special Frequency Generator accepts the 300 KPPS square wave output of the frequency divider in the Time Standard and uses it to generate a number of pulse trains that cannot be directly derived from the normal outputs of the Time Standard. All of the required frequencies are derivable from 4800 pulses per second which can be obtained by doubling the 300 KPPS and dividing by 125. Most of the special frequencies generated are used as the time base for data modems associated with the Tracking Data Processor. One output, namely 60 PPS, is shaped into a sine wave and is used to drive local and remote wall clocks.

Signal Distribution

All of the Signals generated within the Timing System for external distribution, other than for driving displays, are shaped and buffered in the Signal Distrubution unit, while display outputs merely pass through the unit to connector panels. A summary of the outputs provided by the Timing System are shown in the table below. All of these outputs are available either at connector panels located within the equipment or at the system patch panel. The system patch panel contains all the signal wire outputs of the system such as pulse trains, sine waves, serial time codes, and the serial binary time of year.

TIMING SYSTEM OUTPUT SUMMARY

FUNCTIONS	NO. OF FUNCTIONS	NO. OF SIGNAL LINES
Sinewave Patch	14	90
Pulse Train Patch	32	102
BCD Time of Year	22	660
Binary Time of Year, MS, 1SEC, SEC	6	93
BCD Frequency Divider	2	48
60 Cycle High Level	4	4
TDP Timing Signals	16	73
APP Timing Signals	8	28
Displays	3	1500

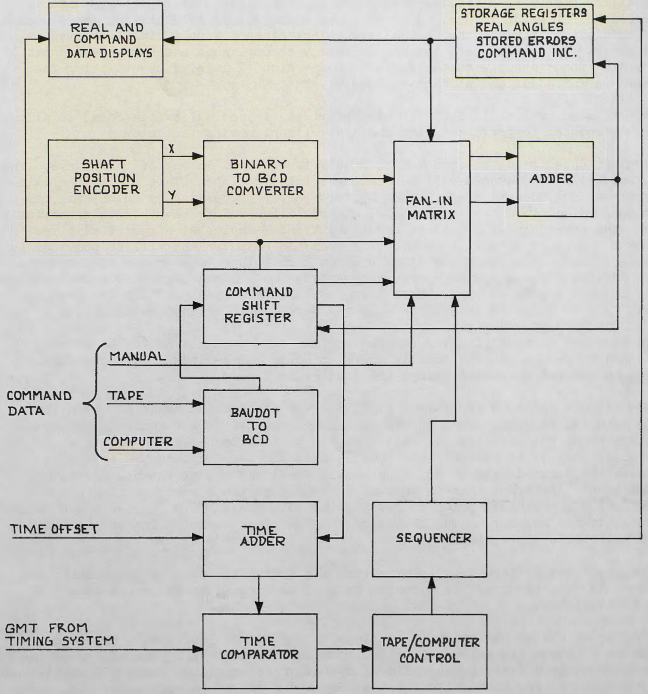
Physical Characteristics of the Equipment

The Timing System proper is housed in six racks fastened together as a single unit. Each rack is 24" wide and 69" high and with an overall depth of 26".

One rack is physically separate from the Timing System proper and contains the Frequency Standard, which is supplied as government furnished equipment by GSFC. Access to both front and rear is provided for maintenance and checkout purposes, and covers are provided over all areas not requiring normal access.

ANTENNA POSITION PROGRAMMER

The basic function of this unit is to provide antenna steering signals. This function is accomplished by comparing predicted and actual data and generating an analog steering signal proportional to their difference. Several modes of operation and optional inputs are utilized to increase the system flexibility.



ANTENNA POSITION PROGRAMMER UNFIED
S-BAND

Actual antenna position is obtained ten times per second as two seventeen-bit plus sign binary words for the X and Y axes. Because the remainder of system inputs and its display outputs are decimal quantities, it was decided to perform the internal arithmetic in a decimal manner. Thus, the binary shaft position data is converted to BCD prior to use. Conversion is accomplished by utilizing the system's adder to successively add the decimal equivalent of each binary digit received in a "1" state. In this manner, scaling is easily accomplished and hardware is held to a minimum consistent with the speed of conversion (1 μs/bit) by utilizing the already present adder and storage registers.

A simulated real angle input is also provided (in decimal switch form) to allow station personnel to perform system checkout without moving the antenna.

Command (predicted) antenna position data is obtained in any of three ways. The most frequently used manner will be reading a teletype tape. This prediction data is received from Goddard Space Flight Center. After processing by an on-site computer to provide coordinate conversion, interpolation and to remove data transmission errors, the tape data will contain predicted X and Y angles at a specified time. An alternate source of data will be directly from the computer and will be provided in the same format. Command angle data obtained from either tape or computer sources may be modified by the system operator by adding (or subtracting) numbers entered via manual decimal digit switches. When these switches are used exclusively, that is without tape or computer input, the mode of operation is defined as manual.

In addition to modifying the command angles, the command time may be altered by adding manually-entered time data in hours, minutes and seconds. This compensation is used to correct operation delays and prediction errors.

The Antenna Position Programmer (APP) has two fundamental modes of operation, called Auto and Program. When in the Auto Mode, the APP is not actively positioning the antenna but is using the fact that the vehicle is being tracked in a satisfactory manner to evaluate its command data source. Because the system is on track, the command data at any time should equal the actual antenna position at that time. Any error that is present is stored at the operator's discretion or automatically immediately prior to leaving the Auto Mode. This "stored error" will be available for use during the following Program track period. Its use is again at the operator's discretion.

Program track differs from Auto in that the system is actually positioning the antenna. No "stored error" is computed in Program because no assurance of a good track is available.

A cycle of system operation is completed every one or ten seconds depending upon which of these two intervals is the command data interval. Regardless of the command interval, a smaller sub-cycle of operation is completed every 100 milliseconds. A cycle of operation, based upon the one sample per second command mode, will serve effectively as an example of the Programmer's operation. The pertinent steps in an operating cycle are listed in the table below.

1. Immediately following real time 1 PPS transition.
    a. Generate delayed tape start command.
    b. Sample pulse to shaft encoders.
    c. Add tenth increment.
    d. Convert real angles to BCD.
    e. Compute error function.
    f. Allow tape start.
    g. Upon tape stop, compute command increment.

    h. Add "stored error".
    i. Add offset angles.

2. Immediately following real time 10 PPS transitions except that transition coincident with the 1 PPS signal.
    a. Sample pulse to shaft encoders.
    b. Add increment.
    c. Convert real angles to BCD.
    d. Compute error function.

If it is assumed that time synchronism of the command data source has been obtained and that a 1 PPS transition has just occurred, then events will proceed in the order listed above. Because the real time data word has just changed, it is necessary to advance the tape (or computer) to regain synchronism. A tape start signal is generated, but is delayed because the data from the previous (presently used) sample is still required as will be seen shortly. An encoder sample signal is also generated at this time, but the shaft position will not be available for approximately 100 µs. During this time, a new command sample will be computed for the just begun 1/10 second period.

It was previously mentioned that regardless of the command data rate, the real angles are sampled every 100 ms and a new error signal computed. This computation, therefore, requires new command angles every 100 ms and because they are provided only every one or ten seconds, it is necessary to interpolate between these points to obtain the desired value. Interpolation is accomplished by storing two successive command samples at all times and computing, by linear interpolation, the necessary command increments. Step (c) in the above table refers to the addition of this increment for the tenth time to the command angles used during the previous second. When the tenth increment is added, the sum will equal the value of the upcoming command angles.

Following the incrementing of the command angles, the real angle data is obtained and converted from binary to BCD (step d). Step (e), the computation of the error function, is accomplished by subtracting the real angles from the command angles and converting the result to an analog voltage. The scale factor for this operation is 1 volt = 1 degree. Once the digital to analog converter has been strobed, the delayed tape start signal (step a) is allowed to operate the tape reader. At this point, approximately 170 µs have elapsed since the 1 PPS transition.

Once started, the tape reader will read the next block of command data and stop. This operation requires about 75 ms. It is because this period of time is such a large portion of the 100 ms effective command data interval, that it was necessary to compute the command angles (by adding the tenth increment) prior to advancing the tape. Upon receipt of a tape stop (and valid data) signal a new command increment is computed. This increment will be used for the next ten error function computations.

Step (h) refers to the use of the error stored in Auto track. If the system is operating in the Program mode, and if the system operator so desires, the "stored error" may be used at this time to modify the command data. This is done by subtracting the stored error from the command angle. At Step (i) the manually-entered offset data may be used to further modify the command data, again under operator control. Steps (g), (h), and (i) are completed well before the end of the first 100 ms following the 1 PPS transition and no further operations are performed until the following 10 PPS transition.

Item 2 in the above table depicts the sequence of operations that take place every 100 ms, immediately following the 10 PPS signal, except when the 10 PPS and 1 PPS transitions coincide. These steps are those required to compute a new error function every 100 ms, and are identical to steps (b), (c), (d) and (e) already described. If the system is operating with a one sample per ten seconds command interval, then the steps in item 2 would be performed 99 times for every item 1 time, as opposed to the 9 to 1 ratio in the example chosen.

The APP is implemented through the use of Collins standard computer-type logic cards and cabinets. It occupies three and one-half cabinets (sharing a cabinet with the Tracking Data Processor) containing the shaft position encoders, logic cards, tape handling equipment, digital-to-analog converters, and the system controls. A remote control panel is also provided and will serve as the normal system operating panel.

The shaft position encoding system utilizing a precision instrument servo, is supplied by DATEX Corporation, Monrovia, California.

TRACKING DATA PROCESSOR

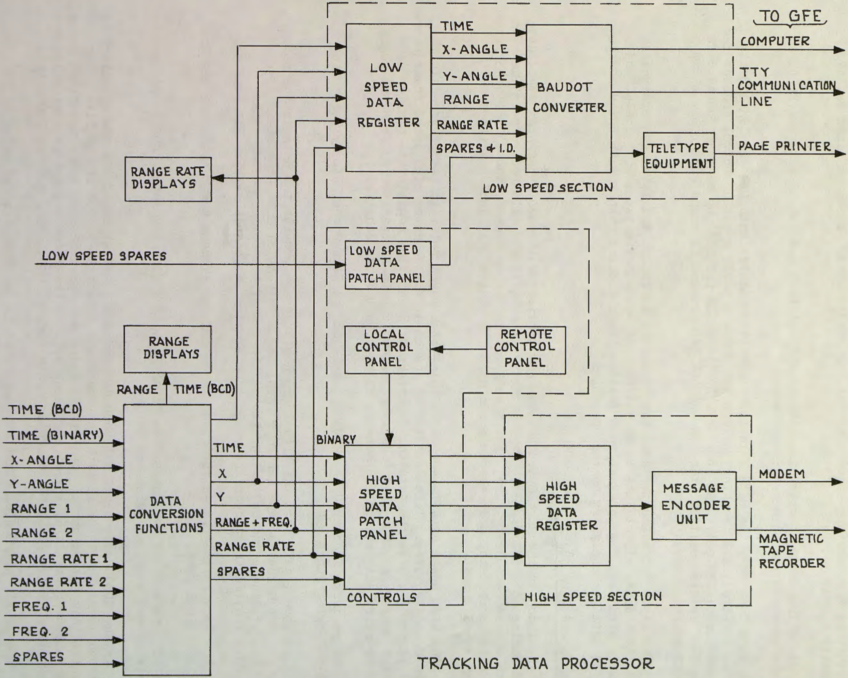
Figure 5 is a functional block diagram of the Tracking Data Processor (TDP). The TDP accepts various forms of data from the ranging system, antenna shaft angle encoding system, timing system, and the servo system. This data is processed and arranged in specified formats for transmission over two types of communication links: High speed modem and low speed teletype. Doppler signals are accepted in analog form and processed using selectable sampling rates and measurement periods. The doppler measurement is transmitted as a 35 bit binary word. The transmitted frequency signal is accepted in analog form and measured by the TDP. The resulting frequency word is automatically transmitted whenever the ranging system indicates acquisition. The remaining TDP inputs are accepted in binary form either as contact closures or at fixed voltage levels. A test mode of operation can be selected by the equipment operator. This mode provides fixed patterns which are displayed and processed by the TDP.

Data Conversion Section

The Data Conversion section adapts, processes, and selects the various input signals for transmission. This section includes a Doppler Counter, Data Selection circuitry, and the necessary input buffering.

N-Counter techniques are used to measure the received Doppler Signal. The N-Counter will count a pre-selected number of Doppler cycles. The time required to reach the pre-selected count of Doppler cycles is monitored by a 100 mc time interval counter. Two N-Counters and associated shaping and gating circuitry are required in a dual TDP. The N-Counter is used for both destruct and non-destruct operating modes.

In the destruct mode, the N-Counter and time interval counter are reset prior to each Doppler measurement at the selected frame rate. The first Doppler cycle received after the counters are reset will start the new counting period. The interval counter will count at a 100 mc rate until the N-Counter reaches the selected number. At this time, the interval counter contains the measured Doppler period (to a resolution of 10 ns). This information is shifted to the high speed and low speed output registers prior to the next counting period.



TRACKING DATA PROCESSOR

In the non-destruct mode, the N-Counter counts continuously without ever being reset. In this mode, the contents of the N-Counter are sampled at the selected frame rate and transferred to the output register. The transfer is made without disturbing the counting sequence. The interval counter is not utilized in this mode of operation.

In either mode of operation, theoutput registers are loaded with the Doppler measurement at the selected frame rate.

In a Dual TDP, the Data Selection circuitry enables both LEM and CSM signals to be accepted, and transferred from the TDP. A panel mounted control enables the selection of LEM only, CSM only or DUAL (both LEM and CSM) to be transferred. In the DUAL switch position, the LEM and CSM information is transferred from the TDP on alternate frames.

The Input Buffering performs the necessary isolation and level conversions to the input data. Input data is in the form of relay contacts, logic levels, and analog signals. The internal test feature inserts fixed patterns in place of the input data for analyzing system operation.

High Speed Data Section

Included in the High Speed section are provisions to record the high speed data and timing on a GFE Magnetic Tape Recorder to provide for data recovery in the event of a communications failure, insert an error detection code at the end of each frame of high speed data, and rearrange and manually control all data positions in the high speed format.

The high speed data is sent to a data patch panel prior to being stored in the High Speed Register. This register is loaded at the selected high speed frame rate. The register stores the data and functions as a shifting register to provide data to the Message Encoder Unit (described below). Data is transferred from the register by shift pulses from the Message Encoder Unit frame counter.

The Message Encoder Unit (MEU) operates on the High Speed Data by performing the following functions:

1. Accept data from the High Speed Register and provide the data to the modem, the Magnetic Tape Recorder (MTR) and a Polynomial Code Generator.
2. Originate and add check bits to the end of the corresponding data.
3. Provide the proper interface to the modem in accordance with EIA Standard RS-232-A.
4. Provide the proper interface to an MTR for storage and playback of the High Speed Data.

The MEU operates in two modes, the Error Detection Code Generator (EDCG) mode and the Playback mode, as described below.

In the EDCG mode, panel switches determine the operation of the MEU by selecting the code word length of 12 bits and the frame length to be 200 or 240 bits. The two combinations establish the quantity of spare and check bits in the transmitted format. The output of the data, spare, and check bits to the modem and MTR is controlled by a counter, triggered by the selected modem timing (600, 1200, 2000 or 2400 PPS).

The 12 bit polynomial functions generated by the MEU were furnished to Collins Radio Company for implementation by NASA. The codes are of type known as Bose-Chaudhuri codes and are described in several publications.

On playback of the data, the MEU synchronizes the data and timing from the MTR for application to the modem. The synchronization is accomplished by storing several bits of reproduced data under control of the playback timing, and controlling the output to the modem by comparing the relative phase difference between the reproduced and modem timing.

Low Speed Data Section

This section converts the binary TDP data to a Baudot representation of its octal equivalent for transmission and recording on TTY equipment. Selected characters within the transmitted format may be manually arranged and controlled by the equipment operator. The data thus arranged is stored in the Low Speed Register.

The Low Speed Register is loaded at the low speed frame rate. This register stores the binary information to be converted for TTY use. The data is transferred to the Binary-Baudot Converter at a character rate which is dependent on the selected TTY equipment, (60 or 100 wpm). Test patterns are also loaded into the register during the TDP internal test mode of operation.

The converter provides for the conversion from binary or BCD to Baudot Code. Included in this section is a communication heading and ending format which is added to the transmitted low speed data for compatibility with communication equipment to Goddard Space Flight Center. The information contained in the teletype heading and ending is controlled by the equipment operator. The data is recorded on punched paper tape at the same time it is being transmitted.

The TDP is provided with a low speed punch, and a transmitter-distributor (TD) which are capable of operating at sixty or one hundred words per minute. A teletype page printer is used to monitor the recorded data from the punched tape. This printed copy is used for "real time" monitoring and test purposes.

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