OPERATOR'S MANUAL

BERGEN UNIVERSITY

NAVIGATION SYSTEM

Prepared by

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INTRODUCTION

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This manual describes the system operating procedures and the specific characteristics of the NAV System. This manual is intended to be used by the operator of the system as a guide and ready reference.

The Magnavox Navigation System program has been developed to provide accurate positioning from the integration of the Navy Navigation Satellite System, the Radio Navigation Systems, the Magnavox sonar, the Arma-Brown gyro, and the other associated navigation sensors.

DISTANCE UNITS IN THIS PROGRAM ARE GENERALLY EXPRESSED IN KILOMETERS; ALL SPEEDS ARE IN KNOTS

The capabilities of the system include the following:

- It is a fully integrated system intended for both near shore high precision surveying and deep ocean surveying.
- Extensive logging of navigation and sensor data on 9-track magnetic tape is performed.
- Satellite position fixes are computed using refraction corrected short doppler counts. The most advanced features of satellite navigation are incorporated in the program. 3D and Velocity North as well as the standard 2D fixing are included.
- The computer program will restart automatically and continue to operate after a power failure.
- Time ordered alerts for the satellites is a program feature. This permits the operator to obtain a time ordered list of when the satellites will appear and what their elevation angles will be.

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- Time ordered alerts for the satellites is a program feature. This permits the operator to obtain a time ordered list of when the satellites will appear and what their elevation angles will be.

- The program includes capabilities for displaying computer memory on the CRT in various formats.
- The system will operate on the WGS-72 satellite geoid or on operator defined local datums with offsets.
- The system performs precise navigation using Loran, Mainchain and Pulse-8.
- The system will provide relay closures to control seismic or other external equipment.

CHAPTER 2

NAV SYSTEM DESCRIPTION

SYSTEM STRUCTURE

The NAV system is designed to provide high precision navigation using a combination of radio nav aids, other navigation devices (sonar, gyro), and the Transit (NNSS) Satellite system. The system also provides a full seismic shot control and survey capability.

The NAV system provides for logging of the acquired navigation and sensor data by writing various types of data on the magnetic tapes.

The system contains a variety of devices to provide control and communication capability for the system operators. These include the Operator terminals (prime NAV system control element) and the CRT for displaying navigation data.

Figure 2-1 shows the structure of the system. The following sections will examine the elements of the system.

SYSTEM COMPONENTS DESCRIPTION

The following is a description of some of the major components in the system.

Nav Computer

The Nav computer is an HP2113E. It serves as the processing and control element of the system. It accepts data from and provides control to the devices attached to it, and communicates with the system operator. The computer performs the navigation function based on information from the navigation sensors attached to it.

The computer architecture provides facilities for interfacing various devices to the computer. In general, each device attached to the computer requires an interface card which is plugged into the computer. A cable connects this interface card to

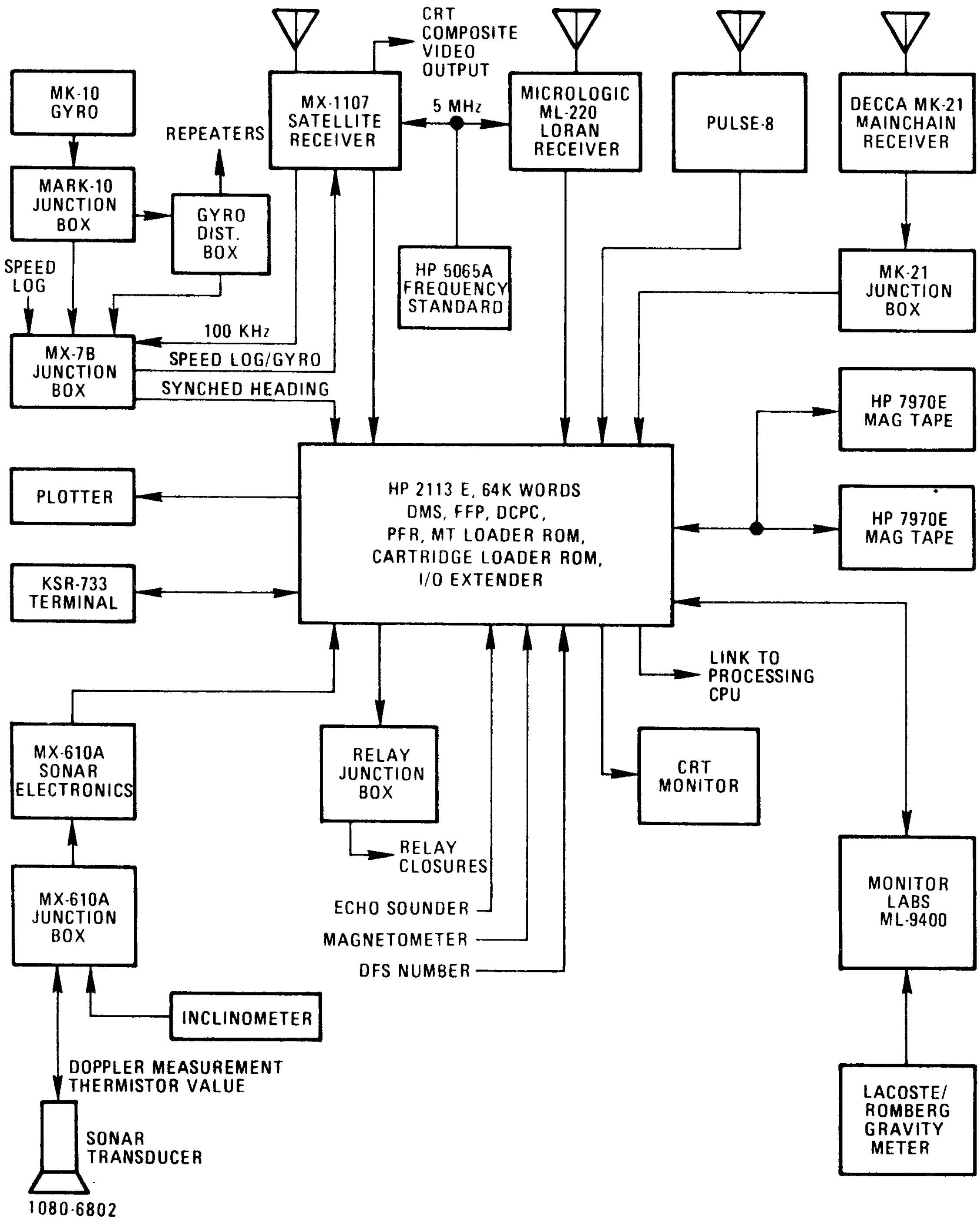

Figure 2-1. Nav System Block Diagram

the device and provides a signal path for transmitting data between the device and the computer. The memory section consists of 64K words of solid state memory. The computer includes built-in loaders so that operator entry of bootstrap loader programs is never necessary.

Further information on the HP CPU is available in the HP document entitled "21MX E-Series Computer Operating and Reference Manual."

Loran

A Loran chain has a set of shore based transmitters, one designated as Master and the others as Slaves. The Loran receivers measure the difference in the time of arrival between the signals transmitted by the Master and the two Slaves. This gives two time differences which represent hyperbolic lines of position. The intersection of these lines of position represents the vessel position.

When the receivers are operated in hyperbolic mode, the use of an extremely stable frequency reference is not required since the measurement of time difference between receipt of master and slave signals is made over a period of only a few milliseconds. When the receiver is used to provide ranging information, any frequency difference between the Loran master and the local receiver oscillator translates directly into apparent but artificial vessel motion. For this reason, an atomic Rubidium frequency standard is employed to control the Loran receiver.

Sonar/Gyro

The system includes a Magnavox sonar and a MK-10 gyro for accurate determination of vessel velocity. The sonar provides velocity information in the ship axes coordinates, and the gyro is used to convert this information to geodetic North-South velocity. An inclinometer is used to correct the doppler frequency readings from the sonar for the effects of ship pitch and roll.

When the sonar is tracking on the ocean floor (bottom lock mode), the velocity measurement is relative to the Earth. When the sonar is in reverberation mode and tracks a water mass which may be moving, the velocity measurement is relative to the water mass. Any motion in the water mass will distort the perceived vessel motion, and the sonar measurement becomes degraded. In deep, clear water, no signal return from the sonar may be received, and the sonar can provide no velocity measurement at all.

Navigation CRT

The CRT is used to summarize the system operation. It contains information such as the latitude and longitude, time, ship speed, and the relation of the ship to a desired survey line.

Magnetic Tapes

The magnetic tapes are used to record the various types of data which should be preserved for subsequent analysis. The eleven types of records written are:

1 - Processed Satellite Pass Data
2 - Satellite Fix Data
3 - Shot Data
4 - Operator Action Data
5 - Gravity Data
6 - Operator Comment Data
7 - Raw Radio Nav Aid Data
8 - Raw Satellite Pass Data
9 - System Update Data
10 - Sail Line Data
11 - Position Fix Data

The magnetic tapes are also used to load the navigation program into the computer.

Operator's Terminal

The NAV system contains a Texas Instruments KSR terminal which is used for operator control and communication.

The operator's console accepts the operator's commands and acts as a logging device for hard copy output. It prints at a rate of 30 characters per second using a line width of 80 characters.

1107 Satellite Receiver

The satellite receiver acquires and tracks two signals from a satellite passing overhead. The receiver measures the doppler shift in these signals to determine the changes in range to the satellite. The two satellite signals are phase-modulated with information describing the satellite orbit, and the satellite receiver extracts this information as well as the doppler shift. This data is transmitted to the computer during a satellite pass. The computer will combine this data with dead-reckoning estimates of the boat's position during the pass to produce a satellite fix.

The solution for geodetic position (latitude and longitude) is made with respect to a satellite datum, World Geodetic System 1972 (WGS 72), which is different from more commonly used datums such as the European datum. Care must be taken when satellite results are compared to map locations for this reason. The program contains provisions to permit all entries and displays of latitude and longitude to be in an operator selected datum.

The satellite fix is quite sensitive to errors in the knowledge of velocity during a satellite pass. Thus, some method of obtaining accurate velocity is necessary. This is provided by the sonar/gyro, the radio nav aids, or some combination of them.

Relay Closures

Relay closures are provided at operator controlled rates. These closures are based on the occurrence of a "shot" which is defined either by the passage of an operator specified time interval, or by the travel of an operator specified distance. Four separate types of closures are provided:

Relays	1-3	Each pop time (for 1/4 second)
	4-6	Each shot time (for 1/4 second)
	7-9	At RLYD 1/4 seconds after each pop (for 1/4 second)
	10-12	Every RLYN shots (for 1/4 second)
	13-15	Every RLYM shots (for RLYH 1/4 seconds)

RLYD, RLYN, RLYM and RLYH are specified by this operator.

NAVIGATION STRUCTURE

The navigation structure used in the NAV system is shown in block diagram form in Figure 2-2. The system accepts navigation inputs from:

Gyro
Sonar
Operator speed/heading estimates
Radio nav aids
Satellite navigation

The navigation structure is based on considerations of the type of measurements available from each of the above sensors.

The sonar/gyro provide measures of the high frequency components of vessel motion. These sensors have low noise components and respond very rapidly to vessel motion. Unfortunately, they also have long term drift characteristics which may build to unacceptable levels over a few hours.

Sensors such as Loran, on the other hand, provide measures of the low frequency components of vessel motion. These sensors have high noise components which forces the use of long term filtering. The long term filtering renders these sensors unsuitable for measuring high frequency vessel motion, but makes them ideal for removing the slow drift characteristics of the high-frequency sensors.

The satellite navigation provides a reset capability for the system and enables the system to remove systematic bias effects in the radio nav aids. Depending on which sensors are in use, it may or may not be advisable to update to satellite fixes and use this reset capability. For example, if sonar/gyro and Loran are in use, resetting the system to a high quality satellite fix is generally quite beneficial. It enables the secondary anomaly effects in the Loran signal to be removed, it partially compensates for any mislocation of the Loran stations, and it provides an updated position to enable the vessel to make corrections to return to a survey line.

To further explain the navigation structure, consider Figure 2-2 and suppose that no radio nav aids are in use. The operator selects either the sonar or manual speed to provide a speed estimate, and either gyro or manual heading to provide a heading

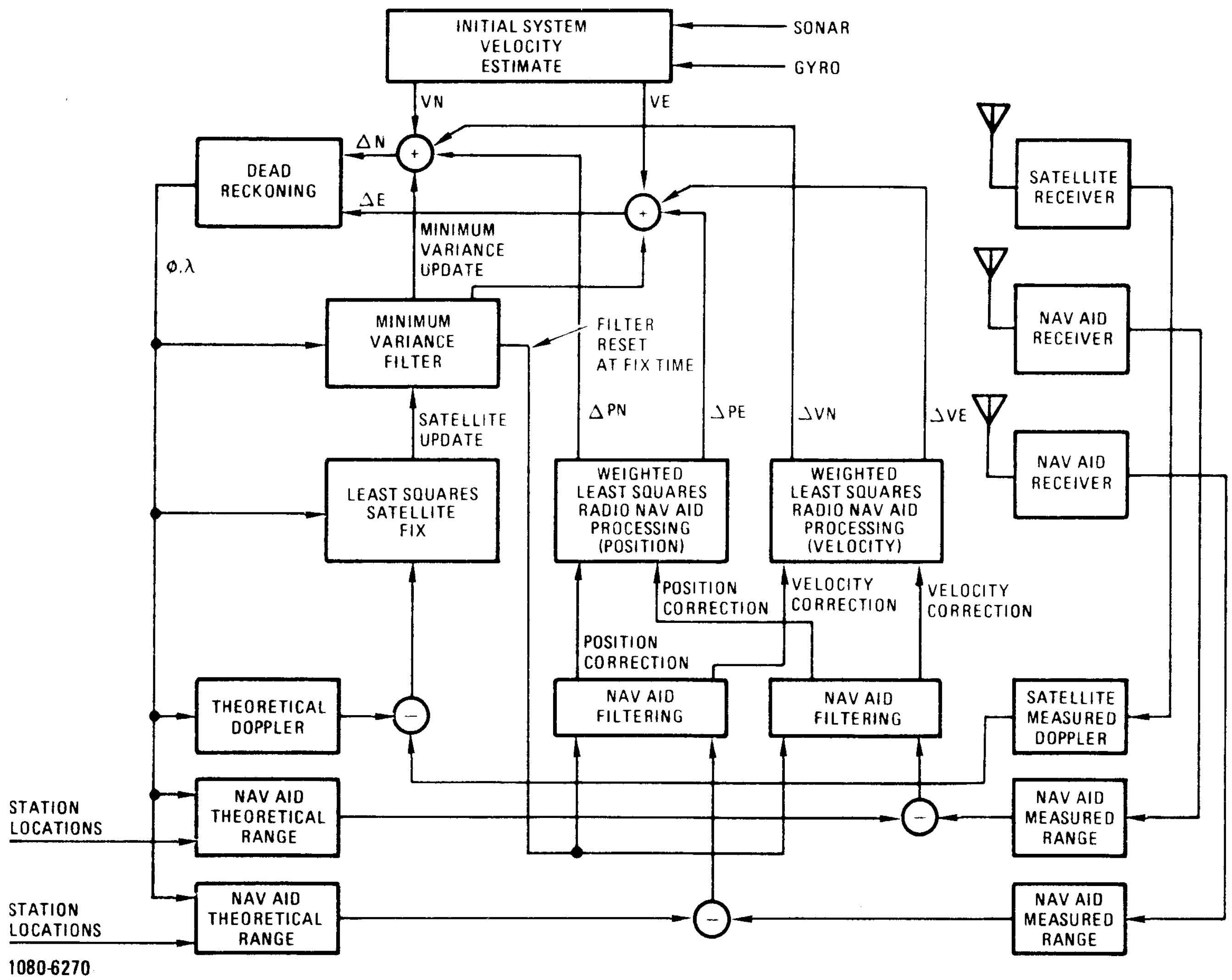

Figure 2-2. Navigation Structure

estimate. These initial estimates of system speed and heading (V_N, V_E) are sampled every 1/4 second to provide a measure of distance north (ΔN) and distance east (ΔE) moved.

Every 1/4 second, the distance north and distance east measurements are used by the deadreckoning routine to update the previous value of system latitude and longitude. In the absence of the use of a radio nav aid, this is essentially the full navigation cycle.

To consider the use of a radio nav aid, suppose that the estimates of system position provided by the initial sensors are incorrect by a heading $\Delta\theta$ and a speed ΔV. The size of the errors depends on the sensors in use as well as their calibration.

These errors $\Delta\theta$ and ΔV result in the dead-reckoning routine producing latitudes and longitudes which are momentarily incorrect. Every second, each nav aid in use computes the ranges from these incorrect system positions to the appropriate shore based transmitter and forms either a "theoretical range" or a "theoretical hyperbolic difference," depending on whether the nav aid is operating in ranging or hyperbolic mode. In Figure 2-3, for example, the theoretical ranges TA and TB to two shore stations A and B are represented, and in Figure 2-4, the theoretical hyperbolic differences TM - TA and TM - TB are represented.

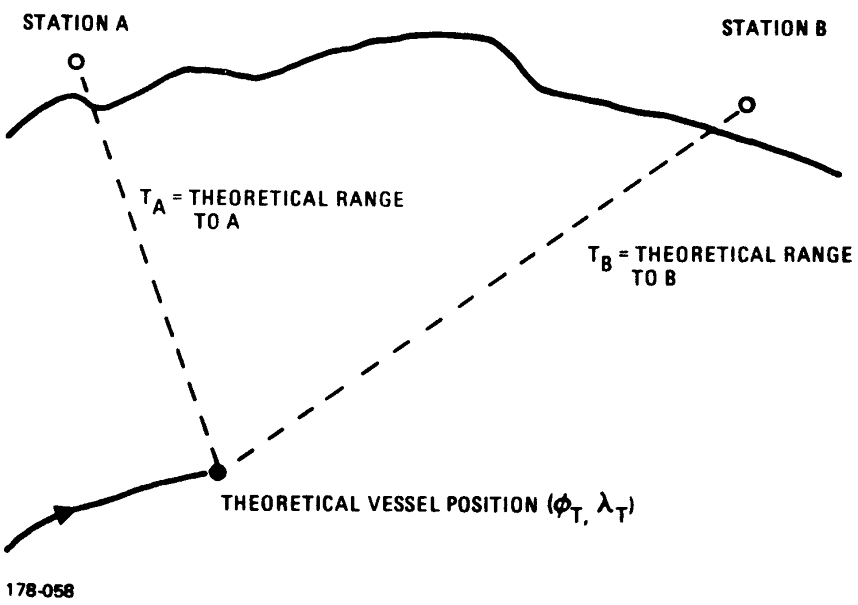

Figure 2-3. Theoretical Range Computation

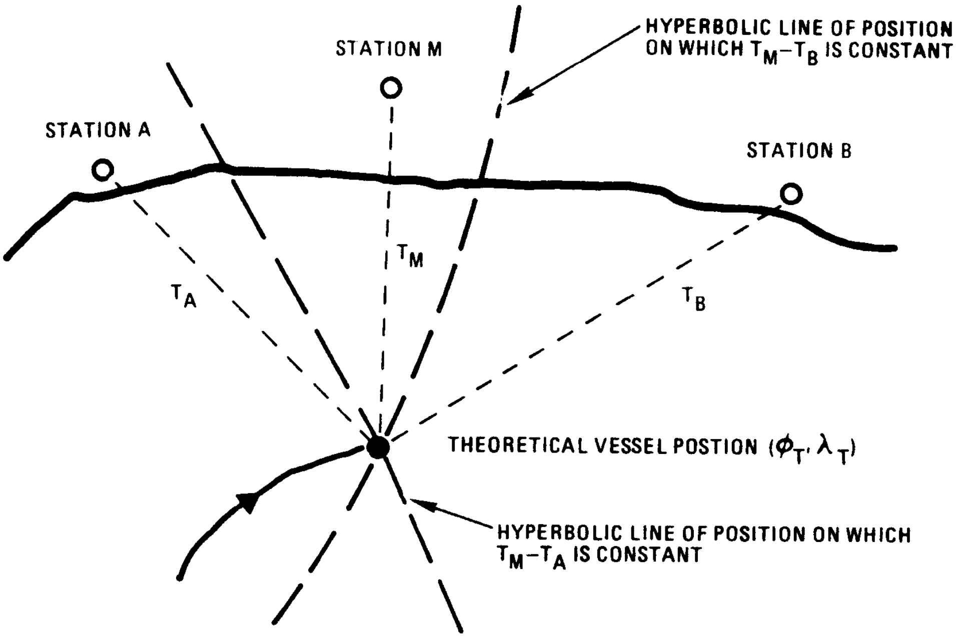

Figure 2-4. Theoretical Hyperbolic Difference Computation

Because of the errors $\Delta\theta$ and ΔV in the computation of theoretical system position (ϕ_T, λ_T), the vessel is actually at some other position (ϕ_M, λ_M). At this actual position the radio nav aid receivers provide an estimate of "measured ranges" or "measured hyperbolic differences," depending on whether the nav aid operates in ranging or hyperbolic mode. These measured ranges or hyperbolic differences will not agree with their theoretical counterparts since the theoretical system position and the actual vessel position do not coincide.

The action of each nav aid processing routine is to filter the difference between the measured and theoretical ranges or measured and theoretical hyperbolic differences in a second order filter. The output from the filter in each nav aid is a position correction and a velocity correction.

The position corrections from all operational nav aids are combined in a weighted least squares sense to produce a position north and position east $(\Delta P_N, \Delta P_E)$ correction. The velocity corrections from all operational nav aids are also combined in a weighted least squares sense to produce a velocity north and velocity east $(\Delta V_N, \Delta V_E)$ correction.

The weighting for this filter is derived from estimates of noise in the signals. Figure 2-5 illustrates the derivation of these noise estimates.

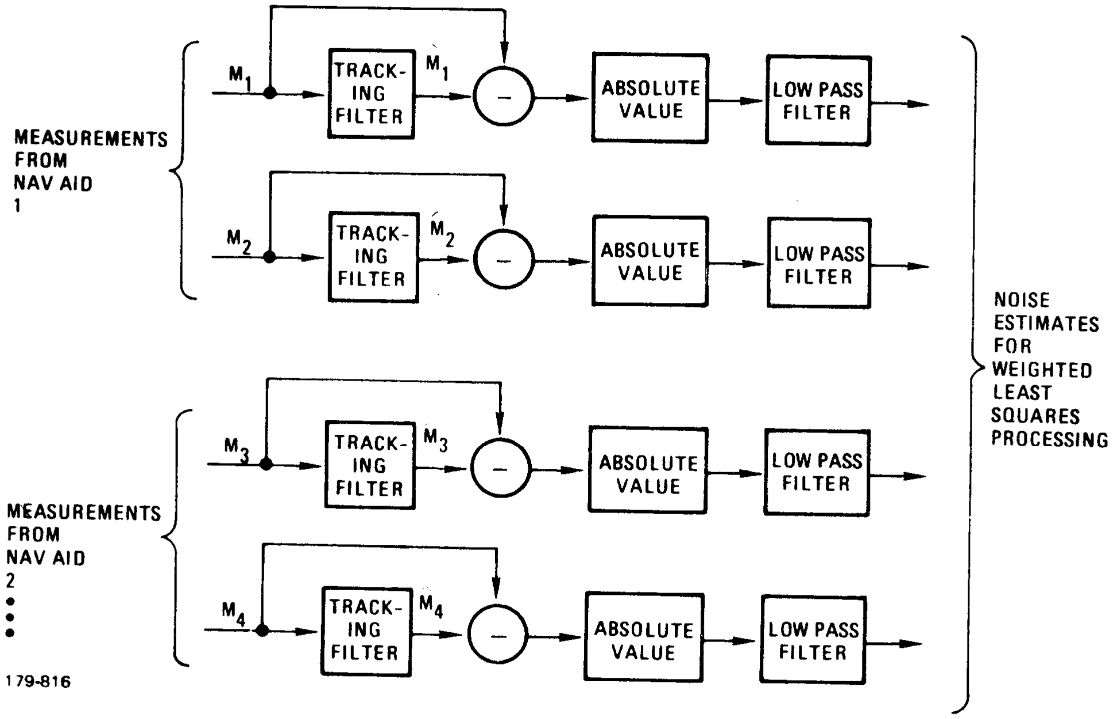

Figure 2-5. Nav Aid Tracking Filters

The track filters have one additional important use; when the difference between any current measurement M_i and the tracked value $\hat{M}_i$ of that measurement becomes excessive, the tracked value $\hat{M}_i$ is substituted for the measurement M_i on that filter cycle. If this substitution is necessary enough consecutive times, the use of the measurements M_i will be terminated.

The corrections (ΔP_N, ΔP_E, ΔV_N, ΔV_E) are then combined with the initial velocity measurements

$$\Delta N = V_N + \Delta P_N + \Delta V_N$$

$$\Delta E = V_E + \Delta P_E + \Delta V_E$$

to produce total corrections ΔN and DE.

These total corrections are input to the dead reckoning module which combines them with the previous estimate of system position to produce an updated system position.

This updated system position is used in the next second to derive a new set of theoretical ranges T_A, T_B to compare to the next set of measured ranges M_A, M_B, resulting in a new set of filtered differences which are input to the weighted least squares resolutions.

The second order filtering applied in each nav aid to the differences between the measured and theoretical ranges or hyperbolic differences is controlled by the operator, permitting the selection of different values for each nav aid.

Since a simple first order filter would produce time-lagged corrections, the filtering scheme used is a second order filter called a "position locked loop." This filter divides its output into position and velocity components, and the velocity component is summed. The position output of this filter corresponds to phase and the velocity component to phase rate in an electrical phase locked loop. Figure 2-6 illustrates this position locked loop.

The weighting applied in the least squares process may be either selected by the operator or supplied by the system. A range or hyperbolic measurement with low noise receives greater weight in the least squares process than a measurement with high noise.

If the system is permitted to derive the noise estimates, it does so by using Alpha-Beta tracking filters on the raw receiver inputs. The amount by which a raw measurement differs each second from the value predicted by the α-β tracking filter is input to an exponential filter to produce a noise estimate.

As is shown in Figure 2-2, the satellite fix process interacts with the nav aid processing. When a satellite fix has been derived, a minimum variance filter is used to combine the satellite fix position with the dead-reckoned position to produce a minimum variance position. This minimum variance position represents the amount by which the dead-reckoned position will be changed if an update occurs.

When a new system position is selected, there may be some difference between the nav aid measured ranges to the stations and the theoretical ranges to the stations based on the new system position. The system presumes that the satellite update position is correct, and each nav aid processing routine computes a bias which will be added to future measurements so that they will be in agreement with the satellite reset

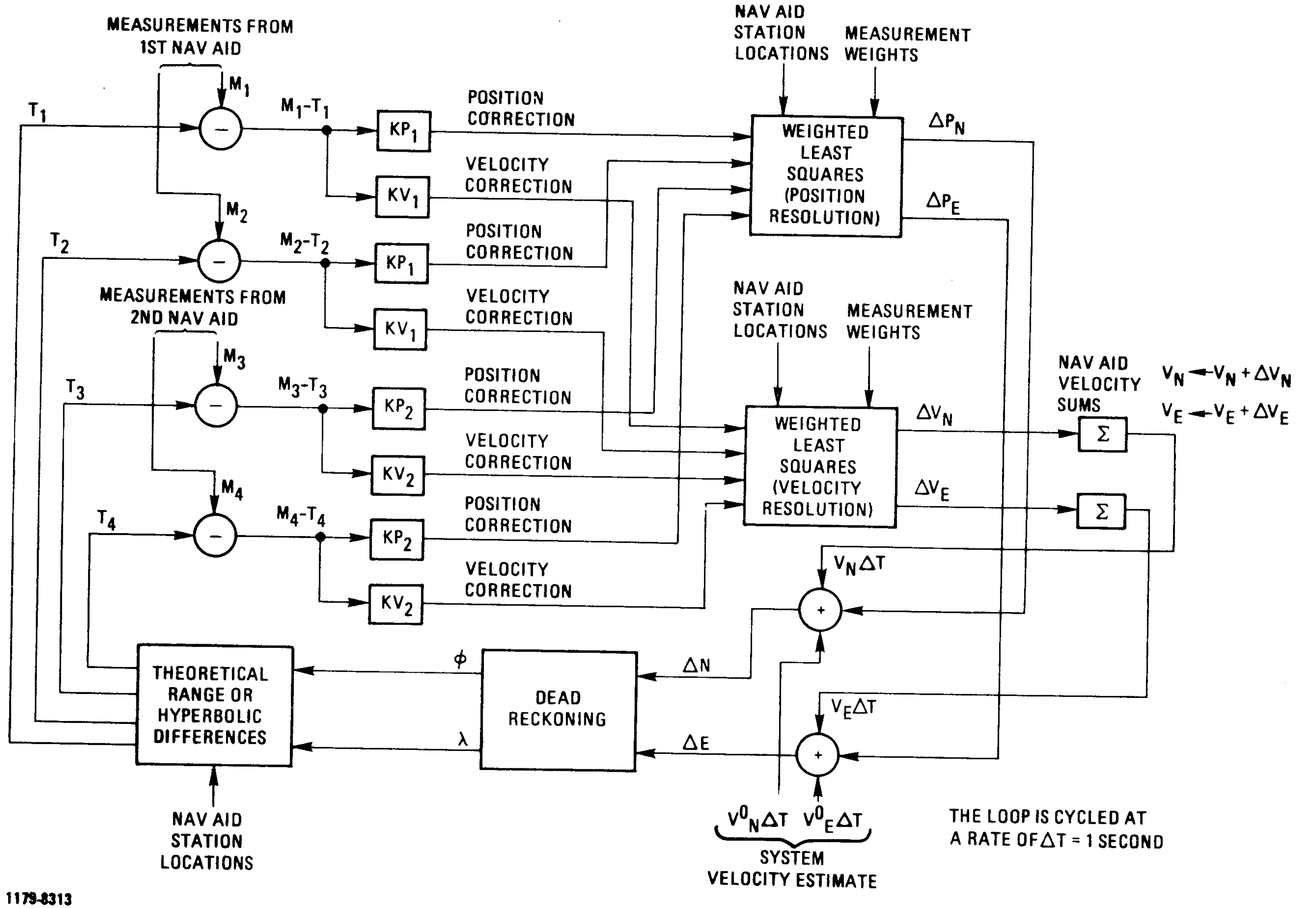

Figure 2-6. Phase Locked Loop on Position

position. This process removes the effect of secondary anomalies in the Loran signals, for instance, and ensures a higher degree of consistency between nav aid measurements until the process is repeated at the next satellite update.

STANDARD DEVIATION OF RADIO NAV AID RESIDUALS

As mentioned above, the radio nav aid processing attempts to navigate the vessel in such a way as to minimize the differences between expected measurements and actual measurements. These differences are called residual errors. These residual errors provide a good indication of the quality of the measurements and how well the system is able to resolve inconsistencies among them. During the time that a radio nav aid is used, the system calculates the standard deviation of the measurements being received from each station according to the following formula:

$$S = \left(\frac{1}{n-2} \sum_{i=1}^{n} R_i^{\,2} \right)^{1/2}$$

where n is the number of seconds over which the calculation is made, R_i is the residual for a given second, and S is the standard deviation that is printed. The value of S is printed in meters. There is one S number printed for each station or measurement that is being used for navigation. These S numbers are printed on a single line immediately following the nav aid data line which is generated by each of the nav aid data line mnemonics. (See the appendices for a list of nav aid letter ID's.)

will store 040000 into memory location 720 and 000002 into memory location 721. Care should be exercised in the use of this command since the navigation program can be destroyed in this manner.

INTG -- Integer Entry. The operator wishes to store a decimal integer value in memory. The program will type "=" and the operator may supply the decimal value he wishes to have stored in memory at the address previously specified with the ADRS command. Each time INTG is used, an address pointer will be advanced by one so that each new use of INTG will put data in successive words. Care should be exercised in the use of this command since the navigation program can be destroyed in this manner.

FPNT - Floating Point Entry. The operator wishes to store a floating point value in memory. The program will type "=" and the operator may supply the value he wishes to have stored in two words of memory beginning at the address previously given in ADRS. For example,

ADRS = 720
720
FPNT = 1.0
040000
000002

will store a floating point 1.0 (040000, 000002) in locations 720, 721. The address pointer will be advanced by 2 so that each new use of FPNT will place values in successive pairs of memory words. Care should be exercised in the use of this command since the navigation program can be destroyed in this manner.

Mag Tape Recording

The system records various types of data on mag tape. The record types are defined below:

TYPE	DATA	FREQUENCY
Type 1	Satellite Pass	Every satellite pass
Type 2	Satellite Fix	Every satellite fix
Type 3	Shot	Every shot
Type 4	Operator Action	Every operator mnemonic

Type 5	Gravity	Every gravity transfer
Type 6	Operator Comment	Every use of CMNT mnemonic
Type 7	Raw Data	Every 10 seconds
Type 8	Raw Satellite Data	During satellite pass
Type 9	Update	Every system update
Type 10	Sail line data	Every sail line setup and line change
Type 11	Position fix data	At completion of all CPFX position fixes and at shot/DR printout time if the automatic position fix feature is used.

A Type 1 record is produced at the end of each satellite pass. These records contain the processed data collected during the pass. This data includes the majority voted message set, the navigator's table, and the doppler data.

A Type 2 record is produced at the end of the satellite fix process. These records contain the results of the fix computation, including the update values.

A Type 3 record is produced with each shot. These records record the systems position at shot time as well as data from attached sensors.

Type 4 records are produced when the operator enters mnemonics. These records may be used to trace the operators action on the system.

Type 5 records are produced whenever gravity data is transmitted to the system.

Type 6 records result from the use of the comment (CMNT) mnemonic. The operator may place up to 64 characters of information in a record to annotate the mag tape for subsequent processing.

Type 7 records are produced every ten seconds unless suppressed with the MTRD mnemonic. These records contain ten seconds of data collected at a rate of once per second from each nav aid.

Type 8 records are written during a satellite pass and contain the raw data from the satellite receiver. These records are provided to enable fix recomputation for post processing.

A Type 9 record is written each time the system position is updated by a satellite update, operator entry of a new latitude or longitude, use of the DLAT, DLON, PFIX, URPF mnemonics, etc.

A type 10 record is written at the end of the sail line initialization sequence, when an automatic line change occurs and when the NLIN mnemonic is used. It contains sail line parameters.

A type 11 record is written after all periodic nav aid position fixes have been completed or after a CPFX computation. It contains information concerning what nav aids and stations were used and the results of each position fix.

When a mag tape record is written, the data is first collected in a write buffer. It is then written to tape and the mag tape status is checked to ensure that the hardware read-after-write detected no errors. If errors were detected, the record is repeated up to three times, after which the deck is placed off line and rewound. The second deck is placed in service to continue mag tape operations.

The operator may impose an additional check by requesting that every Nth record be backspaced over, read, and compared to the write buffer containing the original data to be written.

The remainder of this section describes the mag tape mnemonics.

MTRD - Mag Tape Raw Data. Enter ON to permit Type 7 raw data records, OFF to suppress them. This is automatically turned ON when the shot enable switch on the model 200B is on.

CHNG - Change mag tape decks. Write two EOF's on the deck in use. Place it offline, and start it rewinding. Continue operations on the second deck.

CMNT Comment. Enter up to 300 characters of information which will be placed in a Type 6 record.

MTVR Mag Tape Verify. Enter ON to have records verified, OFF if records are not to be verified.

VINT Verify interval. Enter the number of records which are to be written before software verification. If VINT=1, every record is verified. If VINT=5, every 5th record is verified, etc.

MMSG Enter ON to enable mag tape error messages, OFF to disable mag tape error messages.