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THE UDOP HANDBOOK

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Deputy for Range Engineering

Air Force Eastern Test Range

Air Force Systems Command

Patrick Air Force Base, Florida

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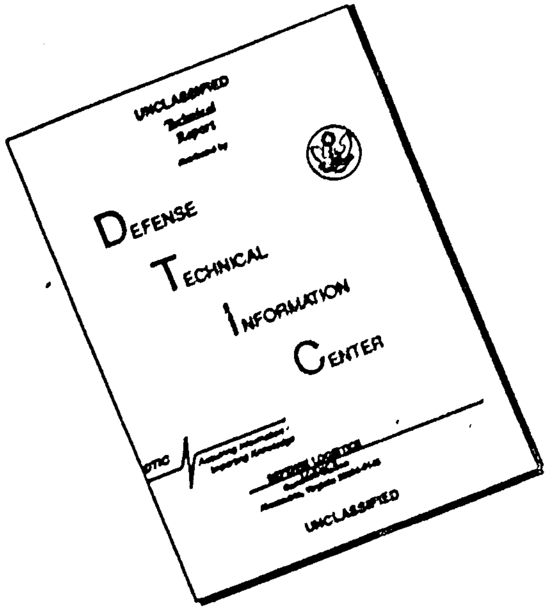

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FOREWORD

This report was prepared under Contract AF 08 (606)-5300, Pan American World Airways Guided Missile Range Division, Patrick Air Force Base, Florida, by Daniel L. Schneid, and monitored by Kenneth R. Ostereich, 1st Lt, USAF, Project Officer. Inclusive dates of investigation are March 1963 through July 1964. Report was submitted by the author July 1964, and provides a complete summary including the capabilities and limitations for the UDOP System used on the Eastern Test Range.

The author wishes to acknowledge the writings of many people who contributed to this report. Particular thanks go to Mr. Gene Smith, RCA Mathematical Services, who collected most of the background for his own particular document, noted in the documentation section. Others who contributed to this handbook are listed below:

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This technical report has been reviewed and is approved.

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ABSTRACT

This document contains a complete description of the UDOP (Ultra-High Frequency Doppler) System used on the Atlantic Missile Range. All phases of the effort involved when UDOP is called up to support a mission are included herein. This document explains the theory, equipment solutions, and mathematical techniques involved. This document is written to satisfy the questions of any technically minded person who is interested in UDOP. If this document does not suffice, further inquiry concerning the system may be satisfied by the documentary lists included.

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INTRODUCTION

The UDOP System is the present culmination of many years of engineering effort spent in developing a doppler measurement system. The most recent massive effort to upgrade the technique of doppler measurement occurred in the Spring of 1961. At that time, Pan American World Airways, in response to the request of the Air Force Range Development Office, AFMTC, undertook to upgrade the limited PERSHING UDOP System to encompass the more stringent requirements placed on the Atlantic Missile Range by the MINUTEMAN Missile Program. Pan American Program Management, Engineering, Facilities and Operations were oriented to the new system. A three-pronged engineering attack was started, and has recently been completed.

This document contains the history, theory and application of the earlier doppler measurement systems, including the most recent effort to upgrade the system. This document also contains descriptions of all the equipment used in the UDOP System. Where necessary, block diagrams and photographs are included. A section is also included on the UDOP Real-Time MINUTEMAN support function. Specifications and characteristics of some equipment are listed in the appropriate sections. As a guide for further investigation, a list of UDOP schematics and a listing of UDOP documentation is part of this document.

The last section of this document contains a photographic appendix so that the reader may acquaint himself with the physical characteristics of UDOP equipment.

THE DOPPLER EFFECT AND A SHORT HISTORY OF AMR DOPPLER TRACKING SYSTEMS

The Doppler effect is a commonly observed phenomenon in sound where there is a rapid relative motion between the source of the sound and the person hearing the sound. The effect is a change in the frequency of the sound as heard by the listener. For example, a person standing beside a highway will hear a horn blowing on a rapidly approaching car at a higher pitch than he would if the car were standing still. At this time he will not be conscious of the Doppler effect for he has no way of judging the normal sound. But the moment the car passes and is receding, he will notice a sharp drop in the pitch of the sound. While the Doppler effect continues, the only time the listener detects it is the moment that the car passes because that is the only time he has a basis for comparison. The same effect would be observed if the listener were in a rapidly moving vehicle and the source of the sound was stationary.

The explanation for this phenomenon is as follows. Assume that sound is emitted from a source as a sinusoidal wave of frequency, f, traveling through the air at a certain velocity, V. Referring to Figure 1-1, assume that the source of the sound is at S, and that the sound will travel to A in one second. The distance, d, between S and A will then be filled with f cycles of sound waves. The length of one sound wave, or the wavelength, λ, will then be

$$\lambda = \frac{d}{f} = \frac{V}{f}$$

If the source is stationary at S, a person standing at A will hear f cycles per second beginning one second after sound starts from S.

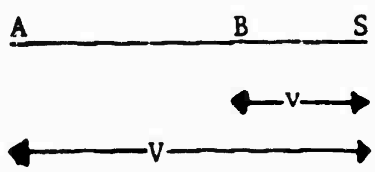


FIGURE 1-1. THE DOPPLER EFFECT

Now consider S as moving toward A with the velocity v. In one second S will have moved to B and will have emitted f cycles of sound, the first of which has arrived at A. But B is closer to A and the f cycles are now crowded into the space BA resulting in a shorter wavelength. Since the sound wave is traveling at the same velocity V, the sound emitted when the source is at B will arrive at A in less than one second with the result that the listener at A will receive the sound at a rate of more than f cycles per second. If λ' is the shortened wavelength, the altered frequency f' will be

$$f' = \frac{V}{\lambda'} \qquad d' = \text{distance between A and B}$$

The wavelength, λ', will be

$$\lambda' = \frac{d'}{f} = \frac{V - v}{f}$$

Substituting this value of λ'

$$f' = f \frac{V}{V - v}$$

This is the formula for computing the frequency of the sound heard when the source is moving toward the observer with the velocity v. When the source is moving away from the observer, it can be shown by similar reasoning that

$$f' = f \frac{V}{V + v}$$

In this case the frequency is lowered and the wavelength is lengthened. These two formulas may be stated as the general formula

$$f' = f \frac{V}{V \pm v}$$

The frequency is also apparently changed in the case where the source of sound is stationary and the observer is in motion. If the observer is moving toward the source with a velocity v, the frequency is raised. The formula for computing the apparent frequency for this condition is

$$f' = f \frac{V + v}{V}$$

When the observer is moving away from the source, the frequency is lowered and the formula for the observed frequency is

$$f' = f\,\frac{V - v}{V}$$

combined, these result in the general formula

$$f' = f\,\frac{V \pm v}{V} = f\left(1 \pm \frac{v}{V}\right)$$

Radio frequency waves are similar in many respects to sound waves. However, there are certain basic differences in addition to the differences in frequency. Sound waves are transmitted through the medium by actual displacement of the particles of the medium. Sound, therefore, cannot be transmitted through a vacuum. The velocity of sound in a medium depends on both the density and elasticity of the medium. Sound waves have a velocity in air of approximately 1100 feet per second at sea level. Radio waves are both electromagnetic and electrostatic and are propagated through space as waves of energy rather than as waves of particles. For this reason, they are similar to light waves and travel at the speed of light. Both radio waves and light waves may be propagated through a vacuum. As a matter of fact, the velocity of radio waves, and of light waves, is greater in a vacuum than in air. The density of the medium affects the velocity of propagation inversely which produces a bending or refraction of radio or light waves as they obliquely pass through a medium of changing density. This effect must be determined and corrected if accurate data are to be obtained using either radio frequency or light waves.

Radio frequency waves are affected by the Doppler effect in much the same way as sound waves. In general, the equations for sound may also be used for radio frequencies at low relative velocities between the transmitter and the receiver. The radio receiver in an automobile traveling toward a radio station will receive the carrier frequency of the station at a slightly higher frequency than the station is broadcasting. However, the velocity at which radio waves travel (approximately 186,000 miles per second) is so great in comparison to the velocity of the car (88 feet per second at 60 miles per hour) that the change in frequency is so small that it is not discernible. For example, assuming that a radio wave is traveling at 186,000 miles per second, the wavelength of a 1.86 megacycle signal would be 528 feet. In this case, at 60 miles per hour, a car would require six seconds to travel one wavelength. If the frequency is raised to 18.6 mc, the time would be 0.6 seconds, and at 186 mc, the time would be only 0.06 seconds, or about 16.6 cycles in one second. Different car velocities would produce a different number of Doppler cycles per second. If the wavelength of the radio signal is known and a means is devised to determine the number of cycles in the Doppler shift, the resulting information may be used to determine the speed of the car.

If a beam of electromagnetic waves of radio frequency is directed toward an object, it will be partially reflected back and may be received by a receiver near the transmitter. If the object reflecting the wave, the transmitter and the receiver are all stationary, with respect to one another, the wave will be received at the same frequency that it is transmitted. However, if the object is moving in such a manner as to change the distance the beam travels, the Doppler effect described previously will be present. Then if the Doppler effect can be evaluated, the radial velocity of the object with respect to the transmitter and the receiver can be determined.

One way of detecting any Doppler change in a received signal is to heterodyne or "beat" the received signal with a signal of the same frequency as the original transmitted frequency. This is done by feeding both signals into an electronic mixing circuit and tuning the output circuit to the difference frequency. When there is no relative motion between the object reflecting the signal and the transmitter and the receiver, the "beat frequency" or Doppler frequency will be zero. But if there is relative motion, there will be a Doppler frequency which will be a function of the velocity of the motion producing the Doppler frequency. This is the principle employed in police radar sets used to determine the speed of cars. The Doppler frequency is detected in a circuit that is calibrated to show miles per hour rather than cycles per second.

The Doppler effect may also be used to determine the distance and the location of an object in space. If an initial location of the object with respect to the transmitter and the receiver is known at the time t_0, the number of Doppler cycles from t_0 to a later time t_1 multiplied by the wavelength of the transmitted frequency will give the change in the total distance that the wave travels between

t_o and t_1. Since the total distance is from the transmitter to the object and back to the receiver, adding the change in distance to the sum of the starting distances will give the sum of the distances from the transmitter and from the receiver to the object at t_1. It will not give the location for there is no means of determining the direction. If the transmitter and the receiver are at the same location and the object remains on the ground, its location may be anywhere on a circle centered at the transmitter and receiver.

If the object is not confined to the ground plane, its location may be anywhere on a sphere. However, the lower hemisphere may generally be disregarded since it would be below the surface of the ground. If the transmitter and receiver are at different locations, the locus of position in the ground plane will be an ellipse with the transmitter and receiver at the focus points. If the locus of position is not confined to the ground plane, it may be anywhere on an ellipsoid.

Since direction cannot be determined by this system, at least three Doppler distances from known points are required to determine the point location of an object in space. This requires a minimum of three receivers and one transmitter. The locus of points determined by two Doppler distances will be along the intersection of the two figures of revolution, which will be a circle, or half circle since the lower half will generally be underground and may be disregarded. Three Doppler distances, however, will intersect in a single point above the surface of the ground and if the geometry of the locations of the transmitter and receivers with respect to the location of the intersection point is good, accurate determination of its locations can be made.

During World War II the Doppler effect was used in several instrumentation systems for obtaining trajectory information on projectiles fired from guns of many different calibers. Reflection Doppler, however, has a limited range and other methods had to be devised for ranges of over 50 miles.

In 1945 the Beacon Doppler System was considered for use in obtaining ballistic data. Instead of depending upon energy reflected from the missile body, a signal of many times greater amplitude is radiated by a beacon in the missile, thus greatly extending the range of the system. The Beacon Doppler System in the most general form involves transmitting a radio frequency wave from the ground to the missile; receiving and amplifying this signal in the missile; and retransmitting back to the ground receivers a second signal which bears a constant phase relationship to the original signal. This is the system which was developed into DOVAP (Doppler Velocity and Position) and later into UDOP.

Basically, the DOVAP System provides for transmitting a stabilized, continuous wave radio frequency signal from a fixed ground station to the missile; amplifying and doubling the frequency of the signal received by the missile in the missile transponder; and retransmitting this doubled frequency from the missile to three or more fixed ground receivers. A second receiver at each ground receiving station receives the transmitter signal directly and doubles it by the same method used in the transponder. The Doppler frequency is obtained by mixing the radio frequency outputs from the two receivers in a demodulator which detects the difference frequency. This system ensures fixed phase relationship (coherence) between the original transmitter frequency, the missile signal frequency and the reference or comparison frequency and eliminates the technical difficulties encountered in attempting to transmit and receive on the same frequency. The resulting Doppler signals are transmitted to a common location for the purpose of making permanent and continuous records along with timing signals by some recording device. The number of Doppler cycles occurring during a desired unit of time can then be determined from these records.

Selection of the operating frequencies of a Doppler instrumentation system requires making compromises between several factors. Because the frequency is doubled in the missile receiver and the received frequency at the ground receivers is heterodyned with twice the transmitter frequency, each Doppler cycle represents a change in total distance, or range sum, from the transmitter to the missile and back to the ground receiver of one half of the wavelength of the transmitter frequency, or one wavelength of the reference frequency. The total change in the range sum from the transmitter to the missile to the receiver for a given interval of time is determined from the number of Doppler cycles counted during that interval. If the spatial coordinates of the missile position are known at a specific time they may be computed for a later time from the changes in range determined from the Doppler cycles recorded by three or more receivers by solving a group of equations representing the intersection of three or more ellipsoids. The accuracy of this determination depends in part on the accuracy of determining the changes in range sums during the given time interval, that is, the number of Doppler cycles of a given wavelength. Since each Doppler cycle represents a change in the total distance equal to one wavelength of the reference frequency, this wavelength becomes the increment by which the change in distance is measured. The shorter this wavelength becomes, the greater will be the number of increments during a given interval of time, or of unit distance. As the number of cycles per unit distance is increased, the accuracy to which the total distance may be determined is increased in almost direct proportion. In general, then, and within reasonable limits, it may be said that the accuracy of the system increases as the wavelength of the reference frequency is decreased.

On the other hand, the transmission and recording of the Doppler cycles become more difficult when the Doppler frequency becomes high. Counting or digitizing the Doppler cycles also becomes more difficult at high Doppler frequencies. For a given reference frequency, the Doppler frequency which must be recorded is directly related to the velocity of the missile and the geometry of the ground receiving stations with respect to the missile position. The relationship, however, is somewhat complex since the Doppler cycles measure the total change in path length from the ground transmitter to the missile and back to the ground receiver. A simple relation exists only when the missile moves along a straight line passing through the transmitter and a receiver. Then

$$F_d = \frac{V_m}{\lambda_d},$$

where F_d is the Doppler frequency, V_m is the missile velocity, and λ_d is the Doppler wavelength, which is defined as the wavelength of the reference frequency.

This is the maximum frequency which can occur for a given missile velocity. Geometry of the station locations will normally cause the actual Doppler frequency to lower. At certain points on the trajectory the Doppler frequency may be very low or zero even though the missile velocity is high because the direction of motion is such as to cause little or no change in the total transmission path length.

The original DOVAP transmitter frequency of 38.5 mc was chosen because of the electrical characteristics of the antennas already installed in the A4 rockets which were to be tracked and because of the certain types of equipment which were available. The missile-borne transmitter operated at approximately 77 mc at which the Doppler wavelength was approximately 12.76 feet.

The maximum expected velocity of the missiles tracked by the original DOVAP was approximately 5,000 feet per second resulting in a maximum Doppler frequency of about 400 cycles per second. The range of frequencies to be recorded was thus between zero and 400 cps which was approaching the maximum frequency that could be recorded by the equipment that was available at that time. In the original DOVAP System the Doppler frequencies were transmitted from the outlying receiver stations to a master station where they were displayed on cathode ray tubes which were mounted side by side in a rack so that they could be simultaneously and continuously photographed by a 35 mm camera. Each Doppler frequency was applied to the horizontal deflection plates of a separate four-inch cathode ray tube. No vertical sweep was used therefore the Doppler cycles produced a horizontal line across the screen. The 35 mm camera was mounted so that the film motion, which was continuous and uniform, was transverse to the horizontal line produced by the Doppler frequency. The film motion, in effect, supplied the vertical sweep resulting in a sine wave record of the Doppler frequency. Timing lamps mounted between the cathode ray tubes were flashed by timing signals to expose the necessary time base on the film. The Doppler cycles were also recorded by magnetic wire recorders so that they could be audibly monitored for background noise. In the event of failure of the photographic process, these wire recordings could be displayed on a cathode ray tube oscilloscope for making a new film record. Counting the Doppler cycles was largely done by visual means. The first successful DOVAP-supported missile launch occurred in 1953.

As missile velocities and ranges increased and higher accuracies were required, DOVAP became inadequate for the purpose of missile tracking. The long wavelength of 12.76 feet coupled with the fact that a missile could be traveling at a high velocity along a course that would produce a very low Doppler frequency resulted in a condition where each Doppler cycle could represent a missile movement of several hundred or several thousand feet. The loss of even one Doppler cycle could then produce a very large error in the trajectory measurement.

One attempt to reduce the errors in the DOVAP System for longer range missiles was a combination of an up range and a down range system into a single extra long baseline system called XTRADOP. Phase coherence between the two systems was attempted by using the subcable carrier frequency as the basic frequency from which both the interrogation and reference frequencies were derived. With this system, both transmitters would operate simultaneously to transmit phase coherent reference frequencies to their respective receivers while one transmitter would provide the interrogation signal. However, this system was not successful due, in part, to crosstalk in the subcable which could not be eliminated. In the meantime, another system was developed which was proving to be successful and XTRADOP was dropped.

Another way to reduce errors would be to decrease the Doppler wavelength. However, decreasing the Doppler wavelength increases the Doppler frequency which must be recorded. The development of high speed multi-channel magnetic tape recorders made it possible to record Doppler frequencies many times higher than could be recorded by photographic means. The DOVAP System had been improved through the years and magnetic tape has been used as the recording medium since about 1956. About 1958, the DOVAP System was revamped to operate on a frequency more than ten times the original frequency. The transmitter frequency was first changed to 448.2 mc resulting in a reference frequency of 896.4 mc. This was later changed to 450 mc resulting in a reference frequency of 900 mc and a Doppler wavelength of 1.0928 feet per Doppler cycle. The new system was given the name UDOP - Ultra High Frequency DOPpler. This system is constantly being refined and is the system currently in use.

THE UDOP SYSTEM

The excellent quality of the data produced by the DOVAP Stations in the GBI area while supporting the Redstone, Jupiter, and Thor Programs, made this type of CW rate system a natural choice for evaluating the guidance package performance of the PERSHING weapons system. To increase the precision of the proposed velocity measurements, the operating frequency of the DOVAP System (then 73 mc) was changed to 900 mc. This was the birth of the U.H.F. Doppler System known as UDOP.

To adequately cover the PERSHING flight trajectory, three UDOP complexes were planned. The first, to be operated by ABMA (Army Ballistic Missile Agency) personnel would be located near the launch area at Cape Kennedy. The second complex, to be installed and operated by AMR personnel would occupy the old DOVAP sites at Walker Cay, and Carter Cay and would include two new sites, one at Big Carter Cay and the other at Great Sale Cay. The third complex, also AMR operated, would be in the Marsh Harbor, Dundestown, Mangrove Swamp area of Great Abaco. New receiving, transmitting, and communications equipment was ordered for the second and third complexes and facilities construction started at the upper Cay sites. Due to land acquisition problems the Abaco Sites were deleted and all equipment scheduled for that area was diverted to the upper Cays complex thus giving each UDOP site a 100 per cent equipment redundancy. The first PERSHING missile supported by the UDOP System was launched on 25 February 1960. All equipment operated satisfactorily and the test was termed a success. The Down Range UDOP System supported 13 tests between 30 June 1960 and 15 March 1961 with no loss of data encountered due to system or equipment failures or inadequacies. These 13 tests utilized the full UDOP capability, including both passive and active tracking.

Systematic and random errors based on the results of the analysis of these tests are as follows:

DOWN RANGE UDOP

Systematic	.224 meters
Random	.022 meters

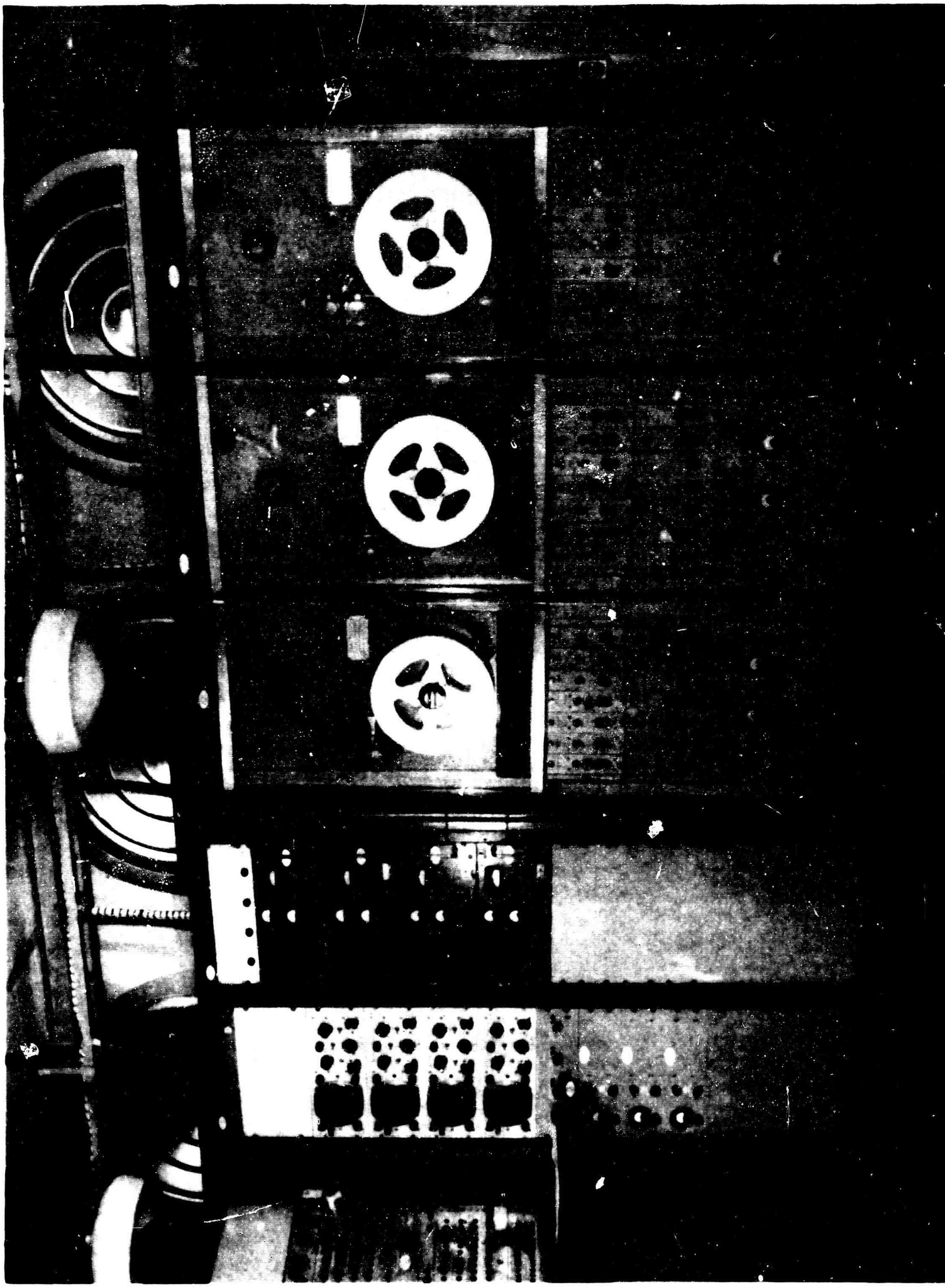


Figure 3 - 1 Photo of Old UDOP Cental Record Station

UP RANGE UDOP

Systematic	.218 meters
Random	.022 meters

The UDOP System used for supporting the PERSHING Program consisted of a 450 megacycle transmitter, a 50 megacycle reference transmitter, 900 megacycle receivers and 50 megacycle VHF receivers. All the doppler gathered at each Cay was sent via data link to Little Carter Cay, which at that time was the UDOP Central Record Station. The doppler data was recorded on CEC Magnetic Tape Recorders. See Figure 3-1.

One of the problems inherent in the PERSHING UDOP System was that the doppler frequency would pass through 0 cps for some trajectories. No offset bias system was used on this program.

Much of the equipment used to support PERSHING is still in use to support MINUTEMAN. Because of its excellent performance record, the Down Range PERSHING UDOP System was formally accepted as an operational range system on 15 May 1961.

Shortly afterwards, it was decided that the UDOP System would be ideal for meeting the data commitments for MINUTEMAN. Since the MINUTEMAN was a solid fueled missile, the flame imposed severe limitations on any precision tracking system which would see the missile from the rear. The NASA Up Range UDOP System, in conjunction with the range operated down range system, could alleviate this problem by looking at the front or side of the missile.

In June 1961, modifications were begun to the down range system to expand its capabilities to handle the MINUTEMAN Program while maintaining its PERSHING capability. On 26 February 1962, the first MINUTEMAN launch to be supported by UDOP took place. To achieve the proper configuration for MINUTEMAN support, two new receiver stations were added to Allans Cay and Bassett Cove, GBI. Later the Great Sale site was relocated to West End, GBI. This station configuration provided good GDOPS for the period of track required by the MINUTEMAN trajectory. In addition to this, four narrow-band phaselock receivers were placed at Walker Cay, Bassett Cove, Allans Cay, and Little Carter. These allowed better signal acquisition and tracking since they were much more sensitive than

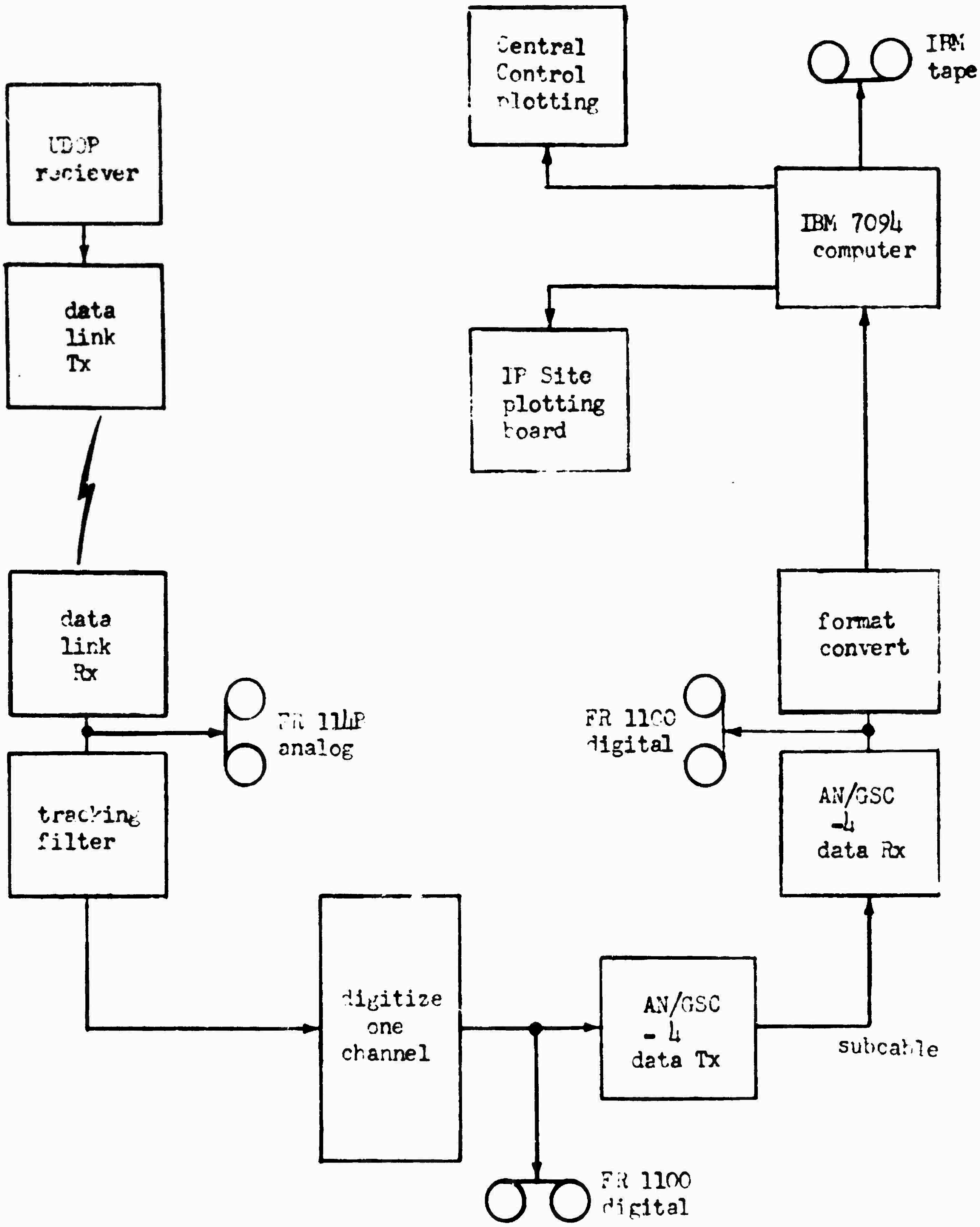


FIG. 3-2 REAL TIME DATA FLOW OF UDOP INFORMATION

the standard receivers. Presently, the West End site has the phaselock receiver from Carter, and Carter operates with two standard receivers. Several other improvements were undertaken including a steerable transmitting antenna, new helical receiving antennas and a new Data Handling System at Bassett Cove for real time support. The first MINUTEMAN flight to utilize this real time capability took place on 27 June 1963.

For a comprehensive view of the UDOP real time flow, see Figure 3-2. The doppler frequencies are derived from the UDOP receivers at all sites. There are 10 receivers in the UDOP System. Eight of these are located in the Cays and at West End, GBI. These outlying sites require a data link system to transmit the UDOP data from the receiver to the central record station at Bassett Cove, GBI. Because of atmospheric noise inherent in VHF data links, tracking filters are used to clean up the doppler signal before it is passed into the UDOP digitizer.

The data format of the six available digitizer words in real time are as follows:

Word 1	Carter Cay Receiver System C
Word 2	Allans Cay Receiver System L*
Word 3	Bassett Cove Receiver System O
Word 4	Walker Cay Receiver System J*
Word 5	Bassett Cove Receiver System P*
Word 6	West End Receiver System H*

The digitizer format for real time use was selected for the IP routine by a combination of optimum geometry and UDOP receiver performance. It will be noted from the format that all the phase-locked UDOP receivers are used in the real time solution. This was because of better performance during the critical flame period and because the phaselocked receivers can indicate whether they are tracking or not by relay closure.

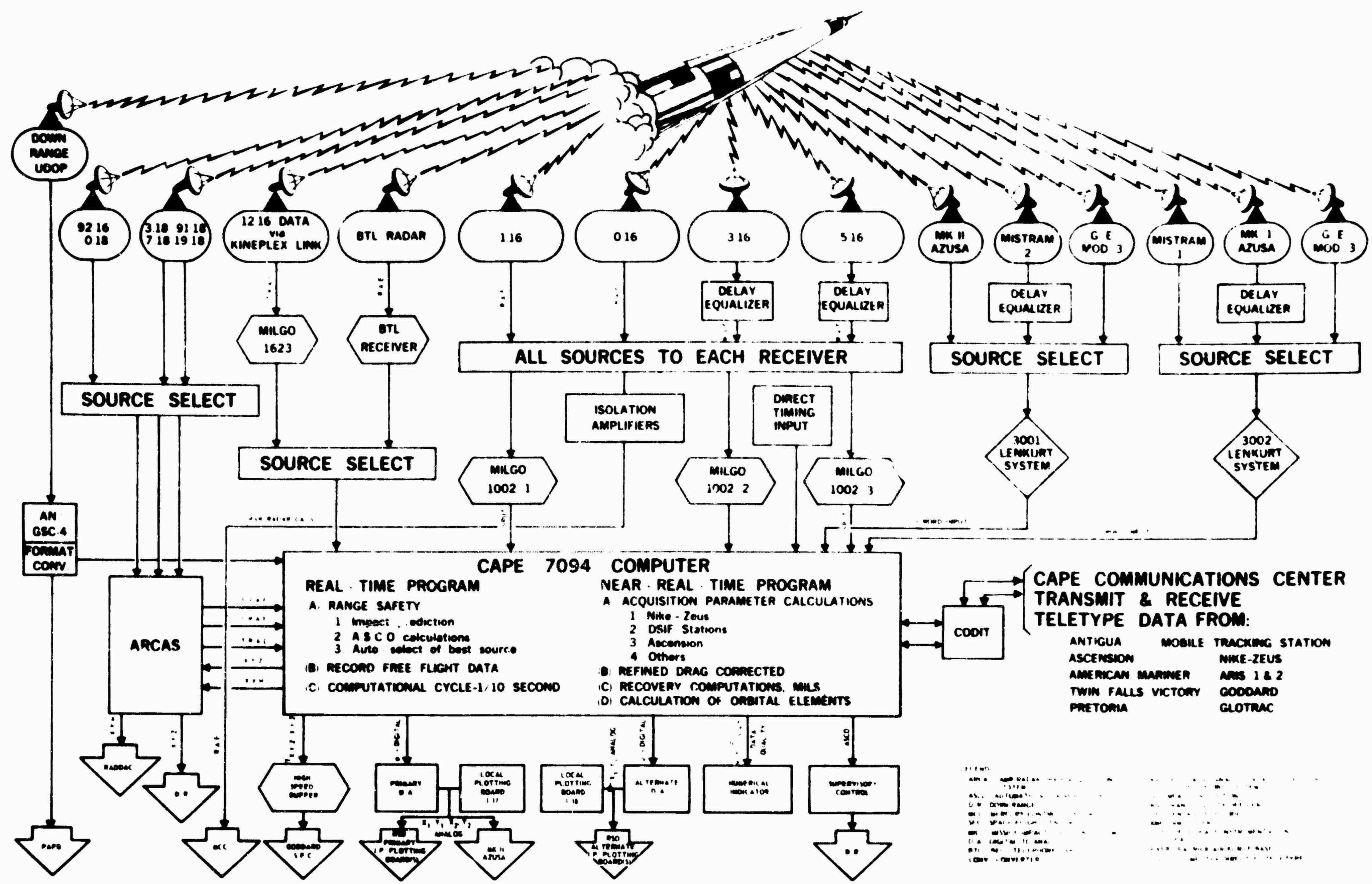
The real time program requires that some sort of validity check be included in the data train, so that the computer will not operate on bad data. It is possible for the UDOP receivers to be locked onto the wrong doppler signal, which is disastrous to the impact prediction routine. For this reason, the relay closure of each phaselocked receiver is combined with the relay closure of each associated tracking filter, so that a "flag" is inserted in the data train only when both units are locked to the doppler signal. These validity checks are called the on-track bits.

Those stations suffixed with an (*) are phaselocked receiver systems. It will be noted here that the Bassett Cove System P, the phaselocked receiver in the same building as the digitizer, does not go through a tracking filter. The standard UDOP receiver located at Bassett Cove does go through the tracking filter because of its lower signal to noise ratio, and generally poorer performance.

The digitizer converts all six input doppler signals to digital mode, inserts a range time and other data (see section on digitizer) and drives the AN/GSC-4 data transmitter. The data is sent via four miles of 19 guage twisted pair from Bassett Cove, GBI, to the GBI subcable terminal, where it is placed on the submarine cable for transmission to the Cape Impact Predictor Facility. The AN/GSC-4 data receiver, which is located in the Impact Predictor Facility with the format converter, converts the serial data output of the AN/GSC-4 to parallel digital information and feeds the IBM 7094 Computer at the proper rate and time.

The Impact Predictor Facility uses the UDOP data to compute a predicted impact location in the event the missile terminates thrust any time during powered flight. The output of the UDOP computer routine is fed to the alternate IP plotting boards as a back-up to other range safety sources. The alternate plotting boards are located in the Impact Predictor Facility and at Central Control.

As noted from the flow diagram, the UDOP data is recorded (raw doppler) in analog mode before it is digitized and also in various digital modes. During real time operation, the computer generates a tape on which the UDOP is written, along with all other IP input data. For a block diagram of the complete Impact Predictor Facility, and the way in which UDOP fits into it, see Figure 3-3.



(PREPARED AUGUST 1963)

FIG. 3.3

As noted in the real time data flow, the raw UDOP data is recorded on Ampex FR-114B Analog Tape Recorders. This is the primary raw data recording. There are also recorders on the output of the digitizer, the input of the format converter, and on the IBM 7094 Computer used with the metric data of the UDOP System. (See Figure 3-4.)

The recorder at the output of the digitizer records only that data being digitized and has only a 6-station capability. This recorder uses serial digital recording techniques, although the transport is an analog machine. The same type of recorder is used at the input of the format converter. The format converter recorder can serially record all the digital data coming from the AN/GSC-4 data receiver. This FR-1100 at the Impact Predictor Facility is the playback unit for the FR-1100 recorder at Bassett Cove, in the event the subcable is not available for use, and the tapes must be transported up range at a later date.

The most important feature of the FR-1100 at the Impact Predictor Facility is that all the raw data can be played back through the subcable immediately after a mission, copied on the FR-1100 in three or four passes, and then played into the computer in one continuous run, as computer time is available. It will be noted in the flow diagram that there is a data link between the Impact Predictor Facility and the Technical Laboratory on Patrick Air Force Base. The format converter has an output which transforms serial digital data into Lenkurt FM Tones, compatible with existing Lenkurt Data Receivers. This Lenkurt-type data is transmitted via equalized phone lines to the Technical Laboratory where it is fed into a tape to tape converter for conversion into IBM digital information. This data link eliminates all physical transport of magnetic tapes and the resulting possible damage and eliminates the use of the IP machine for format conversion.

The Ampex FR-114B is a 14 channel analog recorder with precision speed control. There are two of these recorders at Bassett Cove for the recording of all the UDOP data from all sites. Included on the tape with the doppler information are such signals as timing, servo control etc. The tape format of each of these analog recorders is as follows:

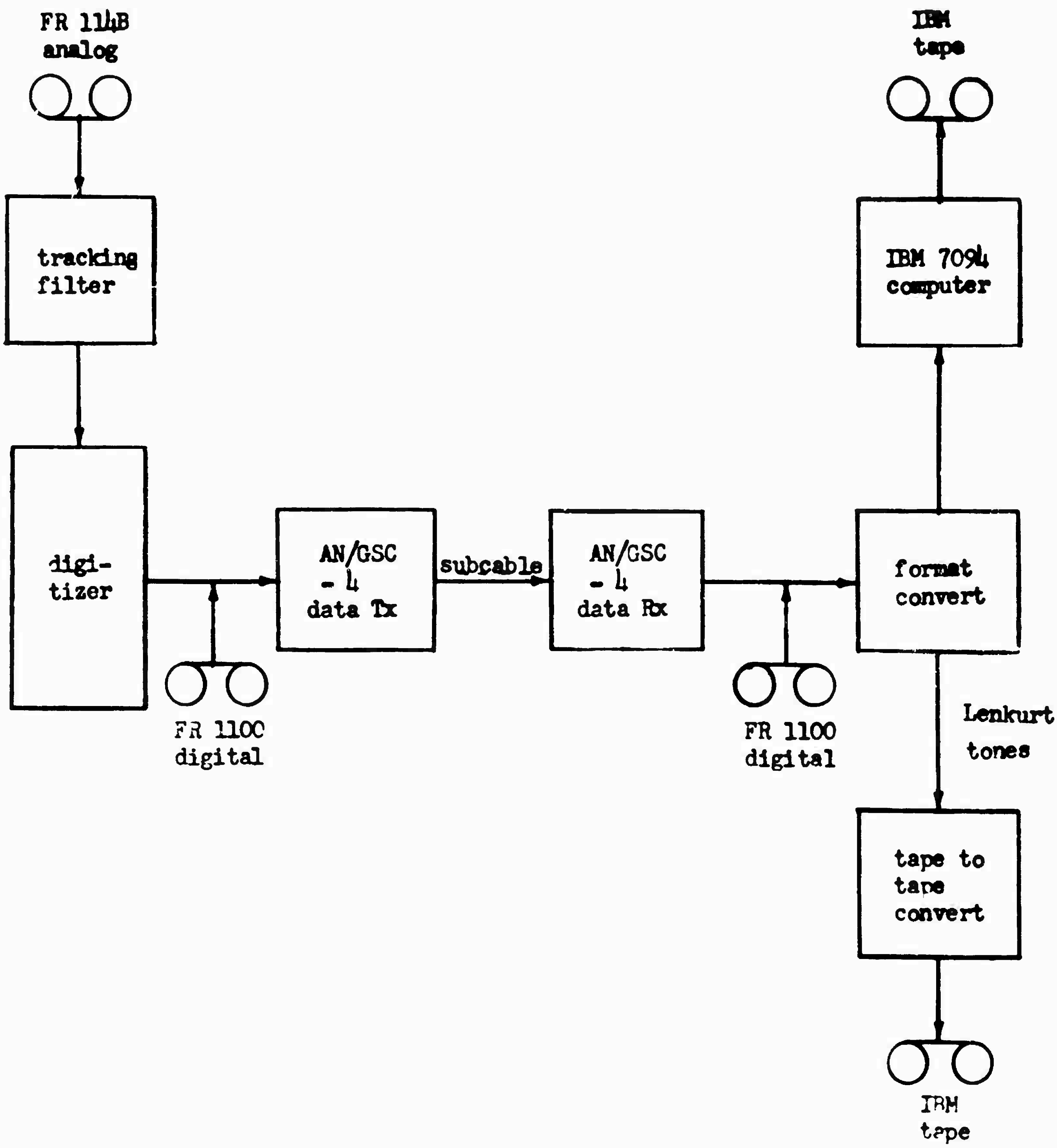


FIG. 3.4 POST FLIGHT METRIC UDOP DATA FLOW

CHANNEL	RECORDER #1	RECORDER #2
1	500 pps Identifiers	500 pps Identifiers
2	5 KC	5 KC
3	Walker K	Walker K
4	10 pps	10 pps
5	Bassett O	Bassett O
6	Allans M	Allans M
7	100 pps 17 bit time code	100 pps 17 bit time code
8	Walker J*	Walker J*
9	Carter C	Carter D
10	West End H*	West End G
11	Bassett P*	Bassett P*
12	Allans L*	Allans L*
13	500 pps 21 bit time code	500 pps 21 bit time code
14	Servo Control	Servo Control

Those stations with an (*) are phaselocked receiver sites.

It will be noted here that the 5 KC signal recorded on these tapes is used for mathematical tape speed compensation over and above the servo control feature. The 5 KC is digitized along with five doppler signals during playback. Any deviation from 5 KC results in mathematical compression or expansion of the associated doppler signal during data reduction.

No matter what route the metric data takes, through DARE or through the down range digitizer, the results are an IBM compatible digital tape suitable for computer entry.

The following paragraphs cover the intersite communications net for the Down Range UDOP System. This includes both voice and data transmission.

VOICE

Intra-coordination between Carter and the outlying Cays is accomplished via VHF point-to-point communications gear. The equipment involved is standard An/TRC gear, multichannel, fixed frequency and of ancient vintage. Communications between Carter Cay and Bassett Cove, GBI, and between West End, GBI, and Bassett is via Motorola microwave. For a detailed resume of communications channels and frequency assignments, see C-602519. (Figure 3-5)

Status of any station is passed from the sites to Bassett Cove, where it is relayed to the CW systems coordinator. During real time operation for mission support, status information is also relayed to the impact predictor site at CKMTA via the CWC net. The CWC net is also used to coordinate any countdown checks with the computer and for post flight data playback.

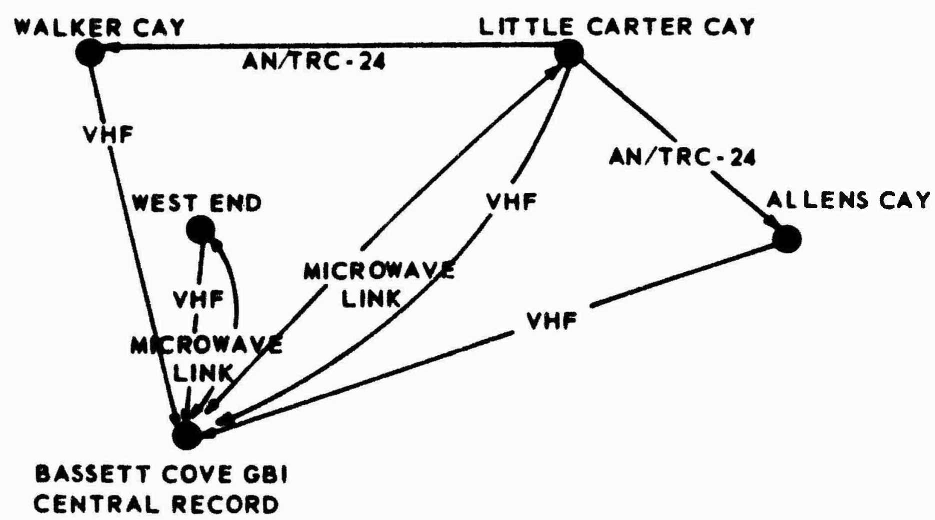
DATA

The doppler data links are Gates CS 1976 FM transmitters. These data links convey the output doppler signal from each receiver site to Bassett Cove. There is a separate data link channel for the standard receiver and for the phaselocked receiver from each site. There are eight data link receivers at Bassett Cove to gather all the necessary signals from the outlying sites. These receivers are tunable and are connected to directional antennas mounted on the tower at Bassett Cove.

In addition to the doppler data links within the system, the final output of the UDOP System is fed by means of a data transmission system from Bassett Cove to GBI subcable central over 19 AWG pair and from GBI central to CKMTA via the submarine cable circuit 10CC89 (Channel 6).

CIRCUIT DESCRIPTION

	RF PATH	CIRCUIT	MOD	BANDWIDTH	FREQ	DUPLEX	CHANNELS	USE
1	BASSETT COVE → LITTLE CARTER CAY	P-19	FM	12 KC	7295 MC	7615 MC	12	VOICE
2	LITTLE CARTER CAY → BASSETT COVE	P-19	FM	12 KC	7135 MC	7455 MC	12	VOICE
3	LITTLE CARTER CAY → ALLENS CAY	P-11	FM	68 KC	393.5 MC		12	VOICE
4								
5	LITTLE CARTER CAY → WALKER CAY	P-11	FM	68 KC	396.5 MC		12	VOICE
6	ALLENS CAY → LITTLE CARTER CAY	P-11	FM	68 KC	372.5 MC		12	VOICE
7								
8	WALKER CAY → LITTLE CARTER CAY	P-11	FM	68 KC	376.5 MC		12	VOICE
9	WALKER CAY → BASSETT COVE	P-6	FM	100 KC	141.93 MC	136.25 MC		DATA
10	WEST END → BASSETT COVE	P-6	FM	100 KC	141.10 MC	138.25 MC		DATA
11	ALLENS CAY → BASSETT COVE	P-6	FM	100 KC	137.61 MC	139.50 MC		DATA
12	LITTLE CARTER CAY → BASSETT COVE	P-6	FM	100 KC	142.75 MC	143.75 MC		DATA



NOTES:

A. VOICE AND DATA CENTRAL AT BASSETT COVE. CONTROL MAINTAINED FROM THIS POINT

B. CHANNEL ASSIGNMENTS ON EACH FREQUENCY. MAY VARY WITH SUPPORT FUNCTIONS

C. VOICE CONTACT WITH CWC NET AT BASSETT COVE ONLY.

STATION CALL SIGNS (UDOP)

WALKER CAY	CRIMSON 41
ALLENS CAY	CRIMSON 44
LITTLE CARTER CAY	CRIMSON 42
LITTLE CARTER XMTR.	CRIMSON 42 XMTR.
WEST END	CRIMSON 3-6
BASSETT COVE	CRIMSON 3-0

FIG. 3-5 UDOP COMMUNICATIONS LAYOUT

The 500 pps position identifiers are a time code which, in conjunction with the 500 pps 21 bit time code, is loaded into a digital register directly. These two codes are used by the UDOP digitizer to obtain the proper time tag for each data sample.

The 100 pps. 17 bit time code is recorded on these tapes for use by DARE.

The 10 pps time code is the code used by the digitizer for synchronizing the data sampling rate with the taped range time signal.

The servo control channel contains the error signal generated by the recorder, in the record mode, so that when the tape is reproduced, the speed of the tape can be made to follow the same profile as when it was recorded. This is a means of controlling tape speed enough so that mathematical techniques can resolve the fine grain tape speed variations. (5 KC reference source) The raw doppler tapes are played back after a test through tracking filters into the digitizer, then up the sub cable and into the Impact Prediction Computer. Copies can be made at the input to the format converter or by the computer. Because the digitizer can only process six channels at a pass, the metric data (raw doppler) is run through the digitizer twice. The formats for these two passes are as follows:

	PASS #1	PASS #2
Word 1	Allans L	Allans M
Word 2	Walker J	Walker K
Word 3	West End G	West End H
Word 4	Bassett P	Bassett O
Word 5	Carter C	Carter D
Word 6	5 KC reference	5 KC reference

Upon completion of successful data playback, the raw doppler tapes are sent to Patrick Air Force Base for data reduction passes through DARE. DARE, in this case, provides back-up data reduction capability in the event the digitizer data is bad or cannot be used.

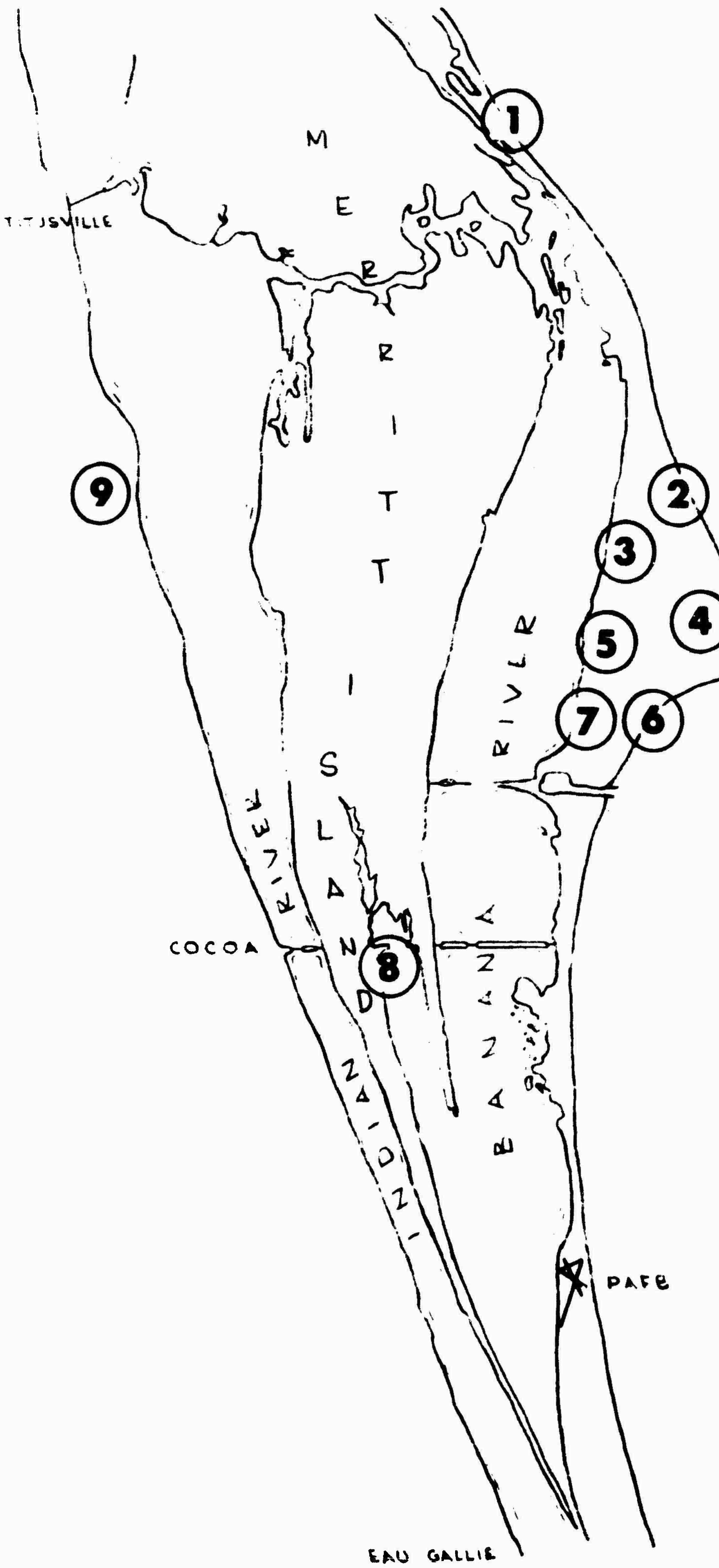
The NASA UDOP System (see Figure 3-6), is similar to the Down Range UDOP System in all respects. There are minor differences in operation due to the fact that the NASA System has to support missions from lift-off. The normal limits of NASA coverage is from T-0 to T+65 seconds during a MINUTEMAN launch and longer on NASA shots. The NASA System can also copy doppler information from the missiles in a passive mode. The down range system is the interrogation source in this passive mode and the NASA receivers have no coherence to the transmitted signal.

One of the differences of the NASA System is the offset frequency employed. NASA uses a 5 KC offset frequency system, which is additive to the doppler signal. Due to the geometry involved, the doppler signal received at all NASA sites is always increasing and never passes through a null. On the pad, the output doppler frequency of all NASA sites if 5 KC and any doppler signal from lift-off onwards is greater than 5 KC. The 5 KC offset system utilizes the transmission of 277.7 cps plus the basic 50.00 mc from the reference transmitter. Multiplied by 18 in the UDOP receivers and compared to the 900 mc data signal, it produces an output of 5 KC and doppler.

A second difference in the NASA UDOP System is the final output. At the present time, all doppler signals gathered at Hangar D (UDOP Central) are recorded on magnetic tape. This output tape is sent to the Technical Laboratory for reduction through DARE and also sent down range immediately after a launch for post-flight reduction through the Down Range UDOP Digitizer.

NASA has presently under contract a digitizer for real-time digitization of their doppler signals with the final output being an IBM compatible tape. The NASA UDOP System uses only an internal communications net for coordination. No other communications to AMR is used other than Go/No-Go indication derived from transponder interrogation before lift-off. The format of the NASA UDOP tapes are as follows: Note that NASA uses two 1" and one 1 1/2" magnetic tape recorders.

CHANNELS	Ampex No. 100 1" Tape	Ampex No. 400 1/2" Tape
1	Voice	Voice
2	Playalinda Beach (PL)	Site C



NASA SITE IDENTIFICATION

1. Playalinda Beach
2. Blockhouse
3. Hanger D (UDOP CENTRAL)
4. Site C
5. Mandy
6. Cactus
7. Site B
8. Merritt Island Airport
9. Cocoa-Titusville Airport

FIG. 3-6

CHANNELS	Ampex No. 100 1" Tape	Ampex No. 400 1/2" Tape
3	Titusville-Cocoa Airport (PL)	Site B
4	Merritt Island Airport (PL)	Cactus
5	100 pps	100 pps
6	500 pps P.A.	Direct Offset
7	500 pps P.I.	Mandy
8	Receiver Offset	
9	Playalinda Beach (STD)	
10	Titusville-Cocoa Airport (STD)	
11	Merritt Island Airport (STD)	
12	Hangar D (STD)	
13	Blockhouse 34 (PL)	
14	Mandy (PL)	

PL - Phaselock

STD - Standard

CHANNELS	Ampex No. 300 1" Tape
1	500 pps I.D.
2	Direct Offset

CHANNELS	Ampex No. 300 1" Tape
3	Titusville-Cocoa Airport (PL)
4	10 pps
5	Playalinda Beach (PL)
6	Merritt Island Airport (PL)
7	100 pps
8	Cactus
9	Playalinda Beach (STD)
10	Titusville-Cocoa Airport (STD)
11	Site C
12	Site B
13	500 pps P.A.
14	60 cycle

The 500 pps presence/absence, 21 bit time code, and the 500 pps position identifiers are placed on the 300 tape unit for the down range digitizer to obtain the range time when the associated doppler signals occurred. The 10 pps timing signal is used to check and drive the down range digitizer signal generated by the tape recorder while it is trying to maintain correct capstan speed. This error signal can be used to drive another recorder so that the second recorder can follow the speed variations that occurred during the recording.

The direct offset frequency is also recorded for post flight reduction to check on stability of the reference signal and as a check on tape speed variation.

Playback of NASA data from GBI after a test usually takes about one hour. The computer at the impact predictor site copies this data and generates an IBM digital tape for further reduction.

The equipment used by NASA to supply UDOP data is very similar to that used in the down range complex. There are some minor differences in complexity and function due to the more stringent support requirements on the NASA equipment for support of other programs. Much of the NASA equipment is similar to that used down range. There is also much equipment redundancy within the NASA UDOP System.

Within the next few months the Up Range UDOP System will be converted to an offset doppler system and will only return to UDOP configuration for MINUTEMAN support.

The offset doppler (ODOP) interrogator system is designed to extend the existing UDOP frequency doubling (450/900 mc) tracking system to phase-coherent offset (890/960 mc) capability. It provides a high power 890 mc interrogation signal to missile or space vehicle-borne transponders and additionally, furnishes a 53 1/3 mc reference signal which can be used to drive existing VHF-UDOP reference transmitters. These output frequencies as well as others are all phase-coherently derived from any of several input frequencies supplied by precision frequency standards or from an internally included stable VCXO (voltage controlled crystal oscillator). All critical systems can be backed up with duplicate systems with a quick change-over feature for uninterrupted operation under field conditions.

The total ODOP System consists of the regular UDOP, VHF and UHF receivers at various locations along with the existing reference and test transmitters. The existing reference transmitters and receivers must be retuned to 53 1/3 mc while the test transmitters must be retuned to 960 mc. A 960 mc transponder simulator is available which takes the place of the test transmitter and provides the system with a complete simulation of the overall ground-to-air and air-to-ground offset doppler system for checkout purposes.

In addition to the above mentioned existing components, the system involves a phaselocked frequency synthesizer which gives the basic output frequencies of 53 1/3 mc, 890 mc and 960 mc. These include the reference, the interrogator and the simulator frequencies. Along with the synthesizer, the additions to the system include an 890 mc transmitter for interrogation of the missile-borne transponder.

The operation of the ODOP System is of course similar to that of the UDOP System. The main differences are as follows. The transponder is interrogated with an 890 mc signal. The transponder receives the 890 mc signal along with an additional doppler frequency and retransmits a phase-coherent 960 mc signal along with the doppler frequency. The receivers capture the 960 mc signal, the original doppler shift and an additional doppler. The doppler is taken from the 960 mc basic signal by comparison with the 53 1/3 mc reference frequency times 18. The data output of the receiver is then a phase-coherent doppler signal which is transmitted via a data link to the central record digitizer site.

The ODOP System possesses several inherent advantages over the UDOP System, primarily resulting from the choice of frequencies. Since the propagation effects vary inversely as the square of the frequency, the ODOP System should have approximately 1/4 of the propagational error of the UDOP System (890 vs 450 mc). Another advantage is derived from the offset technique employed. This technique eliminates any interference from harmonics of the transmitted signal, that might be experienced in the UDOP 450/900 mc frequency doubling scheme. Still another advantage is provided by the phase-coherency of the ODOP System. This eliminates any errors produced by internal phase shift in the equipment. A fourth advantage is realized from the change in transmitted frequency from 450 to 890 mc. There is an ionospheric refraction error present during daytime usage of the UDOP System which will be reduced by a factor of 2.5 with the change to ODOP.

A complete offset doppler interrogator system and spares can be procured. This system may be either a simplex system containing a phaselocked frequency synthesizer, an 890 mc power amplifier with an output of 250 watts and a transponder simulator (test transmitter) with broad band antenna, or a duplex system containing all the above and back-ups for the synthesizer and power amplifier.

Some additional modifications would have to be made to the existing receiver sites to make them compatible with the altered frequencies of the new system. (see Figure 3-7 and 3-8).

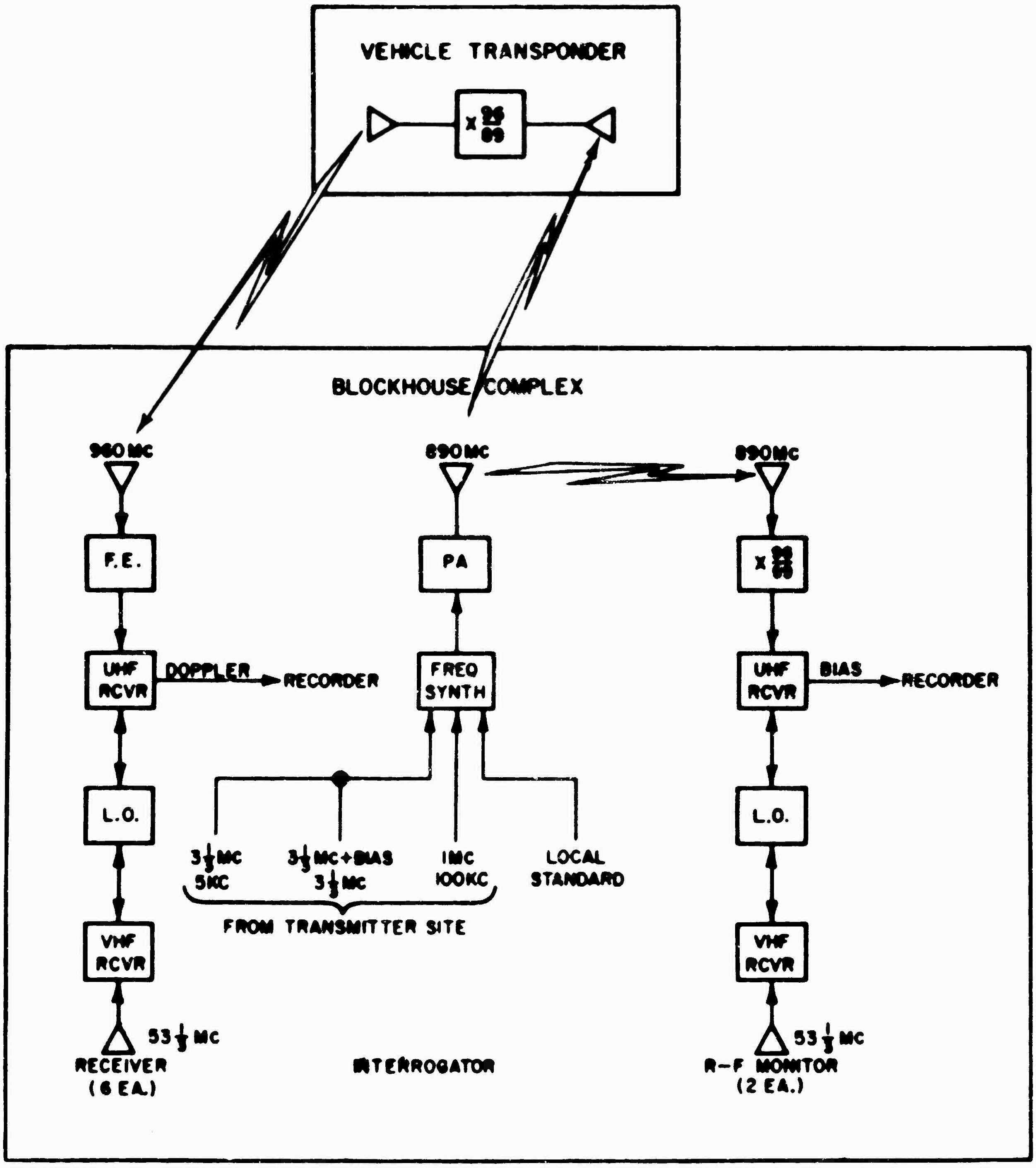
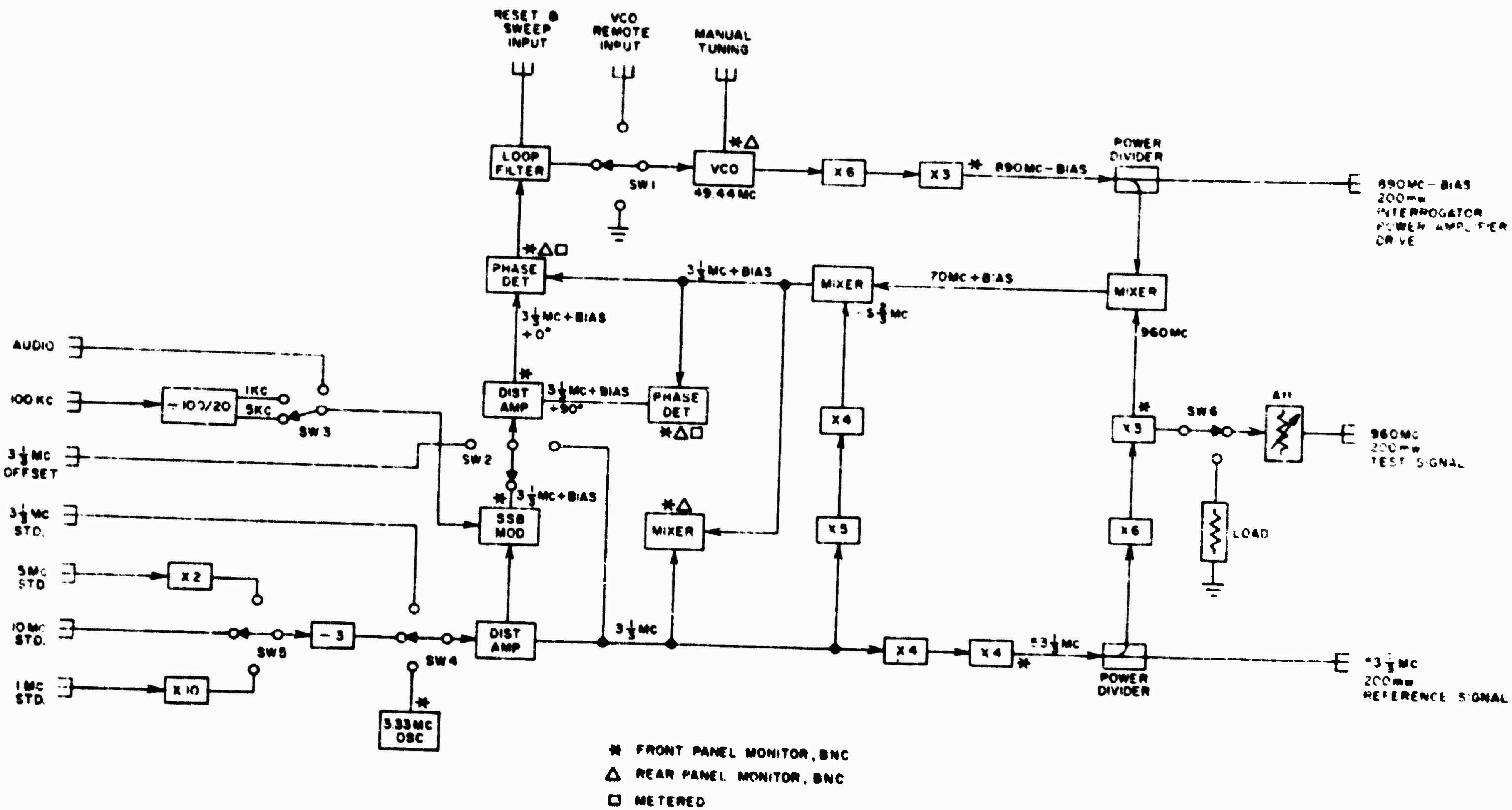

VEHICLE TRANSPONDER
BLOCKHOUSE COMPLEX
960 MC
890 MC
890 MC
F.E.
PA
UHF RCVR
DOPPLER
RECORDER
FREQ SYNTH
UHF RCVR
BIAS
RECORDER
L.O.
L.O.
3 1/3 MC 5KC
3 1/3 MC+BIAS 3 1/3 MC
1MC 100KC
LOCAL STANDARD
FROM TRANSMITTER SITE
VHF RCVR
VHF RCVR
53 1/3 MC
RECEIVER (6 EA.)
INTERROGATOR
53 1/3 MC
R-F MONITOR (2 EA.)

FIG. 3-7



SIMPLIFIED SYNTHESIZER FUNCTIONAL BLOCK DIAGRAM

FIG. 3-8

THE UDOP TRANSMITTER SYSTEM

The UDOP transmitter system contains two 1000-watt, two 800-watt and one 100-watt stabilized frequency, continuous wave transmitters capable of simultaneously transmitting three phase-coherent signals on different frequencies. These three signals are a 450 mc interrogation signal to the missile, a 50 mc reference channel frequency to all of the receivers and a 900 mc test signal to all of the receivers. The 450 mc and 50 mc signals are normally transmitted during the missile flight. The 900 mc test signal may be transmitted for system checkout purposes between flight tests but is not transmitted during a flight.

The down range transmitter system is shown in simplified, functional block diagram form in Figure 3-9. The block diagram shows almost complete back-up facilities in the transmitter system.

Phase coherence between the transmitted frequencies is established and maintained through the use of a common signal generator. Through a patch panel arrangement, the common frequency may be taken from an NC 1001 Atomichron, from any one of the three Gates Model M-5709 Radio Frequency Reference Oscillators, or from the HP 104AR ultra-stable oscillator. Because the Atomichron gives a more stable frequency than the Gates oscillators, it has normally been used during missile tests. The Gates oscillators are used for checking out the equipment and other operations where extreme accuracy is not required. An HP 104AR is the present frequency generator of this system.

The Atomichron is used chiefly as a standard for comparison for the output of the ultra-stable oscillator.

The 50 mc output of each signal generator is brought to a jack on a patch panel where it is available for application to a choice of final amplifiers and transmitters. The signal is fed directly to either of two 1,000-watt, 50 mc VHF transmitters for transmission as the reference channel frequency to the various receiver sites. The 50 mc signal is also fed through either of two times nine multiplier circuits and 1,000-watt, UHF transmitters to be transmitted as a 450 mc interrogation signal to the missile. These two frequencies are the operating signals transmitted by the UDOP transmitter system.

There is also a 900 mc transmitter which may be switched in to transmit a 900 mc test signal to the receiver sites for checkout purposes. The 50 mc signal is fed through a times 18 frequency multiplier to become 900 mc at the final power amplifier. This signal, received at the receiver sites, simulates a signal received from a missile on the pad and has no Doppler components. Because it is derived from the same basic frequency as the reference frequency, the two frequencies will be phase coherent and the output of the receiver should be zero cycles of 18 KC if offset biasing is used.

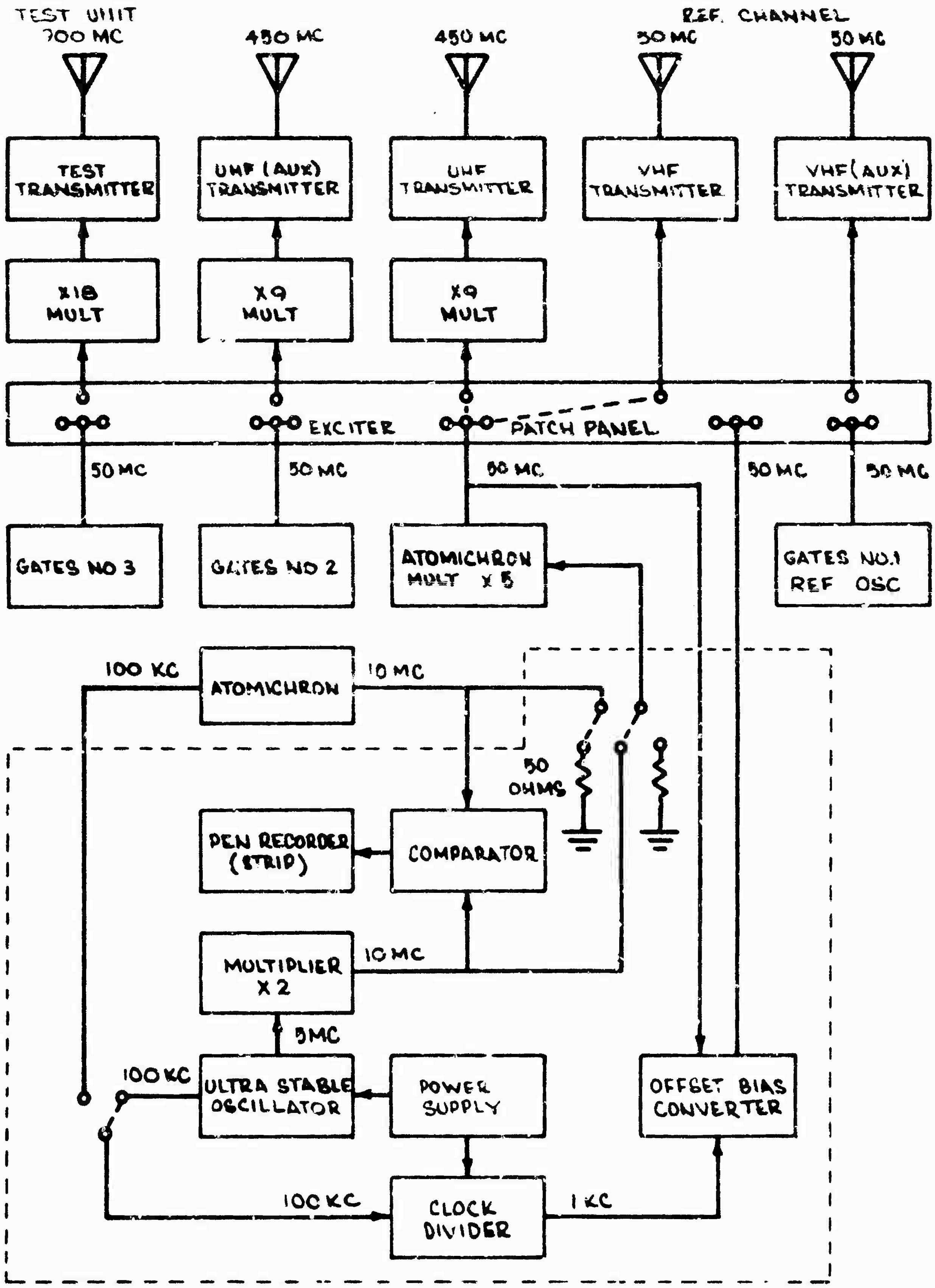


FIG. 3-9 THE DOWNRANGE UDOP TRANSMITTER SYSTEM

During the early days of the down range UDOP system, low velocities and short trajectories were the standard parameters of each missile program that was supported. After MINUTEMAN came on the AMR, with a considerably longer, higher, and faster trajectory, certain anomolies in the doppler signal were apparent. Heretofore, missiles impacted within the UDOP geometry itself. (See Figure 3-10). MINUTEMAN, however, is under thrust as it passes the down range UDOP complex. A new range of doppler velocities is thereby generated.

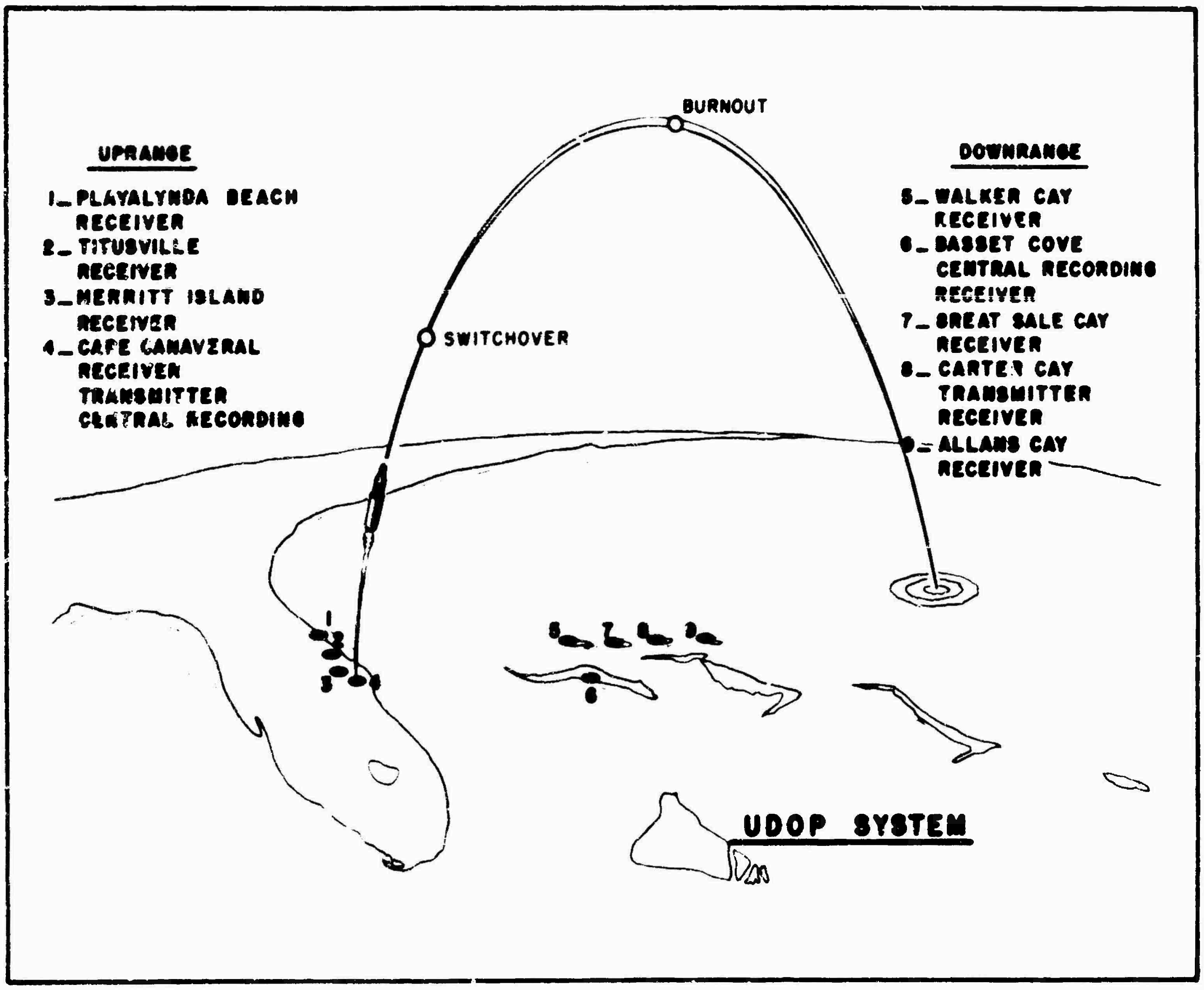


FIG. 3-10

A typical MINUTEMAN trajectory will generate a decreasing doppler during the early phase of its flight. This is due to the position of the missile approaching the down range UDOP sites. As the missile passes tangentially at each receiver site, the doppler frequencies change direction and start increasing. They continue to increase thereafter as the aspect angle of each site is from behind. As a rough doppler frequency plot, see Figure 3-11.

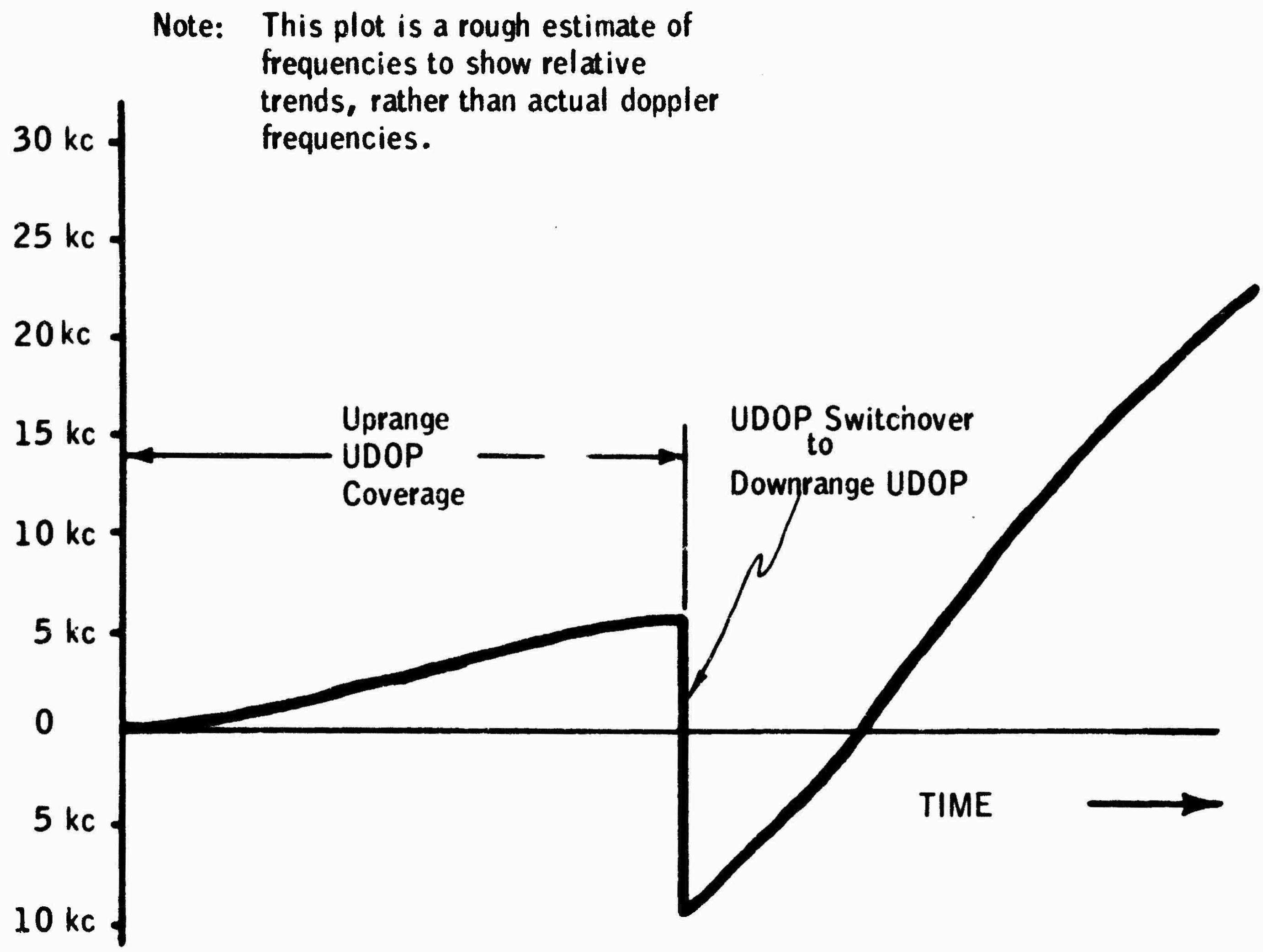
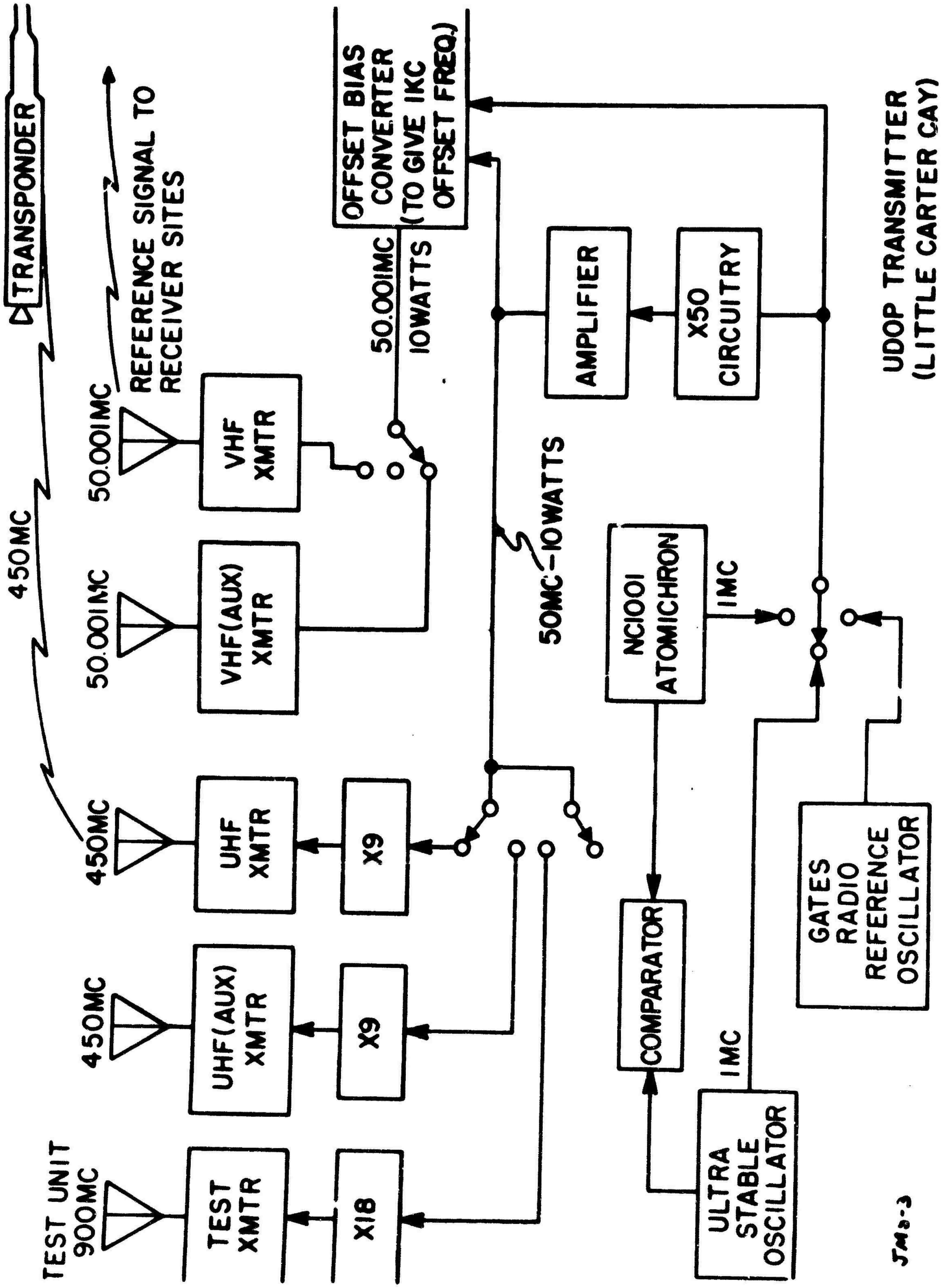


FIG. 3-11 PLOT OF APPARENT DOPPLER FREQUENCIES AS SEEN BY THE DOWNRANGE DIGITIZER

It will be noted from Figure 3-11 that the doppler frequency passes through zero cps. It is very difficult for electronic quantizing apparatus to digitize this region of extremely low doppler frequencies. Such measurements have been accomplished by visually counting doppler cycles from oscillograph recordings. With the tremendous volume of UDOP data generated during a test, this method is not feasible and not very accurate.



TRANSPONDER
REFERENCE SIGNAL TO RECEIVER SITES
OFFSET BIAS CONVERTER (TO GIVE 1KC OFFSET FREQ.)
50.001MC 10WATTS
450MC
50.001MC
VHF XMTR
50.001MC
VHF(AUX) XMTR
50MC-10WATTS
AMPLIFIER
X50 CIRCUITRY
UDOP TRANSMITTER (LITTLE CARTER CAY)
NC1001 ATOMICHRON
1MC
450MC
UHF XMTR
X9
450MC
UHF(AUX) XMTR
X9
TEST UNIT 900MC
TEST XMTR
X18
COMPARATOR
1MC
ULTRA STABLE OSCILLATOR
GATES RADIO REFERENCE OSCILLATOR

Figure 3 - 12

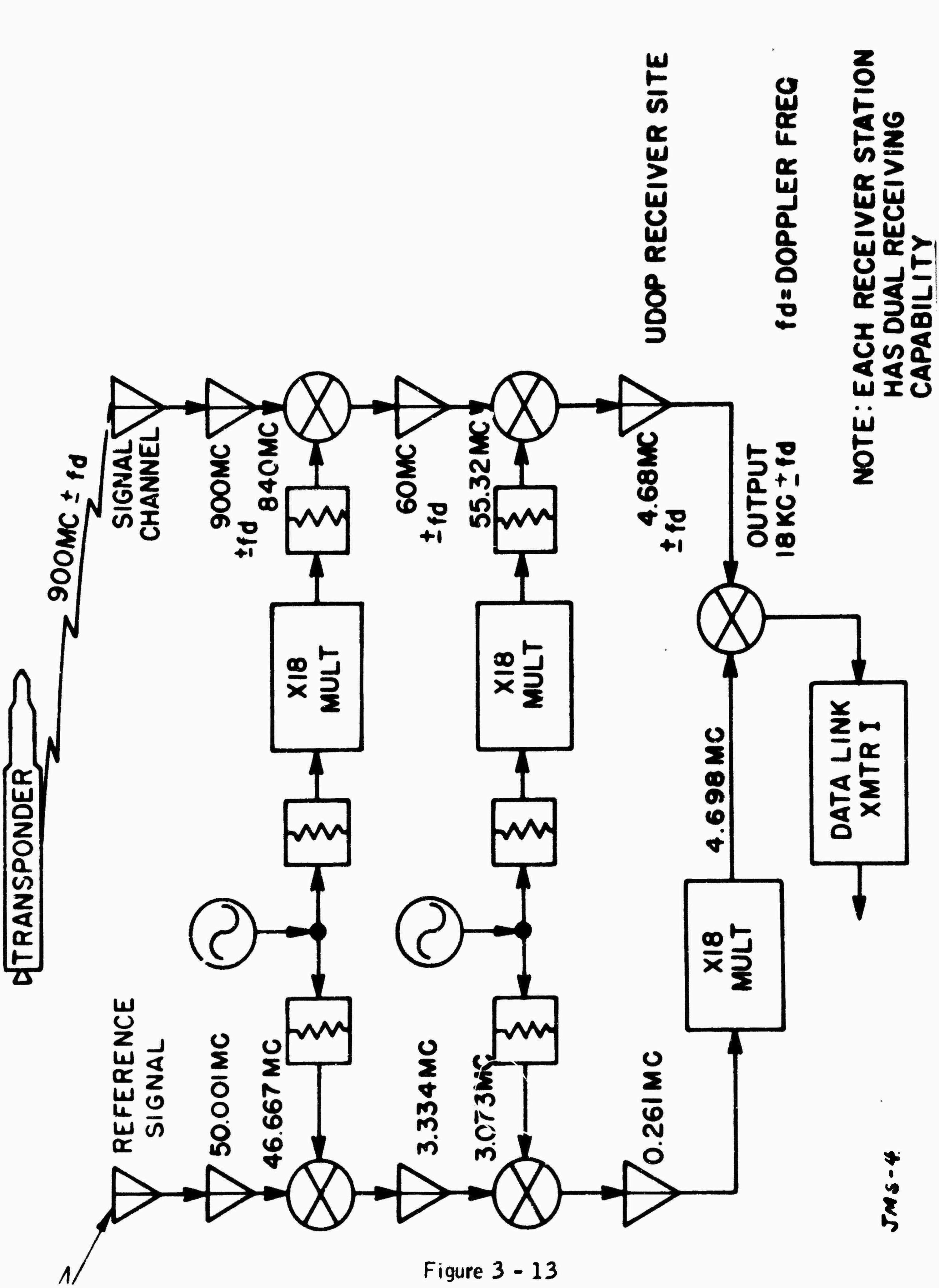

TRANSPONDER
900MC ± fd
SIGNAL CHANNEL
900MC ± fd
840MC
60MC ± fd
55.32MC
4.68MC ± fd
OUTPUT 18KC ± fd
X18 MULT
X18 MULT
X18 MULT
4.698MC
DATA LINK XMTR I
REFERENCE SIGNAL
50.001MC
46.667MC
3.334MC
3.073MC
0.261MC
UDOP RECEIVER SITE
fd=DOPPLER FREQ
NOTE: EACH RECEIVER STATION HAS DUAL RECEIVING CAPABILITY

Figure 3 - 13

To eliminate the zero frequency effect, or null, a method was devised to offset the apparent doppler frequency generated from the missile. A 1 KC coherent signal is mixed with the 50 mc reference frequency, (See Figure 3-12) so that the received reference at each site is 50.001 mc. After multiplication in the UDOP Receiver by 18, the reference signal appears, in effect, as 900.018 mc. (See Figure 3-13). For a steady state check of system performance, a 900 mc test transmitter signal is compared at each site with the offset reference signal, and the resulting doppler output is a very stable 18 KC. This method of system checkout is used during the countdown as a measure of system performance, encompassing the entire RF and digital system. As seen by Figure 3-14, with an 18 KC offset, the received doppler frequencies from the missile never pass through zero. This enables both DARE and the down range digitizer to completely digitize the entire MINUTEMAN doppler trajectory.

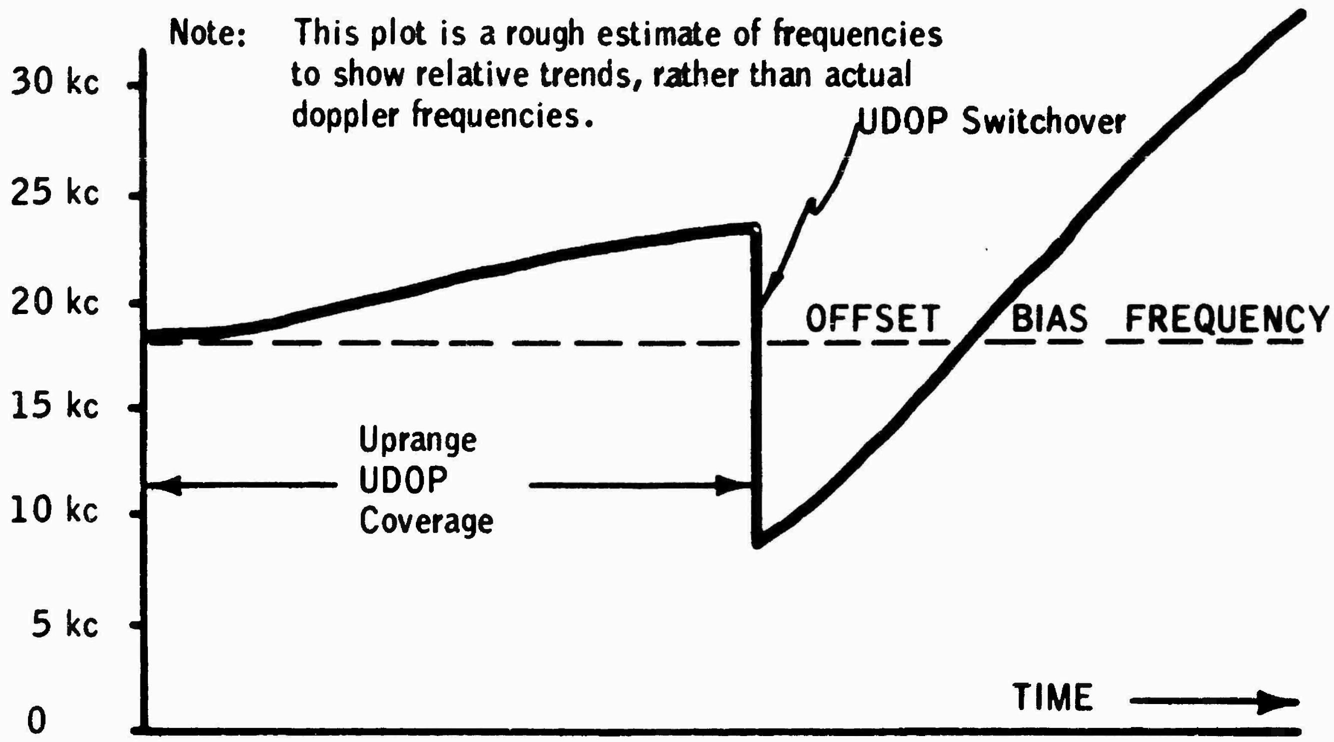


FIG. 3-14 PLOT OF APPARENT DOPPLER FREQUENCIES AS SEEN BY THE DOWNRANGE DIGITIZER USING OFFSET BIAS TECHNIQUES

NASA uses a similar offset method. NASA has the responsibility of doppler coverage from liftoff, so the doppler frequencies generated at the pad are zero and increase very slowly. NASA, therefore, offsets the missile doppler signal by 5 KC, which is sufficient for their needs. NASA sees the missile as an ever-increasing doppler signal and experiences no nulls.

The UDOP central transmitting site, as installed at Carter Cay, consists of the subsystem just described whose characteristics are described herein. (See Figure 3-9).

1. Gates Oscillator Unit - Model M5708

Three of these crystal controlled oscillator units are used, one as a variable frequency source for the 900 mc test transmitter and the other two as standby references in case of primary reference failures.

Tuning range - 47.7 to 53.3 mc by changing crystal

Frequency stability - 1×10^{-7} for 15 minutes
1×10^{-5} for 8 hours

Fine frequency change - 1 part in 20,000 by front panel control

Output impedance - 50 ohms

Power output - 10 milliwatts

2. Gates Buffer Amplifier - Model M5709

Three of these units are used to buffer the M5708 oscillators, provide plate and filament voltages for the oscillators, and amplify the reference signal sufficiently to drive the transmitters.

3. Gates Coaxial Patch Panel - Model M5707

One unit is used to provide a means to drive any combination of these power amplifiers from one buffer amplifier power source of any combination of buffer amplifier and power amplifier as desired.

4. Gates Reference Transmitter - Model M5704

Two units are used, one as a primary reference source and the other as back up. These are power amplifiers only and must be driven by a M709 buffer or equivalent.

RF Input Frequency Range - 47.7 to 53.3 mc

RF Input Impedance - 50 ohms

RF Input Power - 1 watt

RF Output Range - 47.7 to 53.3 mc

RF Output Impedance - 50 ohms

RF Output Power - 1000 watts

Harmonics, 2nd - 80 db min.

All others - 60 db min.

Noise - 60 db

Phase Stability - less than 10° over 1 minute period after one hour warm up.

5. Gates 450 mc Transmitter - Model M5705

Two of these units are used, one as a primary interrogation transmitter, and the other as back up. The transmitter consists of a times nine multiplier and power amplifier and, as such, must be driven from a Model M5709 buffer amplifier or equivalent.

RF Input Frequency - 47.7 to 53.3 mc

RF Input Impedance - 50 ohms

RF Input Power - 1 watt

RF Output Frequency - 430 to 480 mc

RF Output Impedance - 50 ohms

RF Output Power - 800 watts

6. Gates 900 mc Transmitter - Model M5706

One of these units is used as a test transmitter to simulate the missile transponder return during system checks. The transmitter consists of a times 18 multiplier followed by a power amplifier. This unit must be driven by a M5709 buffer or equivalent.

RF Input Frequency 47.7 to 53.3 mc

RF Input Impedance - 50 ohms

RF Input Power - 1 watt

RF Output Frequency - 860-960 mc

RF Output Impedance - 50 ohms

RF Output Power - 100 watts

Harmonics - down 60 db

Noise - down 60 db

Provision is made for a continuous reduction of RF power out, 60 db below the nominal 100 watts out.

7. Gates Monitor Scope - Model M4180B

One unit is used in the system. This monitor scope displays the difference between the 50 and 450 mc transmitters for tuning purposes by means of a 9:1 Lisajous pattern display.

RF Input Frequency - Input 1: 47.7 - 53.3 mc
Input 2: 430 - 480 mc

The basic frequency for the UDOP transmitters is generated by equipment located at Little Carter Cay, GBI. This equipment consists of a Primary Frequency Standard and a Precision Radio Frequency Assembly. The Primary Frequency Standard generates a 10 mc signal which is used as the basis for deriving the transmitter reference frequency and interrogation frequency. The Precision Radio Frequency Assembly consists of a secondary frequency standard, a frequency comparator and an offset bias converter. The rack layout and equipment positions of this assembly are shown in Figure 3-15. Three major functions which are performed by this equipment are as follows:

1. Provide a secondary frequency standard with 10 mc, 5 mc, 1 mc, 100 KC, 10 KC, 1 KC and 1 PPS outputs phaselocked to each other and stable to within 5 parts in 10^{10} per day.

2. Provide a method of comparing these frequencies with those generated by the primary frequency standard.

3. Provide a 50.001 mc signal coherently related to the 10 mc output of the Atomichron or the secondary frequency standard, whichever is selected.

The general subsystem operation has two major modes. One is operation from the secondary frequency standard and the other is operation from the Atomichron primary frequency standard. When operating from the secondary frequency standard (See Figure 3-15), the 5 mc from the oscillator is multiplied to 10 mc by the frequency doubler in the bias converter and then fed to the times 5 multiplier. The 50 mc output of this multiplier and the 1 KC from the frequency divider and clock in the secondary frequency standard are fed to the bias converter where a 50.001 mc signal is generated. The secondary frequency standard can be compared to the Atomichron during operation in this mode if it is desired.

When operating from the Atomichron (See Figure 3-16), the frequency doubler is not used. The 10 mc output of the Atomichron is multiplied to 50 mc directly and fed to the bias converter. The 100 KC output of the Atomichron is divided down by the frequency divider to 1 KC and fed to the bias converter. The 50.001 mc is fed to the buffer amplifier.

The National Radio Company Model NC 1001 Atomichron is the Primary Frequency Standard used in the down range UDOP system. See Figure 3-17 for relative position of the Atomichron in the down range system. See also Figure 3-12.

The following discussion and block diagram were taken from the Instruction Manual of the NC 1001 Atomichron.

The Atomichron is a frequency generator of exceptional accuracy and stability. When supplied with 60 cps alternating current at 115 volts, it is capable of producing five output frequencies which are accurate to one part in a billion and stable to five parts in ten billion. The General Specifications list all of the important operating characteristics of the Atomichron. A short description of how it functions to achieve its rated accuracy and stability is given in the paragraphs which follow.

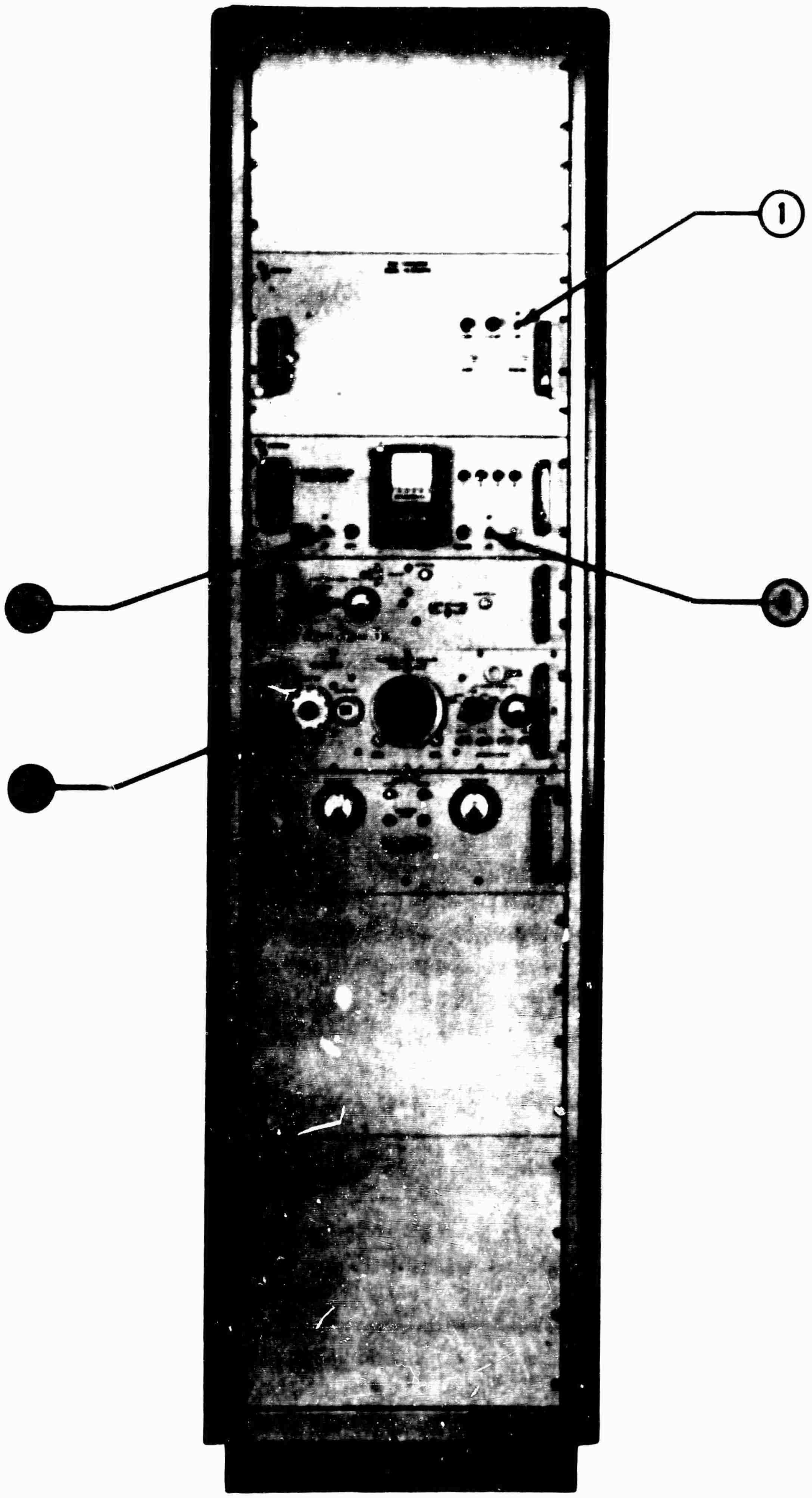


Figure 3 - 15   Bias Converter, Frequency Comparator, and Ultra-Stable Oscillator

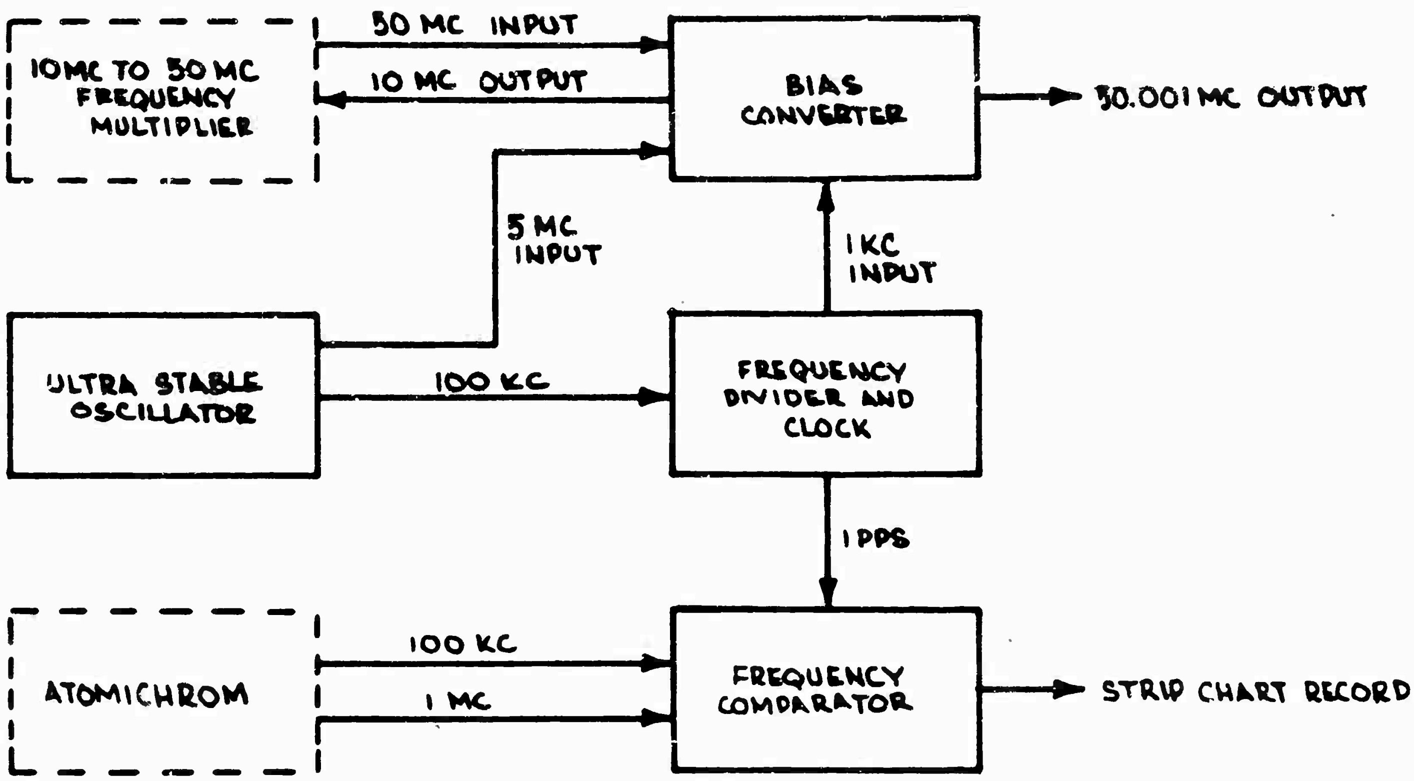


FIG. 3-16 BLOCK DIAGRAM OF THE SYSTEM OPERATION FROM THE SECONDARY FREQUENCY STANDARD

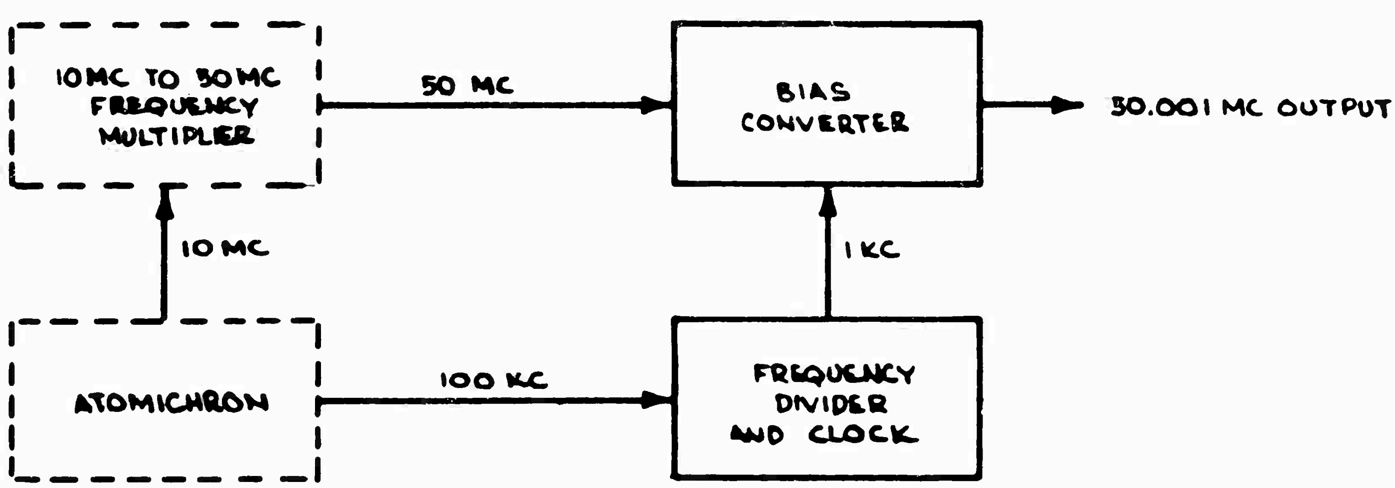


FIG. 3-17 BLOCK DIAGRAM OF THE SYSTEM OPERATION FROM THE ATOMICHRON

The Atomichron owes its exceptional accuracy and stability to a unique frequency-stabilizing system in which atoms of the element Cesium (Cs) are used as a frequency reference. Cesium atoms may exist with more than one internal arrangement of their electrons and changes in these arrangements are accompanied by the radiation or absorption of an electro-magnetic wave. The frequency of a wave corresponding to a given transition is characteristic of the atom and under proper conditions is not affected by environment temperature, pressure or aging effects. The Atomichron utilizes the very stable resonance which is characteristic of Cesium atoms when they are excited by an electro-magnetic wave at a frequency of 9192.631840 mc. Frequency generating circuits in the Atomichron produce a signal at 9192.-631840 mc and the accuracy of this signal is monitored continuously by comparing it with the Cesium resonance frequency. For this purpose, the Cesium atoms are directed through an rf chamber which is excited by the locally generated signal which, if oscillating at the resonance frequency, brings about a reorientation of the outermost electron of each atom. A detector senses the rate of flow of atoms which have undergone internal changes during their passage. If a maximum number has been reorientated internally the frequency of the field in the rf chamber corresponds exactly to the resonance frequency of the Cesium atoms and no correction is required. If, however, the majority of Cesium atoms do not change internal orientation while passing through the rf chamber, the locally generated frequency is other than 9192.631840 mc. This means that the primary frequency generator in the Atomichron must be adjusted so as to return the rf chamber excitation frequency to 9192.631840 mc. A servo system which responds to the error signal from the detector effects the required adjustment to a crystal oscillator which is the basic frequency generator for the system. The output of this oscillator is processed to produce the 9192.631840 mc signal which excites the rf chamber, thus closing the servo loop. Harmonics and sub-harmonics of the stabilized crystal oscillator output are taken from the frequency processing circuits and amplified to become Atomichron system outputs. A brief general description of the Atomichron frequency-stabilizing system is given in the following paragraphs.

Figure 3-18 is a simplified functional block diagram of the Atomichron system. As shown in this diagram, the system can be broken down into three major sub-divisions; a frequency source, a frequency reference and a frequency control section. These three sections are connected to form a closed-loop servo system. In this diagram the frequency source section is further sub-divided to show the manner in which the output of the basic oscillator for the system is frequency processed to produce the required 9192.631840 mc signal. The functional blocks used in Figure 3-18 are not intended to correspond to physical sub-divisions of the equipment, nor is the following explanation, based upon this diagram, intended to cover any but the most general functional details of the Atomichron.

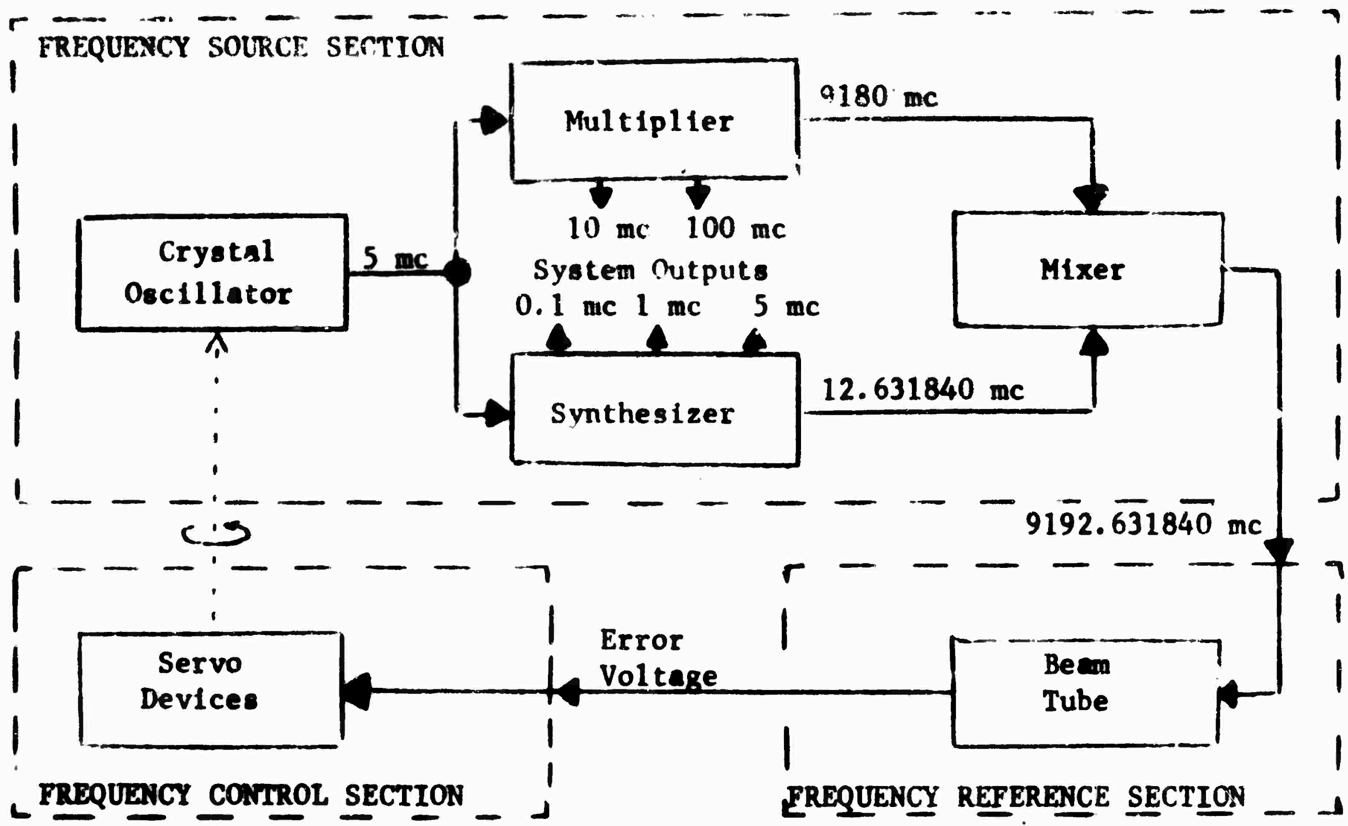


Figure 3-18 Atomichron, Simplified Functional Diagram

As shown in Figure 3-18, the 9192.631840 mc signal required to cause Cesium energy level transition is obtained by processing the output of a 5 mc crystal oscillator in the Frequency Source Section. The 5 mc signal is applied simultaneously to multiplier and synthesizer circuits. The multiplier increases the frequency by a factor of 1836 to 9180 mc, while the synthesizer, through a system of dividers, multiplers and mixers, raises the 5 mc to 12.631840 mc. The two signals thus produced are combined in the mixer circuits to produce a frequency of 9192.631840 mc which is the transition frequency of the Cesium atoms. This 9192.631840 mc signal is then applied to the Frequency Reference Section.

The Frequency Reference Section contains a beam tube in which the 9192.631840 mc signal is compared with the stable transition frequency of Cesium atoms. When the signal from the Frequency Source Section differs from the Cesium transition frequency, an error voltage is produced. This error voltage is applied to servo devices in the Frequency Control Section. These servo devices are mechanically coupled to frequency-stabilizing components in the 5 mc oscillator circuit, by which means they effectively adjust the output of the oscillator to a precise 5 mc correct to one part in a billion.

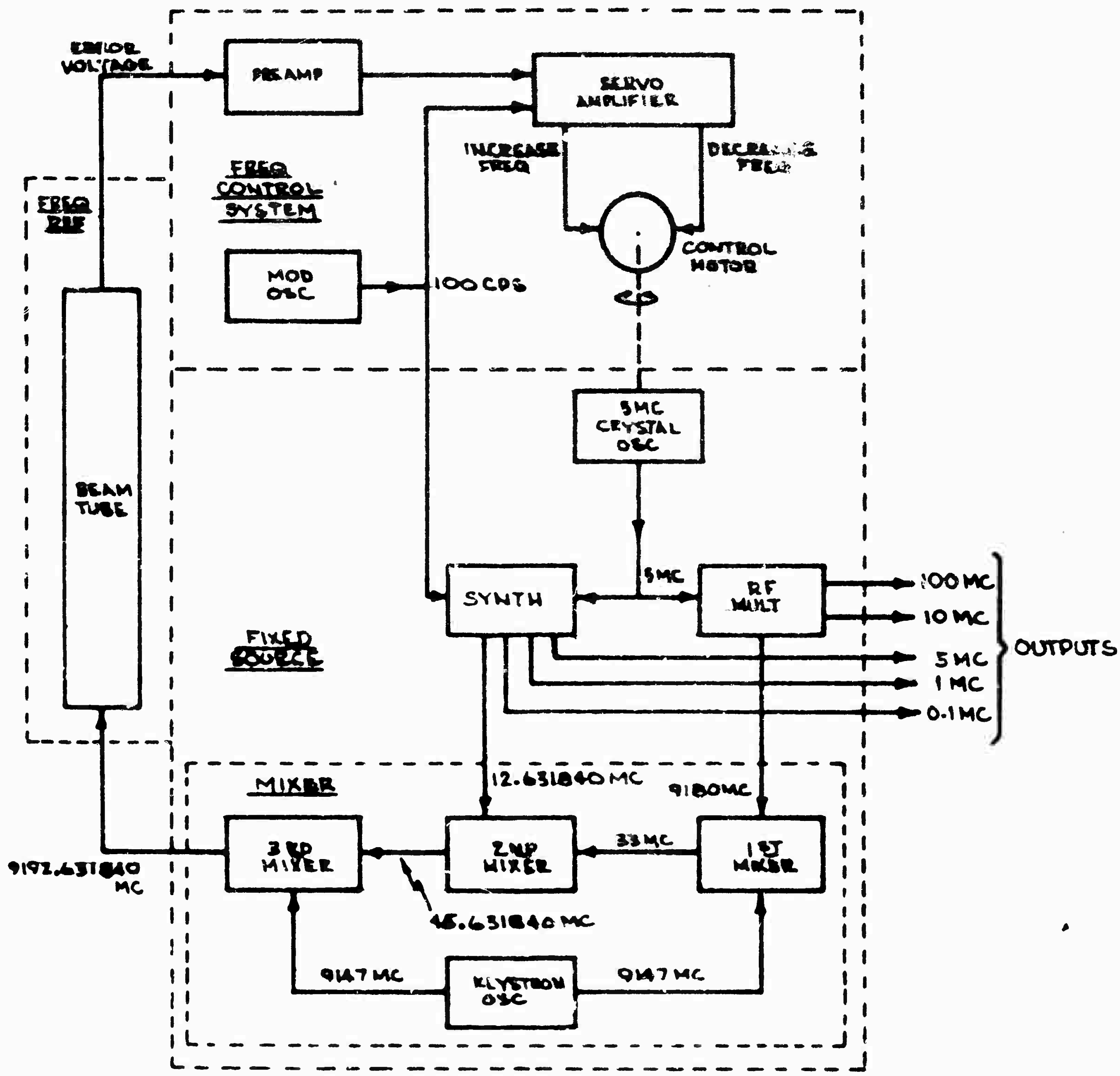


FIG. 3-19 ATOMICHRON, BLOCK DIAGRAM

In the process of generating the 9192.631840 mc signal, the Frequency Source Section also develops the five usable outputs of the Atomichron System. Since these outputs are obtained by direct multiplication and division of the 5 mc oscillator output, they are accurate and stable to the same degree.

GENERAL SPECIFICATIONS

1.	Output Stability:	Minimum stability* of 5 parts in 10^{10} parts for the life of the instrument. (After 2 hour warm-up, when measured by a device with a response time greater than five seconds).
2.	Atomic Beam Tube:	The beam vacuum tube is a static system. This is a completely sealed system not requiring mechanical pumping.
3.	Accuracy of Output Frequencies:	Output frequencies of 100 mc, 10 mc, 5 mc, 1 mc, and 0.1 mc are available with a power output of 10 dbm and an impedance level of 50 ohms nominal by means of convenient panel connections. These frequencies are accurate* to within one part in 10^9 under all specified environmental conditions.
4.	Lock-in Indicator:	Automatic warning provides visual indication of proper operation.
5.	Power Line Stability:	Equipment meets all performance specifications when operated from a power line source of 115 volts ± 10% at a frequency of 60 cps ± 10%. The unit operates directly from the line without further equipment.
6.	Shielding:	The equipment is so shielded that its accuracy will not be impaired when operated in magnetic fields, AC or DC, of 10 oersteds, peak.
7.	Size and Weight:	7 foot relay rack (22" x 18" x 84"), approximately 25 cu. ft., weight approximately 600 lbs. uncrated.
8.	Environment:	Normal variations in environmental conditions produce negligible effect on stability.
9.	Operating Position:	Normal operating position of the unit is upright. During shipment it should be mounted upright, but may be tilted as much as 60^{o} from the vertical during loading and unloading.

* Stability and Accuracy as used here denote the following:

Accuracy:	A degree of conformity to an absolute or generally accepted standard. At present frequency is defined in terms of measurements of celestial motions. Meas-

urements of the Cesium resonance have been made to one part in 10^9.

Stability: The degree to which a frequency standard retains its initial frequency within a fixed time interval. In the Atomichron NC-1001 the degree of stability is indicated in (1) above.

The secondary frequency standard is a Hewlett-Packard Model 104AR Quartz Oscillator. In this system, the standard is furnished with a Model 113BR Frequency Divider and Clock and a Stand-by Power Supply Model 724BR. For a detailed discussion of individual equipment operation, refer to Section I of the respective operating and servicing manual associated with each instrument.

The operation of the secondary frequency standard is as follows: A stable quartz crystal oscillator generates a 1 mc signal. This signal is then multiplied up to give a 5 mc output and divided down to give a 100 KC output. This 100 KC output is entered into the Frequency Divider and Clock. Here it is further divided down to give 10 KC, 1 KC, and 1 PPS outputs. A twenty-four hour clock is also included which operates from the countdown string. The manufacturer's operating and servicing manual should be referred to for a complete description of this equipment. (Hewlett-Packard).

The operation of the ultra-stable oscillator and the Frequency Divider and Clock should be continuous and relatively trouble free. If a malfunction does occur or it is suspected that the equipment is not operating correctly, refer to the maintenance sections of the manufacturer's Operating and Servicing Manuals. It should be noted here, however, that this oscillator is a precision piece of test equipment and any deviation from its normal operation should be considered serious. Care should be taken to determine the trouble as near as possible without turning off the equipment, and a careful study of the suspected area should be made before any decision is made on what to do. Note also at this point that all countdown circuits, both in the oscillator and the Frequency Divider and Clock are regenerative and a loss of only one cycle will stop them from operation. This is normal and does not in any way affect the oscillator stability unless the power to the oven is removed in the process. Refer to the manuals for proper start procedures of the countdown string.

The frequency comparator supplied with this equipment is an EDP Model 444A053. It provides a means of comparing the 1 PPS output of the secondary frequency standard to a primary frequency standard such as the National NC 1001 Atomichron. A Rustrak strip chart recorder is also provided to give a permanent record of the results of the frequency comparison. (See Figure 3-20).

With reference to the frequency comparator, the 1 PPS "tick" output of the Hewlett-Packard Model 113BR Frequency Divider and Clock is introduced and serves as the START impulse for the counters. The "tick" output is derived from the Quartz oscillator and is a direct function of oscillator frequency. Available Atomichron outputs of 1 mc and 100 KC are utilized as TIME BASE and STOP inputs.

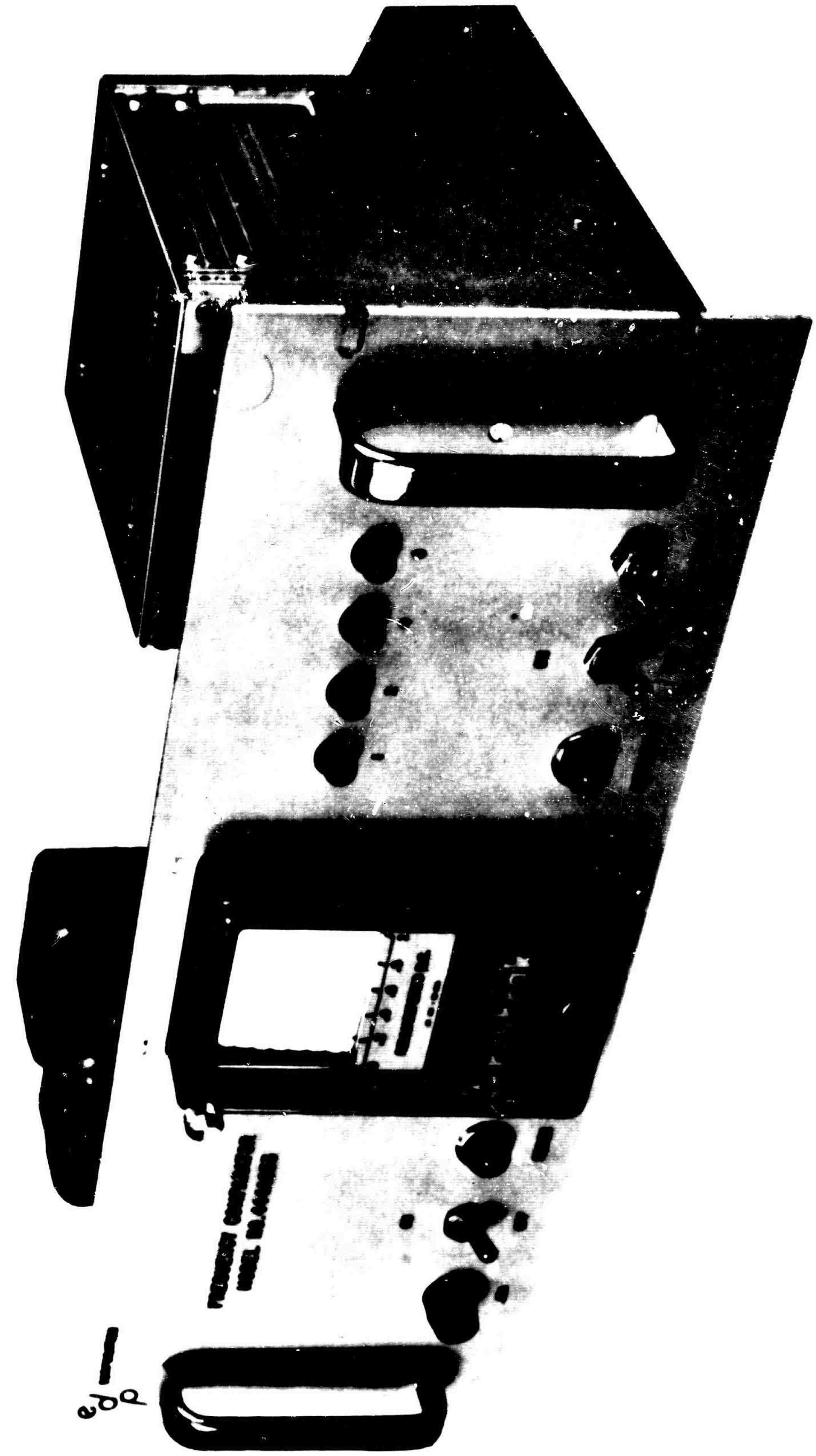


Figure 3 - 20 The Frequency Comparator

The counting cycle is initiated upon receipt of a positive "tick" pulse from the Frequency Divider and Clock. The pulse is shaped by a MSMV whose output resets a four-stage counter and sets the output of a BSMV negative. This output opens an "AND" gate and allows inverted 1 mc pulses to enter the counter string.

The first negative half cycle of 100 KC after the 1 PPS "tick" closes the "AND" gate. The number of 1 mc pulses allowed to pass through the gate is retained by the binary states of the counter stages. It can be seen that no more than ten pulses of 1 mc will be allowed to pass due to the phase-lock relationship of 1 mc and 100 KC.

A resistance network and the resistance of the Rustrak meter sums the voltage states of the BSMV counter stages. A current flows through a resistor and the meter which is proportional to the sum of the voltages which appear at the counted outputs and hence the actual cycles counted. Lamps serve as visual aids in determining the count at a particular time. To allow drifts in either positive or negative directions to be plotted, the comparator is set initially to a mid-scale value of 5 cycles by adjusting the TIME REFERENCE control of the Frequency Divider and Clock.

The frequency comparator has simple alignment procedure. The frequency comparator is designed to be used in conjunction with an external Atomichron primary frequency standard and a Hewlett-Packard secondary frequency standard. Any records taken without the proper input connections made to the comparator will be meaningless. With the POWER switch ON, RECORDER switch OFF, allow a warm-up time of at least five minutes.

Rotate the TIME REFERENCE control on the Hewlett-Packard Model 113BR Frequency Divider and Clock slowly clockwise until a count of ten appears on the indicator lamps (8 and 2 only). The counter recycles once per second. When a count of ten has repeated several times, adjust the F. S. ADJUSTMENT control with a screwdriver so that the pointer of the Rustrak recorder reads 1.0 ma. Lock the shaft of the F. S. ADJ control with the lock nut provided.

NOTE: The Rustrak recorder has a chopper bar which periodically clamps the pointer against the paper. In the event the chopper bar has clamped the pointer so that it is not free, it may be released by manipulation of the RECORDER switch to move the bar away from the pointer. Now rotate the TIME REFERENCE control on the Frequency Divider and Clock slowly until a count of five appears on the indicator lamps (4 and 1 only). The pointer on the recorder should drop to half-scale or 0.5 ma.

The recording run may be initiated by operating the RECORDER switch to the ON position. The frequency comparator will automatically compare the frequency of the secondary standard against the primary standard and present the frequency drift in strip chart form. The chart speed is one inch per hour.

Since precision oscillators have a nearly linear drift rate, average frequency during a time interval can be considered equal to the instantaneous frequency at the midpoint of the interval. A one-to-one correspondence exists between the tenths of milliamps on the chart scale and drift in microseconds, thus the relationship below becomes useful:

$$\frac{\Delta f}{f} = \frac{\Delta t}{T} \cdot \frac{1 \text{ hour}}{3.6 \times 10^9 \text{ usec.}}$$

where

$\frac{\Delta f}{f}$ = average frequency error

Δt = drift from zero (center scale) in microseconds

T = elapsed time in hours

Example:

Over a 2 hour period the record shows a positive drift of 3 microseconds. In this case:

$$\frac{\Delta f}{f} = \frac{+3 \text{ usec.}}{2 \text{ hours}} \cdot \frac{1 \text{ hour}}{3.6 \times 10^9 \text{ usec.}} = \frac{+0.416}{10^9}$$

This indicates an error of 0.416 parts in 10^9 high. Average frequency of the oscillator during this period is given by:

$$f_{av} = f_{nom} \left(1 + \frac{\Delta f}{f}\right)$$

where

f_{av} = average frequency

f_{nom} = nominal oscillator frequency

$\frac{\Delta f}{f}$ = average frequency error

If the nominal oscillator frequency in the example above is 1 mc, the average frequency is:

$$f_{av} = 10^6 \left(1 + \frac{0.416}{10^9}\right) = 1{,}000{,}000.000416 \text{ cps}$$

If over a period of measurement, the recording should reach full scale (i.e., 5 usec.), the record will resume at the opposite side of the chart and continue in the same direction. In this event, it is necessary to add the number of microseconds over and above full scale to the full scale value.

The bias converter included in the rack is an EDP Model 444A042. Its purpose is to generate a 50.001 mc signal which is coherently related to the 5 mc from the oscillator or to the 10 mc from the Atomichron. A frequency doubler is included in the converter to double the 5 mc to 10 mc when operating from the oscillator.

The bias converter (See Figure 3-21) is a VHF phasing type single side band generator, as can be seen from the block diagram of Figure 3-22. The function of the converter is to produce a frequency that is the sum of the 50 mc carrier and the 1 KC modulating signal. This sum can be obtained by adding the outputs of two balanced modulators when the amplitudes and phases of the carrier and audio signals driving these modulators are properly selected. To produce the upper side band frequency while eliminating the lower side band and carrier frequencies completely, the following conditions should exist in the converter.

1. The balanced modulators should be identical and should be ideal in the sense that for the same audio and rf input levels they produce equal side band frequency levels and zero carrier level in the output.

2. The input audio and rf levels should be the same for each modulator.

3. The phase shift in both the rf and audio phase shift networks should be either $+90^{o}$ or -90^{o}.

In practice it is, of course, impossible to obtain exactly the above operating conditions. However, these conditions can be approached. The degree of suppression at the carrier and the undesired side band in SSB output will be a function of how closely the desired operating conditions are approached. The audio and rf circuitry used in obtaining input signal amplification and phase shift in the converter should be familiar to anyone with experience in SSB communication equipment. Only in the case of the balanced modulators, the summing network, and the output SSB amplifier was an extension of existing SSB circuitry found necessary. Therefore, only these circuits will be discussed in detail.

A. <u>The Balanced Modulator</u>

The classical balanced modulator is shown in Figure 3-23. The non-linear element could be any switching device such as a diode or class "C" amplifier. In any case, the element must produce a current, I, which is proportional to the product of two applied voltages, Vm and Vc. If the nonlinear elements I and II are identical, the currents I_1 and I_2 add in the summing network to produce an output voltage V_0 which is free of the signal fc but contains sum and difference frequencies fc + fm and fc - fm where the signal amplitudes are proportional to the product of Vm x Vc. Signals, other than those mentioned above, may exist in V_0 but can be removed by filtering if the frequency fc is much greater than fm.

Since the characteristics of the non-linear element will usually change with time and since the amount of change usually will not be the same from element to element, the modulator will not maintain balance indefinitely. The stability of the modulator is a

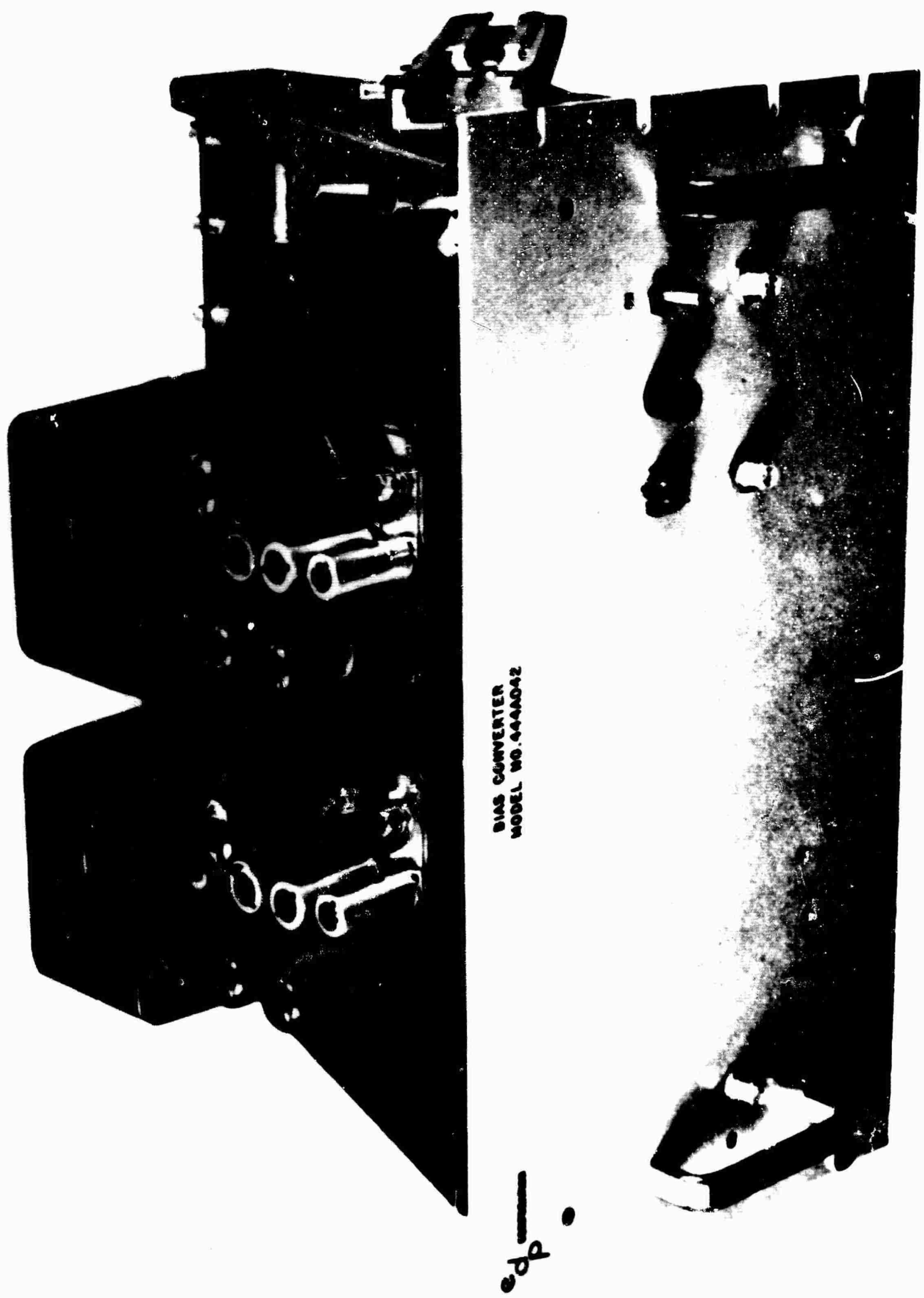


Figure 3 - 21 Bias Converter

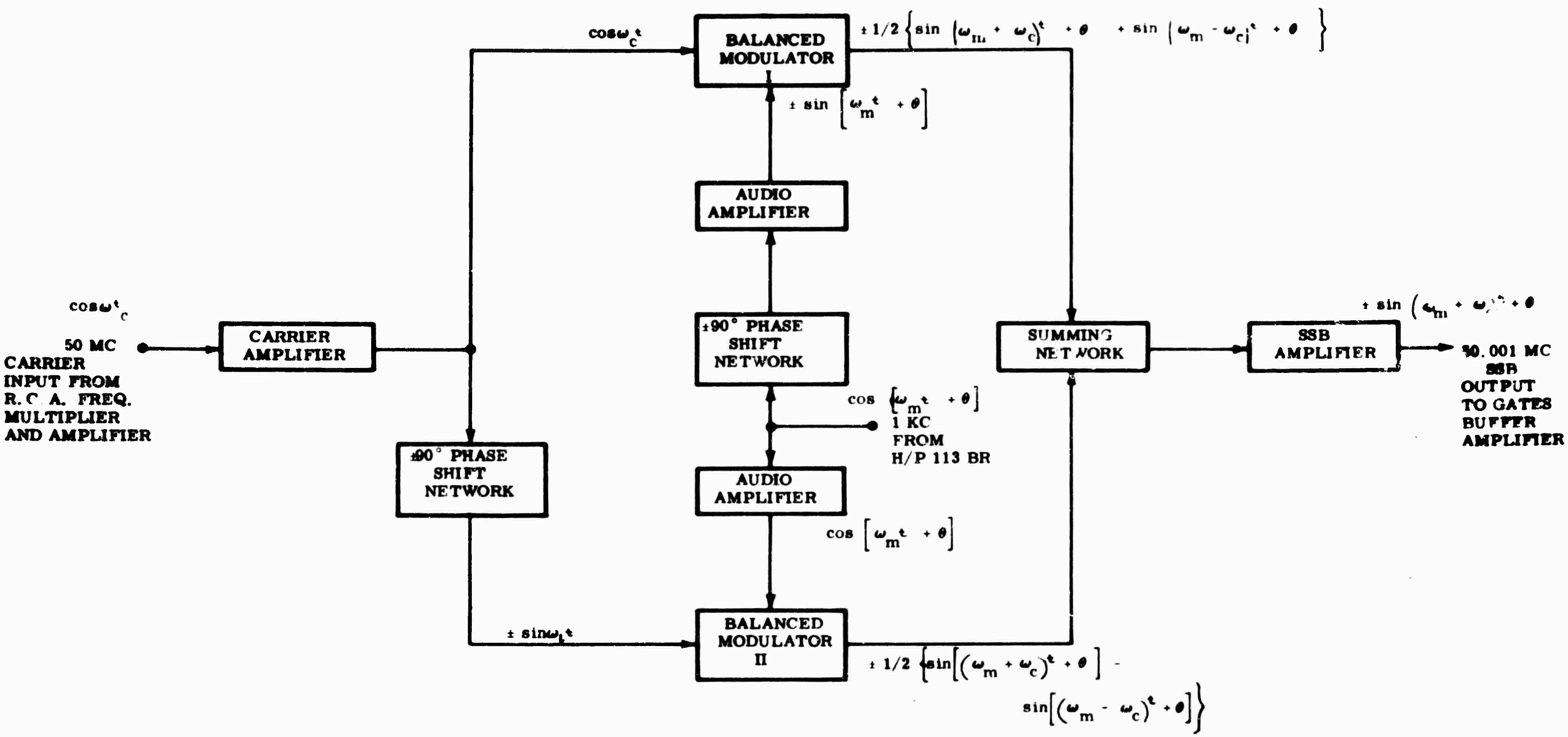


FIG 3-22 BLOCK DIAGRAM OF THE BIAS CONVERTER

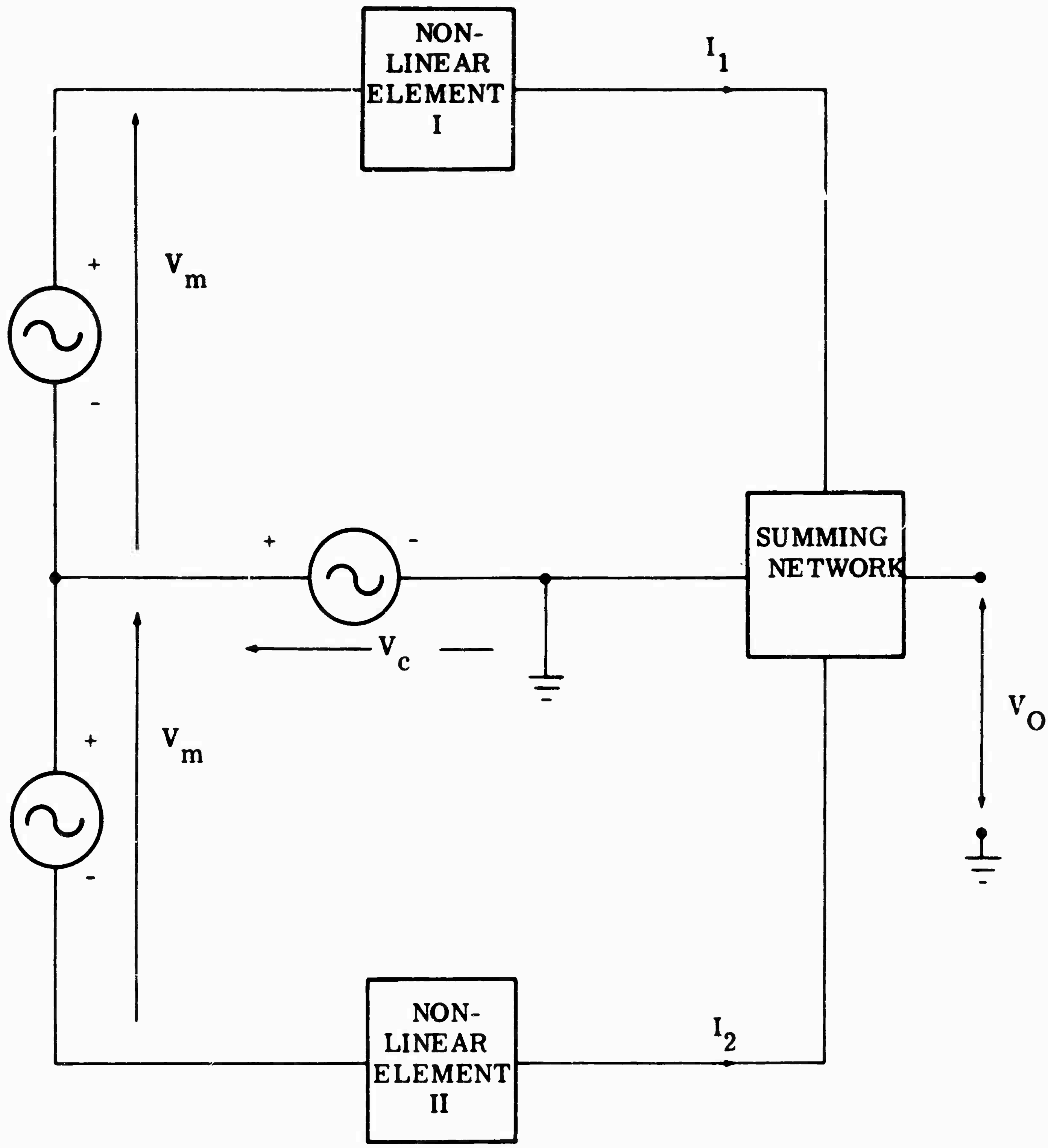


FIG 3-23 BLOCK DIAGRAM OF A BALANCED MODULATOR

function of the type of element used and the frequency fc. Circuits which demonstrate good balance stability at a few mc could have very poor stability at 50 mc.

B. The Summing Circuit

The circuit used to sum the outputs of the two balanced modulators to produce the desired 50.001 mc output is shown in Figure 3-22. It should be noted that the two balanced modulators use a common output tank. With the correct amplitudes and phases of the audio and rf signals the lower side band outputs from the two modulators subtract while the upper side bands add.

C. The Output SSB Amplifier

In the common SSB transmitter circuit the output amplifier must be linear because it must pass a band of frequencies without distortion. However, if the band consisted of only one frequency, there would be no need for linear amplification.

If the bias converter circuit differs slightly from the optimum shown in Figure 3-22, a distortion component can exist in the SSB output in the from of AM modulation. This modulation is removed from the SSB output by using a saturated output amplifier. (This amplifier is composed of the last two stages of the bias converter.)

Operation of the rack in general is simple and straightforward; however, certain precautions should be observed. First and most important is that power must not be removed from the oscillator even for a very short time. If it is, no damage will result to the equipment, but it may take 21 days for the oscillator to regain its specified stability after power is re-connected. A standby power supply is furnished that will supply power for at least 48 hours to the oscillator after loss of the AC input. In normal operation the oscillator and the Frequency Divider and Clock remain energized at all times, even during loss of the 117 VAC input power. A layout of the front of the rack is shown in Figure 2-15. Numbered points in the text refer to this drawing. Refer to Section II to determine which mode of operation is required. Two are possible. One is operation from the H-P oscillator and the other is operation from the Atomichron.

After the connections for the selected mode are made, switch the power onto the bias converter by the AC switch on the front panel (#1 on the layout). Allow about a one hour warm-up period for the bias converter before using it in the system. At the end of this time, the 50.001 mc signal (.7 VRMS minimum) is ready to be entered into the buffer amplifier which in turn drives the transmitter. If the operation is from the Atomichron, the frequency comparator is not used. If the operation is from the oscillator, the frequency comparator in conjunction with the Atomichron can be used to check the stability of the oscillator during operation.

Normally the oscillator stability is such that it is not absolutely necessary to run the recorder and the Atomi.hron continuously in order to make a stability comparison. A five minute run every one-half hour is sufficient if the oscillator is operating within specifications.

The antenna used at Carter Cay for interrogation of missile-borne transponders is a quad-helix, steerable unit. (See Figure 3-24). The beamwidth at the interrogation frequency of 450 mc is 22 degrees. This means that the antenna must be positioned during the flight of a missile. For this purpose a 484B Cartesian to polar converter is used to generate look angles for the UDOP antenna pedestal (See Figure 3-25). Acquisition information is fed up and down the AMR during a shot by means of the acquisition buss. This buss carries digital information occurring at a 480 PPS rate. The acquisition buss can give azimuth, elevation and range to any end instrument provided with a 1005R data receiver (See Figure 3-26) and a Cartesian to polar converter. This converter accepts the information from the acquisition receiver and transforms it into azimuth and elevation servo signals for positioning the interrogation antenna.

The specifications for the quad-helix antenna are as follows:

SPECIFICATIONS

1. Type: Quad-Helix transmitting antenna and pedestal.

2. Function: Used to supply the ground-to-air interrogation link for the Down Range UDOP System.

3. Characteristics: A Quad-Helix transmitting antenna displaying a uniform power pattern with 22° beamwidth (3 db point) slaved tracking and manual operation capabilities. This antenna has the following characteristics:

a.	Frequency:	440 to 460 mc
b.	Gain:	18 db minimum
c.	VSWR:	1.5:1 over the frequency band
d.	Polarization:	Right Circular
e.	Beamwidth:	22° at 450 mc
f.	Power:	1000 watts
g.	Sidelobe Levels:	15 db below main lobe

The antenna pedestal is as follows:

a.	Operating Modes:	Manual Position or slaved with 1:1 and 16:1 synchros
b.	Positional Accuracy:	Better than $\pm 1^\circ$ in 45 mph winds
c.	Elevation:	-5° to 110°
d.	Azimuth:	Continuous rotation
e.	Rotation Rates:	12° per second in both elevation and azimuth

4. Other Characteristics: The antenna is positioned from a manual-remote control panel or slaved to a remote device supplying 1:1 and 16:1 synchro information. Azimuth and elevation information is provided on the control panel. Controls for the manual remote or slaved remote operation are provided on the control panel. Indicators are also provided on the control panel which display the azimuth and elevation data from the remote device supplying synchro information.

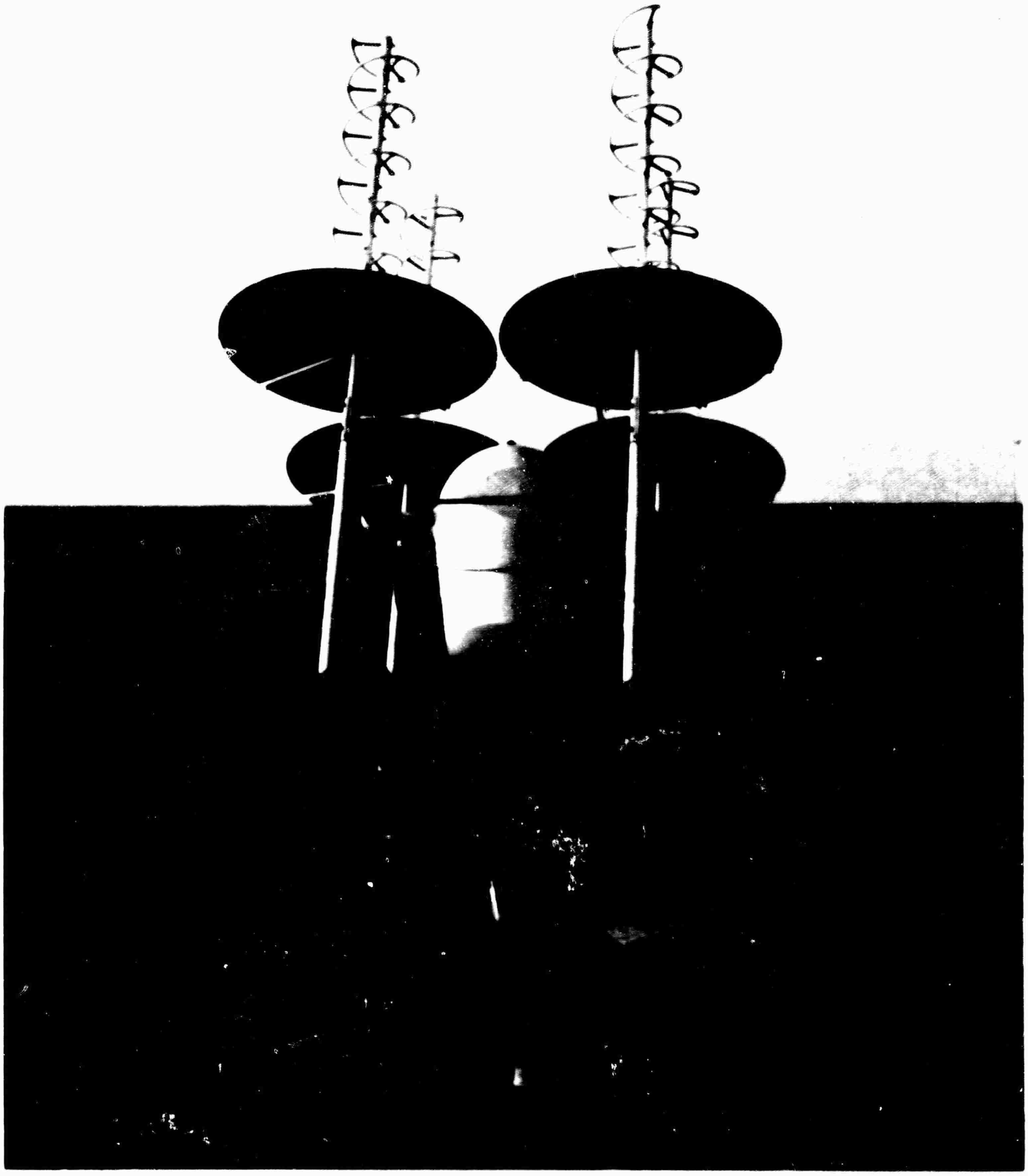


Figure 3 - 24 Quad-Helix 450 MC Transmitting Antenna

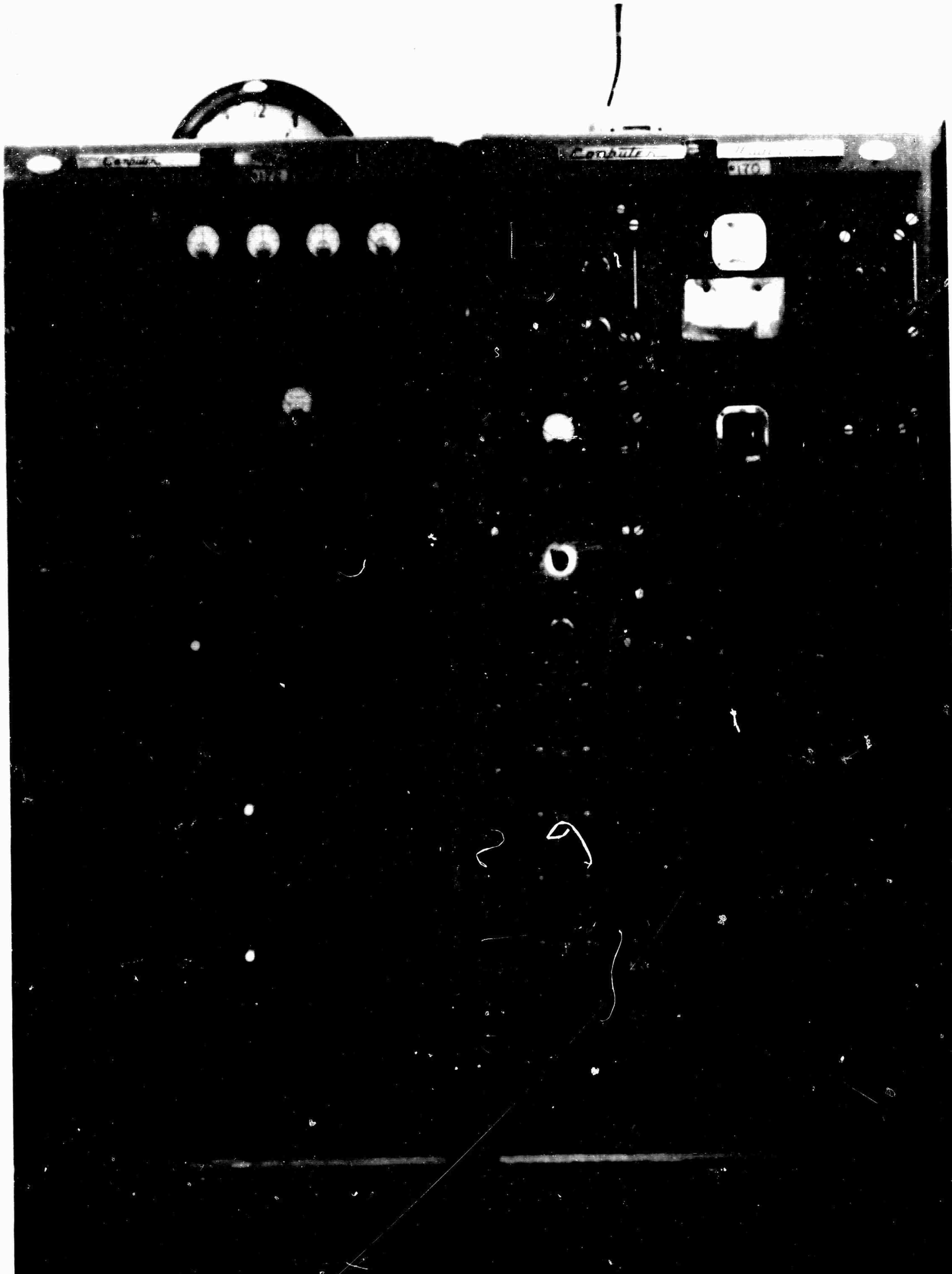


Figure 3 - 25   Cartesian-to-Polar Converter

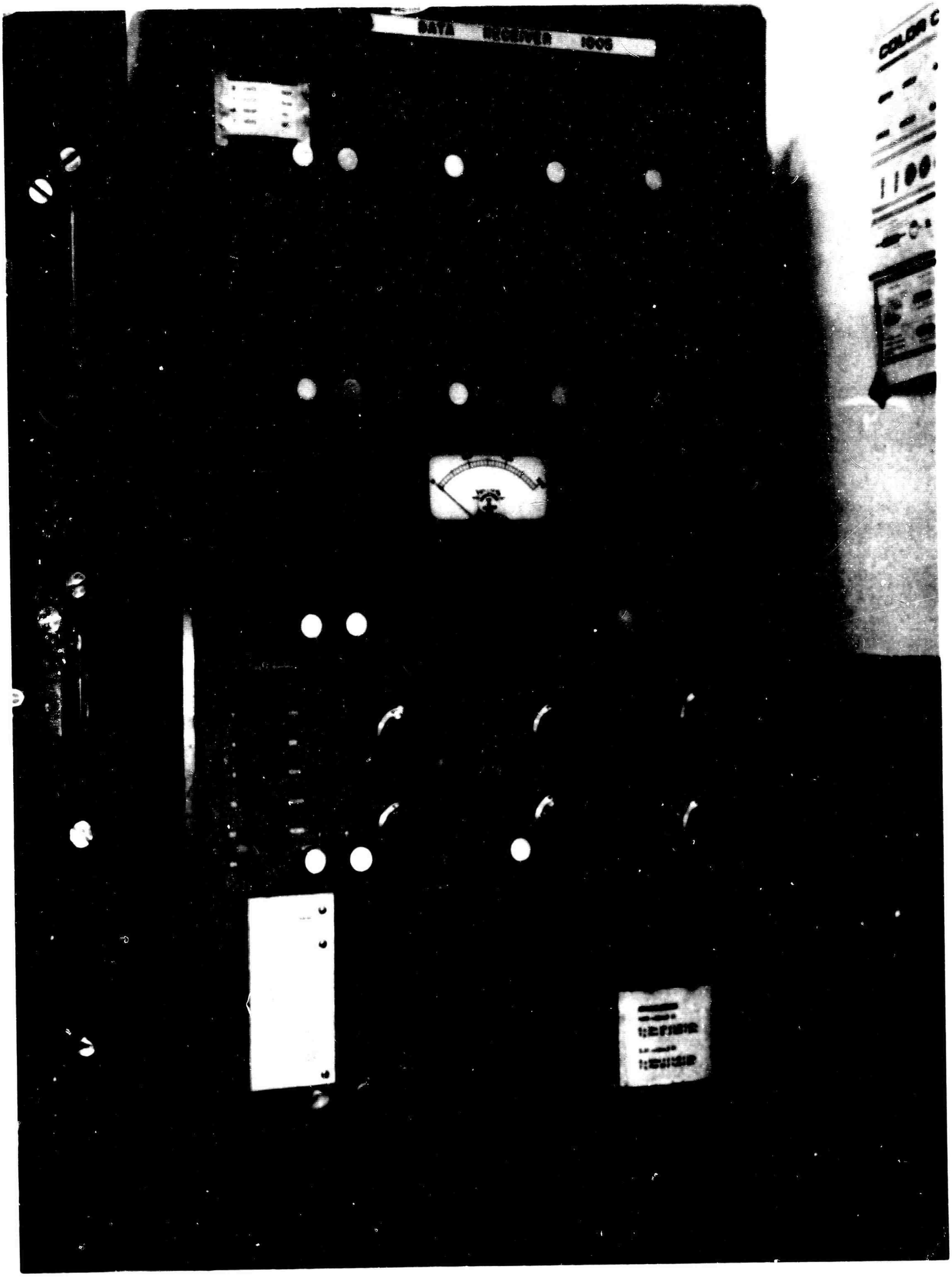


Figure 3 - 26 Model 1005R Data Receiver

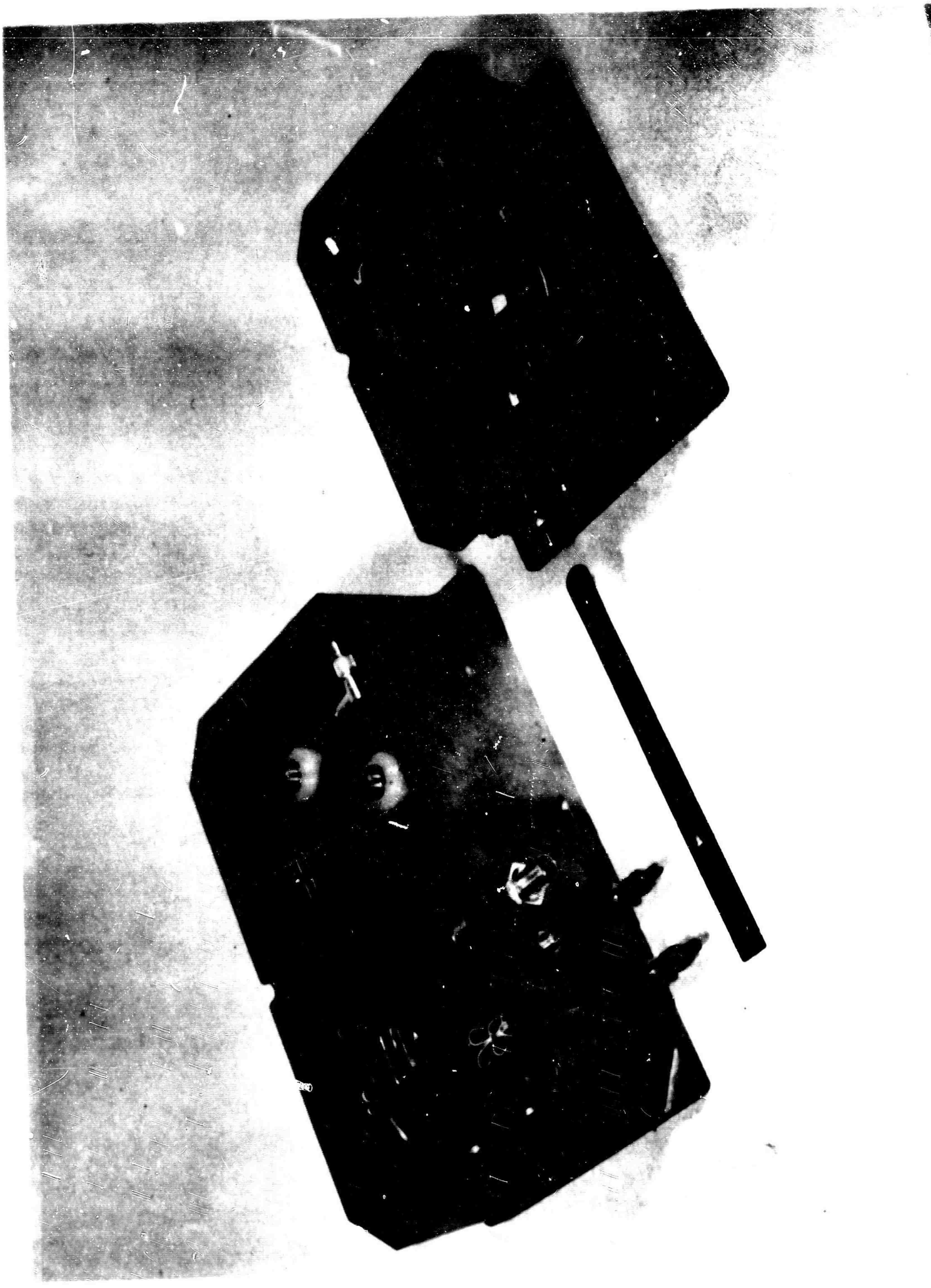


Figure 3 - 27 Resder UDOP T.ansponder

THE UDOP TRANSPONDER

UDOP transponders are manufactured by two companies, Resdel Engineering Corporation, and Motorola, Inc.

The following discussion and description is of the Resdel Model 90710-2 solid state transponder and power amplifier. The transponder itself is Resdel Model 90662-2, and the power amplifier is a planar triode assembly, Model 90688.

The complete unit is miniaturized. (see Figure 3-27).

The following specifications apply to the Resdel transponder.

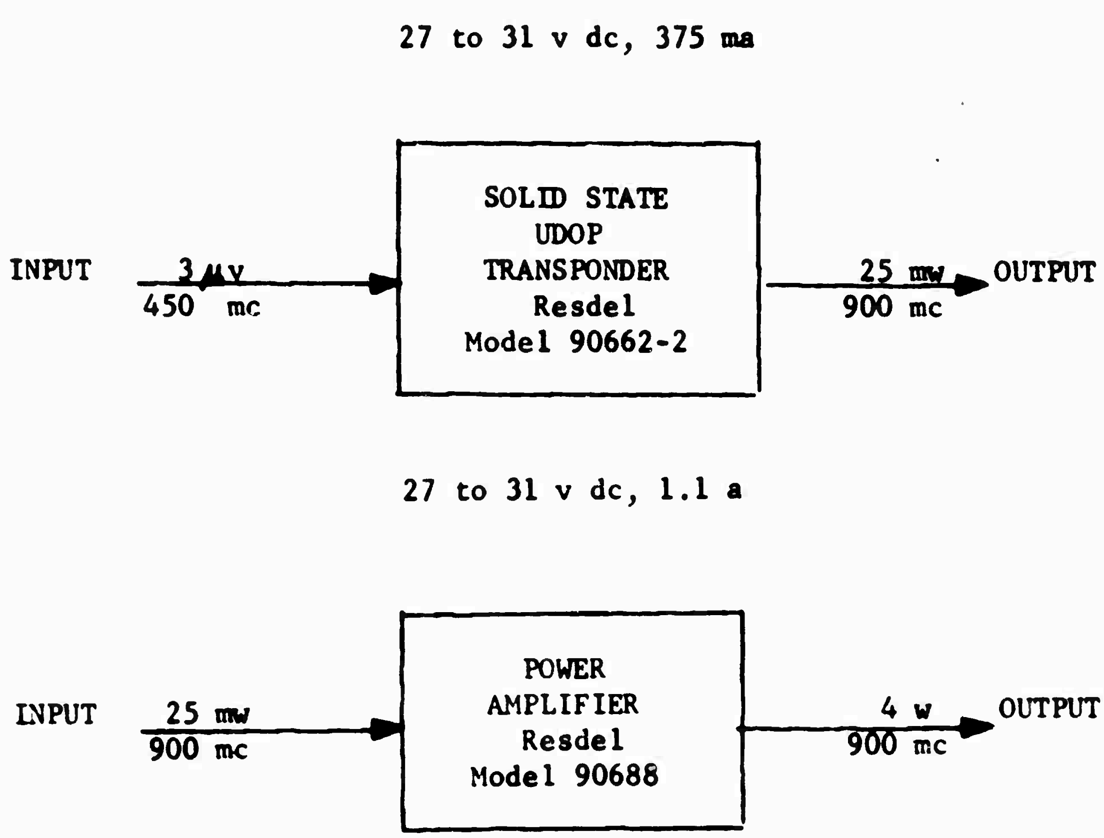


FIGURE 3-28. BLOCK DIAGRAM OF RESDEL SOLID STATE UDOP TRANSPONDER AND PLANAR TRIODE POWER AMPLIFIER, Model 90710-2

With the exception of two planar triodes in the power amplifier, the transponder and power amplifier utilize all solid-state components.

The cases of both units are gold-plated cast aluminum with the interior space divided into compartments. This method of construction provides the following advantages.

1) Rigid mounting for modules

2) Excellent heat sink

3) Effective shielding between sub-units

4) Great overall strength and rigidity

5) Excellent electrical conductivity

6) Effective protection against tarnish or corrosion

7) Provides for pressurizing and sealing against moisture

The semi-honeycomb design and layout is flexible and readily adapted to other applications and systems.

SPECIFICATIONS

<u>Operating Environment</u>

Temperature	40 F to 130 F
Acceleration.	At least 15 g in three planes
Vibration	Combination random 0.1 g^2/cps, 10 to 1000 cps -- plus sine 3.5 g rms, 10 to 2000 cps 15 min/plane
Altitude	0 ft to 3,800,000 ft

<u>Electrical Specifications</u>

	Transponder 90662-2	Power Amplifier 90688
Nominal input frequency	450 mc	900 mc
Input frequency range	430 - 470 mc	860 - 940 mc
Nominal output frequency	900 mc	900 mc

Electrical Specifications (Contd)

	Transponder 90662-2	Power Amplifier 90688
Power output capability	25 mw	4 w
Spurious radiation		86 db below max output
Sensitivity	0.2 μv	
Stability	Limited only by ground transmitter	
Input impedance	50 Ω nominal	50 Ω nominal
Output impedance	50 Ω nominal	50 Ω nominal
Input signal vs output power	0-μv input 1.5-μv input 3-μv input	500-mw output (max) 1.5-w output 4-w output (min)
Noise bandwidth	200 to 300 kc	
Telemetry output	0 - 3 v dc corresponds to 0 - 100 μv signal input	
Input voltage	27 - 31 v dc	27 - 31 v dc
Input current	410 ma	1.1 amp
Input VSWR	2:1 maximum	
Doppler range	±60 kc	

Mechanical Specifications

	Transponder 90662-2	Power Amplifier 90688	Combination 90710-2
Mounting dimensions			
Length	6-1/8 in.	8-9/16 in.	
Width	4-1/2 in.	5 in.	
Height	2-5/8 in.	3-1/8 in.	

Mechanical Specifications (Contd)

	Transponder 90662-2	Power amplifier 90688	Combination 90710-2
Volume	70 cu in.	130 cu in.	200 cu in.
Weight	$3\frac{1}{2}$ lb	$6\frac{1}{2}$ lb	10 lb
Connections			
Input	TNC (F)	TM (F)	TNC (F)
Output	TM (F)	TNC (F)	TNC (F)
Mounting	Solid to heat sink surface using #10 Allen-Head bolts and floating anchor nuts.		
Housing	Filled with dry gas. Pressurized to 25 psi during test. Gold-plated, cast-aluminum alloy.		

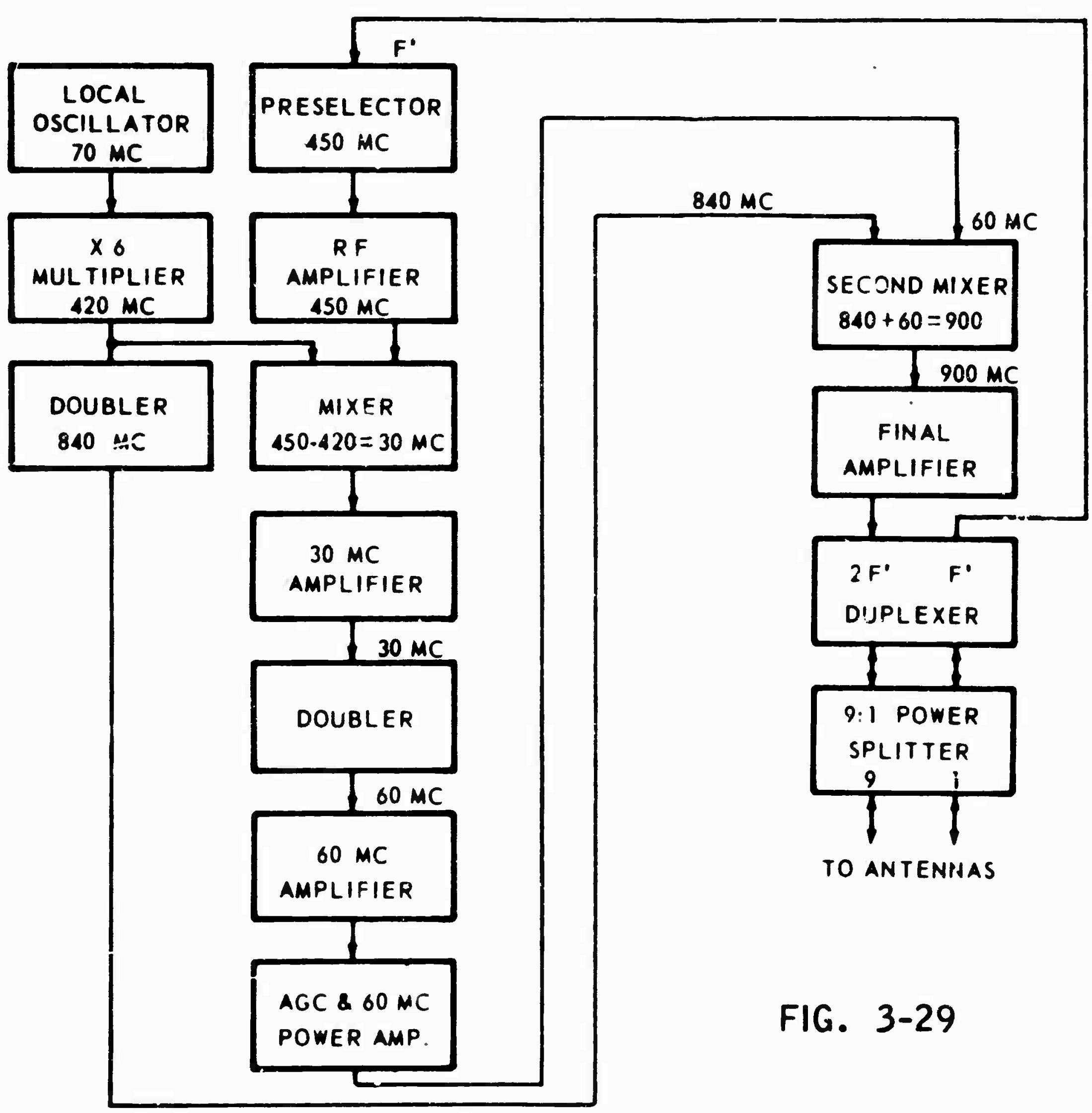


FIG. 3-29

The missile transponder is a transceiver capable of receiving and transmitting at the same time on the same antenna. The transponders used for UDOP receive the signal from the ground transmitter, amplify and double the received frequency and retransmit the doubled signal to the ground receivers. There are several different types of transponders available. The block diagram in Figure 3-29 is a representative transponder but does not necessarily represent any particular model.

Referring to the block diagram, the two antennas are 180° out of phase. One antenna is to receive the transmitter signal F_T modified by a doppler shift F'. This received frequency goes through a duplexer, which is used to separate the antenna input signal from the antenna output signal. The duplexer allows reception and transmission at the same time over the cross-slotted UDOP antenna. The received signal goes to a preselector, and the signal to be transmitted comes from an RF amplifier.

The frequency at the output of the RF amplifier is 450 mc $\pm$ the Doppler shift resulting from the radial velocity of the missile with respect to the ground transmitter. A local oscillator in the transponder generates a frequency of 70 mc which is multiplied six times to become 420 mc. This frequency and the received signal are heterodyned in a mixer resulting in a difference frequency of 30 mc $\pm$ the Doppler shift. This signal is amplified through several stages and then doubled in a doubler circuit. The output of the doubler circuit will be 60 mc $\pm$ twice the doppler shift. After further amplification, the signal is again heterodyned in a mixing circuit. The heterodyning frequency is an 840 mc signal resulting from doubling the 420 mc signal used in the first mixer. The output of the second mixer is the sum of the two input frequencies and consequently will be 900 mc $\pm$ twice the Doppler shift. This signal is now twice the received frequency or 2F'. This signal now goes to the final power amplifier, then through the duplexer which prevents it from being fed back through the receiver. In this transponder, the output is fed through a 9:1 power splitter which delivers the power in a 9:1 ratio to the two antennas. One of the antennas is used mainly while the missile is on the pad and during vertical flight, and the other is used after the missile pitches over and is at longer ranges. The longer range antenna, therefore, receives nine times as much power as the shorter range antenna.

It might be pointed out here that two methods of frequency conversion are used in the transponder and are also used in the receivers. These two methods are heterodyning and frequency multiplication. The UDOP signal might be considered as having two components; a carrier frequency and the intelligence it is intended to convey - in this case, the Doppler change in frequency. In most cases, it is desired to change the frequency of the carrier only. Heterodyning is used for this purpose. The frequency of the signal coming from a heterodyning circuit, or mixer, contains four components; the two input frequencies, the <u>sum</u> of these two frequencies, and the <u>difference</u> between these two frequencies. By making the output circuit resonant to the difference frequency, the carrier frequency can be reduced without affecting the frequency of the information it carries. In fact, if the heterodyning frequency is exactly equal to the carrier frequency, only the information frequency will be left. Likewise, the carrier frequency can be raised by using an output circuit tuned to the sum of the carrier and heterodyning frequencies.

On the other hand, a multiplier circuit multiplies the total frequency coming into it. The output circuit will contain several harmonics of the input frequency and if it is desired to double the frequency, the output circuit will be made resonant to the second harmonic of the desired input signal. The output circuit of a tripler will be tuned to the third harmonic, etc. There is a limit to multiplication in this manner in a single stage, because the harmonics get weaker as the order increases.

In the transponder, the first frequency conversion is done by heterodyning in order to reduce the carrier frequency, without affecting the Doppler shift, to a frequency that can easily be amplified. The doppler wavelength at this point is based on the 450 mc transmitter frequency. However, the doppler wavelength that is desired is the wavelength at the receivers, which is based on the 900 mc reference frequency and is one half that transmitted to the missile. Therefore, the doppler shift must also be doubled along with the carrier frequency. This is done in a doubler. The carrier frequency must now be raised to 900 mc without affecting the doppler frequency so heterodyning is again used. In the first mixer the difference between the carrier and the heterodyning signal is obtained while in the second mixer the sum of the carrier, which is now twice the frequency obtained from the first mixer, and the heterodyning signal, which is twice the frequency of the first heterodyning frequency, is obtained. In this way, phase coherence between the received signal and the transmitted signal is maintained and the doppler frequency shift is in terms of the 900 mc reference frequency.

For a view of the relative placement of the UDOP transponder within the re-entry vehicle, see Figure 3-30.

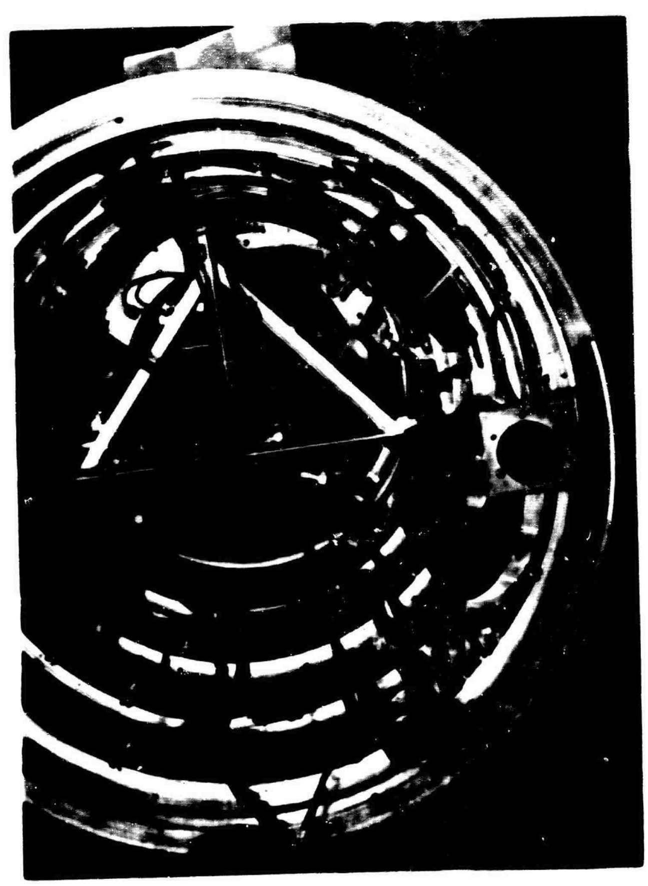


Figure 3 - 30 UDOP Transponder in Position Within Re-entry Vehicle

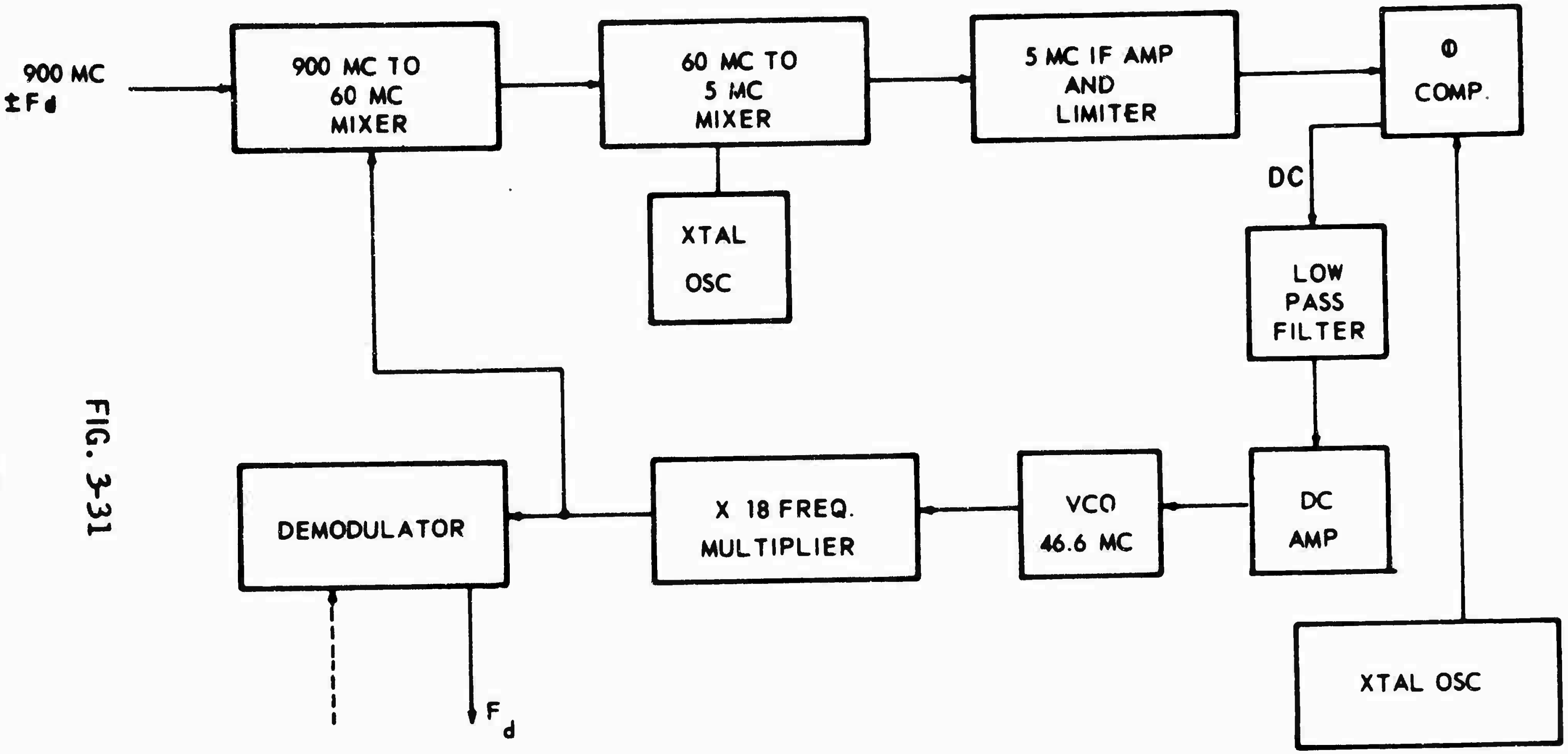

900 MC
±Fd
900 MC TO
60 MC
MIXER
60 MC TO
5 MC
MIXER
XTAL
OSC
5 MC IF AMP
AND
LIMITER
Φ
COMP.
DC
LOW
PASS
FILTER
DC
AMP
VCO
46.6 MC
X 18 FREQ.
MULTIPLIER
DEMODULATOR
Fd
XTAL OSC

FIG. 3-31

THE UDOP RECEIVER

In the existing UDOP System, two receiver configurations are used. The basic receiver configuration is called the Standard receiver (Resdel Model #90191-1). The other receiver used is known as the phaselock receiver and is made up of the Standard receiver and two phaselock converters. Since both receivers contain a Standard receiver, we will only discuss the phaselock receiver in this section.

The use of a UDOP UHF Phaselock Converter, Resdel Model #90315-1, and a UDOP VHF Phaselock Converter, Resdel Model #90694, in conjunction with a Standard UDOP Ground Receiver provides a dual phaselock receiver of excellent sensitivity and flexibility capable of tracking the low level signals encountered in space vehicle, satellite, and missile applications.

This dual channel, dual conversion receiver employs phase-locked oscillators in both the reference channel, which is tunable between 47.7 adn 53.4 mc, and the data channel which covers 860 to 962 mc. Bandwidth switching can be accomplished in either channel during operation without degradation or loss of signal.

The UHF and VHF Sections are independent with doppler information obtained by comparing the outputs of the two voltage controlled first local oscillators. In order to provide phase coherence, the second local oscillator and the reference oscillator are common to each channel.

The basic phaselock loop in each channel consists of a mixer, a phase comparator, a filter compensator with DC amplifier, and a voltage controlled oscillator. Except for the frequencies involved and the loop constants, the loops are the same.

A simplified block diagram of the UDOP servo loop is shown in Figure 3-31.

A block diagram of the phaselock receiver is shown in Figure 3-32.

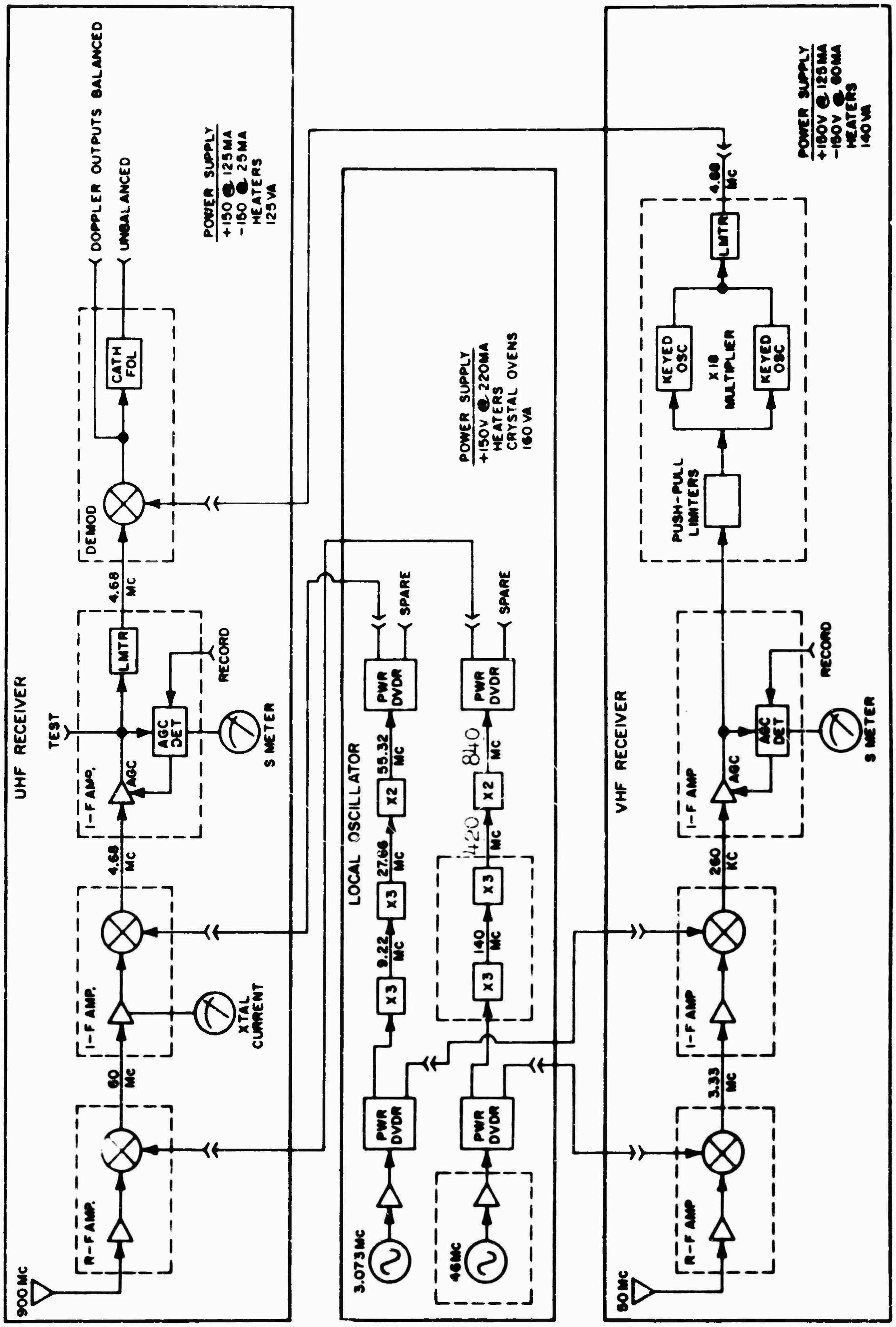

UHF RECEIVER
900 MC
R-F AMP.
I-F AMP.
XTAL CURRENT
90 MC
4.68 MC
I-F AMP.
AGC
TEST
AGC DET
S METER
LMTR
RECORD
DEMOD
CATH FOL
DOPPLER OUTPUTS BALANCED
UNBALANCED
POWER SUPPLY
+150 @ 125MA
-150 @ 25MA
HEATERS
125VA
LOCAL OSCILLATOR
3.073MC
46MC
PWR DVDR
X3
9.22 MC
27.66 MC
X2
55.32 MC
SPARE
140 MC
420 MC
840 MC
POWER SUPPLY
+150V @ 220MA
HEATERS
CRYSTAL OVENS
160VA
VHF RECEIVER
80MC
R-F AMP
I-F AMP
3.33 MC
260 KC
I-F AMP
AGC
AGC DET
S METER
RECORD
PUSH-PULL LIMITERS
KEYED OSC
X18 MULTIPLIER
LMTR
4.68 MC
POWER SUPPLY
+150V @ 125MA
-150V @ 60MA
HEATERS
140VA

FIG. 3-32

Electrical characteristics of the dual channel phaselock receiver are as follows:

UHF SECTION

Input Frequency	860 - 962 mc
Input Impedance	50 ohms nominal
Input Noise Figure	10 db maximum
IF Bandwidth	1000 cycles
Doppler Tracking Range	±72 KC
Manual Acquisition Range	> ±72 KC
Doppler Output	
Balanced Output	500 ohm 2.8 VRMS
Unbalanced Output	100 ohm 3.5 VRMS
Frequency Response	-3 db at 70 KC
Bandwidths (Selectable)	
S/N = 1.0	S/N ≥ 10.0
20 cps	70 cps
50 cps	140 cps
100 cps	230 cps
Sensitivity, S/N = 1.0	
20 cps	-147 dbm
50 cps	-143 dbm
100 cps	-140 dbm

Acceleration Capabilities

Bandwidth Setting	S/N = 1.0	S/N $\geq$ 10.0
20 cps	$\sim$ 60 ft./sec.^{2}	780 ft./sec.^{2}
50 cps	$\sim$ 400 ft./sec.^{2}	3120 ft./sec.^{2}
100 cps	$\sim$ 1500 ft./sec.^{2}	8400 ft./sec.^{2}

Capture Range, S/N $\geq$ 10.0

20 cps	$\sim$ 1000 cps
50 cps	$\sim$ 2000 cps
100 cps	$\sim$ 3000 cps

VHF SECTION

Input Frequencies	47.7 - 53.4 mc
Input Impedance	50 ohms
Input Noise Figure	6 db
IF Bandwidth	6000 cycles
Acceleration Capabilities, S/N = 1.0	
10 cps	$\sim$ 300 ft./sec.^{2}
30 cps	$\sim$ 2700 ft./sec.^{2}
100 cps	$>$ 10,000 ft./sec.^{2}
Tracking Range	$\pm$5000 cycles
Manual Acquisition Tuning Range	$> \pm$5000 cycles

Doppler Outputs

Balanced Output	~3.0V rms into 500 ohm
Single Ended Output	~3.5V rms into 100 ohm
Frequency Response	3 db at 70 KC
Sensitivity, S/N = 1.0	
Bandwidth	
10 cps	-154 dbm
30 cps	-150 dbm
100 cps	-145 dbm
Capture Range, S/N $\geq$ 10.0	> 1000 cycles

THE UDOP DOWNRANGE DATA HANDLING SYSTEM

For real time support purposes, UDOP has a data handling system which feeds data to the IBM 7094 computer at Cape Kennedy. This data handling system is composed of four basic parts, each of which will be explained fully in this chapter.

The doppler data from the UDOP receiver sites is transmitted over Gates data links to the central recording/digitizer facility at Bassett Cove. Here the data is fed into tracking filters to reduce its noise content and then into the digitizer itself. The digitizer counts the doppler cycles from each site at the rate of ten samples per second and feeds its counts into the Collins AN/GSC-4 data transmission system. The Collins data receiver is located at the impact predictor/7094 computer facility at the Cape. The receiver takes the data fed up the subcable and feeds it into the Format Converter, which sets it up for reduction by the 7094 computer. For post flight reduction purposes the data handling chain is also used, but in a slightly altered form.

The Down Range UDOP System employs six Model VIIIB, Interstate Tracking Filters (See Figure 4-1). The tracking filters are in the data path between the data link receivers and the UDOP Digitizer during a real time operation. For tape playback of post flight UDOP data the tracking filters are used between the Ampex FR-114B Analog Recorders and the Digitizer.

The tracking filters remove much of the undesired noise that is added to the UDOP data by the FM data links. The tracking filters also provide a rather constant output level over the operating range for the digitizer. A single tracking filter is used in the input data path of the DARE system. The general description and specifications are included for the tracking filters. The six tracking filters used in real time are similar to that in DARE except for wider bandwidth settings. For the tracking filters used Down Range, the bandwidth settings are as follows:

Tracking Bandwidth	Minimum S/N Ratio
10 cps	-32 db
25 cps	-28 db
50 cps	-25 db
100 cps	-22 db
150 cps	-20 db
300 cps	-17 db

Also included in this section are noise bandwidth curves and a block diagram of the Model VIIIB Tracking Filter. (See Figure 4-2, 4-3 and 4-4).

DESCRIPTION:

The purpose of tracking filter equipment is to reduce the noise bandwidth of a noisy Doppler signal. A tracking filter is essentially a bandpass filter whose center frequency is made to track a Doppler signal frequency automatically. The bandwidth is narrow relative to the input signal bandwidth and

Figure 4 -1 Tracking Filter

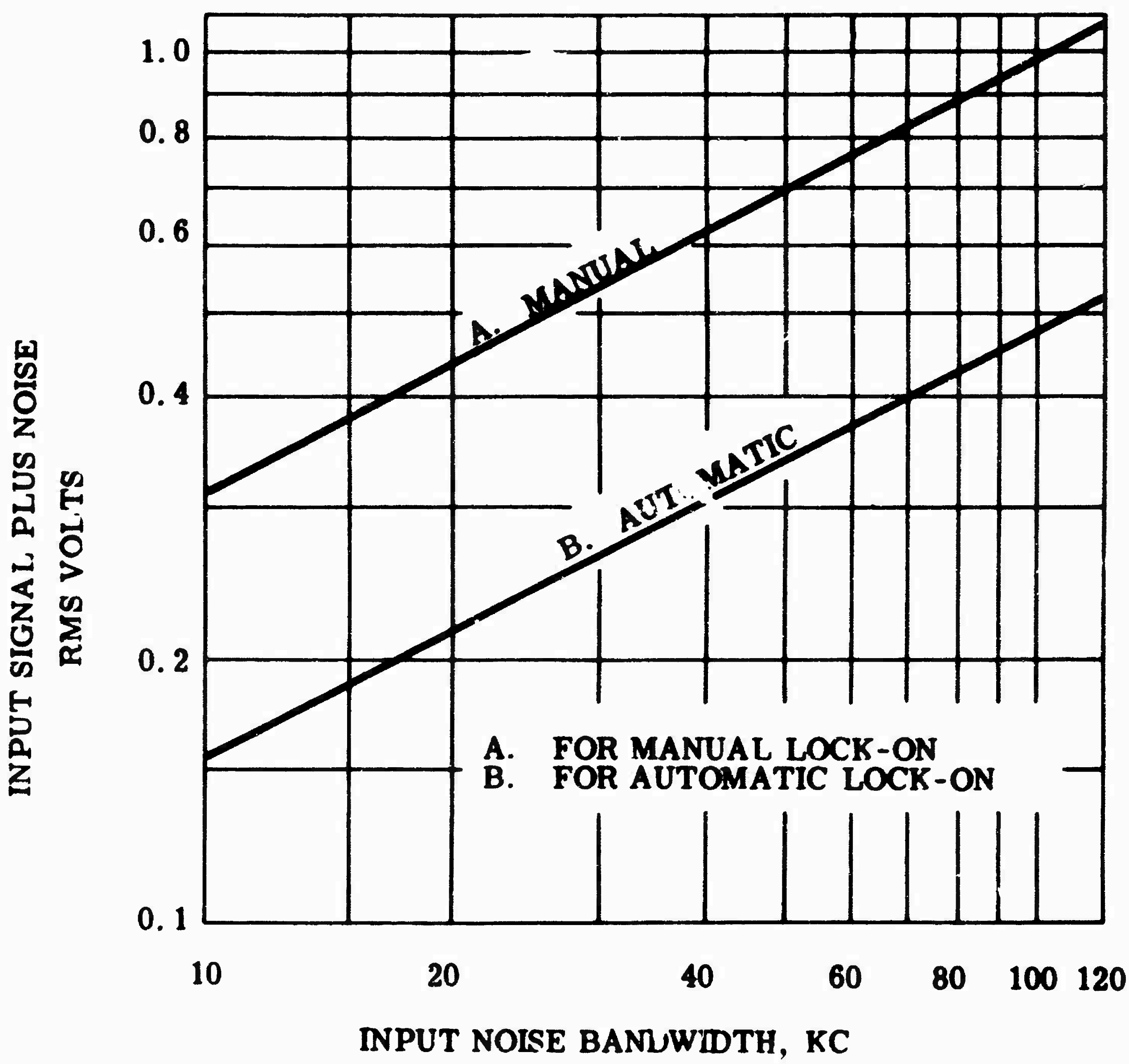


FIG. 4-2 RECOMMENDED INPUT SIGNAL PLUS NOISE VOLTAGE

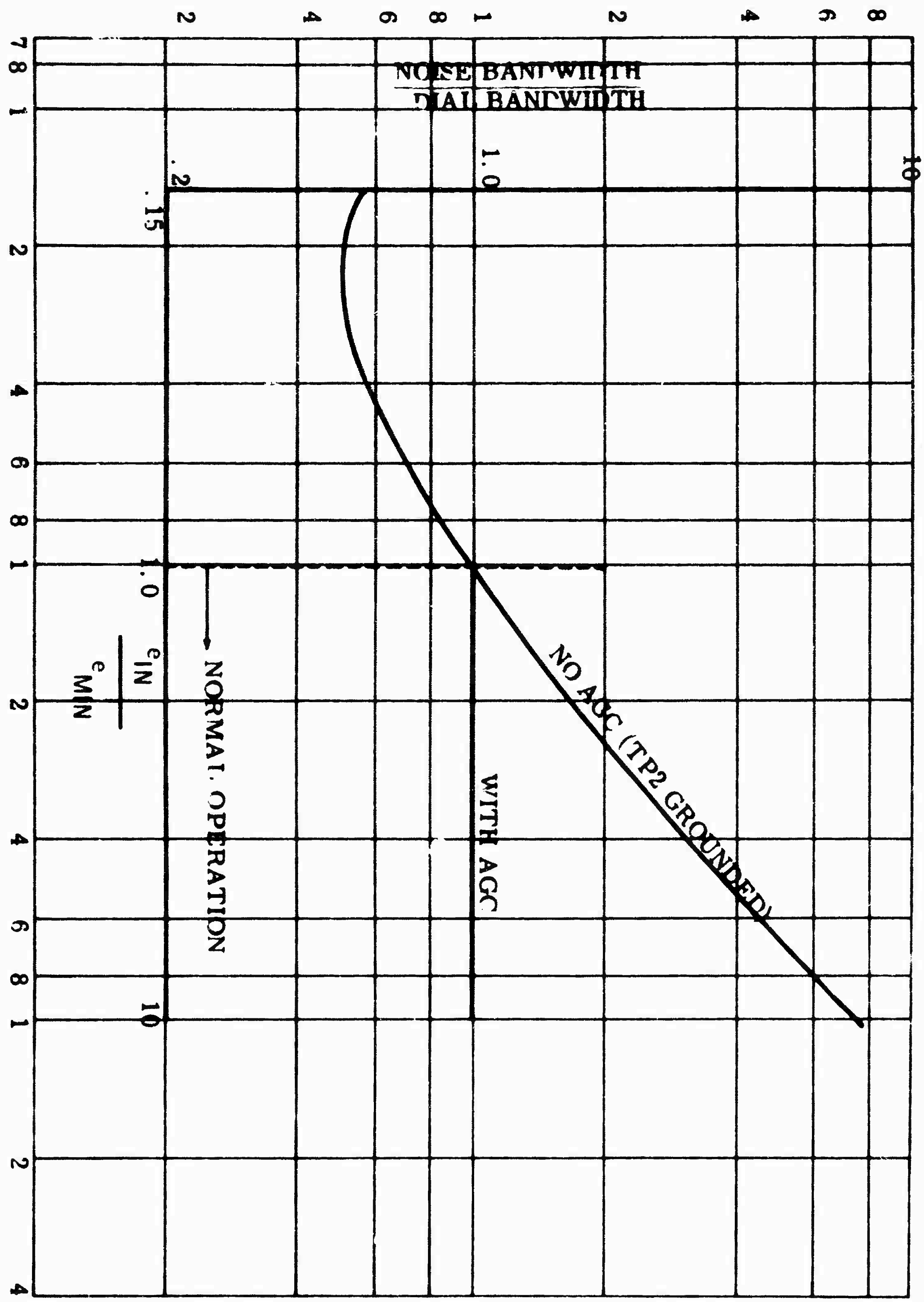


FIG. 4-3 THEORETICAL NOISE BANDWIDTH AS A FUNCTION OF LOOP GAIN

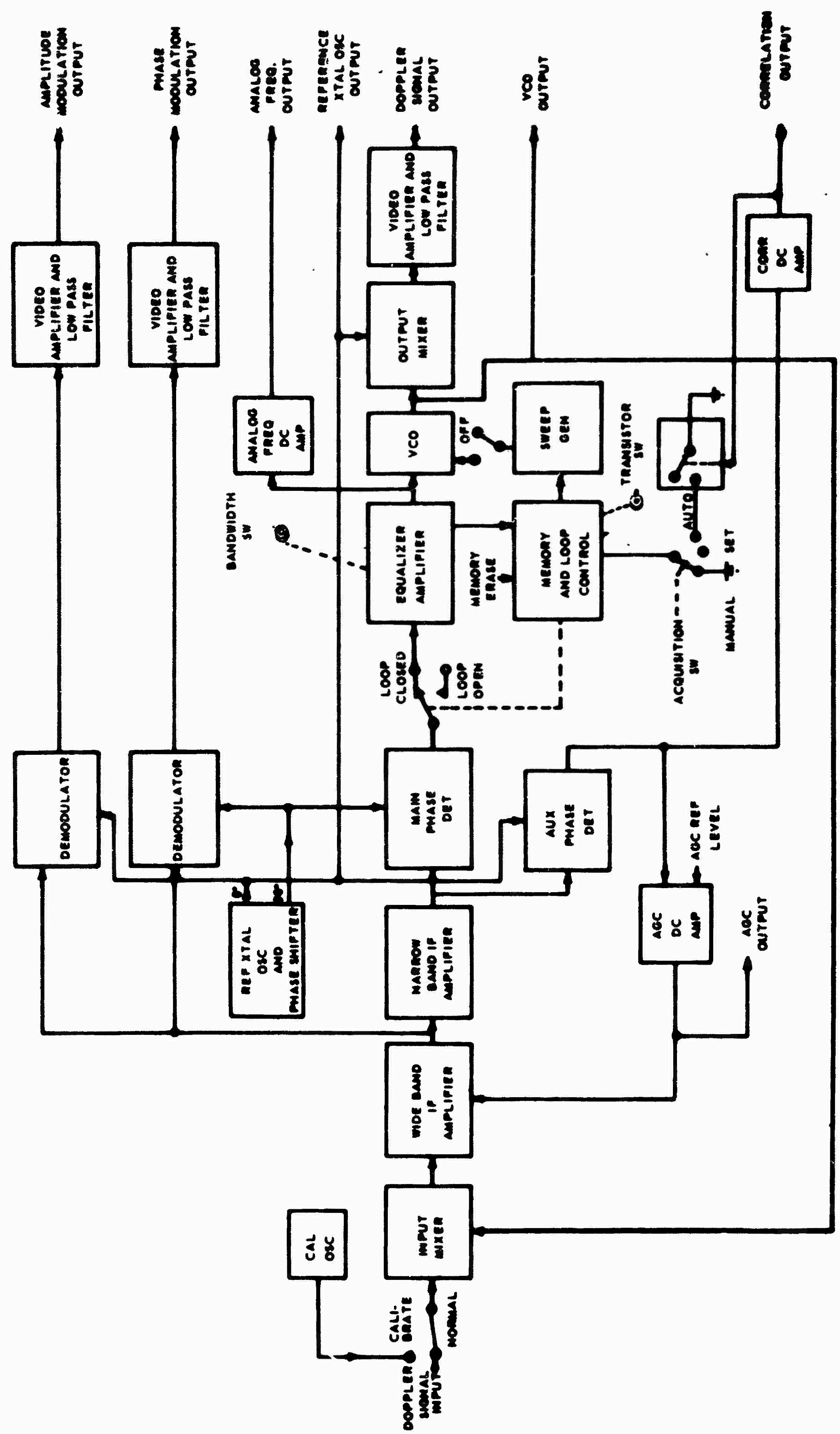


FIG. 4-4 BLOCK DIAGRAM OF TRACKING FILTER SYSTEM

can be manually changed, even during actual tracking. This equipment was designed for general real time use in C-W Doppler Systems.

Acquisition of the input signal, i.e., phase-lock, can be effected either automatically or manually. In the automatic acquisition mode the operator manually sets the controls to automatically sweep a preset band about a preset center frequency. Phase-lock then takes place automatically whenever a signal is present within the selected band. The operator may alternately provide manual frequency sweep instead of automatic, but still utilize the feature of automatic loop closure.

In manual operation the operator manually searches the frequency spectrum of interest. Then by utilizing the aural and/or visual aids provided, he can manually close the tracking loop when a successful lock-on appears probable.

A memory system is employed which "remembers" the last known frequency in event of the dropout of the input signal. If the automatic sweep feature is being used, the sweep will be centered about this last known frequency. A tracking filter consists of the following two units:

Tracking Filter Chassis	8-3/4 by 19-inch panel
Power Supply Chassis	8-3/4 by 19-inch panel

Controls are conveniently located according to the degree of anticipated use, and are divided into three types: (1) front panel controls, all of which must be used in actual operation; (2) calibration controls which may require occasional adjustment; and (3) controls which provide circuit calibrations and adjustments which do not normally require frequency re-setting.

SPECIFICATIONS:

(1) General

System	Phase-lock loop with correlated AGC. Manual or automatic frequency sweep system for signal acquisition.
Input Frequency	100 cps to 120 kc.
Input Level	Approximately 0.5 volt rms. (See Figure 7)
Tracking or Information Bandwidth	Adjustable to 2.5, 5, 10, 25, 50 or 100 cps.

	Tracking Bandwidth, B	Minimum S/N Ratio
Minimum S/N ratio in 120 kc input noise bandwidth based on 1/3 radian rms tracking error.	2.5 cps	-38 db
	5 cps	-35 db
	10 cps	-32 db
	25 cps	-28 db
	50 cps	-25 db
	100 cps	-22 db

Signal Acquisition	Automatic or manual.
Sweep Time (Automatic)	Adjustable to 10, 3, 1, 0.3, or 0.1 seconds.
Sweep Rate (Automatic)	$(\text{Bandwidth})^2$ cps/second (Depends on bandwidth setting)
Memory Circuit	Last known frequency retained if signal drops out. If in automatic acquisition mode, automatic sweep resumes, centered about last known frequency.
Power Requirements	105-125 vac, 50-60 cps; approximately 300 watts.
Size (Including Power Supply Chassis)	Rack Mounting - 19 x 17-1/2 by 17 inches deep. Slide tilt hardware.

(2) Outputs

Doppler Signal

Frequency	100 cps to 120 kc
Level	1 volt rms minimum
Impedance	Less than 500 ohms

Analog Frequency

Level	0 to -40 volts for 0 to 120 kc
Impedance	Less than 500 ohms (1 ma maximum)
Linearity	± 3% full scale

Correlation Output

Level	-4.0 volts for 100% correlation
Impedance	6000 ohms
Bandwidth	Approximately same as tracking bandwidth (B)

Correlation Relay

Purpose	Provides contacts for external circuitry to indicate tracking
Rating	2 amps, SPDT

Correlated Detector, Amplitude Modulation

Purpose	To detect AM on carrier
Bandwidth	Adjustable; 1, 3, 10, 30 and 60 kc
Impedance	Less than 500 ohms
Level	Adjustable, 0 to 2 volts rms for 30% modulation

Correlated Detector, Phase Modulation

Purpose	To detect PM on carrier
Bandwidth	Adjustable; 1, 3, 10, 30 and 60 kc.
Impedance	Less than 500 ohms
Level	Adjustable, 0 to 2 volts rms for 0.3 radian modulation

Phone Jack

Purpose	Aural aid for noisy signal acquisition
Impedance	Less than 500 ohms
Level	Adjustable, zero to audible for minimum input

Phase Detector Monitors (2)

Purpose	Visual aid for noisy signal acquisition (requires DC oscilloscope)
Impedance	0.5 megohm
Level	0.5 v minimum

Reference Crystal Oscillator Output

Frequency	262 kc
Level	Approximately 4 volts
Impedance	Less than 500 ohms

VCO Output

Frequency	262 kc to 382 kc
Level	Approximately 4 volts
Impedance	Less than 500 ohms

AGC Output

Purpose	Provides a measure of input signal level when calibrated
Level	0 to -10 volts (approximately)
Impedance	Less than 500 ohms (1/2 ma maximum)

(3) Front Panel Indicators

Frequency Meter

Range	0 to 120 kc
Linearity	± 3%

Correlation Meter

Range	0 to 150 units (100 normal)

Memory Lamp	Memory is in operation when light is lit
Correlation Lamp	Correlated tracking when light is lit

(4) Front Panel Controls

Set Frequency

Bandwidth Switch

Acquisition Switch

Sweep Time Switch

Frequency (Meter) Balance

Memory Erase Button

AGC Time Constant Switch

AM, cutoff frequency

AM, output level

PM, cutoff frequency

PM, output level

Phones, output level

(5) Top Chassis Controls

Calibrate Switch

Phase Detector Monitor Switch

There are six tracking filters used in the Down Range UDOP system. Whether the input doppler signal is from tape or directly from the data link receivers, the tracking filter is patched into the appropriate data channel, and fed to the UDOP digitizer. The tracking filters have an output, the correlation relay, which activates the associated indicator on the loss-of-lock indicator panel, and also generates an indication to the digitizer as flag in the data train. (See Figure 4-5).

Figure 4 - 5 Loss-of-Lock Indicator Panel

The UDOP digitizer is a 6-channel frequency counter. Unlike an ordinary frequency counter, however, the digitizer resolves any input frequency within its limits, to ± 100 nanoseconds. The input frequency limits are 5 KC to 72 KC. The digitizer operates at two sampling rates; 10 samples per second and 20 samples per second. At either rate the data is similar, as is the resolution and the format. For real time use the digitizer operates at 10 samples per second.

In functional terms, the digitizer counts whole cycles of an input signal, which can best be described as frequency counting. For every zero-crossing of a sinusoid or other waveform the digitizer adds a count of one to its whole cycle count. To resolve the small increment of time between the last zero-crossing and the end of a sample period, the digitizer goes into a method of time measurement (period). This is accomplished by counting the number of 10 MC pulses occurring between the last zero-crossing and the end of a data sample. (See section for digitizer arithmetic)

In addition to counting frequency the digitizer decodes the range time signal, senses for lock-unlock of the tracking filters and feeds the Collins AN/GSC-4 data transmitter. Many other functions are performed by the digitizer as noted in Figure 4-6 and Figure 4-7.

The critical area of digitizer performance is the time sequence of events, both internal to the digitizer and external to other units. For this purpose the digitizer contains a 10 MC clock stable to 2 parts in 10^8 over a 12 hour period.

The 10 MC clock is the heart of the digitizer, performing all counting, timing and sequencing functions through a timing generator. All strobe pulses that cause any digital operation within the machine are coherent with the 10 MC clock. Even AMR range time is not directly used as an input signal, although the capability exists. Range timing signals are sampled for coincidence with internal timing signals and a flag is used in the data to indicate timing agreement. Actual timing agreement occurs by coincidence of external and internal 10 PPS signals.

The complete digitizer is housed in a single EMCOR rack. (See Figure 4-8). The circuitry is all solid state. (See Figure 4-9). All controls are easily manipulated by the combination indicator/switch buttons on the front panel. As an example, any test pattern can be generated for any word or part of a word in the data format merely by putting the digitizer in test and depressing the appropriate indicator switch.

There is only one fixed, internal test pattern. This is the alternate 1-0 pattern used in the range time decoder. All other test patterns are set by the operator.

The indicator lights represent pure binary numbers and are labeled in binary. Other indications presented at the front are:

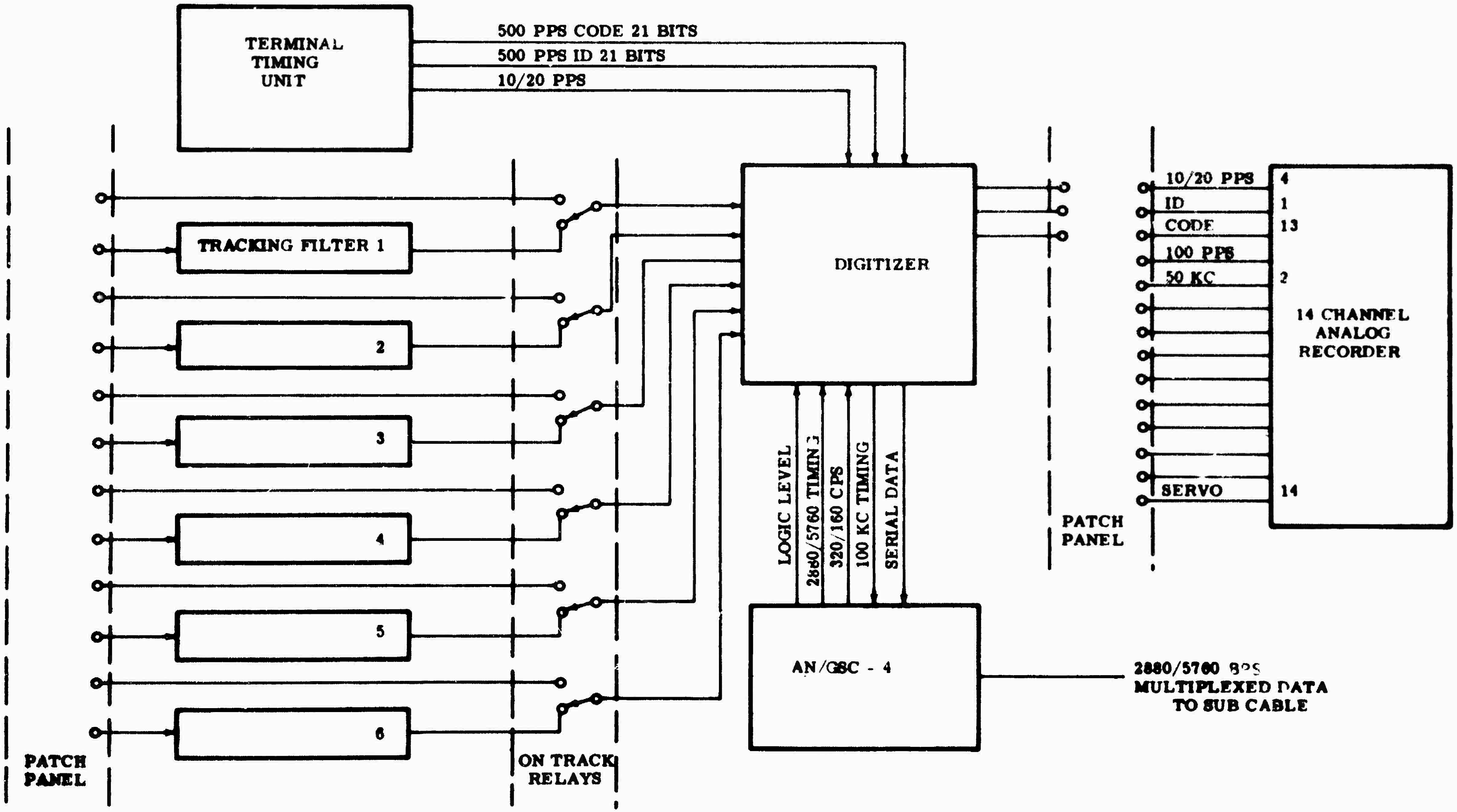


FIG. 4 - 6 DIGITIZER SYSTEM INTERFACE

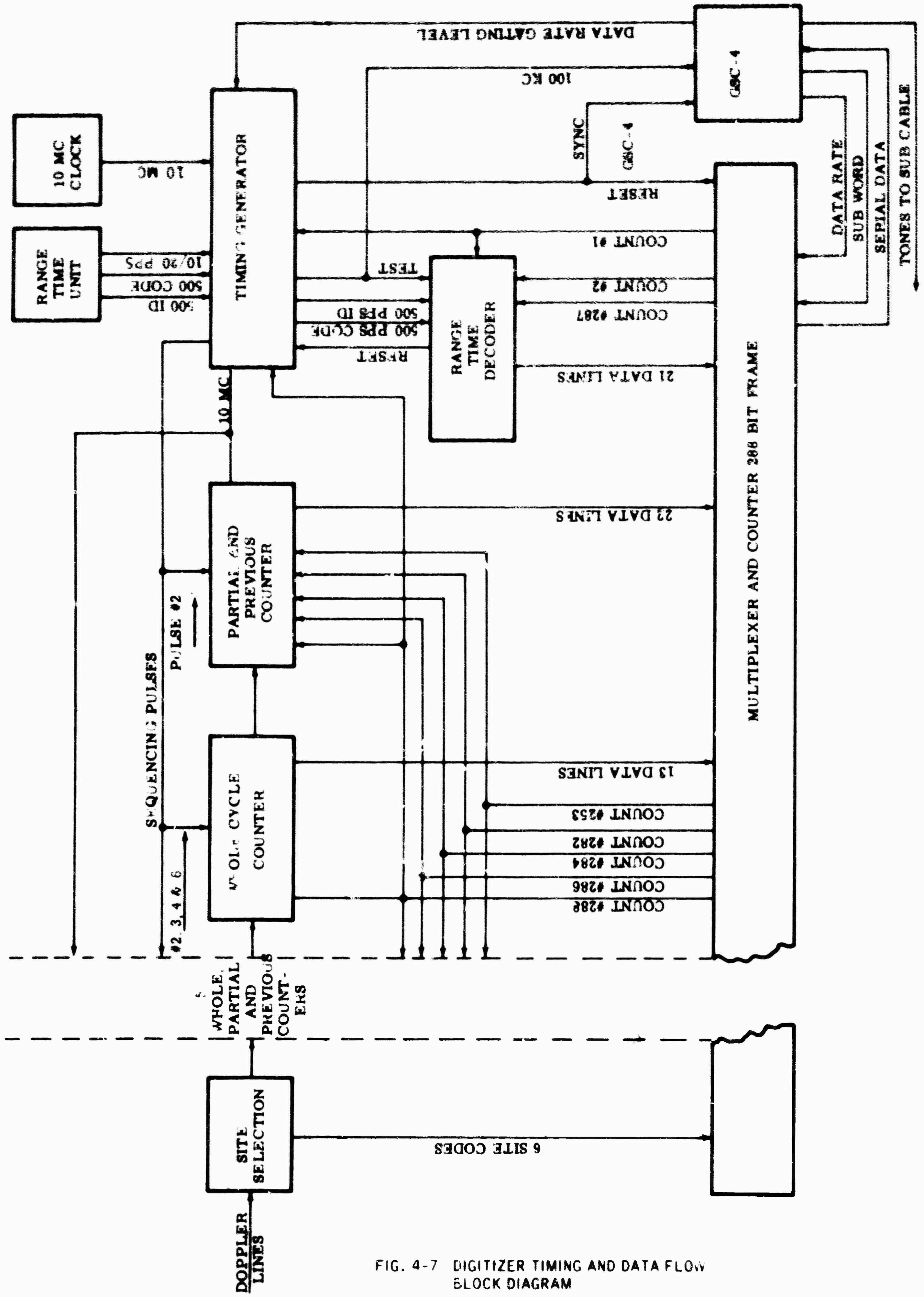


FIG. 4-7 DIGITIZER TIMING AND DATA FLOW
BLOCK DIAGRAM

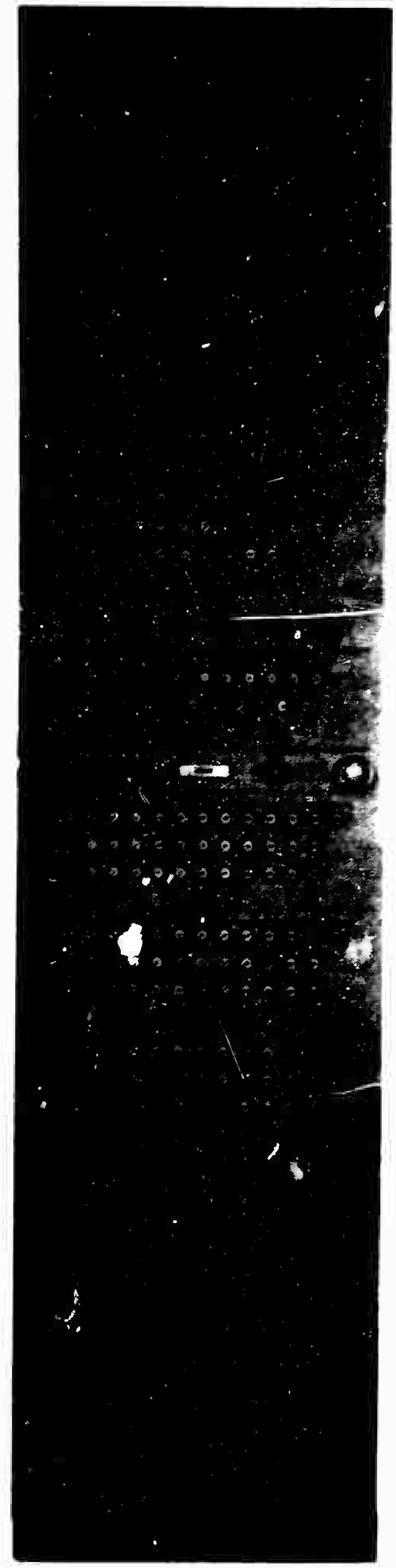


Figure 4 - 8 Digitizer and Control Assembly

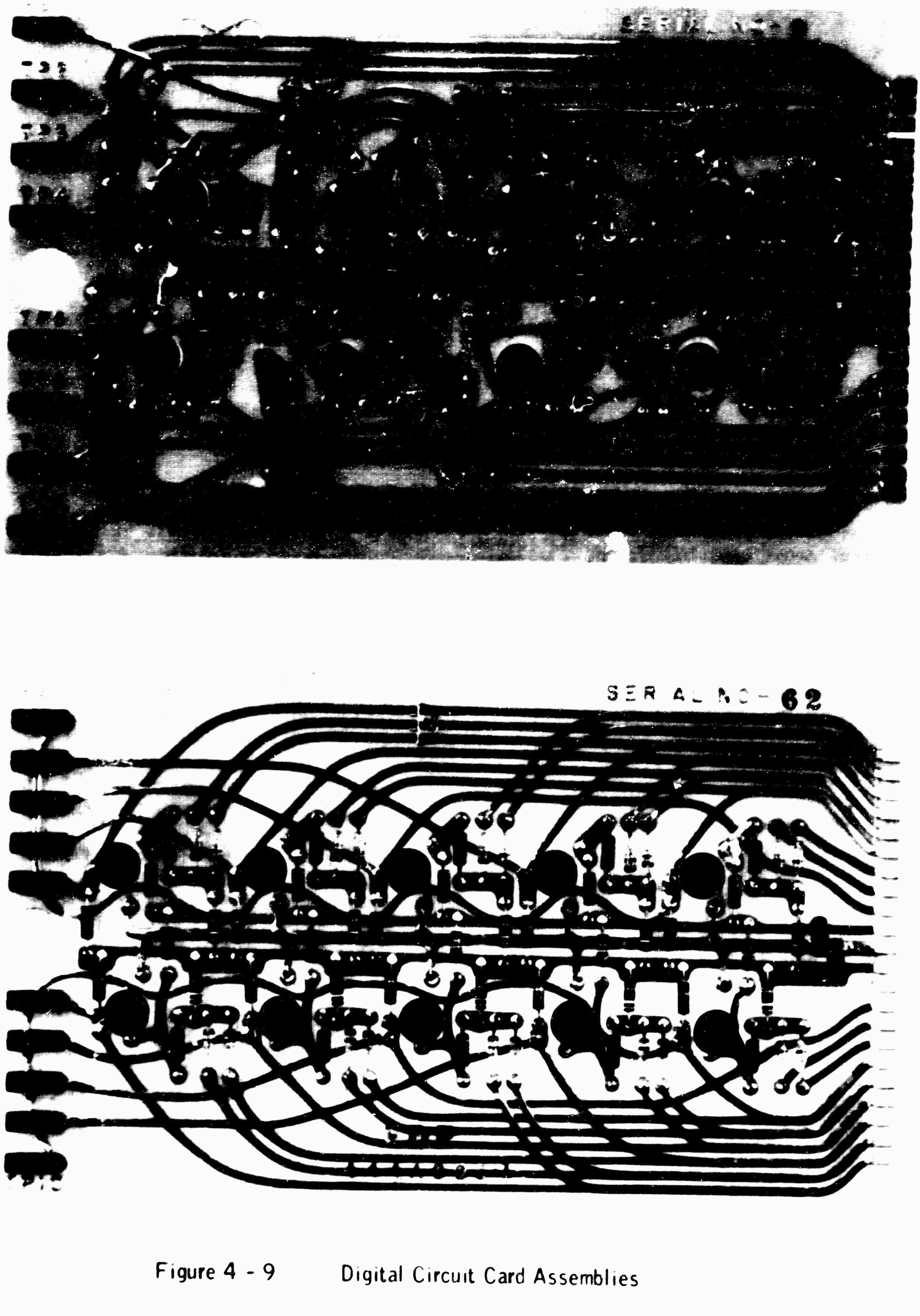


Figure 4 - 9 Digital Circuit Card Assemblies

1) Test or operate*
2) Input monitor
3) Parity for all sub words
4) Range time
5) Timing input
6) Internal/external synch*
7) Timing shift/set*
8) Power*
9) Tape record*
10) Tape rewind*
11) Tape drive*
12) Tape stop*
13) Master operate/test switch*
14) 5760 bit rate indicator
15) 2880 bit rate indicator
16) 100 KC reference indicator
17) Frame rate indicator

Those functions suffixed with an (*) are both indicator and switch. Each of the six channels has 13 whole cycle indicators, 11 previous cycle indicators, and 11 partial cycle indicators. Each indicator doubles as a switch when in the test mode.

The 13 bits in the whole cycle counters will allow no higher than a 8192 maximum count in any sample. 2048 is the maximum count allowable in the previous and partial cycle counters. These numbers determine the digitizer limits as follows:

> The design limit for upper doppler frequency is 72 KC. For 1/10 second this frequency would generate a count of 7200 in the whole cycle counter. Therefore, a maximum count capability of 8192 is sufficient. For the previous and partial cycle counters, (which measure period), the longest single cycle or lowest frequency is 5 KC. The period of a 5 KC signal is .0002 seconds or 200 usecs. Using 10 MC pulses to count this 200 usec period, 2000 pulses could occur. The 11 bit previous and partial cycle counters can count to 2048, which is within limits.

Figure 4-6 shows the inputs and outputs of the UDOP digitizer and their relationship to the other equipment.

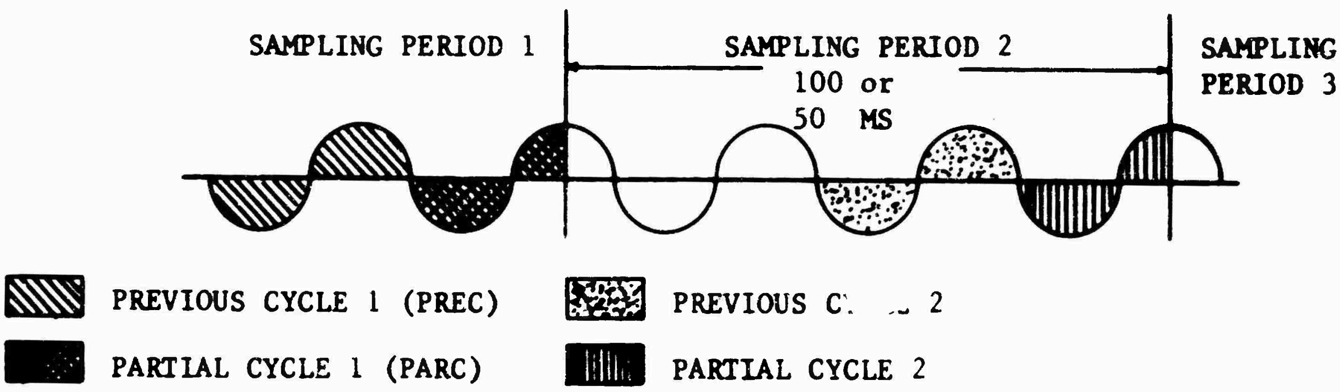
Figure 4-7 shows the sub-assemblies that make up the digitizer and the interrelationships between sub-groups. For a detailed explanation of each sub-group see the technical training manual, DHS-137.

DIGITIZER ARITHMETIC:

The following shows how the digitizer converts doppler signals to an exact frequency.

Each of the six digitizers accumulates data during the sampling period in three forms termed whole cycle count, previous cycle count, and partial cycle count. The sampling period is the same as the multiplexer frame period and is either 100 or 50 milliseconds determined by the bit rate selected on the AN/GSC-4 data modem.

At the end of each sampling period, the data is held in storage until the proper time during the multiplexer cycle when it is read out. Whole cycle count is a count of zero axis crossings in the negative direction of the sinusoidal doppler signal from the tracking filter during the 100 and 50 millisecond frame period. Refer to figure. Previous cycle count is a count of 10 megacycle pulses occurring during the last complete doppler cycle before the end of the sampling period. Partial cycle count is a count of 10 megacycle pulses occurring in the fraction of a complete doppler cycle before the end of the sample. Since the sample width is very accurate, frequency during a sample can be determined by the following formula:



WHOLE CYCLE COUNT (WCC) = NUMBER OF CROSSOVERS IN 100 OR 50 MS

$$FD = WCC - 1 + 1 - \frac{PARC\ 1}{PREC\ 1} + \frac{PARC\ 2}{PREC\ 2}$$

AND SO FOR CONSTANT FREQUENCY, PREC 1 = PREC 2

$$FD = WCC + \frac{PARC\ 2 - PARC\ 1}{PREC\ 2}$$

OFFSET 18 KC = 0 VELOCITY

DOPPLER 18 KC = MISSILE RANGE DECREASE

DOPPLER 18 KC = MISSILE RANGE INCREASE

DOPPLER ARITHMETIC FOR CONSTANT FREQUENCY

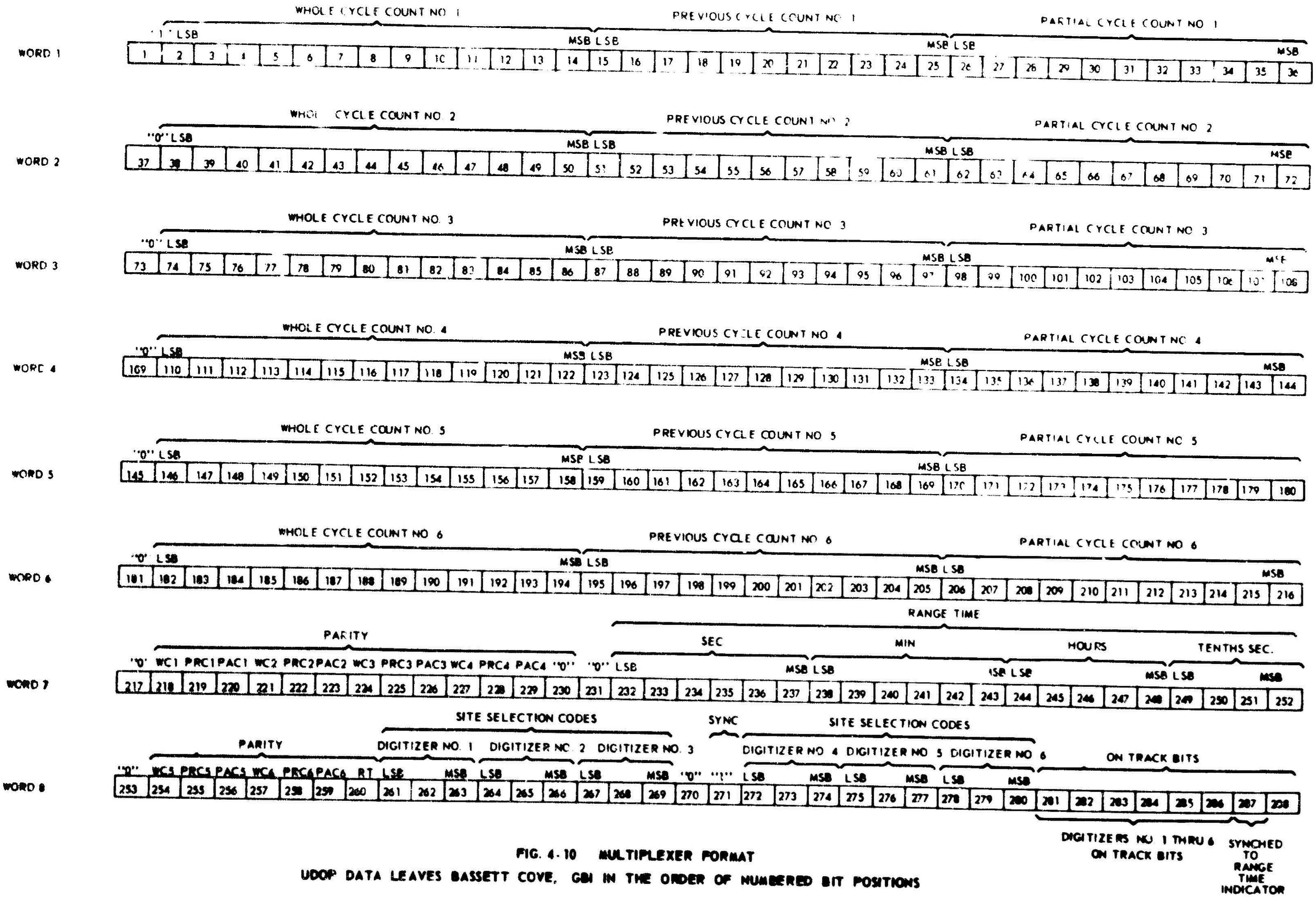


FIG. 4-10 MULTIPLEXER FORMAT

UDOP DATA LEAVES BASSETT COVE, GBI IN THE ORDER OF NUMBERED BIT POSITIONS

The digitizer scans all counters; 6 previous cycle counters, 6 partial cycle counters and 6 whole cycle counters, as well as the range time decoder, all fixed data switches, and 19 parity flip-flops, loads the composite data into the multiplexer, and then sequences the data out serially to the AN/GSC-4 at the proper bit rate. The format of the data is fixed in the multiplexer to generate the data as shown in Figure 4-10. Eight 36-bit words are the result, for a total of 288 bits in each data sample.

The Collins AN/GSC-4 Data Modem is the means used to transfer the UDOP data from Bassett Cove, GBI, to the impact predictor facility at CKMTA. After digitization, the UDOP data is fed serially to the AN/GSC-4 for signal conditioning and such manipulation as necessary to insure proper transfer of data over the submarine cable without degradation due to path characteristics. A series of photographs of the AN/GSC-4 are shown in Figures 4-11 through 4-13.

The following is a brief description of how the AN/GSC-4 converts serial digital information to transmissible FM tone bursts and back again to serial digital information.

A general block diagram of the AN/GSC-4 is included as Figure 4-14 and Figure 4-15.

The AN/GSC-4 is a phase-shift keyed system (PSK). Without referring to timing and sequencing, assume 18 binary bits, in any configuration are loaded into the input serial/parallel (S/P) shift register. As soon as a full 18 bits has been clocked in, the 18 bits are broken up into six 3-bit groups. Each group feeds a phase generator at a particular frequency. The six frequencies are:

935 cps	These frequencies are not the actual phase generator frequencies, but are the results after heterodyning.
1375 cps	
1815 cps	
2255 cps	
2695 cps	
3135 cps	

Assume now that the phase generator (oscillator) is perfectly phase stable and is oscillating at 935 cps. Now, the following 3 bits of binary information come in: 0 1 0. The phase generator now shifts phase backwards by 112.5 degrees. The oscillator is still operating at 935 cps, but its wave form now lags what it was by 112.5 degrees. The phase generator will remain in this state until shifted again. Now let us assume that the next group of bits has been loaded into the S/P register and the bit configuration for the 935 cps phase generator is now 1 1 1. This means that the phase generator will now shift backwards (lag) by 202.5 degrees, and remain that way until a third set of data comes in. This process continues as long as the equipment is left on. See Figure 4-16 for a digital to phase relationship.

The process cited above occurs simultaneously in six phase generators operating at the frequencies listed. The outputs of all six phase generators are mixed together and heterodyned down to the frequencies needed for the communications path in use.

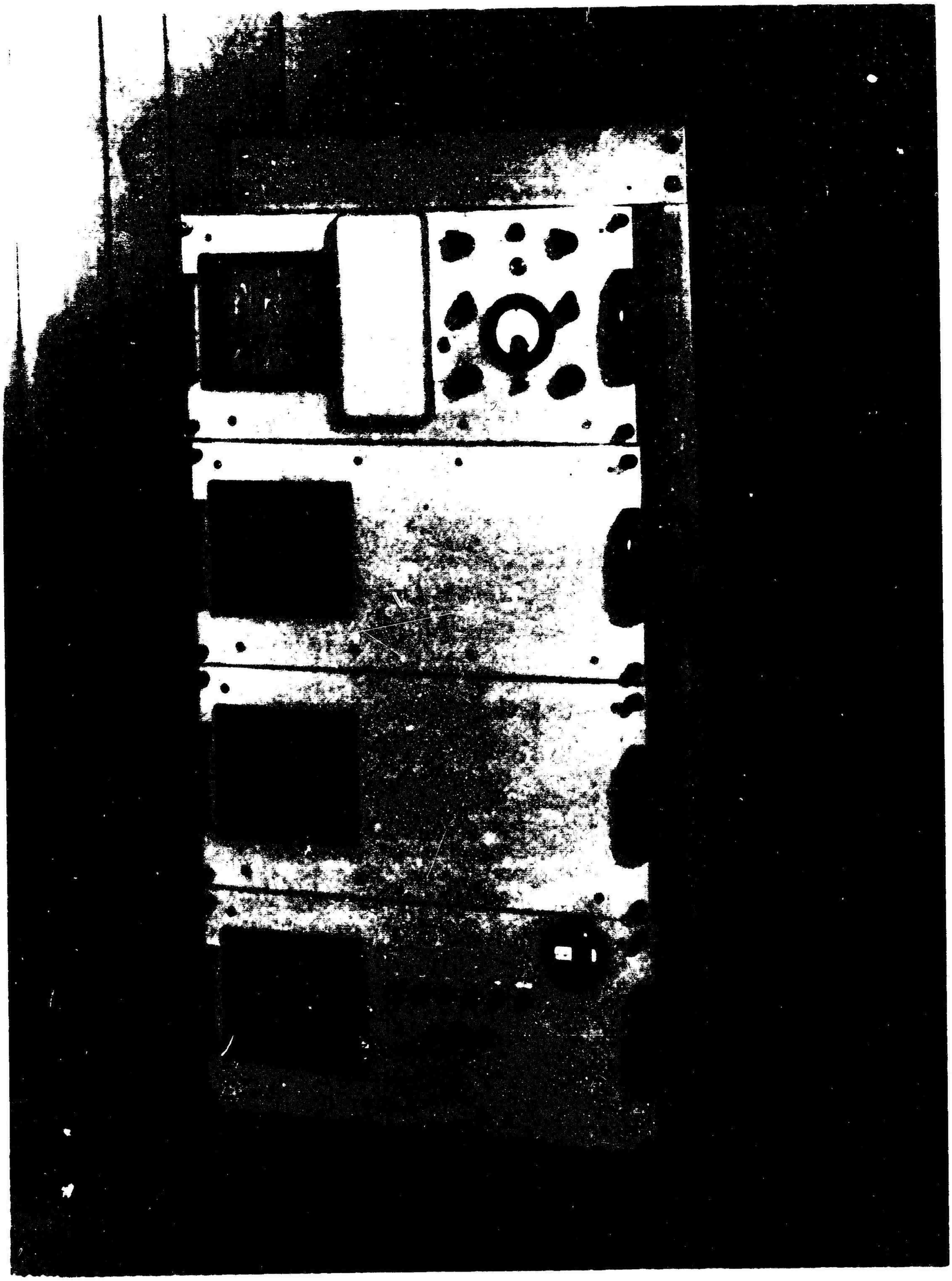


Figure 4 - 11 Front View of AN/GSC-4 Data Modem

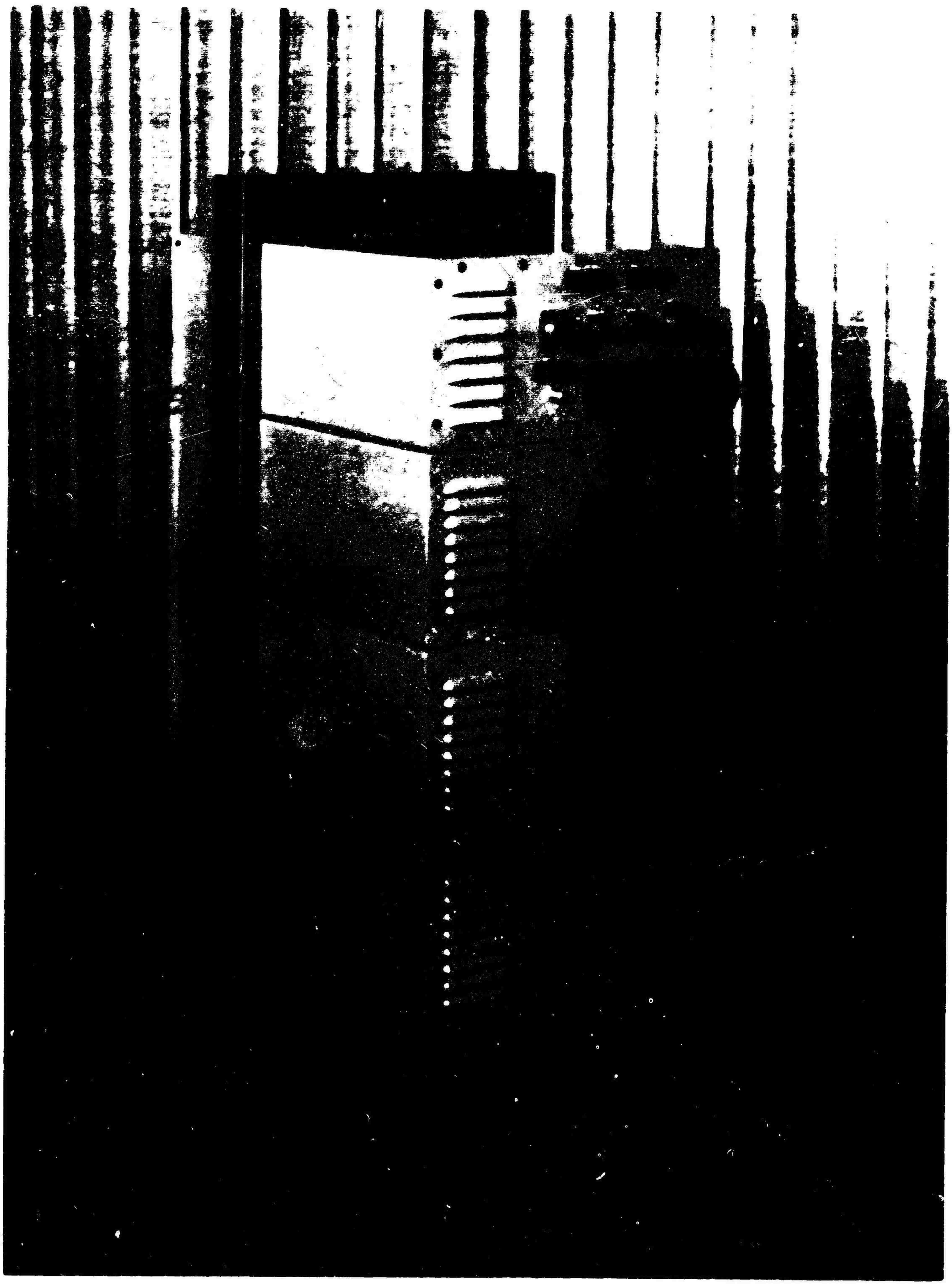


Figure 4 - 12 Rear View of AN/GSC-4 Data Modem

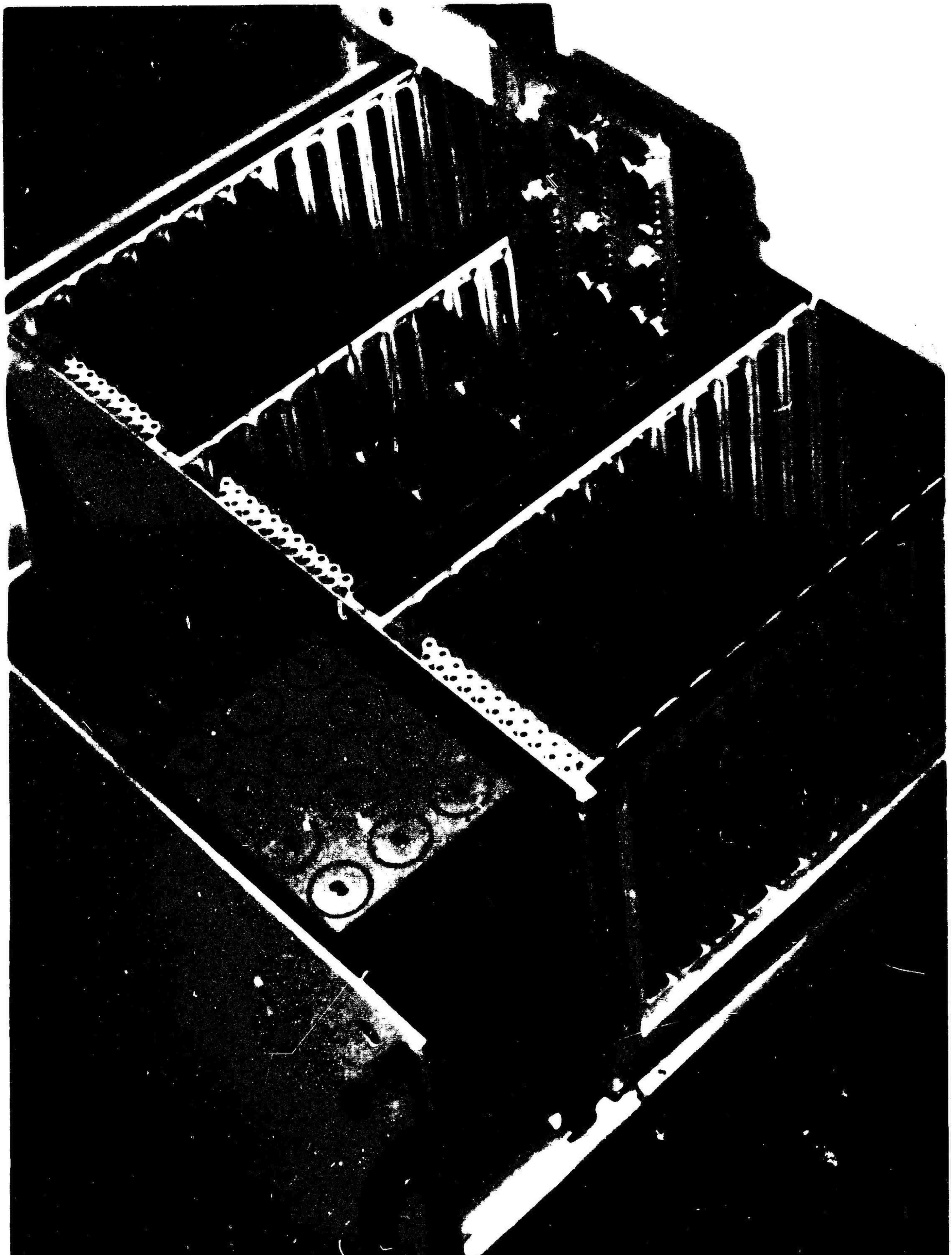


Figure 4 - 13 Circuit Cards [illegible] AN/GSC-4

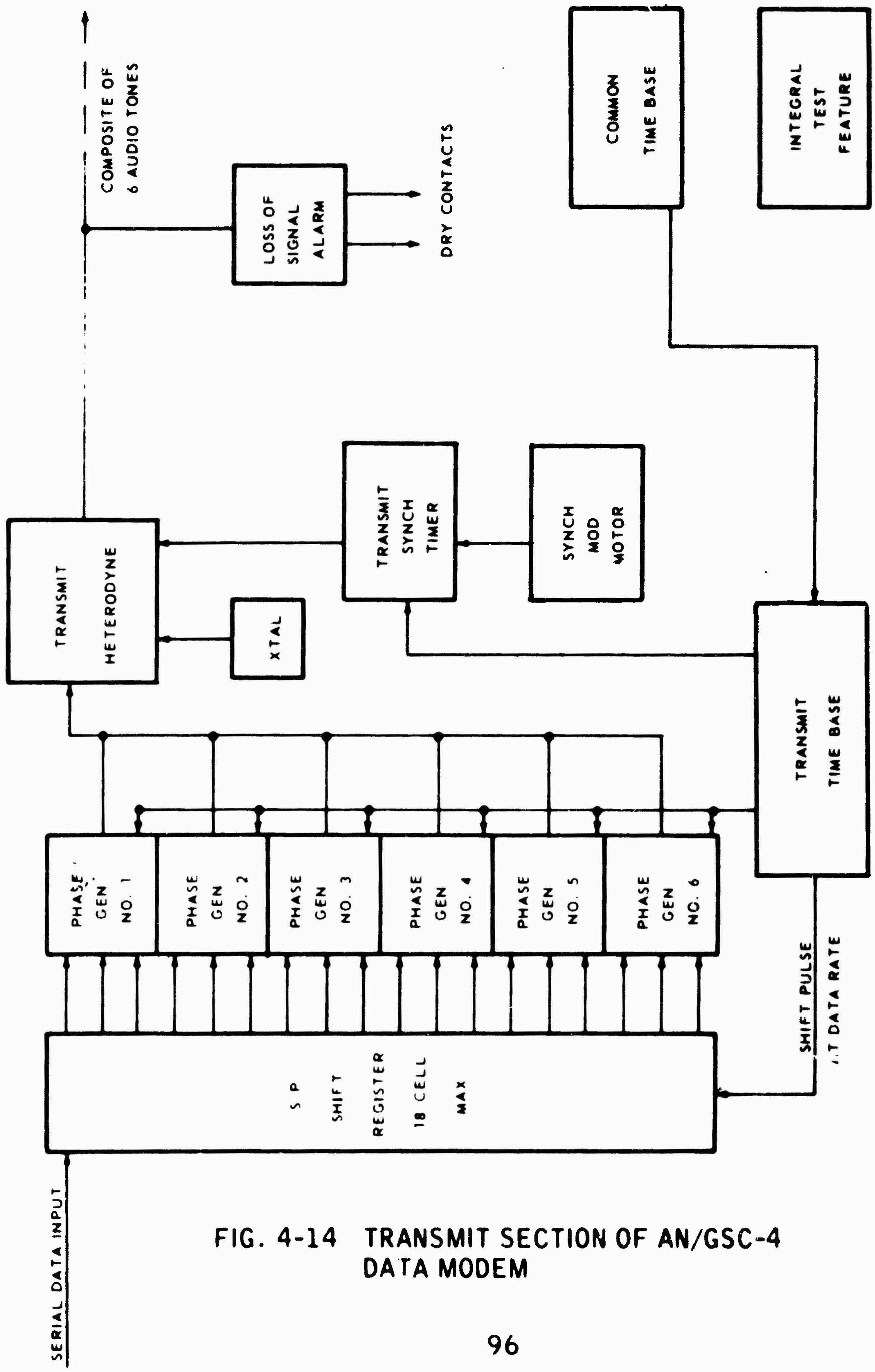


FIG. 4-14 TRANSMIT SECTION OF AN/GSC-4 DATA MODEM

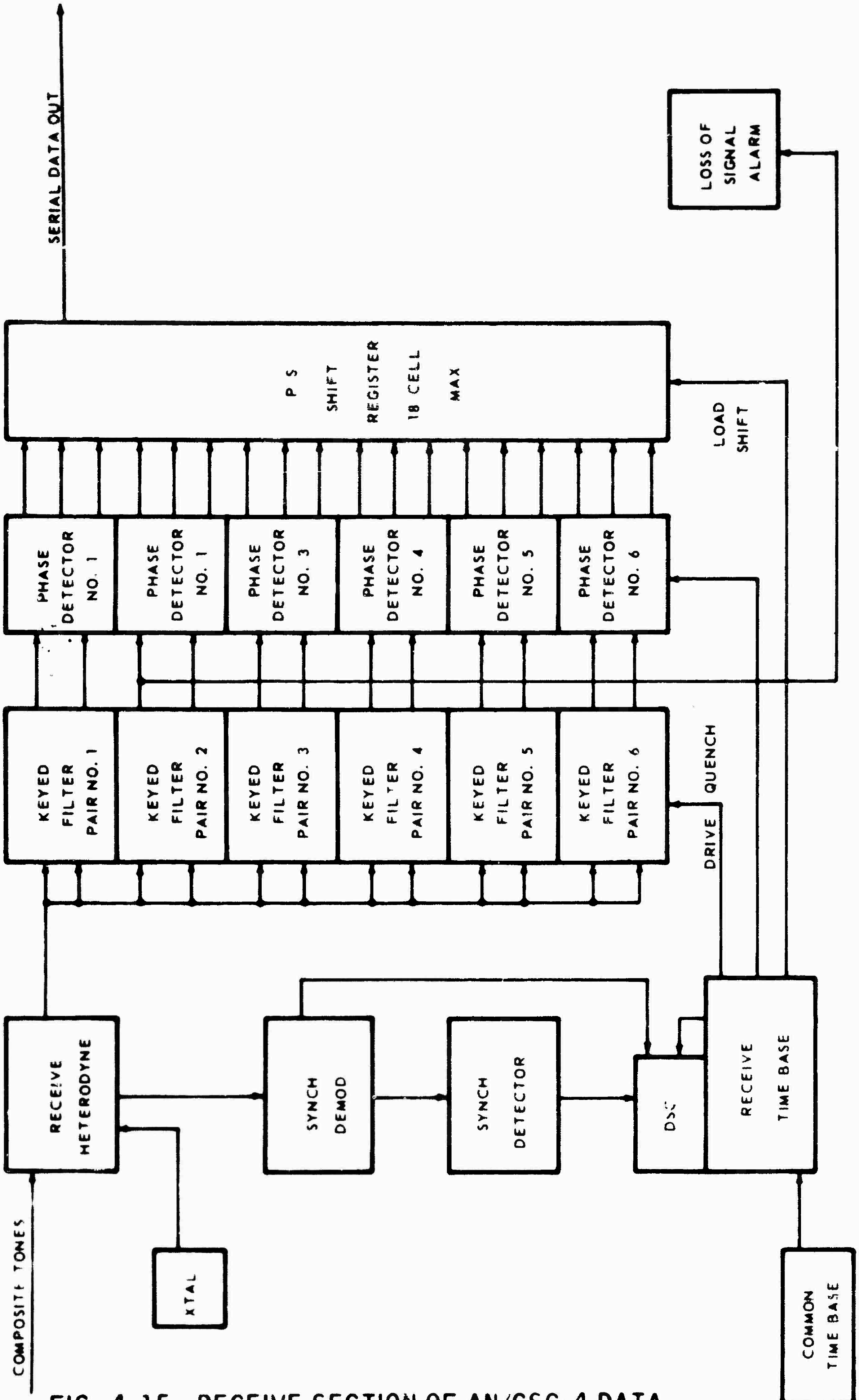
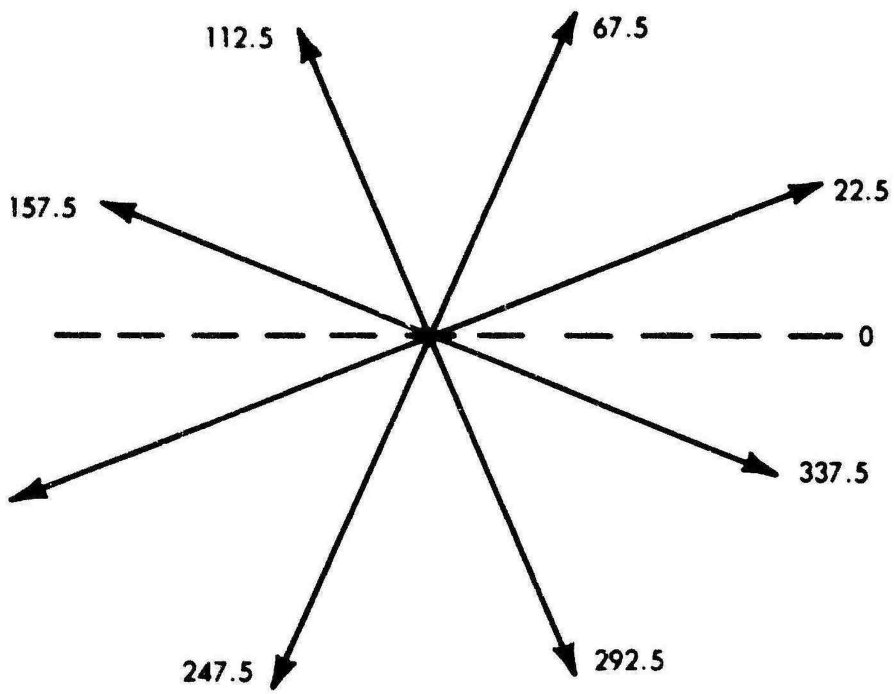


FIG. 4-15 RECEIVE SECTION OF AN/GSC-4 DATA MODEM



CHANGE IN PHASE	BIT CONFIGURATION (3 – BITS)		
22.5	0	0	1
67.5	0	0	0
112.5	0	1	0
157.5	0	1	1
202.5	1	1	1
247.5	1	1	0
292.5	1	0	0
337.5	1	0	1

FIG. 4-16 AN/GSC-4 DIGITAL TO PHASE TO DIGITAL RELATIONSHIP

In addition to the process above, the output signal is further modulated by a 160 cps sine wave, once every minute for a period of five seconds. This is the method of synching the time base of the data transmitter with the time base of the receiver. Synching does not use up valuable data space in the actual messages.

In the AN/GSC-4 Receiver, the exact reverse of what occurred in the transmitter takes place. (See Figure 4-15). The incoming composite signal is heterodyned up to workable frequency. The output of the receive heterodyne then drives six pairs of keyed filters. Each pair of keyed filters is frequency tuned to a corresponding phase generator in the transmitter. Using the same example as before, the first burst of energy at 935 cps is detected and fed to the proper keyed filter pair. A keyed filter pair is two carefully tuned mechanical cavity resonators. One side of the 935 cps keyed filter is excited and oscillates at the frequency and phase at which it was driven. The next burst of energy at 935 cps (1 1 1) is fed to the opposite side of the keyed filter pair from the previous burst. We now have two mechanical resonators oscillating at 935 cps. The second burst, though, was delayed in phase from the first burst by 202.5 degrees. The outputs of each side of the keyed filter is fed to a phase detector which senses the difference between the second and the first burst at 935 cps. Once the phase difference has been sensed, a 3-bit pattern is set up at the output of the phase detector, which is loaded into the shift register. In this manner, each successive burst of energy at 935 cps acts as the phase reference for the following burst. The keyed filter is flipped back and forth so that successive bursts of energy are fed to alternate sides of the pair.

In addition to the phase sensing, the 160 cps AM signal on the signal is sensed, and used to force the receive time base in synchronism with the transmit time base.

The AN/GSC-4 Modem is, in actuality, a duplex terminal. Bassett Cove and the impact predictor site have both a transmit and receive capability. The transmit capability is used at Bassett Cove, and the receive capability is used at the impact predictor site.

There are many signals fed into, and derived from the AN/GSC-4. Some of these are data rate, sub-frame synch, reference time base, etc. These are not shown on the drawings included.

To date, the AN/GSC-4 Data Modem has exhibited unmeasurable errors at the operating speeds used in the UDOP Systems. Two speeds are available to the UDOP System, 2880 bits/second corresponding to a UDOP sampling rate of 10 samples/second, and 5760 bits/second corresponding to a UDOP sampling rate of 20 samples/second. The UDOP Digital System generates 288 bits for each sample taken. (288 x 10 = 2880, or 288 x 20 = 5760). In a twentieth of a second, the full 288 bits must be transmitted by the AN/GSC-4. This is accomplished as follows: (example for 20 samples/second operation).

a) The 18-bit register must be loaded 16 times in 1/20th of a second.

b) Each phase generator must operate 16 times in 1/20th of a second.

c) The transmit time base must strobe out the phase generators 16 times in 1/20th of a second.

All this, of course, is accomplished and the rate at which the transmit time base strobes out the phase generators is 320 times a second.

For operation at 10 samples/second, the phase generators listed as Nos. 1, 5 and 6 are not used. The total data rate is therefore 2880 bits/second. Correspondingly, the associated keyed filter pairs, Nos. 1, 5 and 6 are not used at the slower data rate. For real time impact prediction, where the UDOP Data is fed to a computer for computation of expected impact point, the AN/GSC-4 System operates at 2880 bits/second.

A limitation of the rate used is the path over which the tone bursts are transmitted. The submarine cable system used on the AMR is a Western Electric Type K Carrier System, with severely limited bandwidth on each data channel. Phase delay characteristics of the data path can hamper operation of the AN/GSC-4 at high speed (5760 BPS). During a support mission, the AN/GSC-4 feeds subcable circuit 10CC89, Channel 6, which has the phase delay and frequency characteristics shown in Figure 4-17.

The UDOP Data Format Converter, designed and built by EDP Corporation, is located in the Impact Predictor Building at Cape Kennedy. The equipment converts the UDOP serial data train output of the AN/GSC-4 data transmission modem to a 35 bit parallel word input for the IBM 7094 Computer and to a transmitted tone data signal for a Lenkurt 3001 Data Receiver located in the Technical Laboratory Data Reduction Area.

As shown in Figures 4-18 and 4-19, all circuitry of the format converter is located in one equipment cabinet which also contains the AN/GSC-4 Data Modem and format converter power supplies.

The format converter circuitry is contained on 189 plug-in cards located in 7 card files with 27 cards per file. Four card files, numbered 1 through 4, are mounted in the top half of the cabinet above the AN/GSC-4 which is designated card file 5. Three card files, numbered 6 through 8, are located near the bottom of the cabinet and above the converter power supply at the bottom of the cabinet.

A second equipment cabinet, associated with the converter is mounted adjacent and contains an Ampex FR-1100 Data Train Playback Tape Deck, playback NRZ Amplifiers, control track demodulator and capstan power generator. A control panel for the format converter is also located in the middle of this cabinet between the tape deck and NRZ amplifiers.

Format converter is a descriptive name for three related units. These units or sub-sections are the sequencer, IBM Data Register and Lenkurt Data Storage and Transmitter.

The theory of operation of each of these units will be treated separately.

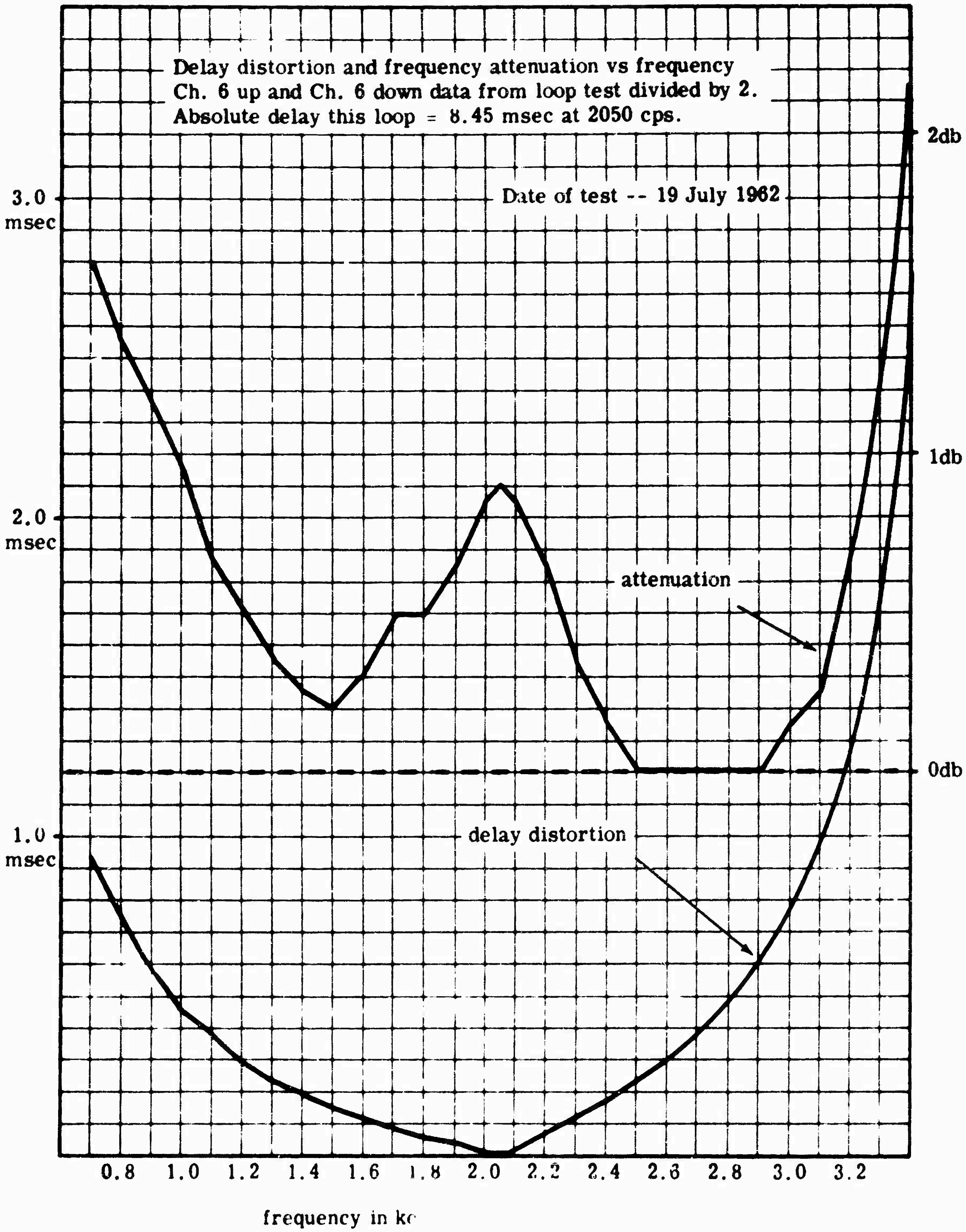

Delay distortion and frequency attenuation vs frequency
Ch. 6 up and Ch. 6 down data from loop test divided by 2.
Absolute delay this loop = 8.45 msec at 2050 cps.
Date of test -- 19 July 1962
3.0 msec
2.0 msec
1.0 msec
2db
1db
0db
attenuation
delay distortion
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
frequency in kc

FIG. 4-17

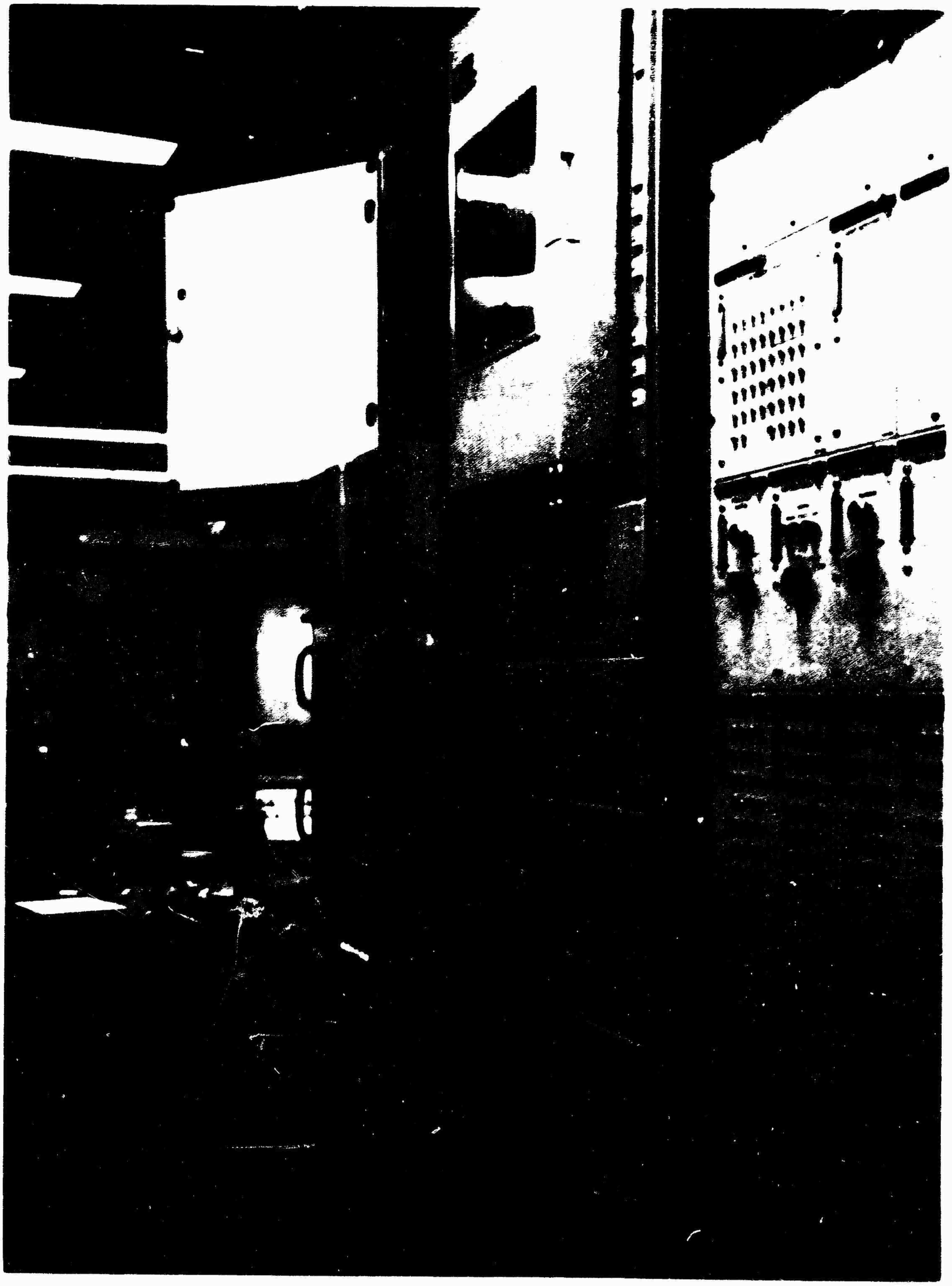


Figure 4 - 18 Format Converter Including AN/GSC-4 Data Modem

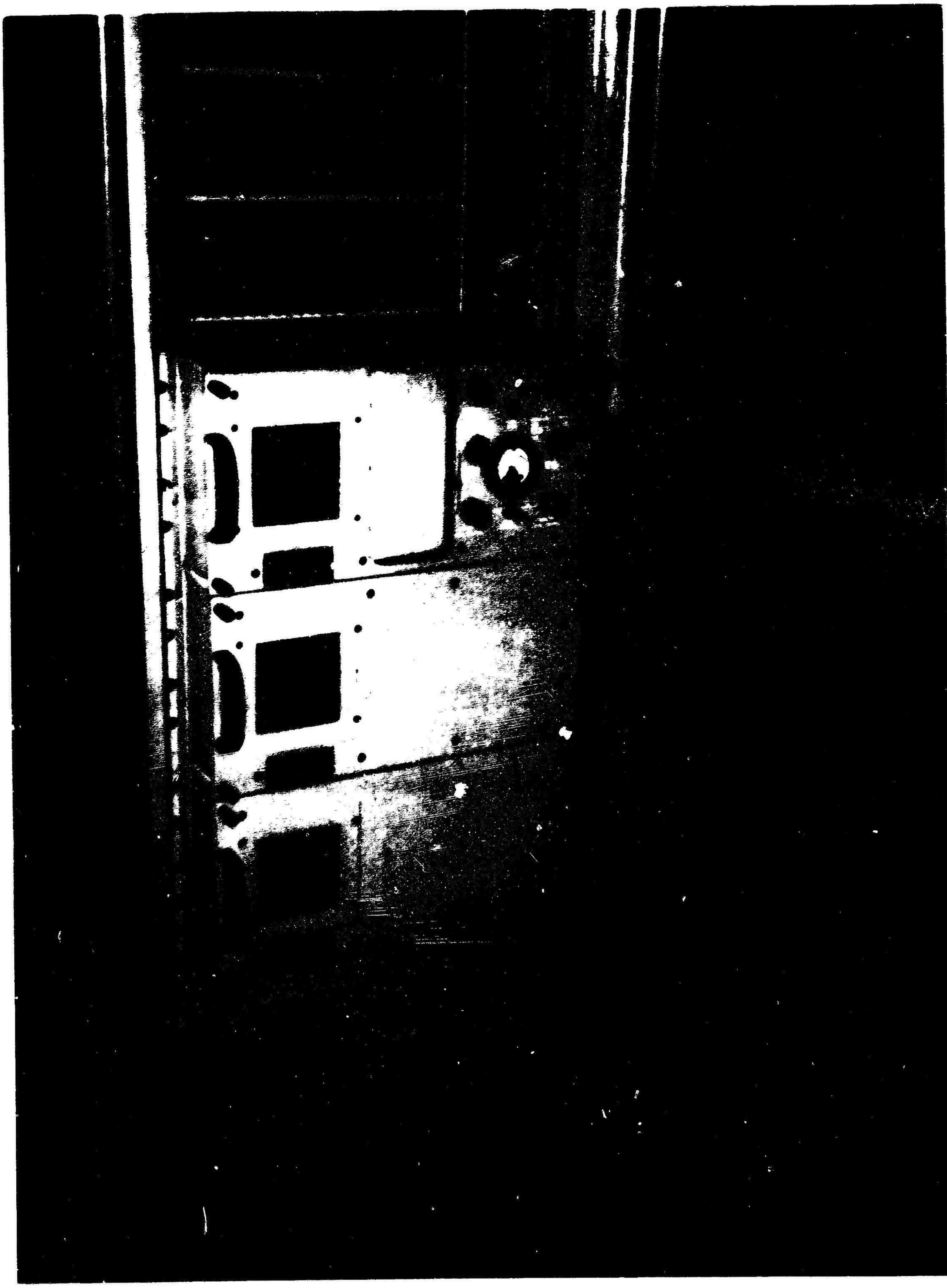


Figure 4 - 19 View of Format Converter Showing Ampex FR-1100 Recorder

The sequencer sub-section of the format converter performs the following functions:

1. Synchronizes and sequences the operation of the IBM Data Register with the AN/GSC-4 Data Train.

2. Synchronizes and sequences the op ration of the Lenkurt Data Transmitter sub-section with the AN/GSC-4 Data Train, simultaneously with (1) above.

3. Provides demand pulses and end of message pulses to the IBM 7094 Computer.

4. Provides a visual indication of synchronous operation.

Inputs to the sequencer are outputs of the AN/GSC-4 Data Receiver, IBM 7094 Computer and FR-1100 Tape Playback and consist of:

1. Data Train (2880 bits/second rate)

2. Data Rate (2880 cycles/second)

3. Sub-word rate (160 cycles/second)

4. 320 cycles/second

5. IBM select voltage

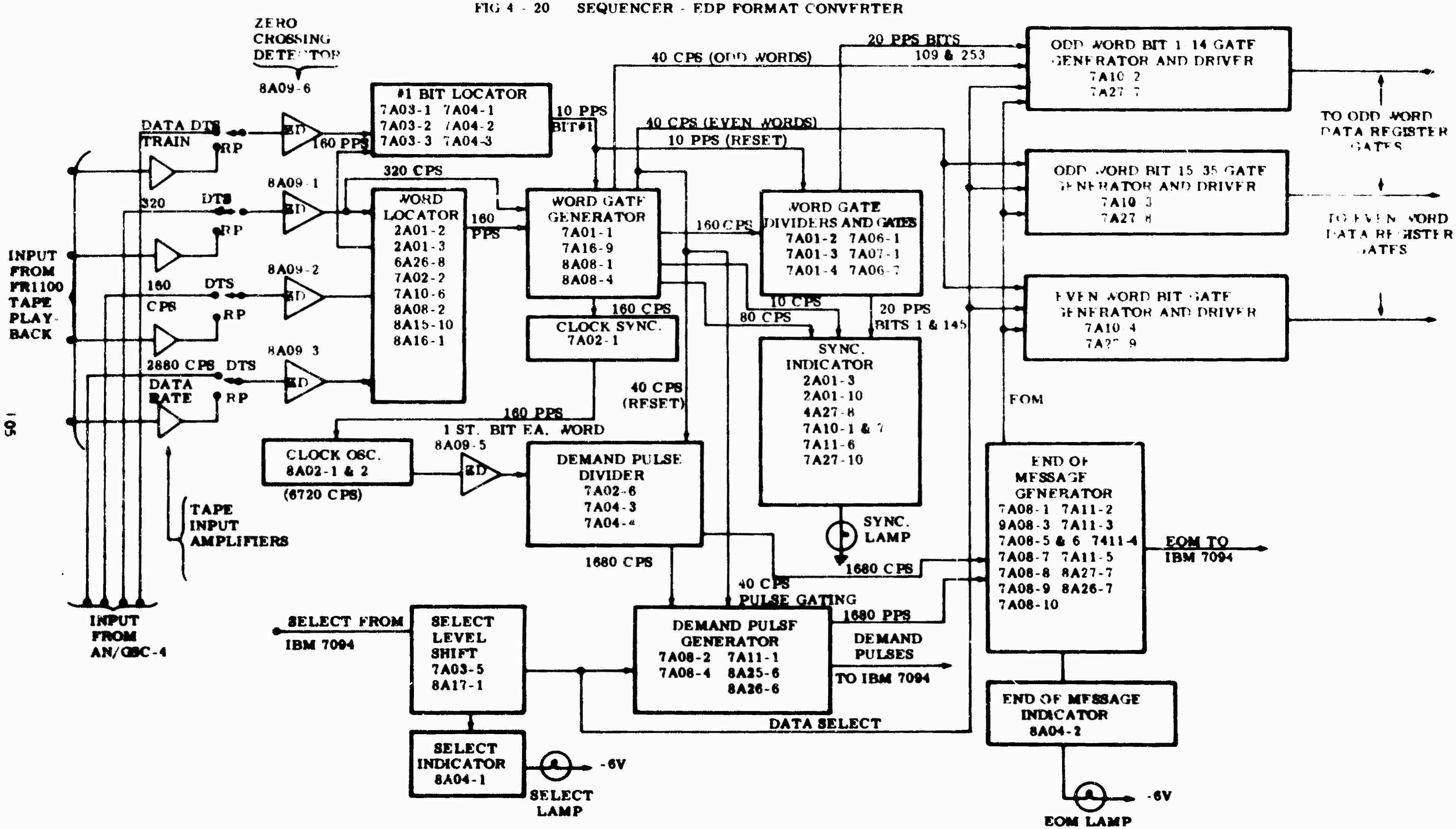
Inputs 1 through 4 above, are switched into the format converter from either the AN/GSC-4 or FR-1100 by a switch located on the control panel. This switch is labeled DTS-RP (Data Transmission System - Recorder Playback).

The Data Registers, under control of the sequencer, produce alternate 35 bit parallel words for the IBM 7094 Computer from the 2880 bit/second serial data train. Either register holds a 35 bit data word for the computer.

Figure 4-20 is a block diagram of the sequencer sub-section of the Format Converter. Each block of Figure 4-20 contains the designations of circuits used to perform the descriptive function of the block.

Each input to the Sequencer is processed by a pulse shaping zero crossing detector circuit. This circuit produces a positive going output pulse of extremely fast rise time for each negative going zero axis crossing of the input waveform.

FIG 4 - 20 SEQUENCER - EDP FORMAT CONVERTER



In order to synchronize the input data train the first bit of each word is located and then bit one of word one is isolated. In the "Word Locator" circuit, 2880 cps data rate, 160 cps sub-word rate and 320 cps all from the AN/GSC-4 receiver or tape, when in the proper phase will produce a 160 pps output. These pulses are positive going at the first and middle bit of each word. The 160 pps output of the "Word Locator" is applied to the "#1 Bit Locator" circuitry with the data train output of the AN/GSC-4. The data train input to the circuit is gated at the first and middle bit of each word. The fixed bit sequence of the data format, will allow the bits gated by the "Word Locator" output to provide counting of ones and reset of counters on zeros. Two consecutive ones, without reset by a zero, will produce an output of the second counter 7A04-2 to one shot 7A02-3. Fixed bits 271 and then 1 will produce a pulse output of the one shot at bit 1. The counter can further count to three when gated bit 19 is a one but the following gated bit 37 is always a zero and will reset the counter. Similarly gated bit 55 can be a one but the following gated bit 73 is again always a zero and will reset the counters before an output occurs. The same thing happens in each word until bit 271, where two consecutive ones again produce an output. The output of the "#1 Bit Locator" is a short pulse occurring at the 10 pps rate.

In the "Word Gate Generator" inputs of 320 cps from the AN/GSC-4 or tape, 160 pps from the "Word Locator" and 10 pps from the "#1 Bit Locator" produces outputs for the "Word Register Bit Gate Generators", "6720 cps clock osc." synchronization and the "Sync. Indicator". The two outputs to the ODD and EVEN "Gate Generators" are 40 cps, one output is negative, during the interval of ODD words and the other is negative during EVEN words. The output of the "6720 cps clock osc." is 160 cps through a monostable (one shot) to produce 160 pps synchronizing pulses. Outputs to the "Sync. Indicator" are 10 cps, negative, during the first 145 bits (one half) of each data frame and 80 cps, negative during bits 19 through 37 and all following alternate 19 bits.

The "Word Gate Dividers and Gates" produce 20 pps, negative during word 1 for the 14 bit ODD word gate generator and 20 pps negative during word 7 for the "Sync. Indicator". These pulses are produced from the 160 cps voltage output of the "Word Gate Generator" synchronized by 10 pps occurring at bit 1.

The "Synch. Indicator" circuit relies upon the proper phase relationship of the three input voltages not changing the state of a bistable (cross connected NOR gate).

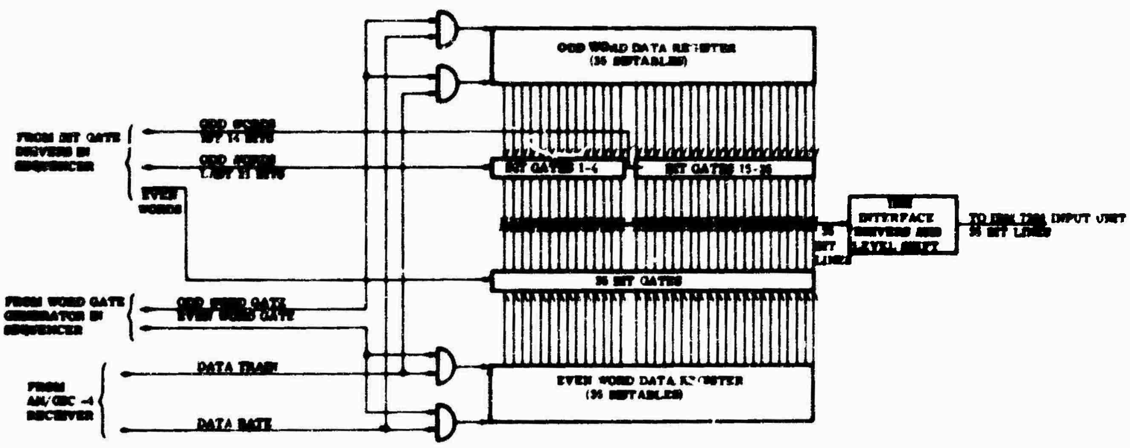
The output of the Synchronized "6720 cps clock osc." is applied to the "Demand Pulse Divider" with 40 cps for synchronization to produce 1680 cps of the proper phase. This voltage is applied to the "Demand Pulse Generator" to produce 1680 pps demand pulses for the IBM 7094 computer and to control the "End of Message Generator".

The "Demand Pulse Generator" is controlled on and off by a select voltage level from the computer. This level also lights the select lamp through the "Select Indicator" circuit.

The "End of Message" level is generated in the "End of Message Generator" from the 1680 cps output of the "Demand Pulse Divider" and the 1680 pps output of the "Demand Pulse Generator". The output level is negative and applied to the ODD and EVEN word gate generators and dividers. Outputs of the "Word Gate Generators and Dividers" are applied to the output gates of the ODD and EVEN Word Data Registers.

Figure 4-21 is a functional diagram of the "Data Registers and IBM Interface Drivers and Level Shift".

FIGURE 4-21 DATA REGISTERS AND IBM INTERFACE



UDOP DATA REDUCTION

UDOP is an elliptical tracking system which measures the total Doppler shift in the frequency of a UHF signal transmitted from the ground, received at the missile through the transponder, doubled in frequency, retransmitted and received back at various ground stations.[1] UDOP is a phase-coherent system; consequently the Doppler shift is dependent on the wavelength, the radial velocity of the missile, and the index of refraction. Because the wavelength of the transmitted frequency is crystal-controlled with an ultra-stable oscillator, the Doppler frequency is a function of missile radial velocity with respect to the transmitting and receiving sites and the index of refraction. Since refraction effects vary as the inverse square of the transmitted frequency and UDOP operates at UHF rather than VHF, the refraction effects are essentially negligible for the gross measurement required in the real time situation, but do constitute a major error source in the final Data Reduction process.

The measurement from each UDOP receiver is given in the form of: whole cycle count, previous cycle count, and partial cycle count at 10 samples/second. See Figure 5-1. The whole cycle count is the number of negative slope zero crossovers between t_j, $t_j + 1$ denoted by W_{cc}. The previous cycle count is the number of ten megacycle pulses between the last two negative slope crossovers in time interval t_j, $t_j + 1$ denoted by P_{cc}. Partial cycle count is the number of ten megacycle pulses between the last negative slope crossover and $t_j + 1$ denoted by P'_{cc}. The total cycle count N is computed by:

$$(1) \quad N_i = W_{cc\,i} + \frac{P'_{cc}}{P_{cc}}_{\,i} + \left[\frac{P_{cc} - P'_{cc}}{P_{cc}}\right]_{i-1} + D_i - 1801$$

where: i = 1, 2, 3, 4.

D_i = the additive delay of Doppler signal travel time from transmitter, to vehicle, to receiver, to central record site.

1801 is the offset biasing frequency subtracted to give true doppler. Offset bias in the UDOP System is 18KC. At 10 samples/second this equals 1800 cps. In addition, W_{cc} = (cycle count -1) for true frequency.

The following equations express the technique for handling the UDOP real-time Impact Prediction situation. The editing of the data is accomplished by a second order exponential filter. The editing is accomplished on the raw cycle count before D_i correction is applied.

[1] The example cited previously noted that UDOP was a spherical tracking system. This was used as an example, for the sphere is the very special case of an ellipsoidal solution, whereby the transmitter and receiver were located at the same point.

The following equations hold:

$$\bar{N}_t = N_{p_t} + \quad (N_t - N_{p_t})$$

(2)
$$\dot{N}_t = \dot{N}_{t-1} + (\beta/.1)(N_t - N_{p_t})$$

$$N_{p_{t+1}} = \bar{N}_t + .1\dot{N}_t$$

The filter is initialized by setting,

$$\bar{N}_o = N_o;\ \bar{N}_1 = N_1;\ \dot{N}_1 = \frac{N_1 - N_o}{.1}$$

Then test:

$N_{p_t} - N_t$ $\qquad$ N_t is replaced by N_{p_t}

This edit may not be carried for more than four consecutive points before the filter is reinitialized. The constants used for α, β, δ are:

$$\alpha = .25$$

$$\beta = .03$$

$$\delta = 6$$

After reinitializing the filter, the next two points must fall within the editing limit before the data from the receiver can be used in the solution. After converting and editing cycle count, a conversion is made to distance by multiplying λN_1 for each receiver. Since the system measures Doppler change over Δt, in terms of distance, the measurement might best be defined as a range sum change.

The delay D_i is computed:

Given:

R_i = range from recording station to each receiver.

$i = 1, 2, 3, 4$

(E_t, F_t, G_t) = coordinates of missile with respect to transmitter.

For first point use $(T_{t_o}, F_{t_o}, G_{t_o})$.

We compute:

$$R_{m-T} = (E_T^2 + F_T^2 + G_T^2)^{1/2}$$

(3) $R_{T_i} = R_{m-T} + R_i$ $\qquad$ $i = 1, 2, 3, 4$

$\dfrac{N_{i-1}}{\Delta t}$ = Doppler cycles/second

$$D_i = \left[\frac{R_{t_i}}{C}\right] \left[\frac{N_{i-1}}{\Delta t}\right] \qquad i = 1, 2, 3, 4$$

where C = velocity of propagation of a wave in vacuum.

Initially, D_i is added to correct the range sum change measurement. Then only ΔD_i is added: $\Delta D_i = (D_i - D_{i-1})$.

To obtain initial position we must use coordinates from another tracking system. Thus, we utilize the source selected by the automatic select portion of ADASP. Then, we compute initial range sum, with respect to each receiver in the solution, using the auto-select coordinates (E_o, F_o, G_o).

$$rk = \left[E_{T_e}^{\ 2} + F_{T_e}^{\ 2} + G_{T_e}^{\ 2}\right]^{1/2}$$

$$S_{i_k} = \left[(E_{T_{e_k}} - E_i)^2 + (F_{T_{e_k}} - F_i)^2 + (G_{T_{e_k}} - G_i)^2\right]^{1/2}$$

$$U_{e_{i_k}} = r_k + S_{i_k}$$

Where:

(E_i, F_i, G_i) = receiver coordinates referenced to the transmitter.

(E_T, F_T, G_T) = (E_o, F_o, G_o) for initial range sum based on coordinates from another system. The cartesian coordinates of the vehicle referenced to the transmitter site.

Next, the extrapolated range sum $U_{e_{i_k}}$ is computed for each receiver.

$$r_k = \left[E_{T_e}^{\ 2} + F_{T_e}^{\ 2} + G_{T_e}^{\ 2}\right]_k^{1/2}$$

$$(5) \quad S_{i_k} = \left[(E_{T_{e_k}} - E_i)^2 + (F_{T_{e_k}} - F_i)^2 + (G_{T_{e_k}} - G_i)^2\right]^{1/2}$$

$$U_{e_{i_k}} = r_k + S_{i_k}$$

The observed range sum U_{i_k} is"

$$(6) \quad U_{i_k} = U_{i_{k-1}} + \lambda N_{i_k} \qquad k = 1, 2, 3 \text{ ---} \quad i = 1, 2, 3, 4$$

$$U_{i_o} = U_{e_{i_o}}$$

A least squares solution for the adjusted coordinates (E_T, F_T, G_T) is computed:

$$A1_{i_k} = \frac{\left[E_{T_{e_k}} - E_i\right]}{S_{i_k}} + \frac{E_{T_{e_k}}}{r_k}$$

$$(7)\quad A2_{i_k} = \frac{\left[F_{T_{e_k}} - F_i\right]}{S_{i_k}} + \frac{F_{T_{e_k}}}{r_k}$$

$$A3_{i_k} = \frac{\left[G_{T_{e_k}} - G_i\right]}{S_{i_k}} + \frac{G_{T_{e_k}}}{r_k}$$

The compute ΔU's:

$$(8)\quad \Delta U_{i_k} = U_{e_{i_k}} - U_{i_k}$$

set up matrices:

$$A_k = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \\ A_{41} & A_{42} & A_{43} \end{bmatrix}_k$$

$$(9)\quad U_k = \begin{bmatrix} \Delta U_1 \\ \Delta U_2 \\ \Delta U_3 \\ \Delta U_4 \end{bmatrix}_k$$

The adjusted coordinates are:

$$(10)\quad \begin{bmatrix} E_T \\ F_T \\ G_T \end{bmatrix}_k = \begin{bmatrix} E_{T_e} \\ F_{T_e} \\ G_{T_e} \end{bmatrix}_k + \left[(A_k)^T \; A_k \right]^{-1} (A_k)^T (U_k)$$

The adjusted coordinates are then transformed to the geocentric system for use in IP computations and for velocity determination.

$$(11)\quad \begin{bmatrix} E \\ F \\ G \end{bmatrix}_k = \begin{bmatrix} E_T \\ F_T \\ G_T \end{bmatrix}_k + \begin{bmatrix} E^1 \\ F^1 \\ G^1 \end{bmatrix}$$

Where (E^1, F^1, G^1) are the geocentric coordinates of the transmitter site. Using the variate difference method we now compute:

$$\left(\sigma_{\lambda N_i}\right)^2 = \frac{\sum_{k=1}^{n-2} \left(\Delta^2 \lambda N_i\right)_k^2}{6n-12}$$

(12) where: n = number of points

$j = (0 \leq j \leq 21)$

N_i = Measurements of four receivers. $(i = 1, 2, 3, 4)$

The system covariance is now computed as follows:

$$(13)\quad \sigma_s^2 = \frac{\left(\sigma_{\lambda N_1}\right)^2 + \left(\sigma_{\lambda N_2}\right)^2 + \left(\sigma_{\lambda N_3}\right)^2 + \left(\sigma_{\lambda N_4}\right)^2}{4}$$

The covariance matrix is:

$$(14)\quad \begin{bmatrix} \sigma E^2 & \sigma EF & \sigma EG \\ \sigma EF & \sigma F^2 & \sigma FG \\ \sigma EG & \sigma FG & \sigma G^2 \end{bmatrix} = (\sigma_s)^2 \quad (A^T A)^{-1}$$

Smoothing UDOP Data for Velocity

A smoothing technique based on fitting the adjusted geocentric position coordinates by a least squares technique to a second degree polynomial over 21 points is used. A set of "almost" least square or power of two multipliers are applied to position coordinates to obtain velocity components which hold for the 17th point of the 21 point span. The equations are:

$$\dot{E}_i = K^1 \sum_{j=-16}^{+4} \left(\beta_j\right)\left(E_{i+j}\right)$$

$$\dot{F}_i = K^1 \sum_{j=-16}^{+4} (\theta_j)(F_{i+j})$$

$$\dot{G}_i = K^1 \sum_{j=-16}^{+4} (\theta_j)(G_{i+j})$$

where K^1 = .0091713954

j	θ	j	θ	j	θ	j	θ	j	θ
-16	2	-11	-1	-6	-1	-1	-1	4	4
-15	1	-10	-1	-5	-1	0	2		
-14	0	- 9	-1	-4	-1	1	1		
-13	-1	- 8	-1	-3	-2	2	2		
-12	-1	- 7	-1	-2	-1	3	2		

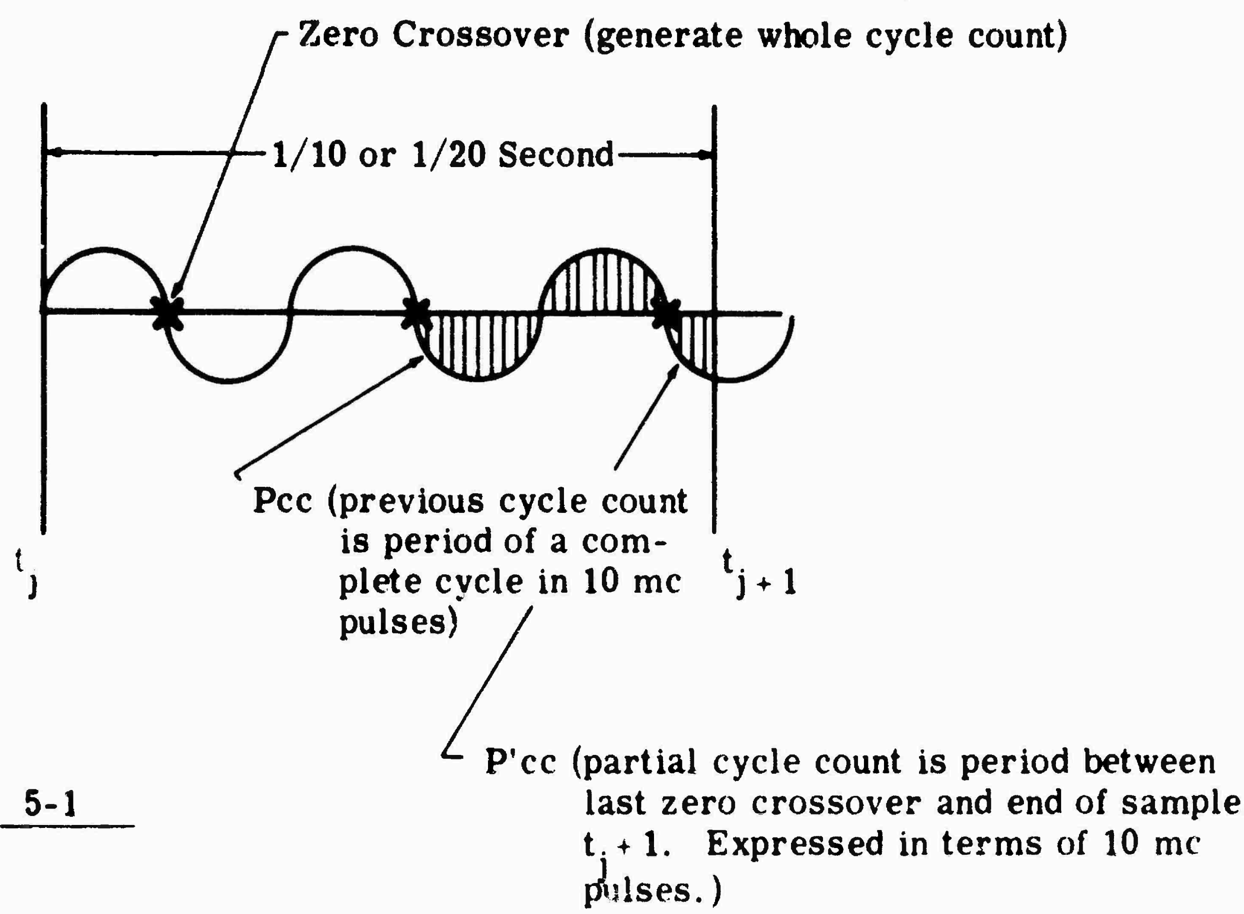


Fig 5-1

To effect postflight reduction , UDOP Data goes through the reduction programs as in Figure 5-2. The editing routine, DOED 5, accepts the digitized output tape from DARE and computes the time for readouts, the total cycle counts, and first, second and third differences in cycle counts. The output tapes are then collated and used as an input for UDSD 2 The editing routine, UDOW 1, does the same thing for the digitized output tape from the down range digitizer. The output of UDOW 1 is used as another input for UBSD 2 and DUPV 1 is a correction table computed by DORR 1, the UDOP Range Rate Correction routine. This routine computes atmospheric and inospheric refraction corrections and transmission delay corrections for each receiver. The UDSD 2 computes the corrected cycle counts, and corrected range sums and differences. The UDSD 2 output is the second input for DUPV 1 which is used to compute position and velocity. However, at the present time, DUPV 1 is used to compute only the position. The velocity is computed by SMVA 3, which also computes acceleration. Before the data is compiled into the Flight Test Report, it is processed through FPRG 2. This program reformats the data and puts in headings and comments. The Flight Test Report is now ready to be released to the Range User. Elapsed time from launch until release is approximately 10 days.

The description, by title, of the programs mentioned above is as follows:

DOED 5	DARE editing routine
UDSD 2	UDOP Range Sum and Range Differences with associated Error Estimates
DUPV 1	UDOP Position and Velocity Routine
SMVA 3	Velocity and Acceleration by Smoothing
UDOW 2	UDOP Downrange Digitized Data Conversion and Editing
DORR 1	UDOP Range Rate Correction Routine
FPRG 2	Full Page Report Generator

One method for postflight reduction of UDOP data is the DARE (Doppler Automatic Reduction Equipment) System. DARE is a system which functions according to Figure 5-3. A review of DARE's capabilities follows.

PERFORMANCE CAPABILITIES

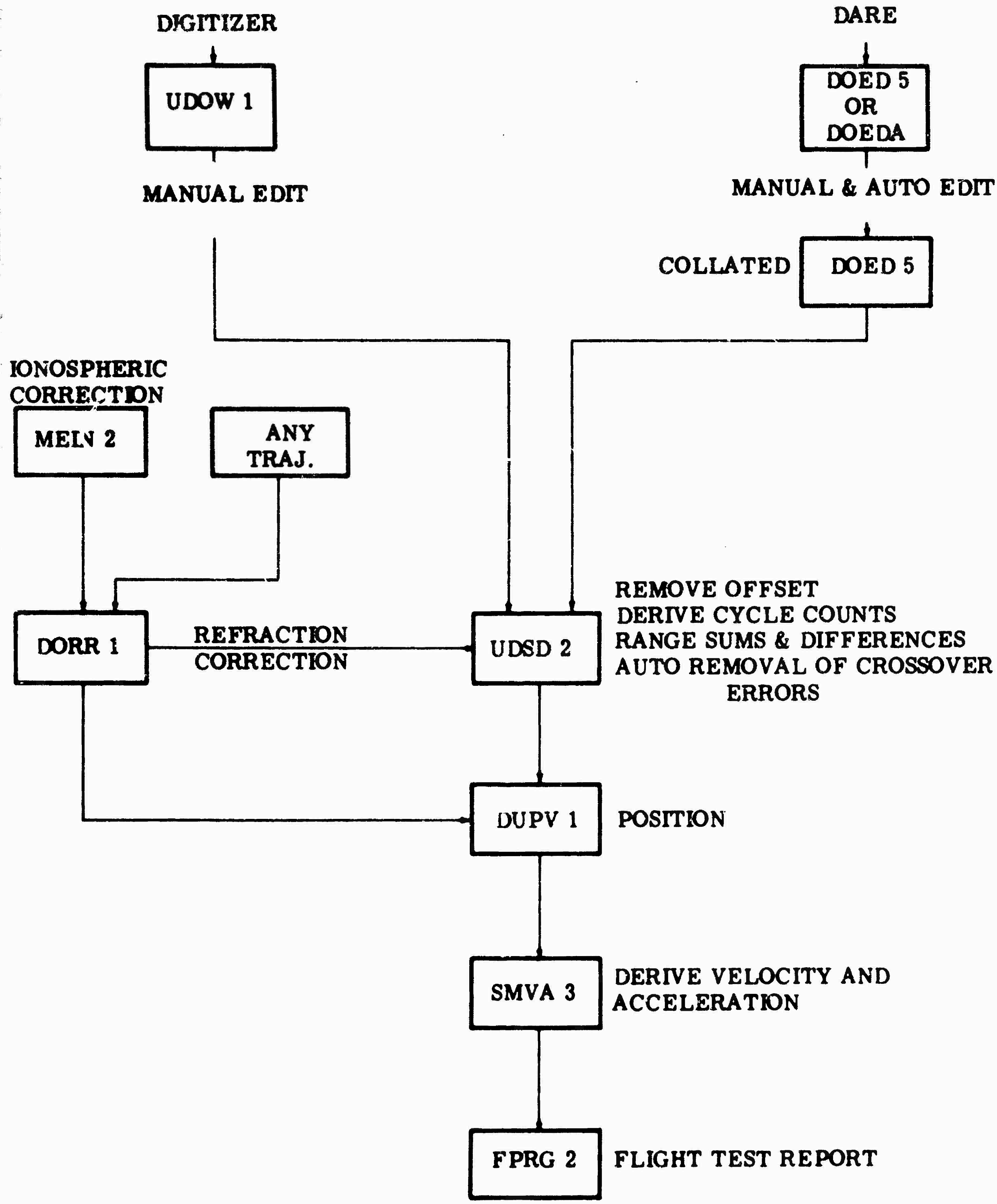
The DARE System can automatically count the total number of doppler cycles of frequencies between 10 cps and 30,000 cycles per second provided that noise filtering is not required. If filtering is required, the upper limit of the system is 12.5 kc. The system measures the period of all cycles to withing ± 20 microseconds. The system can also accept reduced speed playback in order to increase the upper frequencies without diluting accuracies. The output of DARE is on magnetic tape in proper format for IBM 7094 entry.

<u>PERFORMANCE SPECIFICATIONS</u>

The system samples at rates of 1, 2, 10, 20, and 50 samples per second. The DARE System is not limited to use with doppler data but can also be used to count the number of cycles of cyclic telemetry data, to measure the time between events with the same inherent accuracy.

The following digitized information is placed on magnetic tape for each sample.

FIG 5-2 UDOP REDUCTION PROGRAM



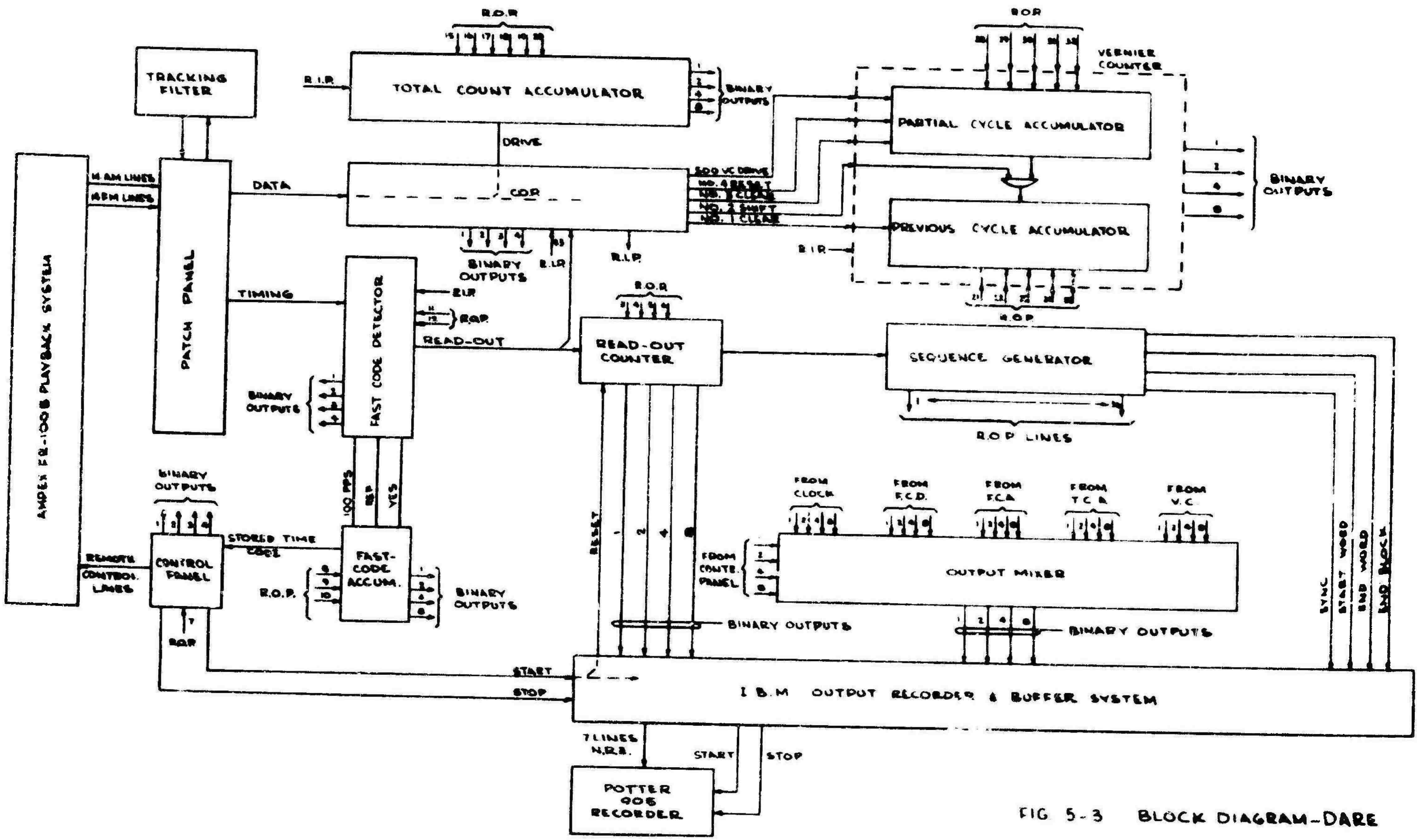


FIG 5-3 BLOCK DIAGRAM-DARE

1. Total number of doppler cycles
2. Time from last cycle to read-out
3. Time duration of previous cycle before readout
4. Time jitter between samples
5. Quality of the doppler data
6. Proper computer format information

FUNCTIONS: (See Figure 5-3)

The function of the one pps circuitry is to furnish automatic start/stop of the output recorder so that any desired portion of the doppler run may be sampled.

The total number of doppler cycles is obtained from an accumulator capable of counting to 999,999 before recycling.

The crossover detector generates a pulse for each positive going zero crossover.

These pulses are synchronized with the clock and

1. Advance total accumulator
2. Clear last cycle storage
3. Shift new cycle value from partial cycle counter into last cycle storage
4. Clear and reset partial cycle counter

The 100 pps timing code is fed to a fast code detector which generates the following functions as well as readout rates:

1. Fast code accumulator inputs of "yes" and scanning pulses
2. Start pulse for the sequence generator
3. Number of 100 pps timing pulses received
4. Start pulse to clock

The fast code accumulator stores the 100 pps timing for a one second period.

The clock received an input from the fast code detector and generates an output which shifts the information in the partial cycle counter, previous cycle counter and total count accumulator into core storage.

The sequence generator receives an input from the fast code detector and generates the following at the correct time to record all the information on the output tape:

1. Readout to all storage units
2. Necessary format characters

The output gate accepts information which is read out of the storage units and presents this information to the tape unit on the proper lines for recording.

The data from the total UDOP System, NASA and AFMTC, is reduced together. As a measure of system performance, the final reduced UDOP Data is compared to the missile's inertial guidance data. In this manner, a common comparison can be made for a series of missile launches. Enclosed in this section are three curves. These curves represent the comparisons of the UDOP Data with the inertial guidance data telemetered back during powered flight. (See Figures 5-4, 5-5 and 5-6)

The data plotted was compiled from the following missile tests:

YEAR 1962	YEAR 1963
Test #3722	Test #116
Test #3721	Test #143
Test #4230	Test #118
Test #5031	Test #976
	Test #1598
	Test #978
	Test #103
	Test #3301
	Test #3302
	Test #3815

Included as outages on the curves are those launches where UDOP performance was sub-marginal. No data has been deleted.

At this point, some terms must be defined:

Final Data - UDOP Data which has undergone all possible electrical, mechanical and mathematical manipulation to eliminate all known errors and error sources. The data which has been thusly corrected is defined as Final Data.

Inertial Guidance Data — That data telemetered back to earth during the period of flight which is the measurement of velocity in all axes as sensed by the associated transducer.

Sigma . Delta X — The measurements of the variations in velocity as compared to the inertial guidance data. These measurements are short span comparisons (In this case, the X axis).

The curves are plotted in terms of velocity, as the UDOP System is a velocity measuring system (range rate). Had these curves been transposed into terms of position, the trends would remain the same, and only the scaling would change.

The X axis is in the easterly direction, along the flight path and down range, the Y axis is northerly and the Z axis is vertical from the launching pad. The curve represented by the dotted line within the envelopes of each curve is the most recent measurement and shows the improvement over previous tests. Figure 5-7 is the summary of UDOP Residual errors before the downrange UDOP digitizer was in operation. The numbers included in Figure 5-7 are presented for relative error sources, not absolute values.

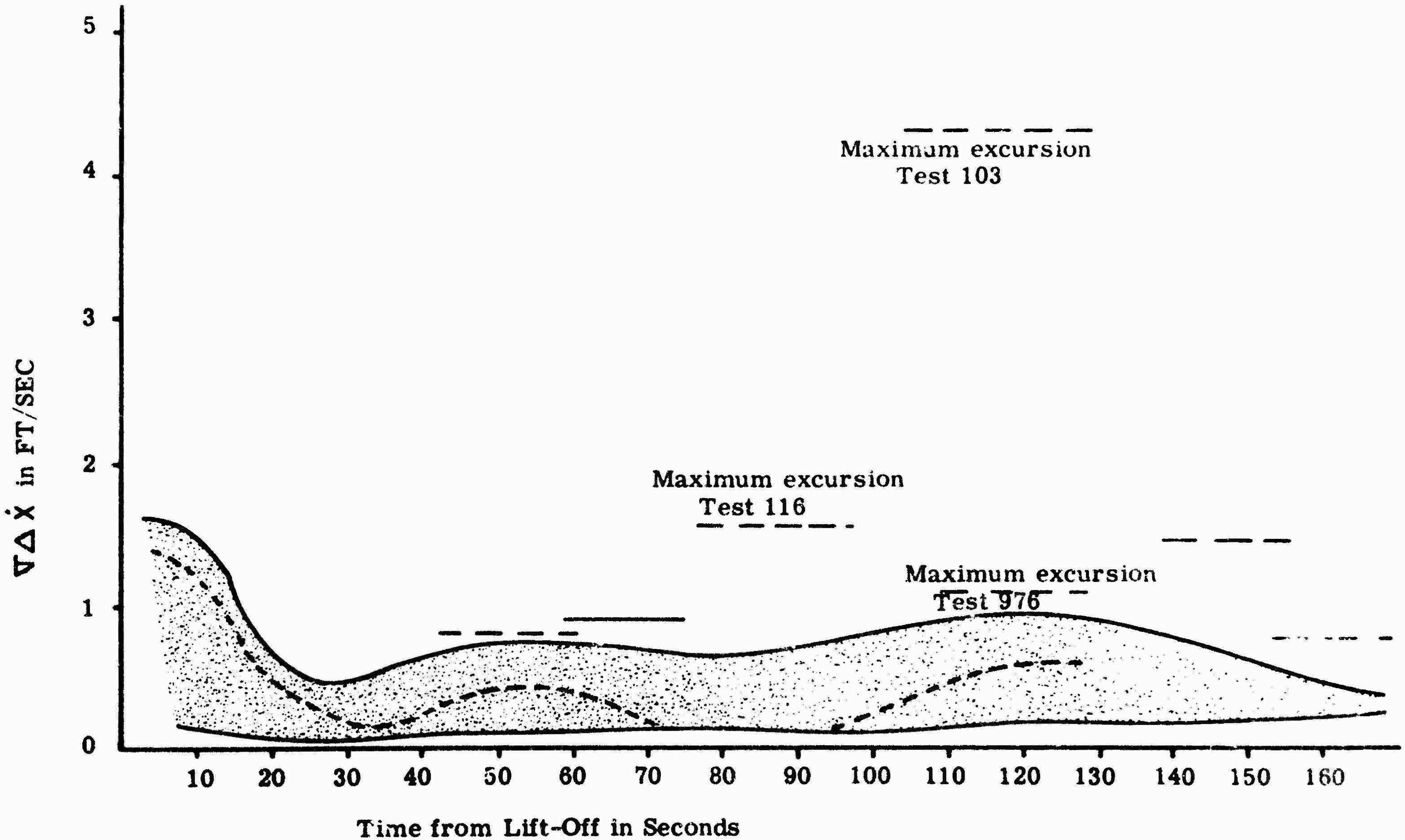


Fig. 5-4 X-Axis velocity differences with inertial guidance data

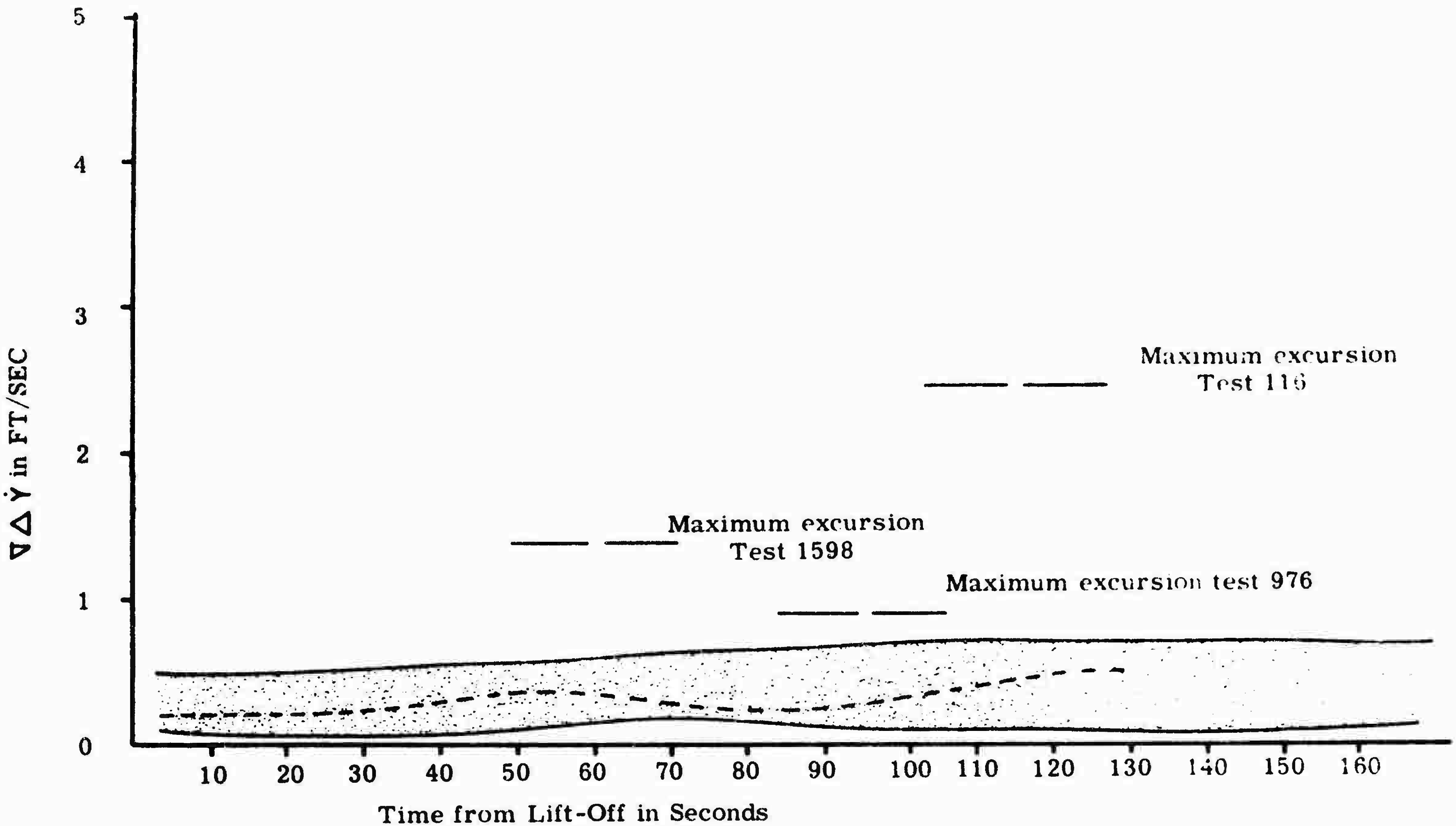


Fig. 5-5 Y-Axis velocity differences with inertial guidance data

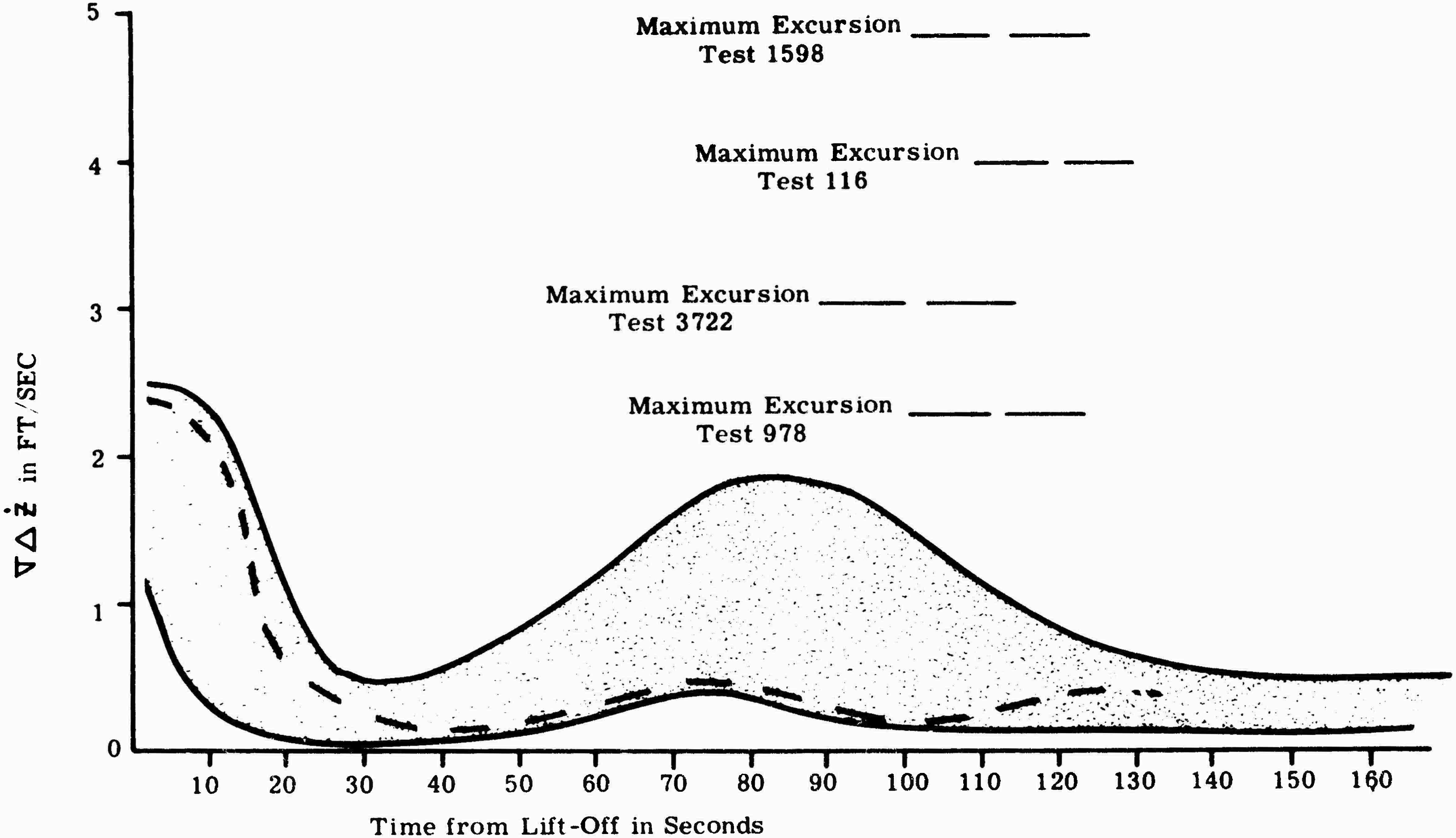


Fig. 5-6 Z-Axis velocity differences with inertial guidance data

UDOP RESIDUAL ERROR SUMMARY

	POSITION ERROR (FT)			VELOCITY ERROR (FT/SEC)		
	STL	THEORY	ACTUAL	STL	THEORY	ACTUAL
SYSTEMATIC ERRORS						
1. Survey	23.0	4.0	20.0	0.2	0.05	0.25
2. Velocity of Light	4.0	0.1	0.1	0.06	0.06	0.06
3. Relativistic Correction	0	0	0	0	0	0
4.&5. Tropospheric Refraction	0.9	0.5	2.0	0.03	0.02	0.10
6.&7. (Day Ionosphere)	25.0	12.0	50.0	0.9	0.9	0.9
(Night Ionosphere)	12.0	6.0	24.0	0.3	0.3	0.3
8. Receiver Phase Shift	8.0	4.0	8.0	--	--	--
9. Antenna Phase Shift	2.0	2.0	4.0	--	--	--
10. Cycle Miscount						
TOTAL (Night)	24.0	16.6	58.1	0.4	0.43	0.45
RANDOM ERRORS						
11. Ionospheric Scintillation						
(Day)	--	--	--	0.10	0.10	0.10
(Night)				0.05	0.05	0.05
12. Tropospheric Scintillation	--	--	--	0.002	0.002	0.002
13. Receiver Spurious Phase Modulation	--	--	--	0.02	0.02	0.02
14. Timing Error (DARE)	1.0	0.02	0.02	0.01	0.01	0.01
15. Receiver Noise	0.3			0.04		
16. Computation Error	N.A.	0.005	0.05	N.A.	0.001	0.01
17. Spin Correction	N.A.			N.A.	0.05	0.05
18. Cycle Count	N.A.	0.01	0.01	N.A.	0.02	0.02
TOTAL (Night)	1.0	0.035	0.08		0.26	0.26
OVERALL TOTAL		16.6 FT.	58.2 FT	0.47	0.69 FT/SEC	0.7 FT/SEC

FIG. 5-7

APPENDIX I

UDOP SYSTEM SCHEMATIC DIAGRAMS

Enclosed in this section are lists of schematics of major and minor pieces of equipment employed in the Down Range UDOP System. The schematics are listed by major sub-groups for easy look- .p. Any authorized person may obtain a print of these listed schematics from either RCA Drafting Services, or PAA Engineering Drafting. Those prints supplied by EDP Corporation, Orlando, Florida, are in a drafting contract file, and require authorization for removal.

These lists do not include numerous engineering sketches, block diagrams, and educational material written within AFMTC.

Much equipment purchased as off-the-shelf items are not documented by schematics other than the associated instruction manuals purchased with each item. These equipments include such items as tape recorders, receivers, transmitters, data links and all test equipment. Instruction manuals for each item of equipment can be obtained from the individual manufacturer. (See section on Equipment Used in the UDOP System.)

SYSTEM

RCA Prints

B-70504	System Block Diagram
B-86977	MTG Clamp 50 MC Antenna
C-97695	Installation UDOP Data Link Antennas
C-97704	Andrews H920D-3 Mounting Details
C-97961	Weatherproof Jack Box Details and Assembly
C-710705	H920D-3 Mounting Hardware Details
D-70686	System Block Diagram
D-94008	900 MC Test Antenna
D-94042	900 MC Test Antenna Reflector
C-94053	900 MC Test Antenna Mounting Detail
C-98207	900 MC Discone Mounting Details
C-98208	H920D-3 Mounting - Carter Cay
D-19003-353	Site Plan - Carter Cay
D-19003-534	PERSHING Terminal Facilities

PAA Prints

C-601935	Data Format for UDOP via Collins AN/GSC-4
C-602519	UDOP Communications, GBI and Cays, Wire and Data Circuits
C-601113	Block Diagram, one channel of the Down Range UDOP System
C-601025	Mating information for 7090 Computer

LIST OF REPRODUCIBLES OF MANUFACTURING DRAWINGS

FOR CONTRACT AF 08 (606)-5024

AS OF JUNE 28, 1963

These schematics are for the digitizer, offset bias converter, ultra stable oscillator, and format converter prints supplied by EDP Corp., Orlando, Florida

Drawing Number

EDP Corporation
EDP Job 444

SHEETS	SIZE	TYPE NO.	TITLE
	D	A 001	4-NAND Gate Printed Boad Assembly
	D	A 004	BSMV Printed Board Assembly
	D	A 005	2-NAND Gate Printed Board Assembly
	D	A 008	Switch Control Panel
	D	A 009	Compilation Detector Printed Board Assembly
	C	S 010	Schematic - Switch Control Panel (4A2)
	D	A 013	L-Driver Printed Board Assembly
	B	S 014	Schematic - 1MC Zero Crossing Detector
	D	A 015	Oscillator & Transmission Gate Printed Board Assembly
	B	S 017	1MC 4-NAND Gate Schematic
	D	A 018	Modulator & Line Driver Assembly
	D	A 020	MSMV Printed Board Assembly
	D	A 021	Card File A05A01
	D	A 022	Card File A05A02
	D	A 023	Card File A05A03
	D	A 024	Card File A05A04
	D	A 025	Card File A05A05
	D	A 026	Card File A05A06

D	A 027	Card File A05A07
D	A 028	Card File A05A08
D	A 029	Card File A05A09
D	A 030	Card File A05A10
D	A 031	Card File A05A11
D	A 032	Card File A05A12
D	A 033	Card File A05A13
D	A 034	Card File A05A14
D	A 035	Card File A05A15
D	A 036	Card File A01A01
D	A 037	Card File A01A02
D	A 038	Card File A01A03
D	A 039	Card File A01A04
D	A 040	Card File A01A06
D	A 041	Card File A01A07
D	A 042	Bias Converter Assembly
B	S 047	Schematic - 2-NAND Gate (1MC)
B	S 048	Schematic - Compilation Detector
D	A 049	Zero Crossing Detector (Assembly)
B	S 050	Schematic - 1MC MSMV
C	S 051	Schematic - 1MC BSMV
B	S 052	Schematic - 100KC Zero Crossing Detector
D	A 053	Frequency Comparator Assembly (Rack A)
D	A 069	Delay Gate Assembly
B	A 071	Terminal Board Assembly - Frequency Comparator
C	L 080	Logic Diagram - Frequency Comparator
D	A 081	Assembly Rack 10 Transit Station

J	A 089	Digitizer Control Panel Assembly
D	A 091	Rack 3 and 4 Assembly
D	A 104	Power Supply (Modified)
D	S 107	Bias Converter Schematic
C	S 108	Frequency Doubler Schematic-Bias Converter
D	W 122	Wiring Diagram - Bias Converter
B	S 152	Delay Gate Schematic
D	S 153	Modulator & Line Driver Schematic
D	A 156	Rack D Assembly Digitizer Assy.
D	A 157	IBM Interface P/B Assembly
D	A 159	IBM Driver Printed Board Assembly
D	S 219	Oscillator & Transmission Gate Schematic
D	A 220	10 MC Clock Assembly
C	A 230	Terminal Board Assembly (10MC Clock)
D	A 231	Computer Input Printed Board Assembly
D	A 244	Format Converter Rack H-01
D	L 277	Site Selection for Digitizer
D	A 294	Power Panel Assembly Rack 6
C	A 295	Power Panel Assembly (For Format Converter)
B	S 296	Schematic - High Impedance 100 KC Zero Crossing Detector
J	L 301	Whole Cycle Counter for Digitizer
J	B 302	Format Converter - Block Diagram
J	L 303	Data Register for Format Converter
J	L 304	Sequencer for Format Converter
J	L 305	Word No. 7 Storage for Format Converter

J	L 306	Storage 1, 2, 4, 5, and 6, for Format Converter
J	L 307	Word No. 3 Storage & Buffer for Format Converter
D	L 308	Translator for Format Converter
D	L 309	IBM Interface & Drivers for Format Converter
J	B 311	Block Diagram Digitizer
J	L 312	Timing Generator for Digitizer
J	L 313	Range Time Decoder for Digitizer
J	L 314	Partial & Previous Cycle Counter for Digitizer
J	L 315	Multiplexer Counter for Digitizer
D	L 316	Multiplexer for Digitizer
B	S 317	10MC Emitter Follower Schematic (10MC Clock)
B	S 318	10MC 2-NAND Gate Schematic
B	S 319	IBM Driver Schematic
B	S 320	Schematic High - 100KC Threshold Detector
B	S 321	10MC MSMV Schematic
B	S 322	L-Driver Schematic
B	S 323	IBM Interface Schematic
C	S 324	10MC BSMV Schematic
D	W 326	Power Distribution for Rack 05 and 06
D	A 327	Card File A01A08
B	S 331	Pulse Shaping Zero Crossing Detector Schematic
D	A 333	Power Supply Assembly
D	A 336	Collins DTS - Rack E 06
C	A 346	Active Crystal Filter Assembly
D	W 347	Power Distribution for Format Converter
		BILL OF MATERIALS
A	A 042	Bias Converter L/M

A	A 091	Rack 3 and 4 Assembly L/M
C	A 348	Drilling Drawing, Tone Generator
C	A 349	Wiring Assy., Tone Generator
D	A 350	Tone Generator Assy.
D	S 351	Schematic Diagram - Tone Generator

RECEIVERS

RCA Prints

D-900316	900MC Helical Antenna
A-710722	Micro Match Modifications
B-70497	Local Oscillator Block Diagram, Stand. Rec.
B-710718	Rack II Inter-unit Wiring
C-70407	VHF Receiver Power Supply
C-70505	Local Oscillator Power Supply
C-86213	Receiving Turnstile Ground Plane
C-98666	900MC Antenna and Pre-amp Installation Details
C-99049	Floor Plan Allans Cay
C-710694	Rack I Cabling Detail
C-710695	Rack II Cabling Detail
C-710697	Rack III Cabling Detail
C-710698	Details - Rack Modifications for MINUTEMAN
C-710723	Micro Match Assembly Detail
D-70406	UHF Receiver
D-70414	VHF Receiver Cabling Diagram
D-70420	VHF Receiver Schematic
D-70421	UHF Receiver Cabling Diagram
D-70425	UHF Receiver Power Supply
D-70506	Local Oscillator Schematic
D-86201	Receiving Turnstile Details
D-86202	Receiving Turnstile Assembly
B-94018	Antenna Boom - Walker Cay
D-94091	Antenna Inst. Details - Carter Cay
D-99031	Floor Plan Walker Cay

D-99032	Racks I, II, III Block Diagram
D-SK-99044	Carter Cay Site Plan
D-99052	Floor Plan - Carter Cay
D-19003-43	Site Plan - Walker Cay
D-19003-551	Floor Plan - Carter Cay
D-19003-552	Power Panel - Carter Cay
D-19003-553	Racks I and II - Carter Cay
D-19003-566	Equipment Layout - Walker Cay
D-19003-567	Elevations Rack 1-4 - Walker Cay
D-19003-568	Wiring Diagram Racks I, II, III - Walker Cay
D-19003-569	Distribution Panel No. I - Walker Cay
D-19003-570	Wiring Diagram - AN/TCC-3 and AN/TRC-24 - Walker Cay
D-19003-571	Cable Layout - AN/TRC-24 Antennas - Walker Cay
D-19003-572	Elevations - Antenna Tower and Poles - Walker Cay
D-710717	Cabling List for Phase Lock Receiver
E-81566	H.F. Transmitting Antenna Field - Carter Cay
D-712153	Data Link Attenuator Panel

TRANSMITTERS

RCA Prints

D-SK-99026	Synchro Data Interconnection - Carter Cay
D-SK-99045	Floor Plan Transmitter
D-19003-544	Floor Plan Transmitter
D-19003-554	Power Panel
D-19003-555	AC Power and Control
D-19003-556	RF Cabling and Elevations
D-19003-557[1]	Interack Wiring
D-19003-557[2]	Monitor Leads
D-560513	Transmitter Turnstile
D-560529	Transmitting Turnstile Assembly
A-70839	Exciter Divider Shield
B-560526	Turnstile Antenna Parts
B-560527	Turnstile Antenna Parts
B-70840	Exciter Shield Assembly
C-70493	Mounting Bracket - Filter Assembly
C-98209	Floor Plan
C-560516	Turnstile Antenna Parts
C-560528	Turnstile Mast. Assembly
C-560569	Turnstile Ground Plane
D-70432	Monitor Panel
C-70838	Exciter Termination Shield
D-86992	Transmitter Site Antennas

CENTRAL RECORD

RCA Prints

D-99075	Rack 7 External Wiring
A-710739	Intercom Panel Speaker Grill
A-710741	Intercom Panel Bracket
C-561686	Distribution Panel
C-710742	Intercom Panel
D-70472	32KC Reference Multiplier
D-97588	Antenna Details
D-97745	Floor Plan
D-97747	Site Plan
D-97775	Cable Pressurizing System
D-98213	Cable Pressurizing System Assembly
D-99057	Racks 2R, 3R, Wiring Block Diagram
D-99059	Rack 1 External Wiring
D-99060	Rack 2 External Wiring
D-99074	Rack Support Details
D-710719	Jack Panel 1 of Panel 8 Detail
D-710720	Jack Panel 2 of Panel 8 Detail
D-710738	Intercom Panel
C-710903	Lock Indicator Panel - Wiring
B-710905	Lock Indicator Panel - Schematic
C-86613	Receiving Antenna Bracket

550-2270-004	AF5 Gated A. C. Amp.
550-2271-004	AF7 2 Input Amp.
550-2272-004	AF8 Generator Filter
550-2373-004	AG2 180KC Osc.
552-5838-004P	Diode Matrix, BS4
550-2282-004P	BU9 And-Or #1
550-2287-004	BZ7 Gen. Mode Switch
550-2293-004	CD3 Peaking Amp.
550-2297-004	CG2 Detector Counter
550-2299-004	CG4 Pattern Gen. Matrix
550-2300-004	CG5 Bias Ckt.
552-5844-004P	Timing Matrix Number 2, CK5
550-2305-004	CK8 And-Or #2
550-2306-004	CK9 Delay Line
550-2309-004	CL5 One Shot #1
550-2269-004	CL7 One Shot #2
552-5803-004P	Limiter, FM7
552-5828-004P	Toggle #2, FM9
552-5767-003P	Test Point No. 2, FN2
552-5791-004P	Corrector, FN3
552-5815-004P	Keyed Filter, FN4
552-5794-004P	Level Correctors, FN5
552-5785-004P	REC. Heterodyne No. 1, FN7
552-5806-004P	REC. Heterodyne No. 2, FN8
552-5773-004P	Sync Demodulator 1, FN9

552-5776-004P	Sync Demod No. 2, FP2
552-5797-004P	Sync Detector #2, FP3
552-5782-004P	Sync Detector 1, FP4
552-5809-004P	Transmit Alarm, FP5
552-5788-004P	Telephone Alarm No. 1, FP7
552-5800-004P	Telephone Alarm #2, FP8
552-5812-004P	Timing Shaper No. 2, FP9
552-5779-004P	Transmit Het. 1, FR2
552-5770-004P	Transmit Het #2, FR3
552-5833-003P	Test Point No. 1, GA7
552-5748-003P	NOR B, GG7
552-5869-004P	Digital Sync Corrector, GG8
552-5874-004P	Comparator, GG9
552-5849-004P	Data Rate, Matrix, GH2
552-5854-004P	Operate Test Matrix, GH3
552-5864-003P	One Shot #3, GH4
552-5859-004P	Timing Shaper #1, GH5
552-5879-004P	Timing Matrix Number 1, GH7
552-5727-004P	Toggle #1, GP3
552-5735-004P	Inverter, GP4
552-5743-004P	Clock Pulse Generator, GP5
552-5756-004P	Sync Shaper, GP7
552-5764-003P	Sync Timer, GP8
552-5823-004P	Load Gate, GP9
RCA D-11621-343	General Block Diagram, AN/GSC-4

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM

Nomenclature	Site	Manufacturer	Provisioning Document
Digitizer	Bassett	EDP Corporation	P-3275
Offset Bias Converter	Carter	EDP Corporation	P-3275
Frequency Comparator	Carter	EDP Corporation	P-3275
Frequency Divider and Clock Model 113BR	Carter	Hewlett-Packard	3356
Standby Power Supply, Model 724BR	Carter	Hewlett-Packard	3358
5 @ Visicorder Model 1406	ALL	Minn-Honeywell	3504
4 @ UDOP UHF Phaselock Converter, Model 90315-1	ALL except Carter	Resdel	3509
4 @ UDOP UHF Phaselock Converter	ALL except Carter	Resdel	3509
2 @ 1" Tape Recorder, FR-114B	Bassett	Ampex	3832
6 @ Tracking Filter, Model VIIIB	Bassett	Interstate	3838

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM (Cont'd)

Nomenclature	Site	Manufacturer	Provisioning Document
Ultra Stable Oscillator Model 104AR	Carter	Hewlett-Packard	3563
5 @ Plus Counter	ALL	RCA/MTP	3613
2 @ ½" Tape Recorder FR-1107	Bassett and IP	Ampex	409
Format Converter	IP	EDP Corporation	3564
2 @ Data Transmission System, Model AN/GSC-4	Bassett and IP	Collins Radio	3565
10 @ UDOP Standard Receiver, UHF Model 90215	ALL	Resdel	464-A
10 @ UDOP Standard Rx VHF Model 90225	ALL	Resdel	464-B
10 @ Local Oscillator Model 90235	ALL	Resdel	464
4 @ Brown Recorder	ALL	Minn-Honeywell	
8 @ FM Data Link Rx Model 1670F & J	Bassett	Nems-Clarke	466

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM (Cont'd)

Nomenclature	Site	Manufacturer	Provisioning Document
4 @ Frequency Meter, Model 500BR	ALL	Hewlett-Packard	1201
Atomichron Prim. Freq. Std., Model NC 1001	Carter	National	1208
5 @ RF Signal Generator Model 90194	ALL	Resdel	1298
Quad-Helix TX Antenna	Carter	Versatronics	P-1584
Magnetic Amplifier Model 22R	Carter	Versatronics	P-1584
Position Controller Model 100M	Carter	Versatronics	P-1584
8 @ FM Data Link Trans, Model CS 1976	ALL	Gates	2601
Computer (Converter) Model 484A	Carter	EAI	02-B
Computer (Converter) Model 484B	Carter	EAI	02-B
Power Amplifier 50MC, Model M-5704	Carter (TX)	Gates	2614

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM (Cont'd)

Nomenclature	Site	Manufacturer	Provisioning Document
Power Amplifier, 450MC, Model M-5705-A	Carter (TX)	Gates	2614-A
Power Amplifier, 900MC, Model M-5706	Carter (TX)	Gates	2614-B
Patch Panel and Buffer	Carter (TX)	Gates	2614-C
Audio Oscillator Model 200CD	Bassett	Hewlett-Packard	601
Loss of Lock Indicator	Bassett	EDP Corporation	3275
Phaselock Indicator	Bassett	RCA/MTP	3614
Tracking Filter Lock Indicator	Bassett	RCA/MTP	
Timing Buffer Amplifier	ALL except	RCA/MTP	217C
3 @ Patch Panels	Bassett	RCA/MTP	
Data Level Panel	Bassett	RCA/MTP	
10 @ Input Monitor, Model 120AR	Bassett	Hewlett-Packard	

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM (Cont'd)

Nomenclature	Site	Manufacturer	Provisioning Document
6 @ Mops Communication Set	ALL	Various manufacturers, MIL Gear	115
2 @ FM Data Links AN/TRC-24	Allans Walker	Various manufacturers, MIL Gear	116
Microwave System, Model MCR-4	Carter Bassett West End	Motorola	290
Trans. Monitor Scope, Model M4180B	Carter	Gates	26140
FM Receiver Model 167-J	Carter	Nems-Clarke	69A
System Control Console	Bassett	RCA/MTP	
Dummy Antenna Load	Carter	M. C. Jones	
Antenna Towers	ALL	Various manufacturers	
Antenna Patch Panels	ALL	RCA/MTP	
Timing Terminal Unit Model 9868	Bassett	Vitro	205 - 210
2 @ Recorder Monitor Bays	Bassett	Ampex	

APPENDIX II

ELECTRONIC EQUIPMENT USED IN THE UDOP SYSTEM (Cont'd)

Nomenclature	Site	Manufacturer	Provisioning Document
Bulk Tape Eraser	Bassett	Ampex	
Playback Monitor Amplifier	Bassett	RCA/MTP	
Intercom Panel	Bassett	RCA/MTP	
Micromatch Unit, Model 485A5	ALL	Microwave Devices, Inc.	
Doppler Simulator	Carter (TX)	RCA/MTP	
10 @ Antenna 900MC	ALL	RCA/MTP	
10 @ Antenna 50MC	ALL	Andrews	
8 @ Antenna Data Link TX	ALL	TACO	
10 @ Antenna Data Link RX	Bassett	RCA/MTP	
Antenna, 900MC Test TX	Carter	Andrews	
5 @ Antenna 900MC Test RX	ALL	RCA/MTP	

APPENDIX III

TEST EQUIPMENT USED IN THE UDOP SYSTEM

Nomenclature	Site	Manufacturer
VTVM, Model 410B	ALL	Hewlett-Packard
Multimeter, Model 260 and 290	ALL	Simpson
Oscilloscope Model 545	ALL	Tektronix
Frequency Counter Model 730C	ALL	CMC
Attenuators	ALL	Various manufacturers
Tube Tester Model T/V-7	ALL	MIL Gear
Power Meter Model 430C	ALL	Hewlett-Packard
Thermistor Mount Model 477B	ALL	Hewlett-Packard
Function Generator Model 202A	ALL	Hewlett-Packard
Oscilloscope Model 555	Bassett	Tektronix
Frequency Meter Model FM3	Carter (TX)	Girtsch
Frequency Counter Model 524B	Carter (TX)	Hewlett-Packard

All sites also have many small items of test equipment for special purpose system testing on specific items in the system.

APPENDIX IV

UDOP DOCUMENTATION

The following is a list of applicable documents necessary to the UDOP System. Many of the listed documents were used to publish this document and others included as a ready reference source for interested persons desiring additional information on various aspects of the UDOP System.

The author wishes to state that many of these documents are and have been used for internal reference only and outside personnel may have extreme difficulty obtaining them.

1. Instruction Manual for the AN/GSC-4 Data Modem. P/N 520-6347-00, 1 August 1962. Collins Radio Company, Information Science Center, Newport Beach, California, under Contract AF 30 (602)-2342.

2. Addendum for the modified AN/GSC-4 Data Modem. P/N 520-6349-00, 1 August 1962, Collins Radio Company, 19700 San Joaquin Road, Newport Beach, California, under Contract AF 30 (602)-2342.

3. Series FR-100B Recorder/Reproducer Magnetic Tape Recorders for Instrumentation, Operator and Maintenance Manual, ME-152, Ampex Corporation, 934 Charter Road, Redwood City, California. Supplied under Contract AF 08 (606)-5026.

4. Series FR-1100 Recorder/Reproducer, Magnetic Tape Recorder for Instrumentation (CPA 9400-016700), Ampex Corporation, 934 Charter Road, Redwood City, California. Supplied as a subcontract under prime Contract AF 08 (606)-5024.

5. General Survey Data, Range Instrumentation Systems, 1 July 1962, G. T. Mead, Optical System Data Reduction, RCA Service Company, MTP, Patrick Air Force Base, Florida, under Contract AF 08 (606)-5300.

6. Instruction Manual for Phaselock Tracking Filter, Model VIII B. Interstate Electronics Corporation, 707 East Vermont Avenue, Anaheim, California, IEC Publication 16200099, revised 12 December 1960. Developed under Contract NAS 5-201.

7. Manual of Submarine Cable Communication System, Part I - System Description. Volume I prepared by Bell Telephone Laboratories, Inc., for Western Electric Company, Inc. Developed under Contract AF 33 (038)-22454.

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8. Instruction Manual, Model 1005R, Data Receiver, Milgo Electronic Corporation, Miami 47, Florida. Developed under Contract AF 08 (606)-1155.

9. Instruction Book for Computer, Model 484B, Prepared by Electronic Associates, Inc., Long Branch, New Jersey.

10. Instruction Book for Computer, Model 484A, Prepared by Electronic Associates, Inc., Long Branch, New Jersey.

11. UDOP SYSTEM. MTOE Technical Memorandum No. 4, dated September 1963. S. Kuen Wong, Lt., USAF.

12. The UDOP System and the Reduction of UDOP Data at the Atlantic Missile Range, Eugene S. Smith, July 1962. Mathematical Services TM 62-9. Prepared by RCA Service Company, MTP, under Contract AF 08 (606)-3413.

13. Interim Offset UDOP System, Frank Bryne, and R. L. Baker. MTP-LVO 63-1, 4 January 1963. Prepared by Electronic Engineering Measuring and Tracking Office, Launch Vehicle Operations Division, George C. Marshall Space Flight Center, NASA.

14. UDOP Digitizer, DHS-137, Technical Training Manual, September 1963. Prepared by RCA Service Company, MTP, Patrick Air Force Base, Florida.

15. UDOP Range Sum and Range Differences with Associated Error Estimates. P. J. Pearson, Technical Document #177. Program identification UDSD 2, 19 September 1962, RCA, MTP, Mathematical Services, Patrick Air Force Base, Florida.

16. DARE Editing Routine, W. J. Kirklin, Technical Document #43, 4 January 1962. Program identification DOED4, RCA, MTP, Mathematical Services, Patrick Air Force Base, Florida.

17. UDOP Position and Velocity Routine, D. R. Lewis, Technical Document #171, 4 April 1962. Program identification, DUPV 1, RCA, MTP, Mathematical Services, Patrick Air Force Base, Florida.

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18. Velocity and Acceleration by Smoothing, S. F. Andrews and V. E. Campbell, modified by B. Page, Technical Document #27, 13 October 1961. Program identification SMVA3, RCA, MTP, Mathematical Services, Patrick Air Force Base, Florida.

19. Preliminary Evaluation Test Report for Collins Radio Company, Model AN/GSC-4 Data Modem, 19 July 1963. D. L. Schneid, Prepared by Pan American World Airways, Data Handling/Translation, Patrick Air Force Base, Florida.

20. UDOP-DARE-FLAC Data System, Space Technology Laboratories, 14 July 1959.

21. UDOP Accuracy Study, Part I, Theoretical, STL/TR 60-0000-00329, 17 October 1960, Space Technology Laboratories, Inc.

22. The Accuracy of AMR Instrumentation, MTC-TDR 63-3, ASTIA Document AD 270800, 17 December 1962 (Published Yearly), H. P. Mann, Systems Analysis, RCA Service Company, MTP, AFMTC, AFSC, Patrick Air Force Base, Florida, under Contract AF 08 (606)-5300.

23. Summary of UDOP System Performance on MINUTEMAN Flights, H. Pickover, 4 January 1963, Space Technology Laboratories, Inc., Florida Division.

24. Monthly Accuracy Memorandum - AMR Instrumentation, H. P. Mann (Published Monthly), Systems Analysis, RCA Service Company, MTP, Patrick Air Force Base, Florida.

25. New Techniques for Phase and Frequency Jitter Measurements, Publication REC-TP-151, April 1962, Resdel Engineering Corporation, Pasadena, California.

26. Analysis of UDOP Modifications for the Down Range System, Ralph K. Weller, 1 June 1961, RCA Systems Analysis, Technical Memorandum #16, MTP, Patrick Air Force Base, Florida, under Contract AF 08 (606)-3413.

27. Technical Manual for the UHF Antenna Preamplifier for UDOP Receiver, Model 90196, Publications REC-M-9, March 1960, Resdel Engineering Corporation, Pasadena, California.

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28. Technical Manual for the UDOP Solid State Transponder, Model 90710-2. Publication REC-M-29, March 1962, Resdel Engineering Corporation, Pasadena, California.

29. The UDOP System, September 1959, Resdel Engineering Corporation, Pasadena, California.

30. Test Procedures UDOP Transponder, Model 90710, Publication REC-T-25. Prepared for AVCO, Contract AD-507-M, Resdel Engineering Corporation, Pasadena, California.

31. Technical Manual for UDOP UHF, Phaselock Converter, Model 90315-1, Publication REC-M-24A, February 1962, Resdel Engineering Corporation, Pasadena, California.

32. Technical Manual for UDOP VHF, Phaselock Converter, Model 90694, Publication REC-M-32, February 1962, Resdel Engineering Corporation, Pasadena, California.

33. Assembly Instructions for the Modification Kit for the VCO/Tripler, Model 90701, Publication REC-M-22A, December 1960, Resdel Engineering Corporation, Pasadena, California.

34. Technical Manual for the Resdel Model 91021-1, UDOP Offset Interrogater System, Volume I, Publication REC-M-47, February 1963, Resdel Engineering Corporation, Pasadena, California.

35. The UDOP System, Publication REC-TF-160, October 1961, Resdel Engineering Corporation, Pasadena, California.

36. Test Procedures, Tracking Filter Subsystem, Rack #3 and 4. Central Digitizing System, EDP Corporation, Orlando, Florida, Item 10 (Partial) Contract AF 08 (606)-5024.

37. Instruction Book, UDOP, 450 mc, 1 KW, Amplifier, 10 December 1958, Gates Radio Company, Quincy, Illinois.

38. Preliminary UDOP RF Reference System, Model M5687, 1 B 882, 16 January 1959, Gates Radio Company, Quincy, Illinois.

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39. Technical Manual for UDOP Ground Receiver, Model 90191, Publication REC-M-7, July 1959, Resdel Engineering Corporation, Pasadena, California.

40. Instruction Manual, Volume I, Radio Frequency Subsystem of the Centralized Digital System for UDOP, Rack #10. Transmitter Station, Little Carter Cay, EDP Corporation, Orlando, Florida, under Contract AF 08 (606)-5026.

41. AMR Instrumentation Handbook, MTL-TDR-63-1, Volume I, Operational Systems, 1 February 1963, Range Planning Department, Pan American World Airways.

APPENDIX V

UDOP SYSTEM MANPOWER REQUIREMENTS

The following is a listing of technical personnel needed to support a normal mission, with full down range UDOP support.

Allans Cay	2 technicians
Walker Cay	2 technicians
Carter Cay Receivers	1 technician
Carter Cay Transmitters	3 technicians
Bassett Cove Receivers	1 technician
Bassett Cove Central Record	4 technicians
West End	2 technicians

Personnel at Bassett Cove include the UDOP System Leader.

The equipment at the Impact Predictor Facility is manned and operated by normal site personnel, with no additional people required for UDOP.

APPENDIX VI

TABLE OF SURVEY DATA FOR THE DOWN RANGE UDOP SYSTEM

This data is accurate as of October 1963. Surveyed points are subject to revision as new surveys are run as a result of severly inclement weather moving the antenna mounts.

SYSTEM	LATITUTE	LONGITUDE	ELEVATION MSL
Allans L (CW)	26 59 10.8084	77 40 27.3159	9.73
Allans M (CCW)	26 59 10.8063	77 40 28.4227	15.02
West End G (CW)	26 39 13.396	78 56 02.519	15.59
West End H (CCW)	26 39 13.509	78 56 02.698	15.04
Walker J (CW)	27 15 29.8830	78 23 37.6569	16.00
Walker K (CCW)	27 15 30.0122	78 23 37.7710	14.04
Bassett O (CW)	26 36 52.3867	78 19 24.8826	51.81
Bassett P (CCW)	26 36 52.9378	78 19 25.4586	52.46
Carter Interrogation Transmitter	27 05 13.8812	78 00 08.1132	18.5760
Carter C (CW)	27 05 09.5396	77 59 49.2202	16.378
Carter D (CCW)	27 05 09.5071	77 59 49.0081	16.168
NASA/UDOP RECEIVER STATIONS			
Blockhouse 26	28 26 37.674	80 34 19.312	18.960
Site C	28 28 25.955	80 33 14.375	14.120
Hangar D	28 29 15.591	80 34 57.621	46.445

APPENDIX VI

TABLE OF SURVEY DATA FOR THE DOWN RANGE UDOP SYSTEM

NASA/UDOP RECEIVER STATIONS (Cont'd)

SYSTEM	LATITUTE	LONGITUDE	ELEVATION MSL
Site B	28 26 35.453	80 35 33.867	14.970
Merritt Island	28 20 38.463	80 41 25.180	8.760
Titusville/Cocoa	28 30 33.5113	80 47 40.7480	40.840
Playalinda	28 38 34.555	80 37 27.176	11.510
Blockhouse 34	28 31 08.4437	80 33 45.0767	
	28 31 17.6521	80 33 47.6009	7.89
	28 31 12.7028	80 33 44.8330	
	28 31 17.3518	80 33 39.9753	

NASA/UDOP TRANSMITTER STATION

Transmitter (1.3.2)	28 26 36.5216	80 34 48.3765	14.522

The following survey data, although not as current as that previously listed, shows the UDOP System in a coordinate system in a more convenient manner for use by the impact predictor and data reduction computer facilities. The following survey data is dated as of July 1963.

DOPPLER SITES

Range coordinates of doppler stations in a system in which the X and Y axis are tangent to the earth's surface at the origin, X true east, Y true north, and Z coincides with the plumb line at the origin (Pad 3).

APPENDIX VI

TABLE OF SURVEY DATA FOR THE DOWN RANGE UDOP SYSTEM

STATION		X (FT)	Y (FT)	Z (FT)
UDOP RECEIVER STATIONS				
Blockhouse 26	(1.2.8)	-11376.10	- 8086.43	4.64
Site C	(1.4.1)	- 5577.38	2848.40	3.52
Hangar D	(1.8.1)	-14789.97	7863.97	30.08
Site B	(1.9.1)	-18031.96	- 8308.21	- 4.11
Merritt Island	(1.10.1)	-49440.90	- 44335.49	- 106.44
Titusville/Cocoa	(1.11.2)	-82871.53	15819.88	- 138.80
Playalinda	(1.12.1)	-28094.42	64326.08	- 116.31
Blockhouse 34	(1.14.1)	- 8313.90	19259.91	- 20.21*
	(1.14.14)	- 8538.88	20190.00	- 13.29
	(1.14.3)	- 8292.07	19690.08	- 20.61*
	(1.14.4)	- 7858.62	20159.52	- 20.89*
L Carter Cay	C	826469.04	-493093.88	-22158.87
West End	D	523530.93	-655335.59	-16855.50
Great Sale	G	751550.69	-529954.11	-20239.37
Great Sale	H	751500.61	-529946.81	-20237.31
Walker Cay	J	696041.66	-432848.43	-16064.67
Walker Cay	K	696031.08	-432835.53	-16066.51
Allans Cay	L	931844.42	-526793.55	-27409.16

APPENDIX VI

TABLE OF SURVEY DATA FOR THE DOWN RANGE UDOP SYSTEM

STATION		X (FT)	Y (FT)	Z (FT)
UDOP RECEIVER STATIONS	(Cont'd)			
Allans Cay	M	931744.52	-526796.20	-27409.74
Bassett Cove	O	722932.62	-666323.23	-23107.06
Bassett Cove	P	722879.43	-666268.61	-23102.83
UDOP TRANSMITTER STATIONS				
Transmitter	(1.3.2)	-13970.82	- 8201.97	- 1.41
Transmitter A	(CW)	824455.44	-492553.86	-22051.74
Transmitter B	(CCW)	824402.11	-492548.12	-22053.72

APPENDIX VII

REAL TIME IMPACT PREDICTION COUNTDOWN CHECKS

The following countdown checks were devised to provide the Impact Predictor Facility with sufficient information to determine the GO/NO-GO status of the Down Range UDOP System. This countdown procedure has been incorporated into the appropriate ROI (Range Operating Instruction) for MINUTEMAN mission support. Coordination of these checks is performed via the CWC voice net.

T-270 minutes	Check on all data and voice circuits to see if they are operating correctly. Run through remote test check on the Collins AN/GSC-4 data set. (If computer time is available, digital test patterns can be observed at this time using the UDOP digitizer and the computer's numerical indicator).
T-250 minutes	Copy 30 seconds of full "zeros" test pattern from the digitizer. Copy 30 seconds of full "ones" test pattern from the digitizer. Copy one minute of live 18KC offset bias data, using normal real time data format. Observe all these modes on the visual indicator before copying with the IP Computer.
T-125 minutes	Observe live offset bias frequency data on the numerical indicator. If time allows, copy one minute for tabout analysis. Copy a doppler slew generated from Carter Cay. The slew shall be a simulated UDOP signal both as to rate of change and frequency. Observe octal, first and second differences from tabbed out data.
T-18 minutes	Observe all "ones" test pattern from the UDOP digitizer on the computer numerical indicator. Depress initial synch on the down range digitizer at this time for re-initialization with range timing.
T-15 minutes	Receive verbal report of complete Down Range UDOP System status at this time. At this time, the Down Range UDOP System is either committed for alternate impact prediction or is declared CNY. Any system malfunction at this time will cause the status to be CNY.

There is available at the Impact Predictor Computer certain programs for checking on the UDOP System status throughout the checks listed above. By use of the numerical indicator, doppler frequency can be displayed either in decimal or in binary (octal). Indication such as:

System synch

On-track indication for each site

Range time

Parity

Site code identification

can be interpreted from the visual display. The data itself can be observed in decimal and is the conversion of whole cycle counts and previous cycle counts for all stations, simultaneously. (see Figure G-1).

There is also a program to detect and print only the errors generated in the all "ones", all "zeros" and slew check d. :a.

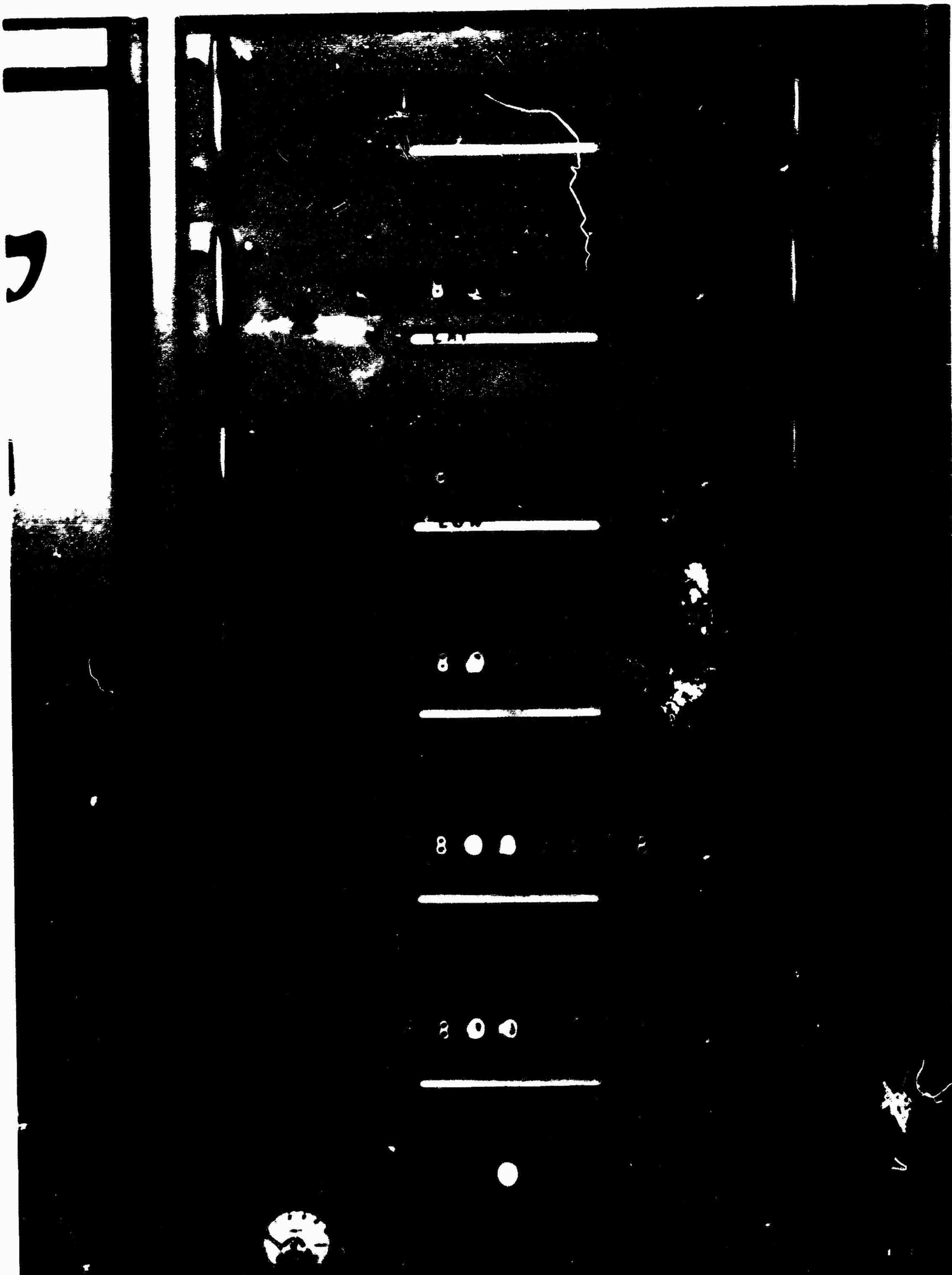

FIGURE VII-I Photo of Computer Visual Indicator Showing All Sites Under an 18 KC Static Test

APPENDIX VIII

UDOP OPERATING INSTRUCTIONS

ROI 11-04-01
6 September 63
Supersedes: 22 July 63

REFERENCE:
1. ROI 03-03-01
2. ROI 03-03-05
3. ROI 08-01
4. ROI 11-04-02
5. ROI 13-12
6. UDOP Preventive Maintenance Program
7. UDOP Transmitter Manual
8. UDOP Receiver Manual

PURPOSE: To establish a standard procedure for operating the Down Range UDOP System for test support.

1. **GENERAL**

1.1 UDOP is a UHF DOVAP System which measures the total doppler shift of a CW carrier transmitted from the ground and doubled and retransmitted by a missile borne transponder. The overall UDOP accuracy depends on the geometry of the transmitting and receiving sites in respect to the missile trajectory as well as the system precision.

1.2 The down range system consists of a transmitting site at Station 42 and receiving sites at Stations 3 (Bassett Cove and West End), 41, 42, and 44. The recording site is at Station 3 (Bassett Cove).

2. **PROCEDURE**

2.1 Pre-Test

2.1.1 Operators at each receiver site will perform F-1 Day and F-Day checks outlined in ROI 03-03-01 and the Preventive Maintenance Program (PMP) instructions.

2.1.2 Data link transmitters at each receiver site will be adjusted to the basic frequency as follows:

2.1.2 (Cont'd)

Site	Type Receiver	Frequency (mc)
Allans - System L	Phaselock	137.61
Allans - System M	Standard	139.50
Little Carter - System C	Standard	142.75
Little Carter - System D	Standard	143.75
West End - System H	Phaselock	141.10
West End - System G	Standard	138.25
Walker - System J	Phaselock	136.25
Walker - System K	Standard	141.93

NOTE: Systems C, G, J and L use right hand circularly polarized antennas; and Systems D, H, K and M use left hand circularly polarized antennas. The Bassett Cove Receiver Site System O uses a right hand circularly polarized antenna and a standard receiver. System P at this site uses a left hand circularly polarized antenna and a phaselock receiver. Systems O and P are hard-wired to the recording equipment.

2.1.3 Each receiver site operator will record a pre-plot of expected doppler frequencies versus plus time on the Brown Recorder at a recorder speed of 6 ipm. Data Reduction will furnish pre-plot data to the sites by F-4 Day. This pre-plot will be used as an acquisition aid for locking on the phaselock receivers.

2.1.4 Each receiver site operator will calibrate receiver signal strength and AGC meters in the following microvolt steps:

10	1.0	0.12
6	0.8	0.10
4	0.5	0.07
3	0.3	0.05
2	0.2	0.03
1.6	0.16	0.00

This calibration will be recorded on the Visicorder at 0.2 ips with 1 pps coded timing. Set up the Visicorder to record phaselock receiver lock/unlock conditions and phaselock receiver phase error in addition to standard and phaselock receiver AGC and signal strength with 1 pps coded timing during the test. Record during the test at 1 ips. In addition to calibration data, record the sensitivity check described under Paragraph 2.1.13 on the Visicorders at 0.2 ips.

2.1.5 The Station 42 Transmitter Site Operators will perform F-1 Day and F-Day checks outlined in ROI-03-03-01 and PMP instructions.

2.1.6 Station 42 Transmitter Site Operators will adjust the reference oscillator frequency on F-1 Day. Record the frequency deviation and keep on file for 30 days, then destroy.

2.1.7 On F-Day, transmitter site operators will adjust the offset converter to furnish an 18 KC bias. Operators will verify this offset bias to be 50.001 mc. If extended holds occur during the countdown, the operators will recheck and readjust the bias if necessary.

2.1.8 Transmitter site operators will operate the test (900 mc) and reference (50.001 mc) transmitters during the system check described in 2.1.13, as directed by the Station 3 UDOP Coordinator. When system checks are completed, the test transmitter will be secured and the reference and interrogation (450 mc) transmitters will be left in the standby condition, i.e., with the exciter on. The reference transmitter will be turned on as specified by the Range countdown, and the interrogation transmitter will be turned on at switchover time.

2.1.9 Recording station operators will perform F-1 Day and F-Day checks outlined in ROI-03-03-01 and PMP instructions. In addition, the current UDOP Coordinator's check list will be used to determine system status on F-Day.

2.1.10 The recording station receiver operator will check with the receiver site operators to determine if the correct data channel is connected to the correct receiver system antenna. Any deviation from the standard assignment listed in Paragraph 2.1.2 will be noted in the UDOP Coordinator's log.

2.1.11 Recording site operators will adjust the tracking filters to receive the expected doppler frequencies after switchover. The expected frequency versus time can be determined from the Brown Recordings.

2.1.12 Recording site personnel will check the analog-to-digital processor and data transmission system equipment by transmitting a test pattern and 18 KC doppler signals from the receiver sites. The UDOP Coordinator will coordinate this check with the Cape Computer Coordinator. The channel assignment for real time Range Safety display for the processor is:

2.1.12 (Cont'd)

Channel	Site	System
1	Allans Cay	L
2	Allans Cay	M
3	Walker Cay	J
4	Bassett Cove	P
5	Bassett Cove	O
6	West End	H

2.1.13 A combined system check will be made as follows:

a. The reference transmitter (with offset converter adjusted to (50.001 mc) and the interrogation transmitter will be placed in normal operation.

b. The test transmitter will be turned on to simulate a doppler frequency equal to the 18 KC bias.

c. The power output from the test transmitter will be decreased from nominal to zero in incremental steps.

d. Recording site operators will determine at what plate current level each receiver site phaselocked receiver becomes unlocked or, in the case of a standard receiver, when the doppler becomes unusable.

e. A log of the minimum plate current reading versus receiver loss of usable doppler will be maintained at the recording site.

2.1.13 (Cont'd)

f. Record 30 seconds of straight 18 KC bias from all receiver sites on FR-114 Magnetic Tape Recorders.

2.1.14 Recorder site operators will record on both of the FR-114 Recorders at 60 ips during the launch test as follows:

Recorder 1	Recorder 2	Channel
500 pps	500 pps	1
50 KC	50 KC	2
Walker System K	Walker System K	3
10 pps	10 pps	4
Bassett System O	Bassett System O	5
Allans System M	Allans System M	6
100 pps Code	100 pps Code	7
Walker System J	Walker System J	8
Little Carter System D	Little Carter System D	9
West End System G	West End System H	10
Bassett System P	Bassett System P	11

2.1.14 (Cont'd)

Recorder 1	Recorder 2	Channel
Allans System L	Allans System L	12
500 pps Code	500 pps Code	13
Internal Servo	Internal Servo	14

2.2 In-Flight

2.2.1 Start the FR-114 Recorders at T-2 minutes and Visicorder Recorders at T-20 seconds. Start the Brown Recorder at T+10 seconds. Turn off the Brown and Visicorder Recorders after final LOS when directed by the UDOP Coordinator. Operate the magnetic tape recorders until out of tape.

2.2.2 The down range system's standard receivers will passively track the vehicle until switchover time and actively thereafter. Phaselock receivers will be adjusted to expected doppler frequencies and locked immediately after switchover. Use the Brown Recorder pre-test plotted expected frequencies to acquire phaselock.

2.2.3 Switchover to the down range transmitter will be accomplished as outlined in ROI 11-04-02.

2.2.4 Immediately after switchover, lock all tracking filters and phaselock receivers to the receiver doppler signals. Re-lock as necessary after signal drop outs.

2.3 Post-Test

2.3.1 Each receiver site operator will calibrate the receivers and record the calibrations on the Visicorder exactly as described in Paragraph 2.1.4.

2.3.2 The UDOP Coordinator will log all test information as specified in ROI 03-03-05. This log will consolidate all events and information from all sites and will normally contain:

a. Equipment malfunctions, cause, corrective action taken, and time of correction.

b. Time of beginning the setup, calibration, teardown, standby, and so forth.

c. Any operating procedure problems which occurred during the countdown and any deviations from these and PMP instructions.

d. Transmitters, transmitter antenna, and reference oscillator used.

e. Transmitter on and off times during the pre-test checks as well as at switchover time.

f. In-line power output meter reading and in-line VSWR meter reading (forward and reflected power) of 50.001 mc and 450 mc transmitter.

g. Times of first signal, phaselock receiver and tracking filter lock/unlock, drop out, and final loss of signal.

h. UHF (900 mc) average and maximum and VHF (50.001 mc) signal strength.

i. Any other observations or information that would be of help to Data Reduction in analyzing the data.

2.3.3 Each receiver and transmitter site operator will record all events and other helpful information pertaining to their sites as specified in ROI 03-03-05. The standard log format will be used for this purpose. Site logs will be retained on site for 90 days, then destroyed as outlined in ROI 03-03-05.

2.3.4 The two FR-114 Magnetic Tapes, Visicorder and Brown Recorder Records, plus the Coordinator's log will be turned in as specified in ROI 08-01.

APPENDIX IX

INSTRUMENTATION EQUIPMENT CHECK LIST

UDOP COORDINATOR F-DAY CHECK LIST	Test Number(s): Date: Console Operator: Station 3.0 Operators:
Receivers:	Recorders:
Digitizers:	Tracking Filters:

Time	Operator	Net	(Times are referenced to T-0, neglecting built-in holds)	ACK	CNY	N/A
T-270	CO		1. All lines up to computer data and voice			
	SO		2. Make remote AN/GSC-4 Test			
T-250	SO		1. Computer check			
	SO		2. First six words - all ones test pattern for 30 seconds			
	SO		3. First six words - all zeros test pattern for 30 seconds			
	SO		4. 18KC check - one minute			
T-220	CO	U	1. All stations verify station check lists completed Station Operator			
			41			
			42			
			42T			
			44			
			50			
			3.0			
	SO		2. Verify operation of digitizer and DTS System			
T-210	CO	U	1. All stations lock up data link transmitters and report frequency and power output J____ K____ M____ L____ C____ D____ G____ H____			

APPENDIX IX

INSTRUMENTATION EQUIPMENT CHECK LIST (Cont'd)

	UDOP COORDINATOR F-DAY CHECK LIST (Continued)					
TIME	OPERATOR	NET		AOK	CNY	N/A
T-200	CO	U	1. All stations verify equipment to be used (Station receiver, data link, antenna). Record in Coordinator's Log.			
	CO	U	2. 42T verify offset on proper side and correct frequency.			
	CO	U	3. Lock phaselock receivers and set doppler level.			
	SO		4. Set attenuator panel levels.			
	CO	U	5. Phaselock operators remove 900mc antenna patch.			
	SO		6. Set lock - unlock panel levels.			
	CO	U	7. Relock receivers.			
	SO		8. Check operation of lock signal through digitizer with MARION LEMON 1 ALPHA			
	SO		9. Verify operation of tracking filters.			
	CO	U	10. Turn all 500 BR meters to 60 cycle position.			
T-185	CO	U	1. Have each station key doppler by switching receiver LO off momentarily to identify link. Enter link signal strength reading in Coordinator's Log.			
	SO		2. Lock all tracking filters and set on automatic.			
	SO		3. Sync digitizer and start recorders, monitor all playbacks.			
			PLAYBACK A OK.			
	CO	U	4. Remove B+ from all phaselock LO.			
	CO	U	5. LO back on.			
	SO		6. Verify tracking filters relock automatically.			
	SO		7. Stop recorders.			

INSTRUMENTATION EQUIPMENT CHECK LIST (Cont'd)

	UDOP COORDINATOR F-DAY CHECK LIST (Continued)					
TIME	OPERATOR	NET		AOK	CNY	N/A
T-170	CO	U	1. All stations standby to give AGC readings. Enter in Coordinator's Log.			
	CO	U	2. All sites standby for sensitivity test.			
	CO		3. Enter results in Coordinator's Log.			
T-165	CO	U	1. 42T secure 450 and 900 mc transmitters.			
	SO		2. Install launch tapes.			
T-140	CO	U	1. 42T bring up 450 and 900 mc transmitters.			
	CO	U	2. Lock all phaselock receivers. Standby for calibration recordings.			
	CO	U	3. All stations this (is___) (is not ___) a realtime Range Safety test. 41_____ 44_____ 42_____ 50_____ 42T_____ 3.0_____			
	SO		4. If Range Safety test, patch appropriate receivers to digitizer.			
	SO		5. Lock tracking filters and sync digitizer.			
	CO		6. Depress voice channel buttons for recorder two and three.			
	CO		7. Start recorders two and three.			
	CO		8. Record tape title script while recording 18kc from all sites along with proper timing signals.			
	SO		9. Monitor playback during recording.			
	CO		10. Cut recorders.			
	CO	U	11. All stations operate visicorders for quick look.			

APPENDIX IX

INSTRUMENTATION EQUIPMENT CHECK LIST (Cont'd)

	UDOP COORDINATOR F-DAY CHECK LIST (Continued)					
TIME	OPERATOR	NET		AOK	CNY	N/A
T-125	SO		1. Computer check 18kc - one minute.			
	CO	U	2. 42T apply sweep frequency 6 to 60 kc at 30kc per minute. Roger when on the air.			
	SO		3. Computer check - two cycles of sweep frequency.			
T-105	CO	U	1. Load brown recorders with launch chart. Set at sweep calibrate point.			
	CO	U	2. Calibrate brown recorders.			
T-100	CO	U	1. Standby to run sweep calibration.			
	SO		2. Prepare to start recorders two and three.			
	CO	U	3. Start recorders (tape and brown) record two cycles of sweep.			
	CO	U	4. Stop recorders. Return frequency meters to 60 cycle position.			
T-95	CO	U	1. 42T secure test transmitter.			
	CO	U	2. All sites calibrate visicorders. Roger when completed. 41_____ 44_____ 3.0_____ 42_____ 50_____			
T-50	CO	U	1. 42T verify transmitters in launch configuration.			
	CO	U	2. All stations set brown recorders to start position with frequency meters to operate.			
	CO	U	3. Reset plus counters to +10 seconds.			
	CO		4. 3.0 verify tape recorders operating in servo mode.			
T-40	CO	U	1. All stations secure all non-operational equipment.			

APPENDIX IX

INSTRUMENTATION EQUIPMENT CHECK LIST (Cont'd)

	UDOP COORDINATOR F-DAY CHECK LIST (Continued)					
TIME	OPERATOR	NET		AOK	CNY	N/A
T-30	CO	U	1. All stations verify your equipment ready for launch. 41 ______ 44 ______ 42 ______ 50 ______ 42T ______ 3.0 ______			
T-19	SO		1. Press initial sync.			
T-18	SO		1. Computer check - all ones for 30 seconds.			
T-15	CO	U	1. All phaselock operators set receivers to switchover frequency using acquisition preplot.			
	CO	0	2. UDOP System ready for launch.			
	SO		3. Report to computer - digitizer equipment ready for launch.			
T-2	CO	U	1. Phaselock operators press and hold filter button.			
	SO		2. Lock up tracking filters.			
	CO		3. Start tape recorders.			
T-20S	CO	U	1. Start visicorders.			
	CO	U	2. Announce T-15 seconds.			
	CO	U	3. Announce count T-10 seconds to T-0.			
T+5S	CO	U	1. Give plus count to 10 seconds for starting plus counters and brown recorders.			
T+	CO	U	1. Give countdown for switchover.			
T+	CO	U	1. UDOP switchover complete.			
T+	CO	U	1. Stop recorders.			
T+	CO	U	1. (After impact) all stations start post-test calibration. Roger when complete. 41 ______ 44 ______ 3.0 ______ 42 ______ 50 ______			
	CO	U	2. Secure receiver sites.			

APPENDIX IX

INSTRUMENTATION EQUIPMENT CHECK LIST (Cont'd)

	UDOP COORDINATOR F-DAY CHECK LIST (Continued)					
TIME	OPERATOR	NET		AOK	CNY	N/A
T+	CO		1. Standby to playback data upon command.			

REMARKS:

SIGNATURE:

APPENDIX X

REAL TIME MINUTEMAN SUPPORT

For a comprehensive view of the UDOP real time flow, see Figure 3-1. The doppler frequencies are derived from the UDOP receivers at all sites. There are 10 receivers in the UDOP System. Eight of these are located in the Cays and at West End, GBI. These outlying sites require a data link system to transmit the UDOP data from the receiver to the central record station at Bassett Cove, GBI. Because of atmospheric noise inherent in VHF data links, tracking filters are used to clean up the doppler signal before it is passed into the UDOP digitizer.

The data format of the six available digitizer words in real time are as follows:

Word 1	Carter Cay Receiver System C
Word 2	Allans Cay Receiver System L*
Word 3	Bassett Cove Receiver System O
Word 4	Walker Cay Receiver System J*
Word 5	Bassett Cove Receiver System P*
Word 6	West End Receiver System H*

Those stations suffixed with an (*) are phaselocked receiver systems.

The digitizer format for real time use was selected for the IP routine by a combination of optimum geometry and UDOP receiver performance.

It will be noted here from the format that all the phaselocked UDOP receivers are used in the real time solution. This was because of better performance during the critical flame period and because the phaselocked receivers can indicate whether they are tracking or not by relay closure.

The real time program requires that some sort of validity check be included in the data train, so that the computer will not operate on bad data. It is possible for the UDOP receivers to be locked onto the wrong doppler signal, which is disastrous to the impact prediction routine. For this reason, the relay closure of each phaselocked receiver is combined with the relay closure of each associated tracking filter, so that a "flag" is inserted in the data train only when both units are locked to the doppler signal. These validity checks are called the on-track bits.

It will be noted here that the Bassett Cove System P, the phaselocked receiver in the same building as the digitizer, does not go through a tracking filter. The standard UDOP receiver located at Bassett Cove does go through the tracking filter because of its lower signal to noise ratio, and generally poorer performance.

The digitizer converts all six input doppler signals to digital mode, inserts a range time and other data (see section on digitizer) and drives the AN/GSC-4 data transmitter. The data is sent via four miles of 19 guage twisted pair from Bassett Cove, GBI, to the GBI sub-cable terminal, where it is placed on the submarine cable for transmission to the Cape Impact Predictor Facility. The AN/GSC-4 data receiver, which is located in the Impact Predictor Facility with the format converter, converts the serial data output of the AN/GSC-4 to parallel digital information and feeds the IBM 7094 Computer at the proper rate and time.

The Impact Predictor Facility uses the UDOP data to compute a predicted impact location in the event the missile terminates thrust any time during powered flight. The output of the UDOP Computer routine is fed to the alternate IP plotting boards as a back-up to other range safety sources. The alternate plotting boards are located in the Impact Predictor Facility and at Central Control.

As noted from the flow diagrams, the UDOP data is recorded now in doppler analog mode before it is digitizer and also in various digital modes. During real time operation, the computer generates a tape on which the UDOP data is written, along with all other IP input data. For a block diagram of the complete Impact Predictor Facility, and the way in which UDOP fits into it, see Figure 3-2.

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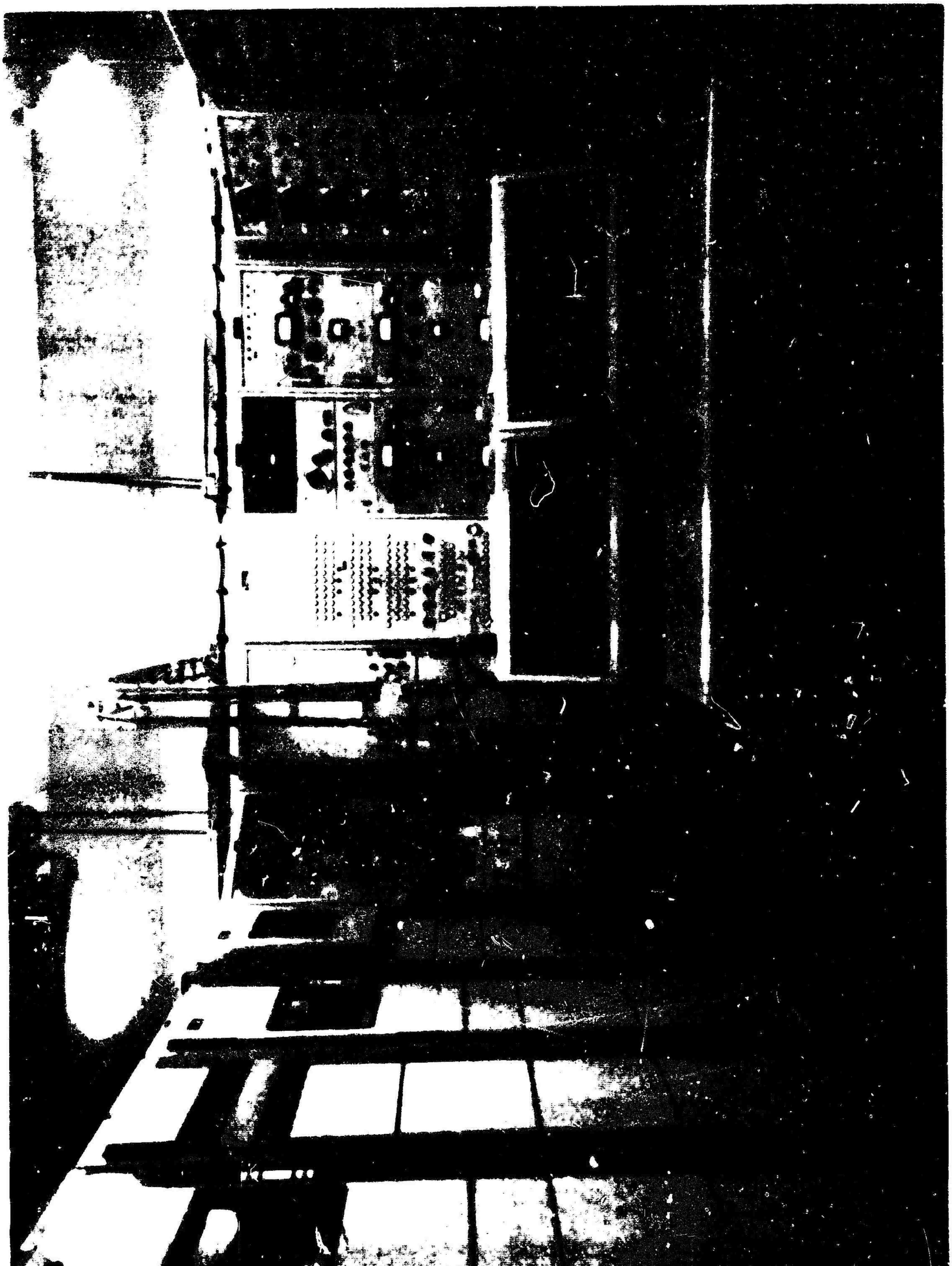

Figure K - 1 Overall View of Bassett Cove Central Control and Digitizer Station

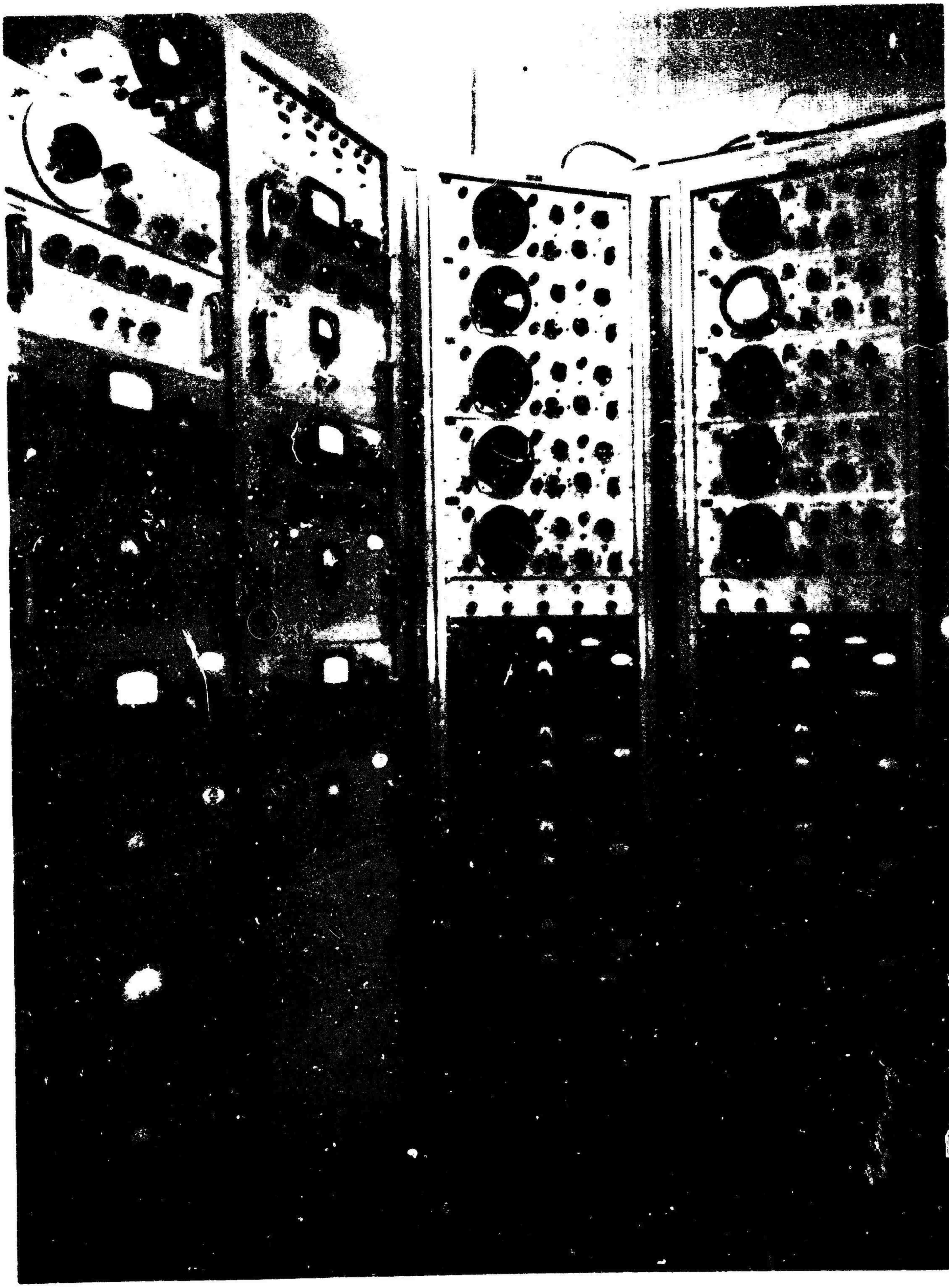

Figure K - 2 View of Tracking Filters, Data Link Receivers, and Monitoring Scope - Bassett Cove, GBI

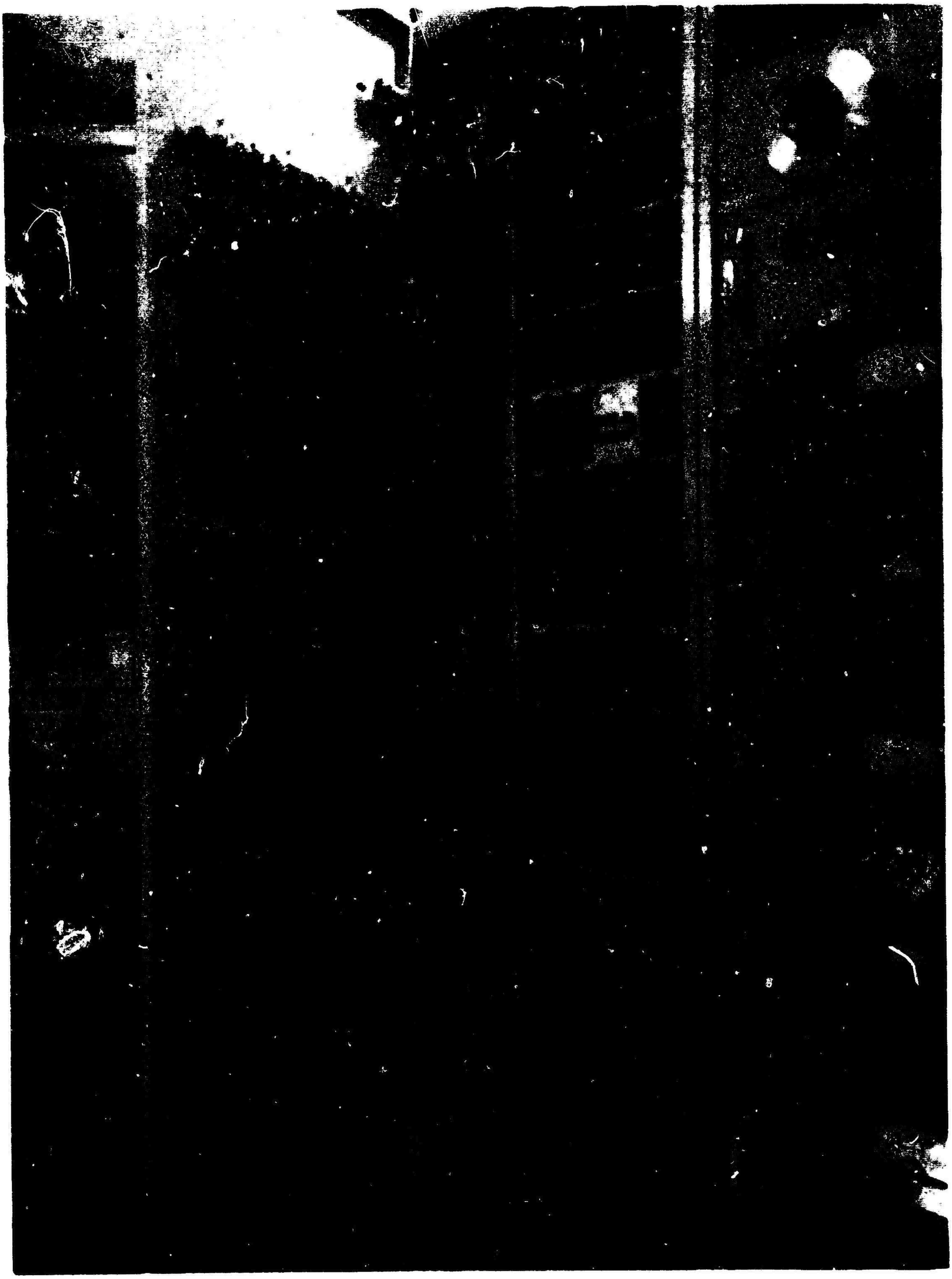

Figure K - 3 Interior View of UDOP Digitizer - Bassett Cove, GBI

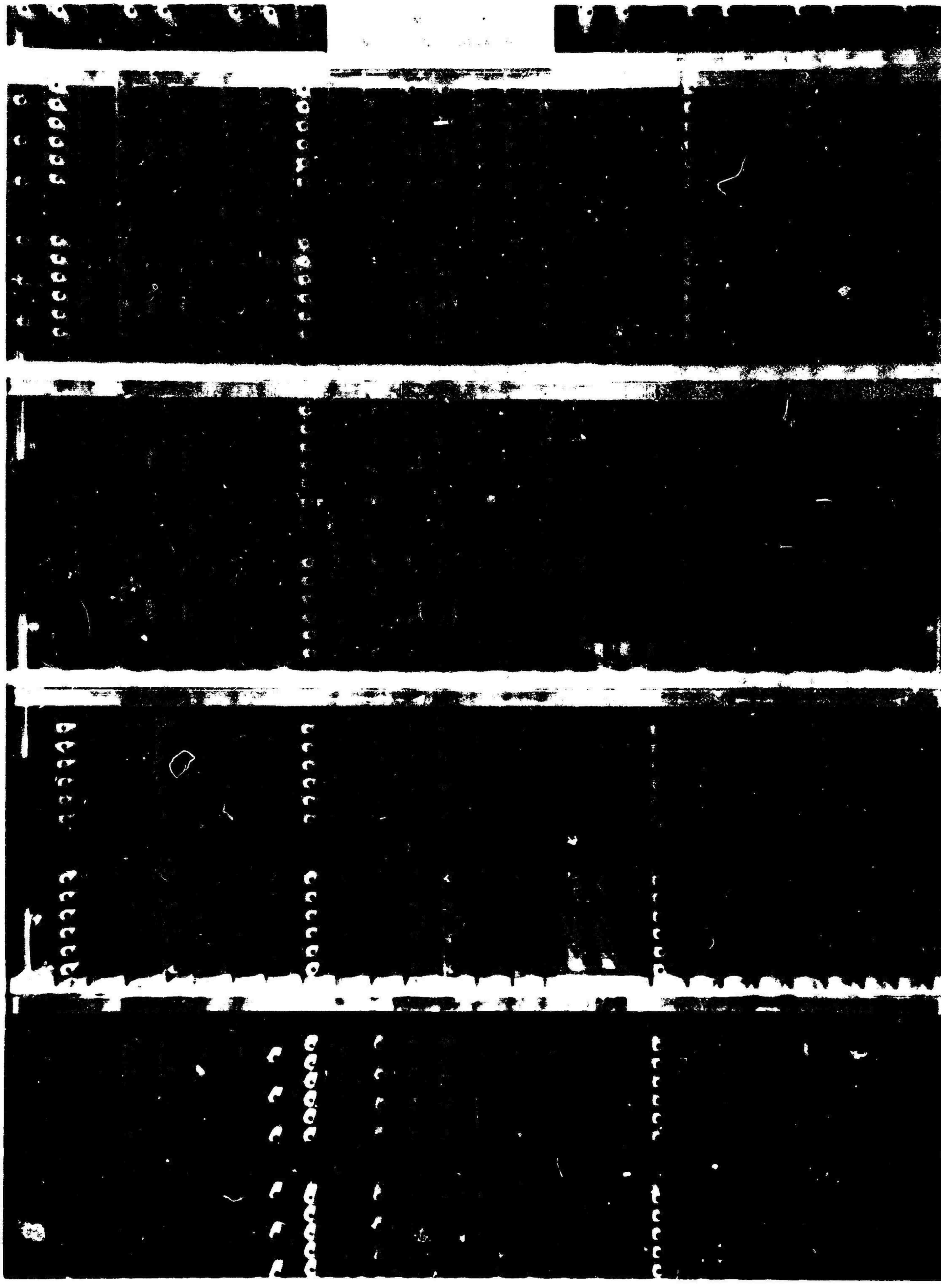

Figure K - 4 View of 4 Card Files in UDOP Digitizer - Bassett Cove, GBI

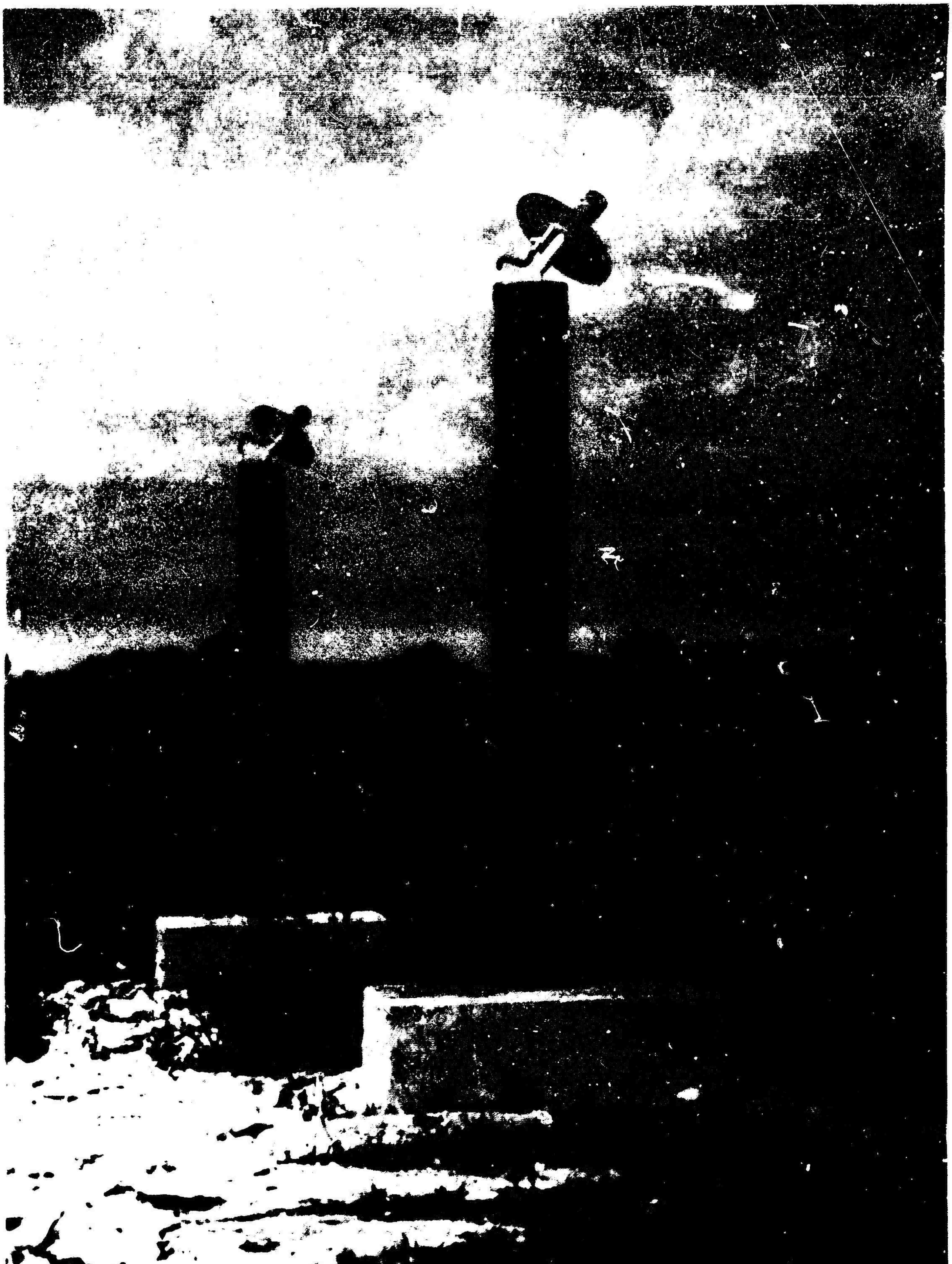

Figure K - 5 View of 3-Turn 900 MC Helix Receiving Antennas - West End, GBI

Figure K - 6 View of 900 MC Turnstile Receiving Antennas with Preamplifiers (obsolete)

Figure K - 7 Aerial View - Carter Cay, GBI

Figure K - 8 Aerial View of Allans Cay, GBI

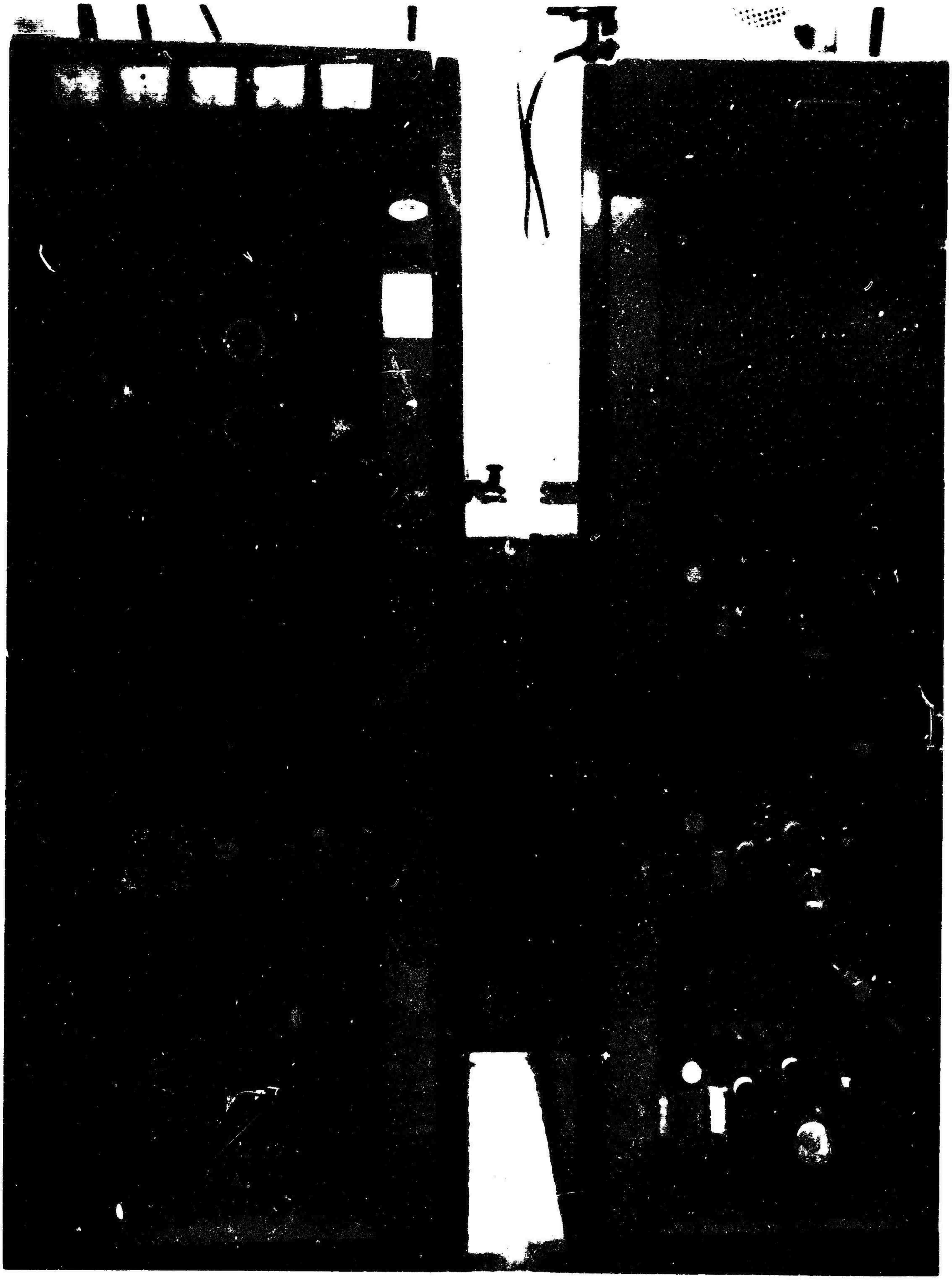

Figure K-9 View of 3 Buffer Amplifiers - Carter Cay, GBI

Figure K-10 Overall View of UDOP Transmitting Equipment - Carter Cay, GBI

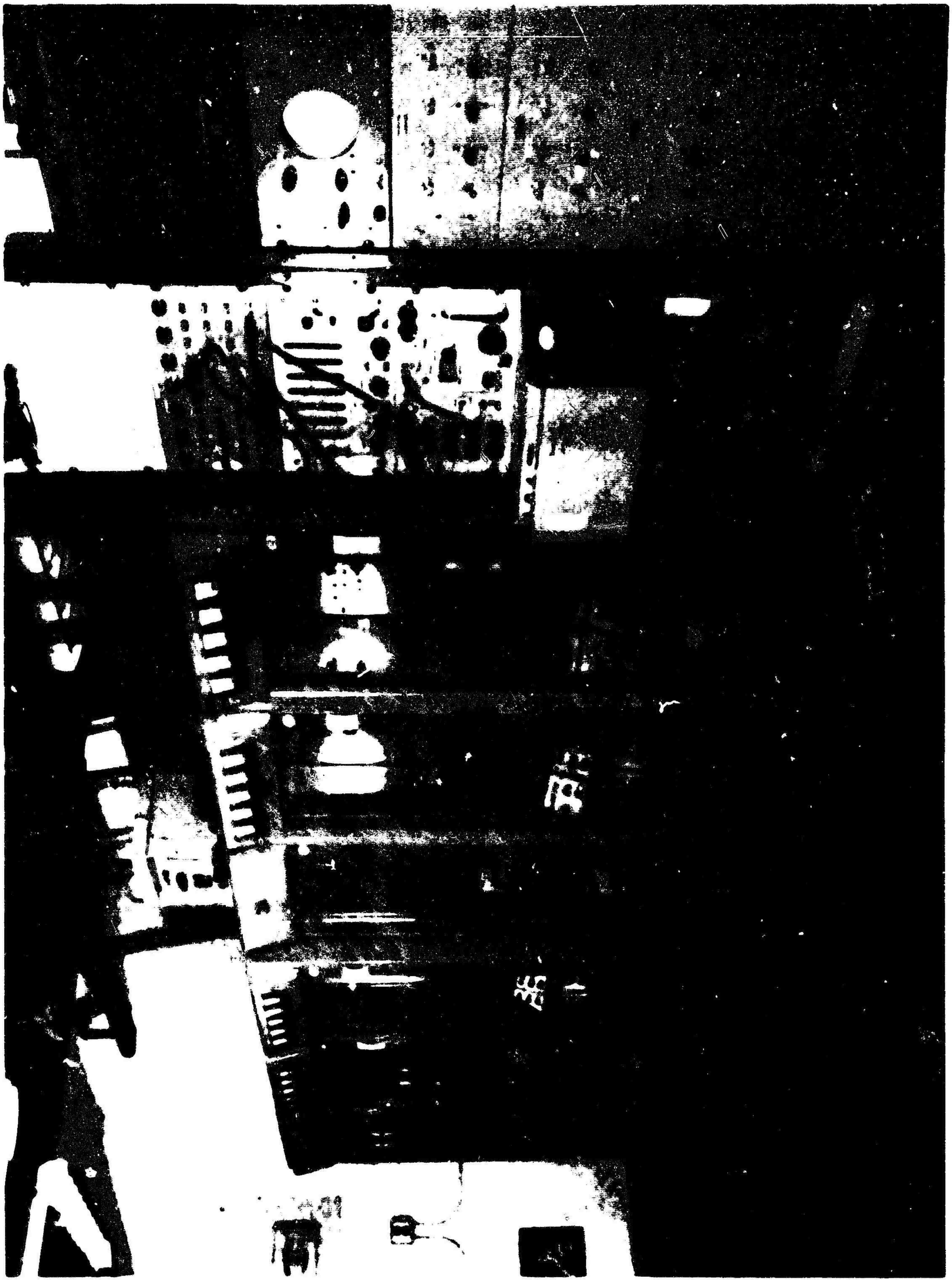

Figure K-11 Overall View of UDOP Transmitting Equipment including Cartesian-to-Polar Converters - Carter Cay, GBI

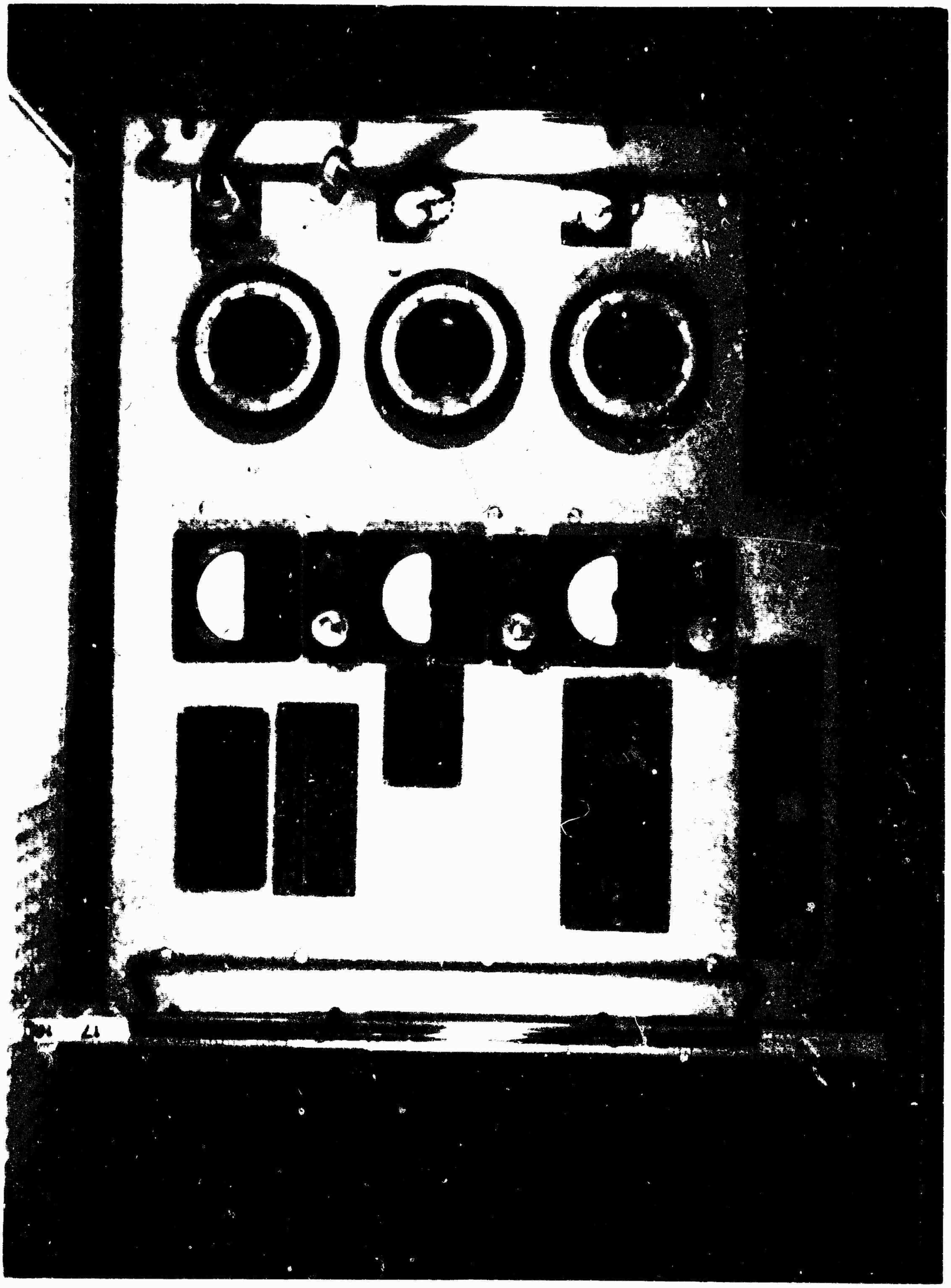

Figure K-12 View of 50 MC, 150 MC, 900 MC Signal Generator - Carter Cay, GBI

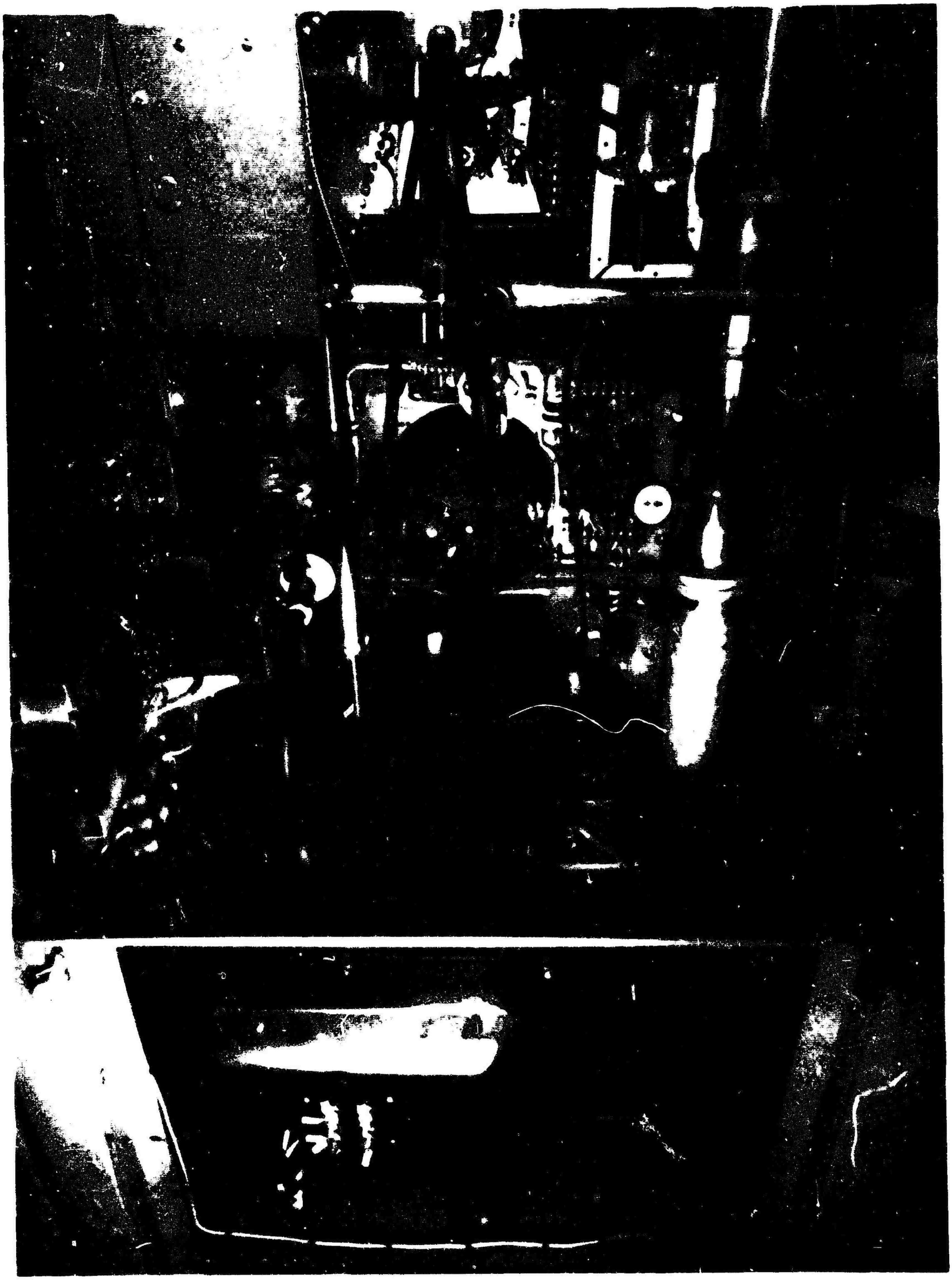

Figure K-[illegible] Interior View of 450 MC Interrogation Transmitter - Carter Cay, GBI

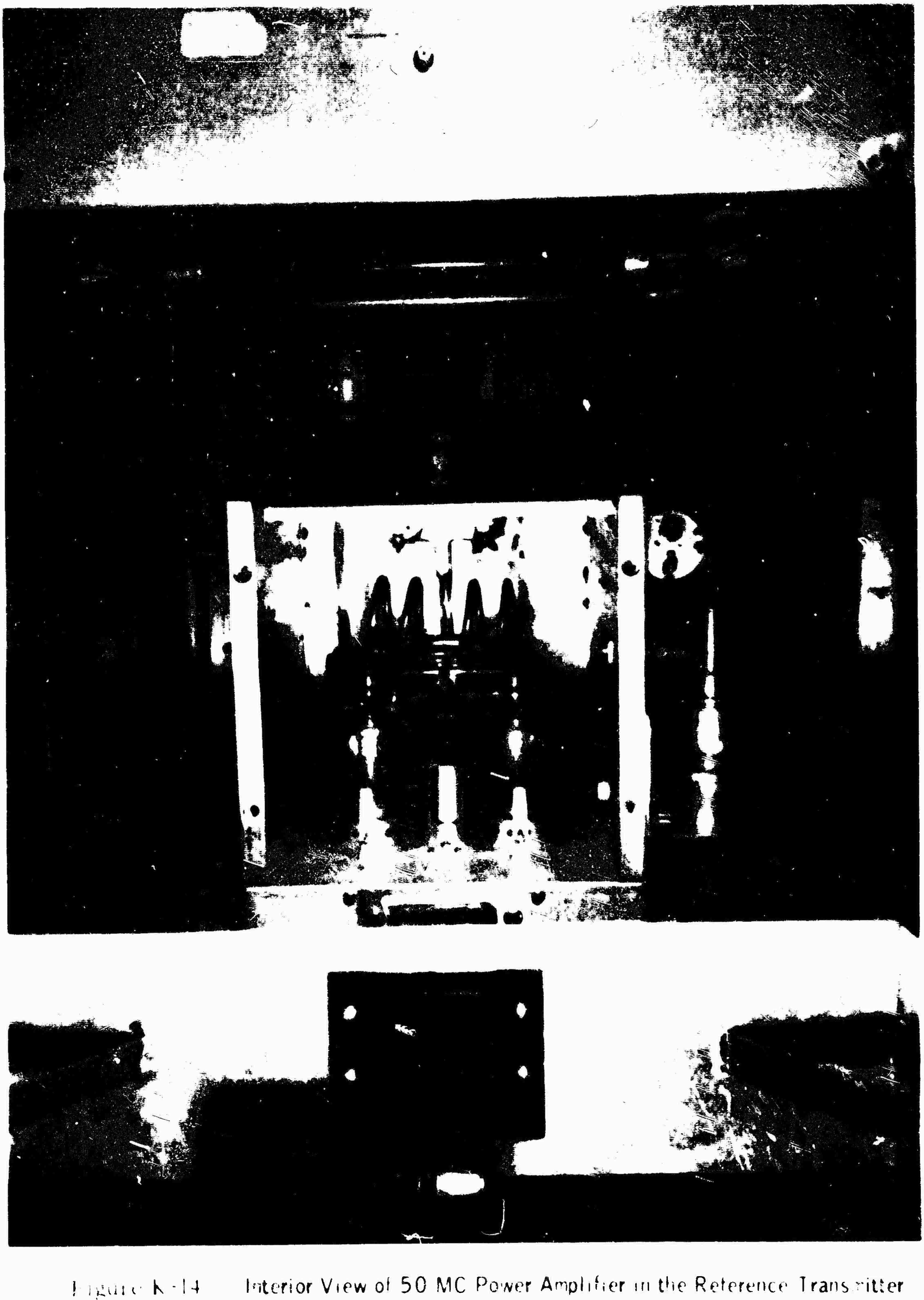

Figure K-14 Interior View of 50 MC Power Amplifier in the Reference Transmitter - Carter Cay, GBI

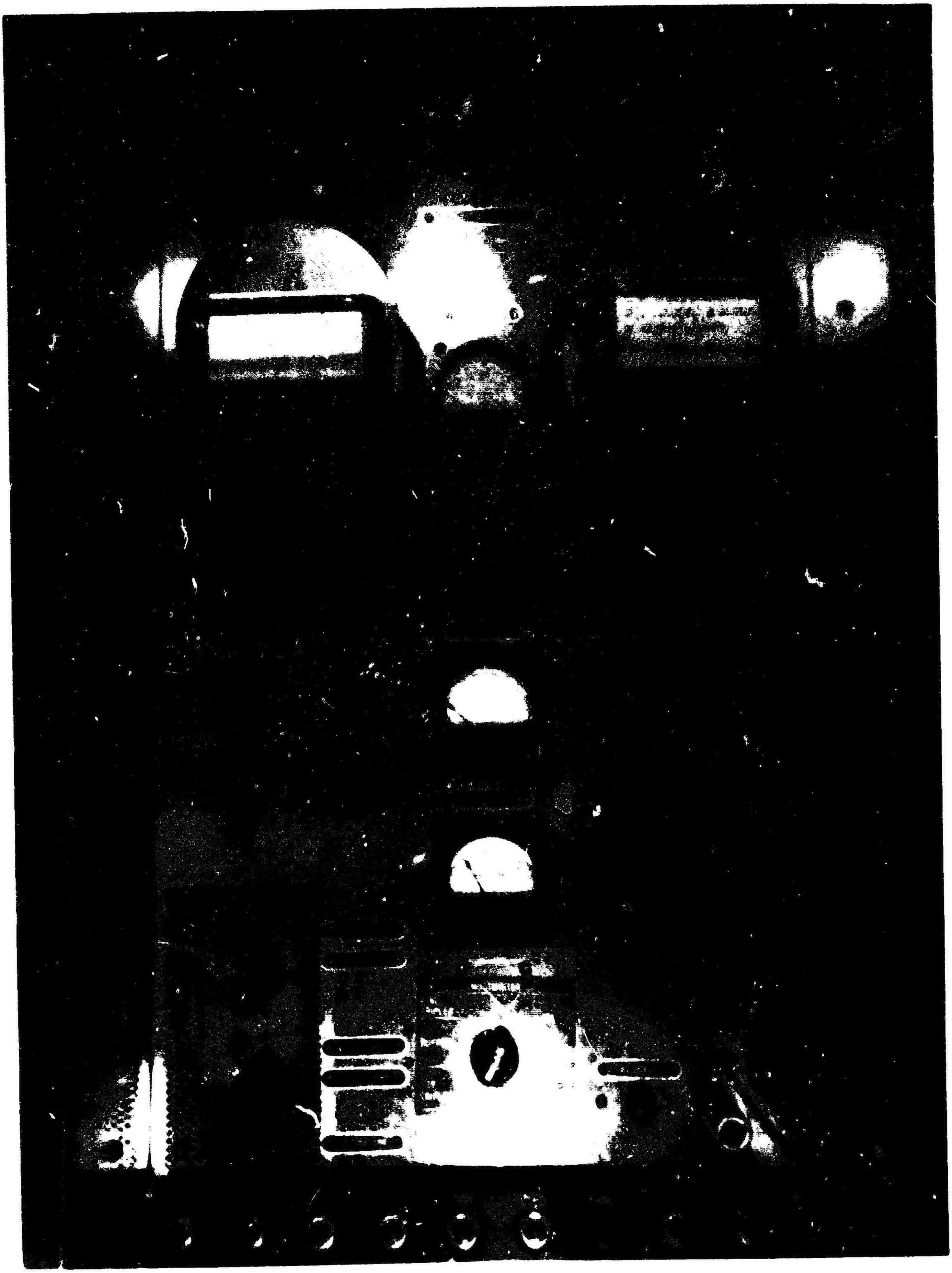

Figure K-15 View of Frequency Multiplier and 900 MC Power Amplifiers - Carter Cay, GBI

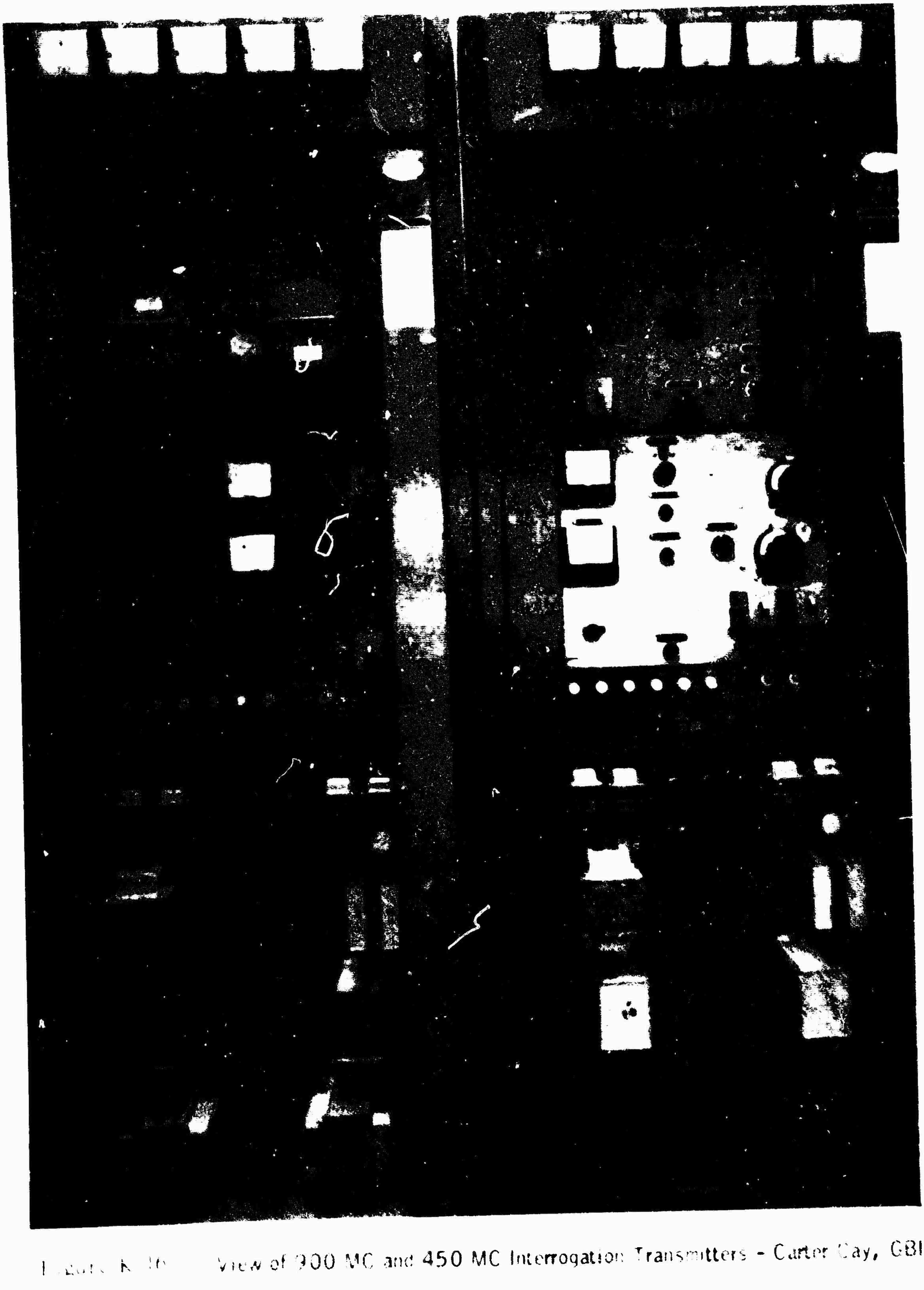

Figure K-16   View of 900 MC and 450 MC Interrogation Transmitters - Carter Cay, GBI

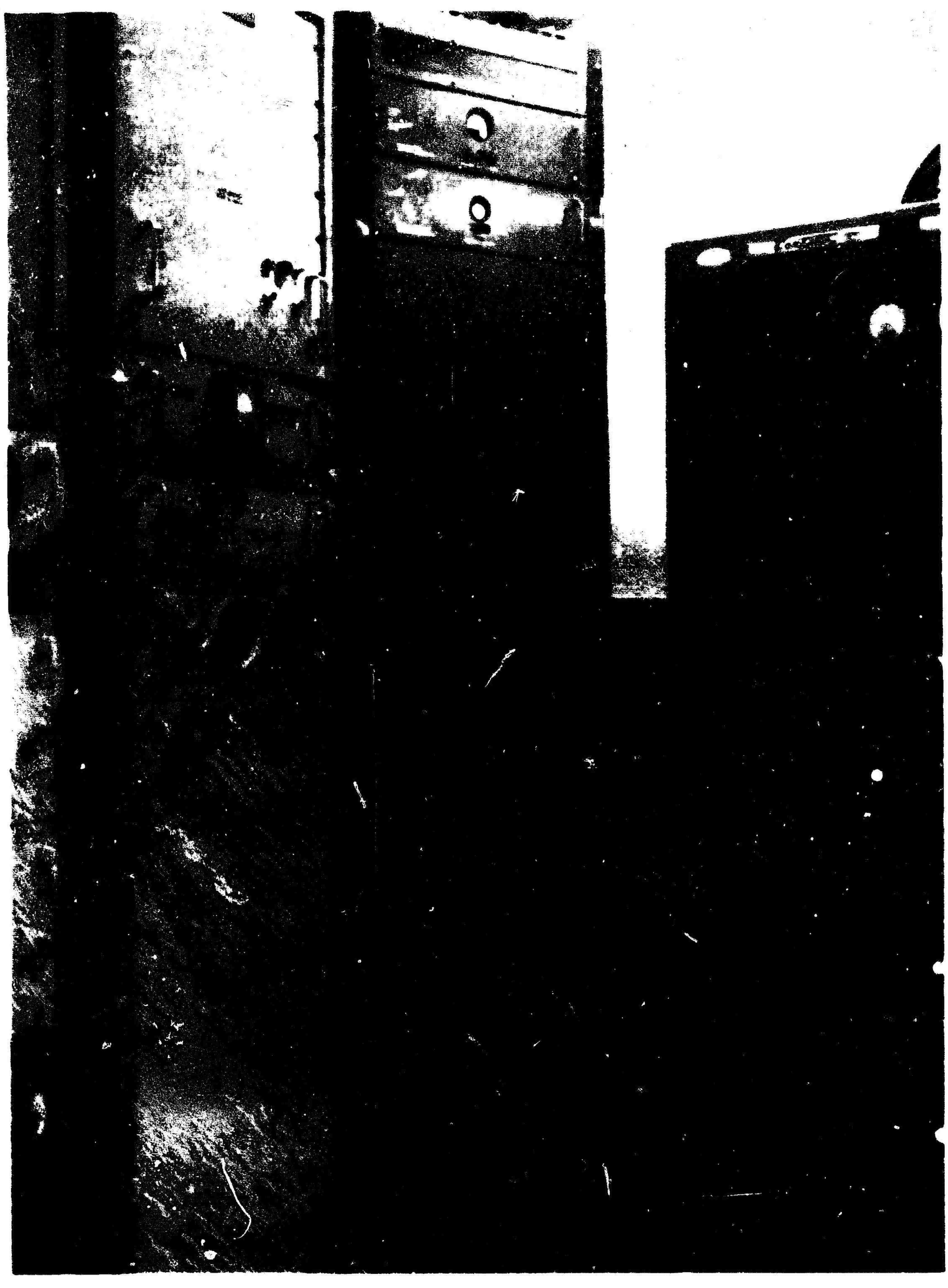

Figure K-17 View of Atomichron and Ultra-Stable Oscillator - Carter Cay, GBI

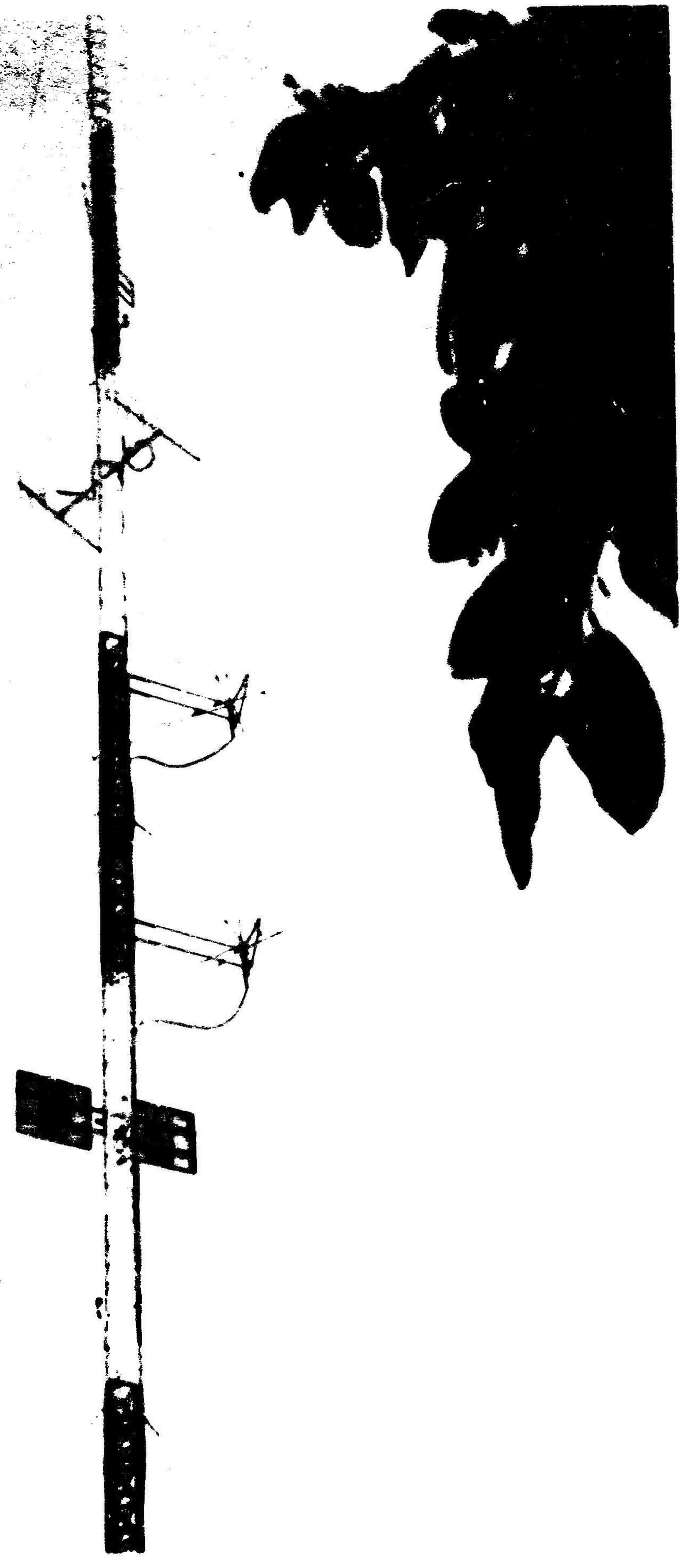

Figure K-18

View of Tower showing from Bottom Upwards; AN/TRC-24 Antennas, Two 50 MC Reference Receiving Antennas, Two UHF Data Link Antennas, and a 900 MC Receiving Test Antenna

Figure K-19 Close View of 900 MC Turnstile Transmitting Antenna - Carter Cay, GBI

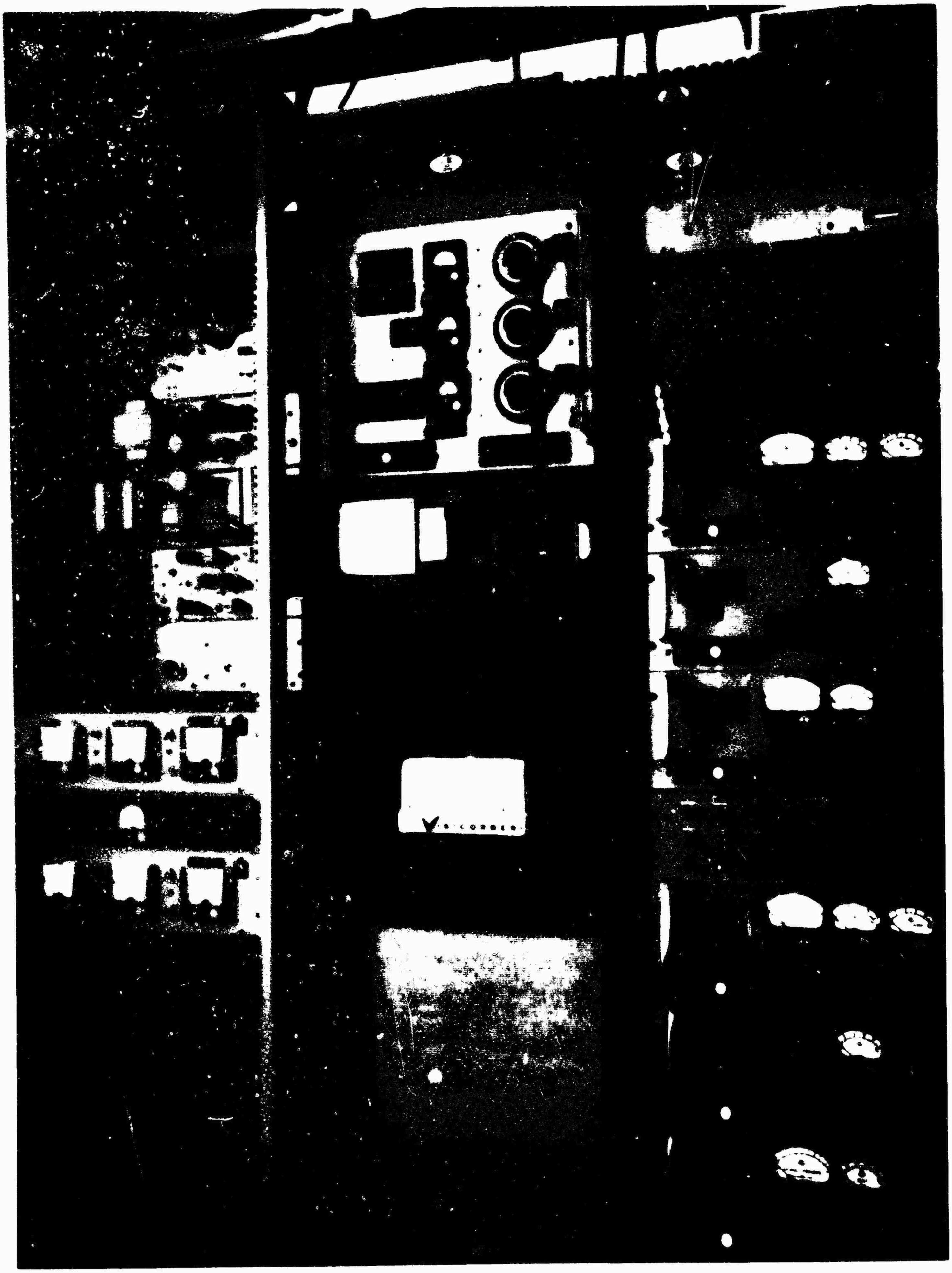

Figure K-20 View of UDOP Standard Receivers and Data Link Transmitters - Carter Cay, GBI

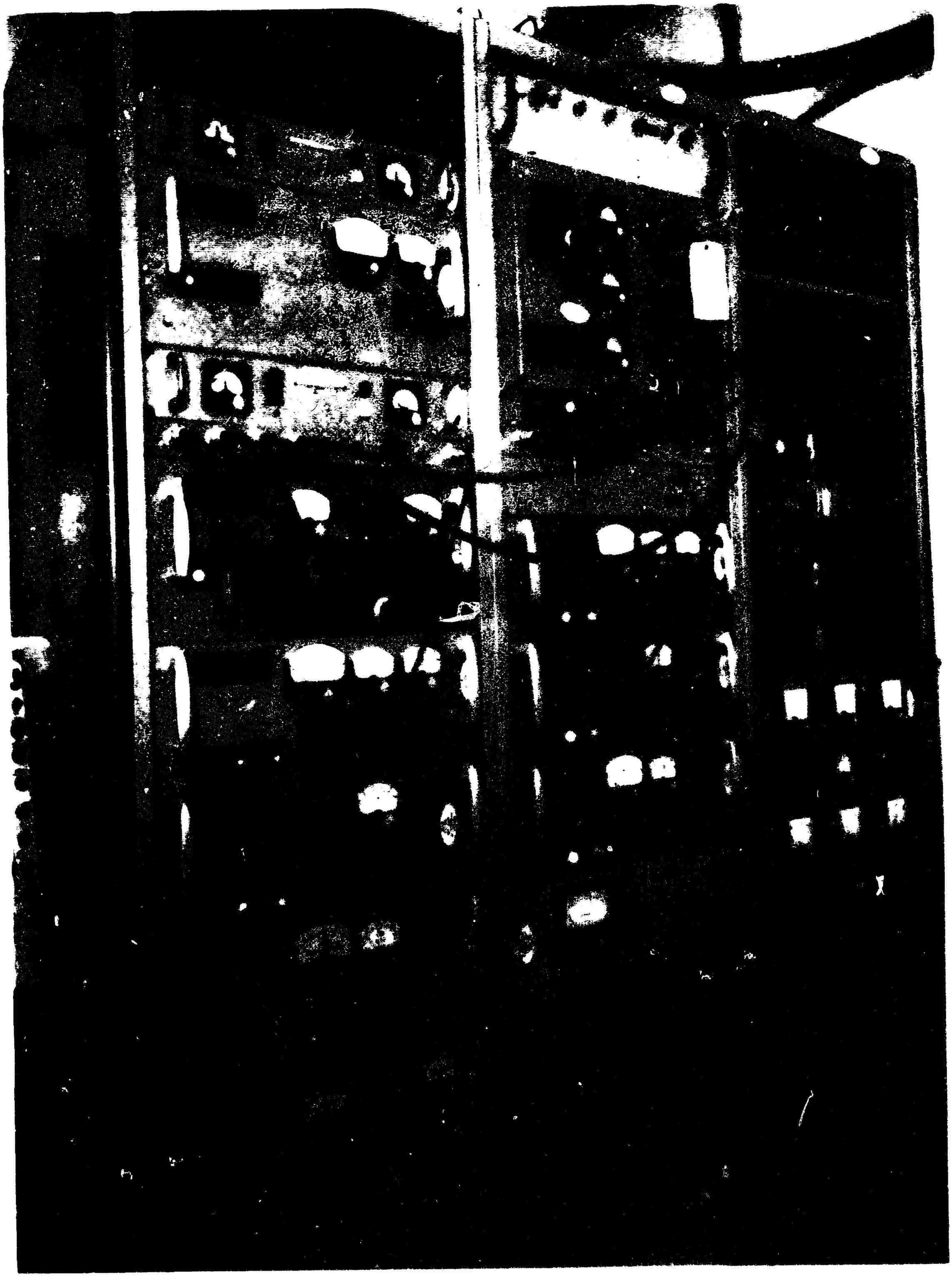

Figure K-21 View of Phase-Lock Receiver, Standard Receiver and Data Link Transmitter - Walker Cay, GBI

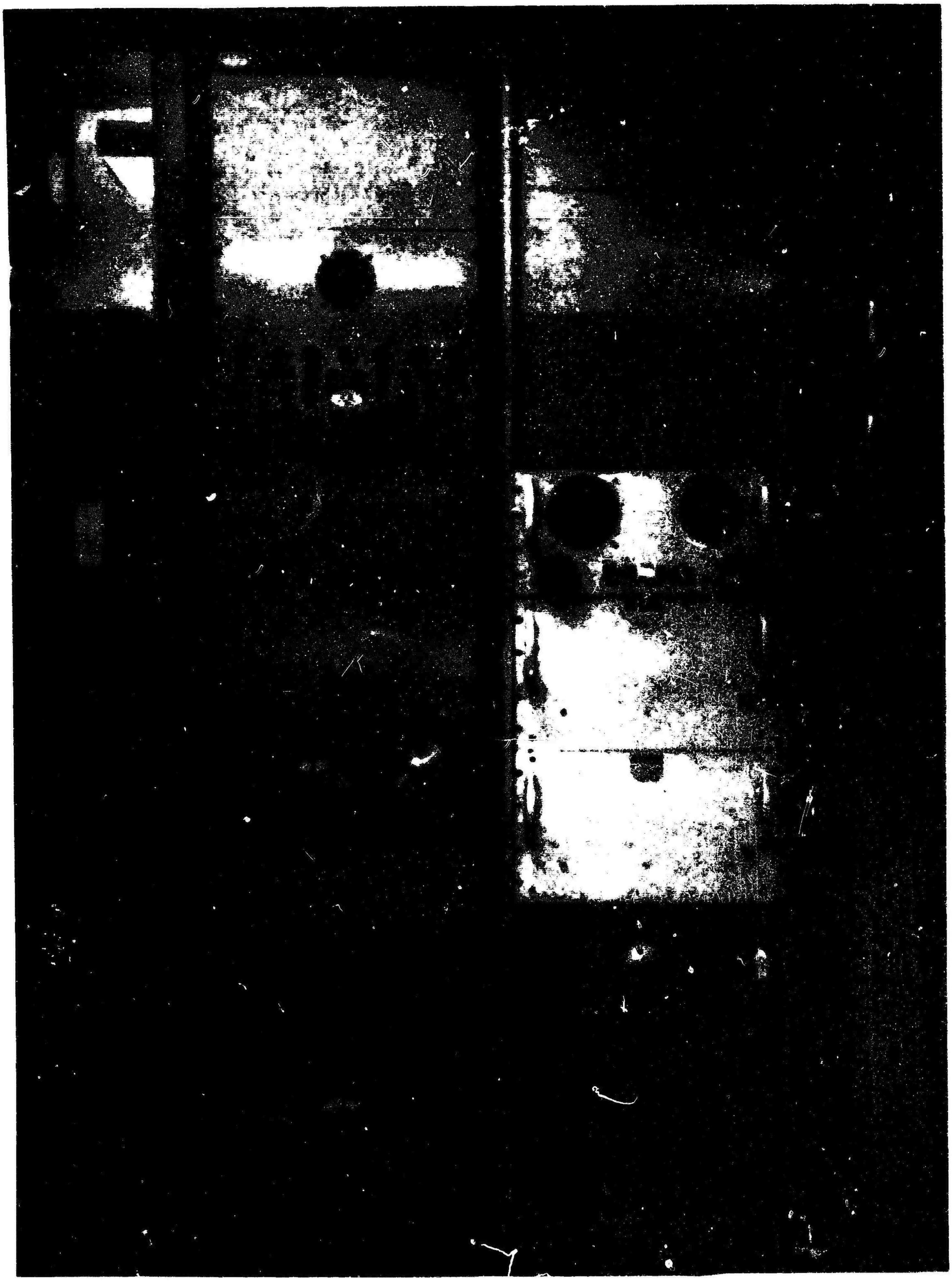

Figure K-22 View of Steerable Quad-Helix Antenna Pointing Equipment - Carter Cay, GBI

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13 ABSTRACT

This document contains a complete description of the UDOP (Ultra-High Frequency Doppler) System used on the Atlantic Missile Range. All phases of the effort involved when UDOP is called up to support a mission are included herein. This document explains the theory, equipment solutions, and mathematical techniques involved. This document is written to satisfy the questions of any technically minded person who is interested in UDOP. If this document does not suffice, further inquiry concerning the system may be satisfied by the documentary lists included.

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