14. NIMBUS COMMAND SUBSYSTEM

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INTRODUCTION

All satellites have one common requirement, known as the command facility. This is usually a real-time direct RF link from a ground transmitter through the satellite receiver and decoder to a relay or controlled circuit. The more sophisticated research and operational satellites require a command facility which will permit storing of commands to activate systems at predetermined future times when the satellite is beyond the range of the command ground station. These satellites require an accurate clock and a source of precision frequencies.

In the Nimbus spacecraft, all these functions are performed by an integrated command and clock subsystem, which includes the command-clock and clock-receiver modules in the spacecraft, plus the associated command ground station. This paper will describe the functions and features of these various equipments.

SPACECRAFT PORTIONS OF COMMAND SYSTEM

COMMAND-CLOCK SUBSYSTEM

The Nimbus command clock, developed and fabricated by California Computer Products, Inc. (CALCOMP), functions in the spacecraft as the final stage in the command link. It also provides precision frequency outputs and serves as the satellite clock. To maintain a minimum component usage, mutual dependence of logic circuitry is maximized in the command clock to provide these independent functions.

Figure 1 is an exploded view of the command-clock module, a 4/4 Nimbus module weighing 18 pounds and dissipating a maximum of 7 watts. The package is a magnesium casting into which are mounted conventional etched circuit boards, a chopper power-supply submodule, a precision oscillator submodule, and the two magnetostrictive delay lines used for the recirculating store-memory functions.

Figure 2 is a diagram of the command clock, a digital subsystem using precision synchronous-logic techniques. The logic mechanization is accomplished by germanium transistor flip-flops and silicon diode gates together with germanium transistor logic drivers and inverters. In this phase of the project, the CALCOMP designers drew on their previous experience in the Minuteman project. This mechanization is typical of much of the circuitry in both the command clock and the ground station.

The input and output interfaces of the command clock are handled primarily with germanium and silicon transistor switching amplifiers. Wherever possible, the -24.5 vdc spacecraft regulated-bus voltage is used directly; however, to conserve power, lower dc voltages are provided by the chopper power supply.

The command clock has two major functions: timing and command. The timing section provides the precision frequencies and the spacecraft clock. The precision frequencies are mutually coherent square-wave outputs which are free-running, and in no way connected with the ground control.

In the timing section, shown in Figure 3, signal frequencies above 100 cps are generated by flip-flop counting chains which count down from the precision oscillator. The precision oscillator is a conventional quartz-crystal type with proportional oven control. Long-term oscillator stability of better than one part per million is expected.

Signal frequencies below 100 cps are generated by using the T-loop (Time Loop) delay line to count pulses and report overflows. The T-loop with its associated logic circuitry also provides the command-input buffer register, plus time storage and time-code generation. The time used to initiate commands is stored in a portion of the T-loop, and is constantly updated with an accuracy determined by the precision of the oscillator.

The command section reciprocates by supplying the timing section with the capability to reset the time to within 0.5 second of ground time upon orders from the ground station. The time is stored in the T-loop in standard time nomenclature, from 1 second to 999 days, and is made available in a special coded form to the command-clock interface. For these interface outputs, the code is transformed to a pulsewidthmodulated format at 100 pps. It appears as a direct output, or on carriers of 10 and 50 kc modulated 50 percent with the code.

A second major function of the command clock is the command facility, Figure 4. Command signals are transmitted to the command clock on three separate input lines which transmit simultaneously to provide command data as well as bit and parity synchronization.

A command message contains the command number, time of execution up to 24 hours after transmission, and memory location for storage, plus flag and identity codes. For example, a command message might be as follows: "Execute command number 120 at 18 hours 32 minutes and 16 seconds ground time, and store in memory location two." Thus, when orbital parameters are accurately known, a satellite system can be activated at any desired point in the orbit.

As shown in Figure 4, the three command signals pass into an input amplifier and sequencer section which inserts the data into the input buffer register, which is a portion of the T-loop. While being inserted into the register, the data is checked for proper format and parity. If at any time an illegal code is received, or parity does not check, the register is dumped and the entire message must be repeated. Command messages are transmitted at a rate of two per second, and each message is transmitted twice, in sequence, to assure reception. At the conclusion of each satisfactory command message, the information is inserted into the memory location in accordance with the address given in the message. A maximum of five commands can be stored in the memory, or M-loop, delay line.

When the satellite-clock time carried in the T-loop agrees with the instruction time, the associated command is executed. Execution may involve up to 128 individual command operations in the satellite. The command clock communicates these instructions to the other satellite subsystems through an 8 by 16 matrix. The matrix drivers have sufficient capacity to drive conventional latching relays. Satellite functions such as AVCS, record, playback, direct picture, camera selection, and iris opening may be controlled through the coded command system. On-off control of experiments, interrogation for stored data, and beacon-transmitter selection are provided. In the telemetry subsystem, the mode of telemetry is chosen through the command link, as is the interrogation for data stored in the PCM tape recorder.

Because of the expected high count of components in the command clock, a special in-house component-reliability program was initiated by CALCOMP at the beginning of the development to select component types; specify production lots; age components; measure parameters, and process parameter data. Silicon components were aged at 100°C and germanium components at 55°C for periods up to 2000 hours. Parameters were measured by electronic test equipment built specifically for this purpose, shown in Figure 5. The test equipment automatically sequences from component to component, measures up to eight parameters, and simultaneously prints out the measurements on IBM punched cards. The resulting data is then processed by digital computers which supply data on parameter shifts as well as parameter distributions.

The command clock incorporates an unusual and very effective thermal design, shown in Figure 6. Semisolid copper planes are permitted to remain on the etched circuit boards after the etching operation; these planes, in close proximity to component leads, serve as effective heat sinks to all components. The copper planes are terminated at the top of each etched board to aluminum straps which, in turn, are terminated directly to the casting. Using this design, the temperature difference between the hottest transistor junction and the coldest mounting bracket of the casting is less than 13°C.

The command-clock flip-flop, Figure 7, is a good example of the circuitry developed specifically for this job. The flip-flop uses six microenergy germanium transistors and dissipates 15 milliwatts. The input buffers save additional gate power, and the output buffers eliminate false triggering due to noise. In all, the command clock uses only 42 flip-flops, at a maximum speed of 800 kc, to perform all of the functions described previously.

COMMAND-CLOCK RECEIVER

Command messages in coded form come to the command clock from the ground by way of the clock receiver. These coded signals are transmitted to the satellite by FM/AM transmissions in which three frequency-shift-keyed subcarriers are multiplexed to amplitude-modulate a radio-frequency carrier. The clock receiver amplifies, demodulates, and processes these signals for subsequent input to the command-clock subsystem.

The clock receiver, shown in Figure 8 with dust covers removed, was developed and fabricated by the Astro-Electronics Division of the Radio Corporation of America. The receiver, contained in a module, weighs approximately 5.6 pounds and consumes less than 1 watt of power. This module also contains the redundant, ultrasensitive, highly selective AM receivers, the two redundant FM-subcarrier demodulators, and the AM tone demodulator.

Figure 9 is a block diagram of the RCA clock receiver. When encoded commands are being transmitted to the command clock, the three FM subcarriers are used; the subcarriers are demultiplexed with filters and are amplified, limited, and fed to the discriminators. The discriminator outputs are coupled to Schmitt triggers which square up the binary signals.

The audio outputs of the parallel, continuously operating receivers are also resistively added and fed to the AM subcarrier-demodulator section, where four single-tone emergency backup commands are produced. The normal command receiver and FM subcarrier-demodulator are used unless failure occurs. Should either the normal receiver or FM demodulator fail, redundant equipment contained in the module can be made operative by switching on the power with one of the single-tone commands. The FM demodulator outputs are "or" gated into the code output lines. Power for the auxiliary receiver and AM demodulator is supplied by special auxiliary regulators, so that these portions will operate even if the main regulators should fail. The other single-tone commands provide emergency telemetry readout, activation of backup power-supply feedback amplifier, and turn-off of the S-band transmitter. Satisfactory commands can be received with less than a 3-microvolt RF signal at the clock receiver RF input terminal.

Reliability was the principal design criterion for the clock receiver. This receiver, which provides the command link with the satellite, must operate at all times if the satellite is to fulfill its mission. To obtain the necessary reliability, the clock-receiver design specified maximum use of extremely high-reliability components, and selection of components on the basis of proven performance. As an example, the AM receivers are similar to those used on TIROS. Redundant receivers and demodulators were included when studies indicated that they were required to achieve the desired reliability goal. Subsystem simplicity was emphasized throughout to obtain inherent reliability, and all components were baked and checked carefully.

All prototype and flight models of the clock receivers and the command-clock subsystems have been subjected to, and have successfully survived, the severe environmental testing specified for all Nimbus spacecraft equipment. Bench checkout equipment, specifically designed for the purpose, is provided for both the command-clock and clock-receiver subsystems. This equipment contains all items necessary to rapidly determine the operating condition of the spacecraft subsystems. Test procedures have been developed to assure consistency of test methods.

EARTH-BASED COMMAND GROUND STATION

The command-clock ground station, Figure 10, was designed and fabricated by California Computer Products, Inc., concurrently with the development of the spacecraft command-clock subsystem.

Reading from the left in the figure, the command ground station contains a tape-preparation and readout bay, a control console, a modulator-verification bay, a clock-computer bay, and a transmitter bay.

Normally, the encoded command programs are prepared and stored on punched paper tape. If desired, operation of the ground station can begin automatically when the satellite comes into view of the command antenna; however, commands can also be generated immediately by the operator at the control console. The encoded command messages are transformed into frequency-shift-keyed signals on the three FM subcarriers in the modulator bay, for transmission to the satellite by means of the command transmitter. The four single-tone commands are also generated in this ground station.

In addition to the above capabilities, the command ground station can independently verify the transmitted messages and provide a permanent record of all transmissions. It also accepts the satellite time code from the beacon, compares the satellite time to ground time, and prints out the difference as a permanent record. Simultaneously, the ground-station clock is synchronized with the satellite clock so that present-time commands can be easily generated. The ground station facilitates the present-time command operation by automatically inserting satellite or ground time plus 3 seconds into the command message, when so directed. This results in the execution of the command 3 seconds after transmission to the satellite. (All commands are future commands;

present-time commands are just in the very near future.) Accurate time is maintained at all command sites by time-code generators, designed and fabricated by NASA, and by associated WWV receiving equipment.

PRESENT STATUS OF NIMBUS COMMAND SUBSYSTEM

The entire command system has been in a "go" status since early in 1962.

CALCOMP delivered the first qualified prototype command-clock subsystem and bench test equipment in late December of 1961. Another qualified prototype, and five qualified flight-model, command-clock subsystems followed in rapid succession thereafter.

In addition, CALCOMP has delivered three command ground stations: one for the launch van in February 1962, one for integration in April 1962, and the Alaska CDA station in May 1962.

RCA delivered the first qualified prototype clock receiver and bench test equipment in March, 1962, followed in rapid succession by a second qualified prototype, and two qualified flight-model, clock receivers.

Complete operation and maintenance documentation has been delivered for all of this equipment.

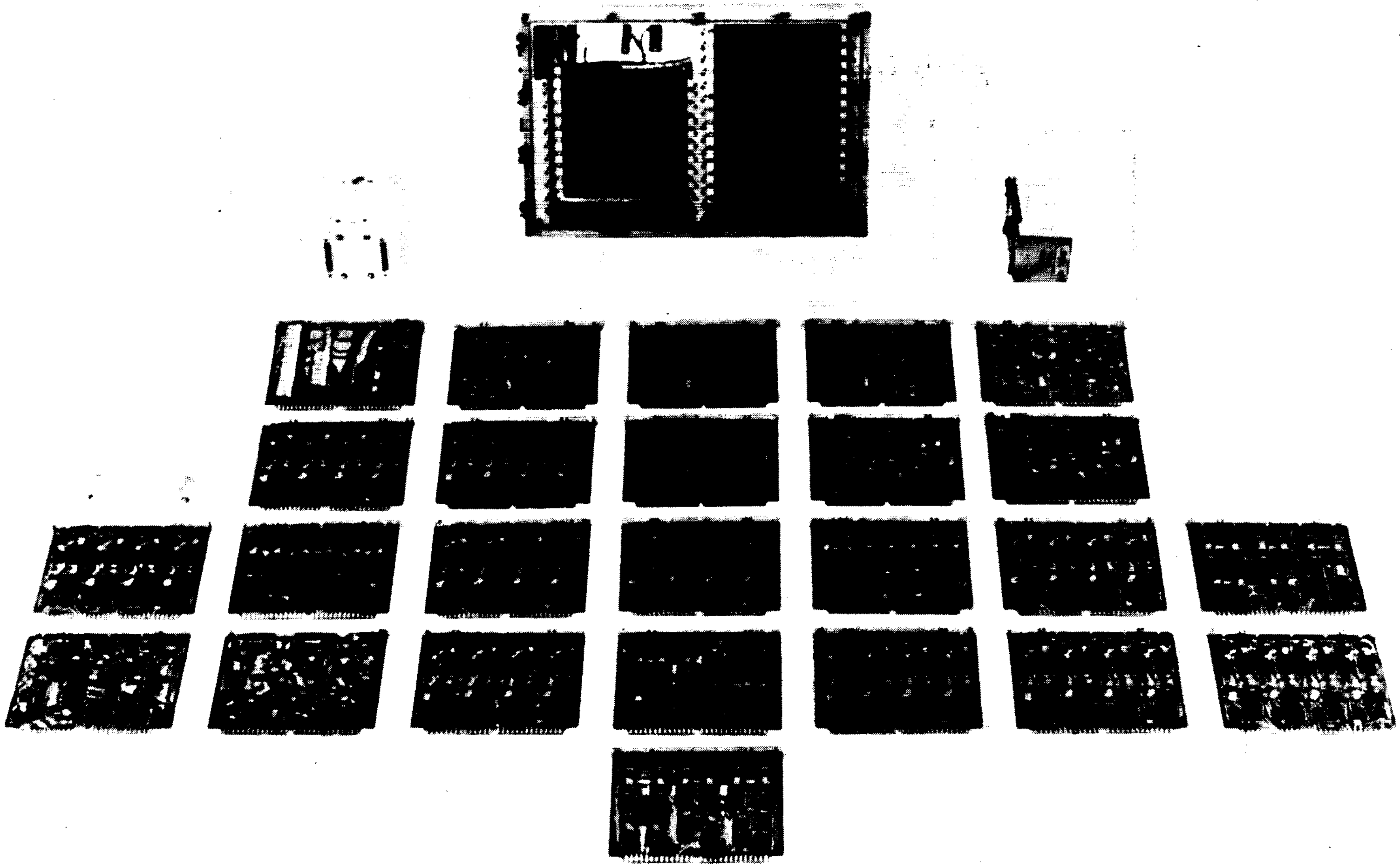

Figure 1 - Exploded View of Command Clock

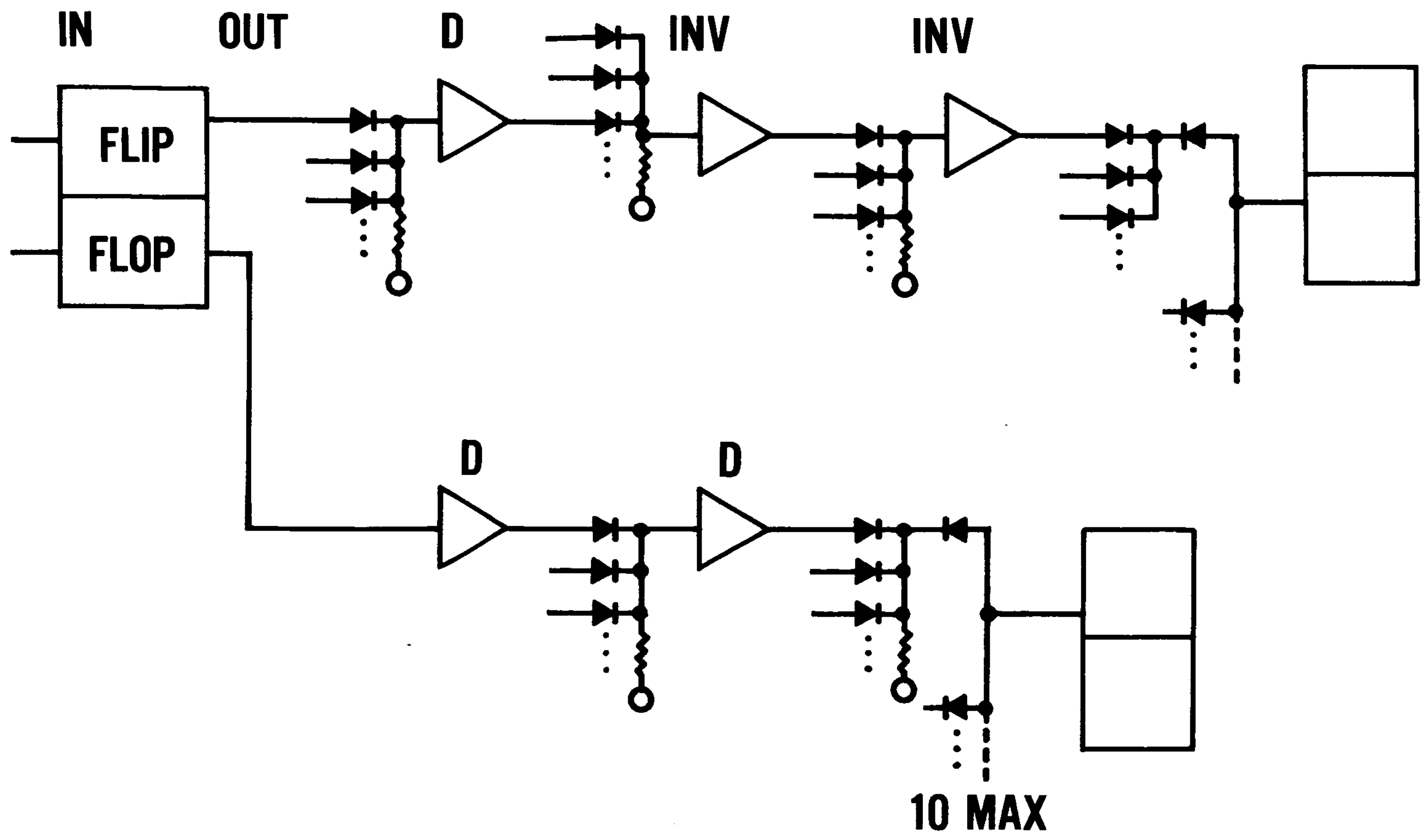

Figure 2 - Typical Logic Mechanization

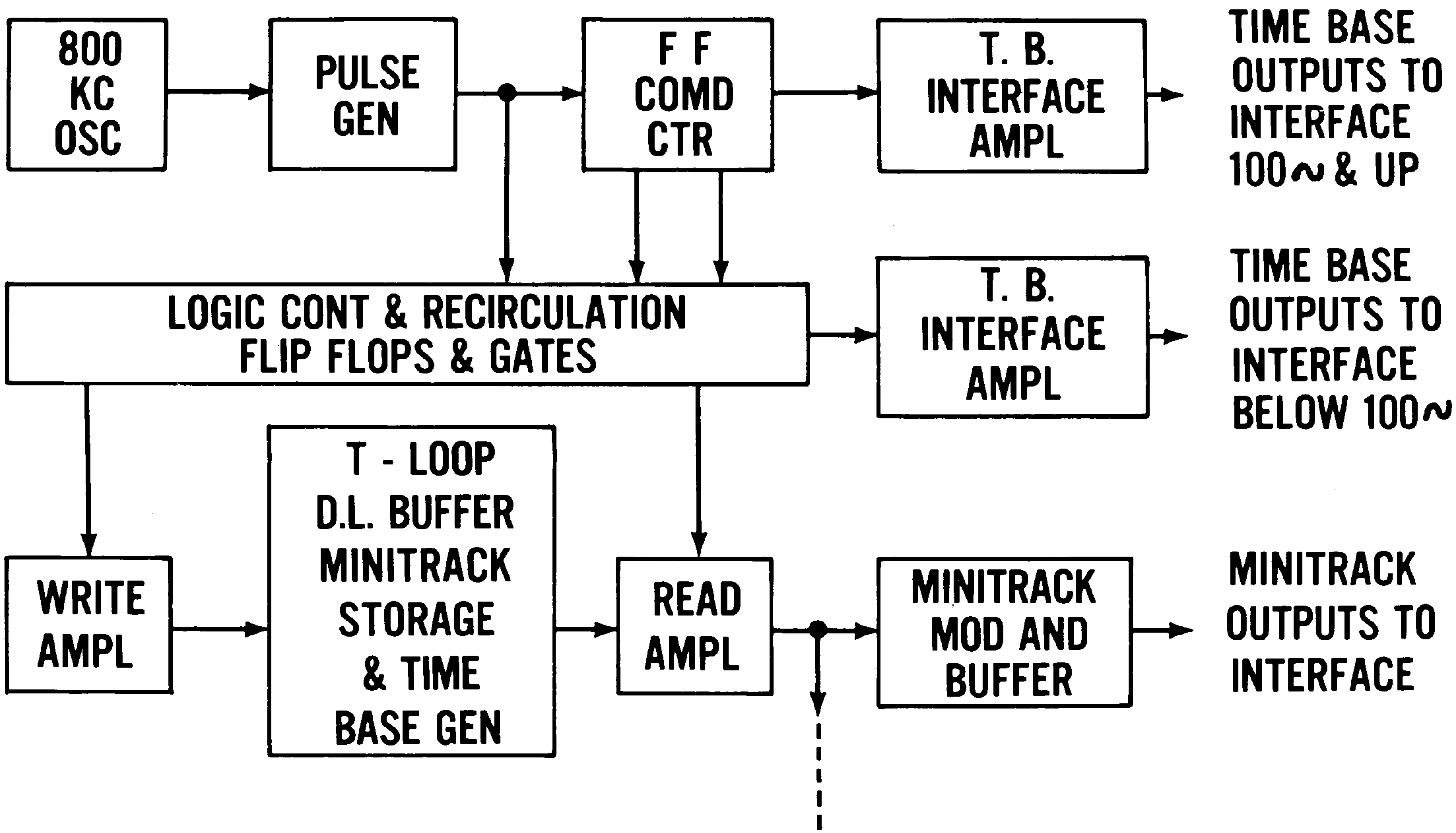

Figure 3 - Timing Section, Block Diagram

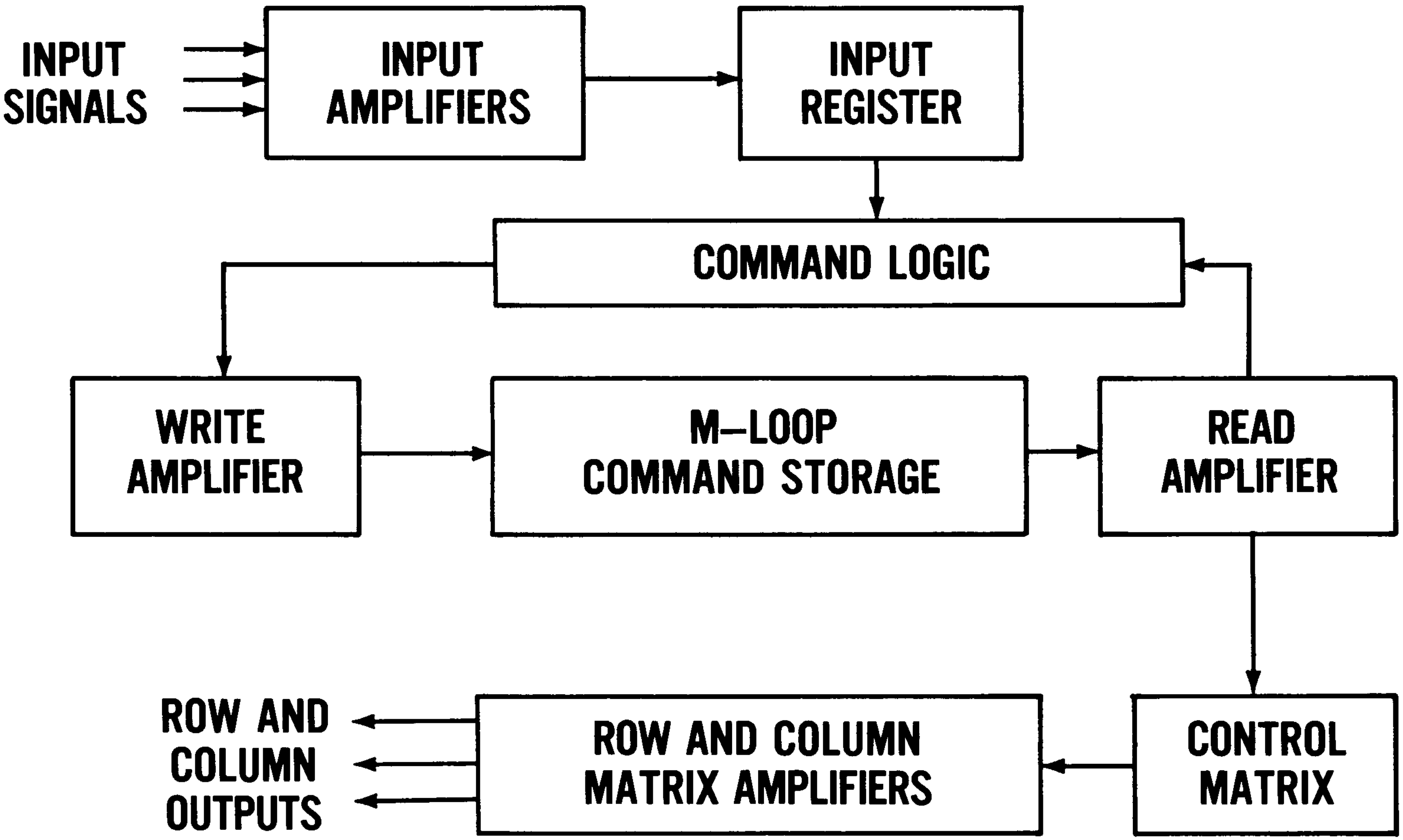

Figure 4 - Command Section, Block Diagram

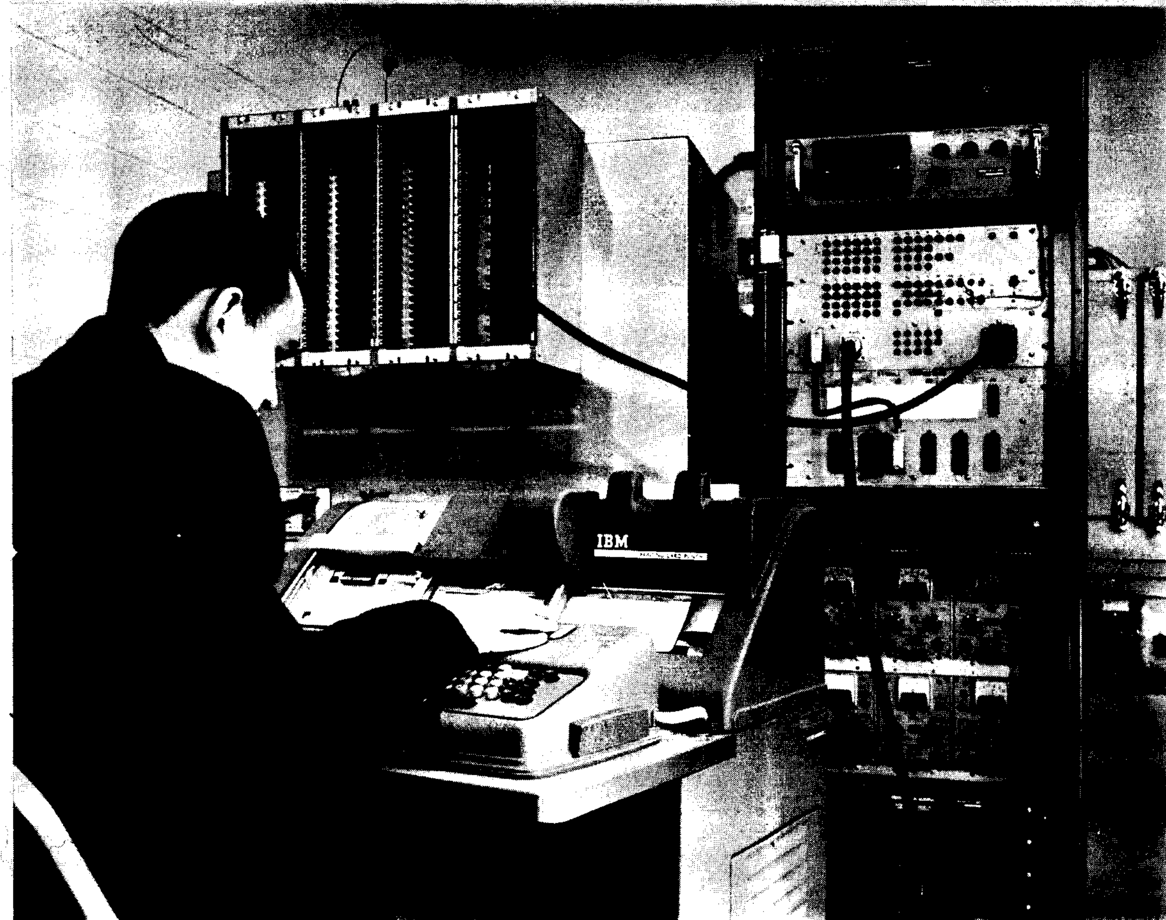

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Figure 5 - Reliability Program Equipment

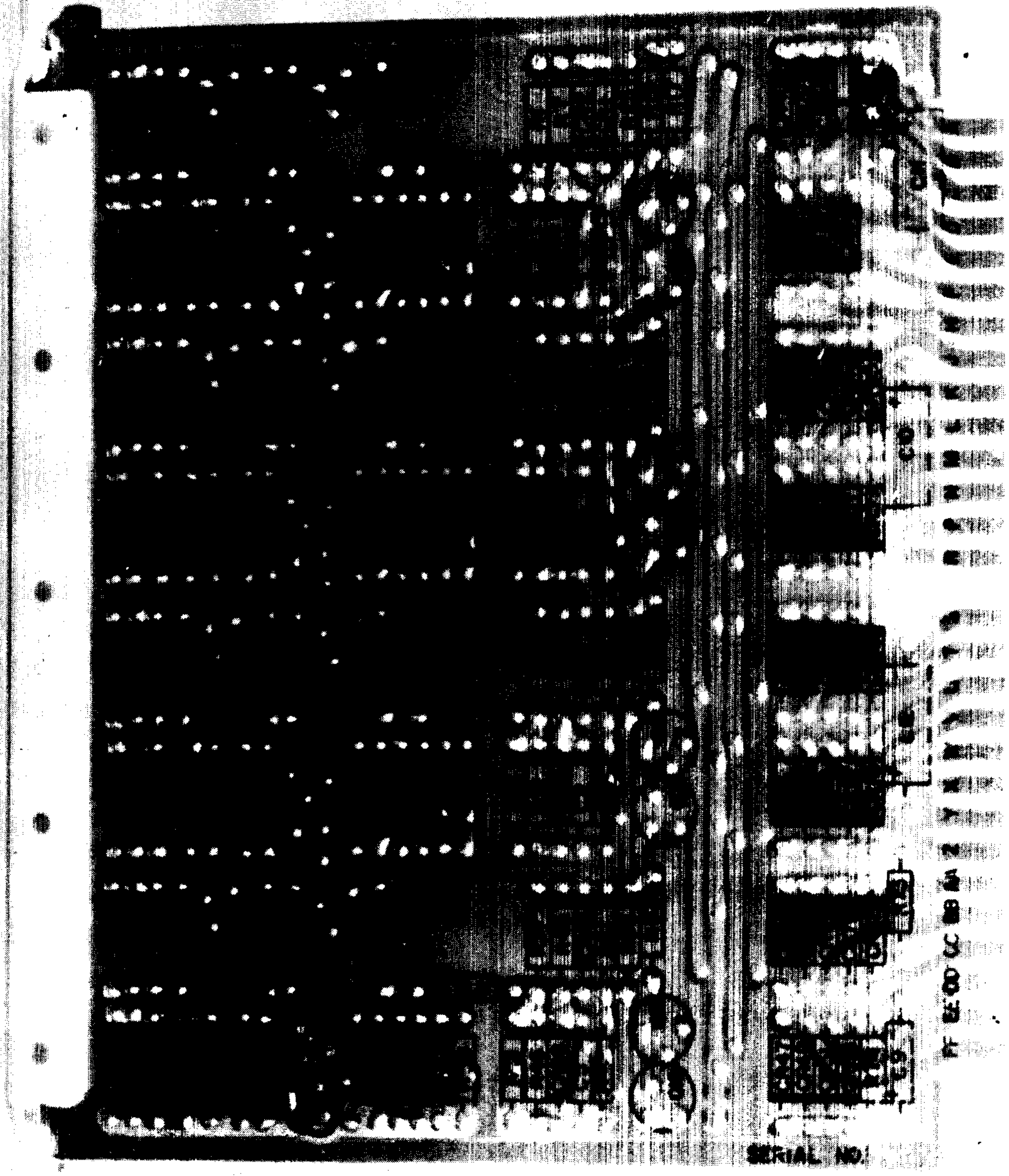

Figure 6 - Rear View, Etched Board

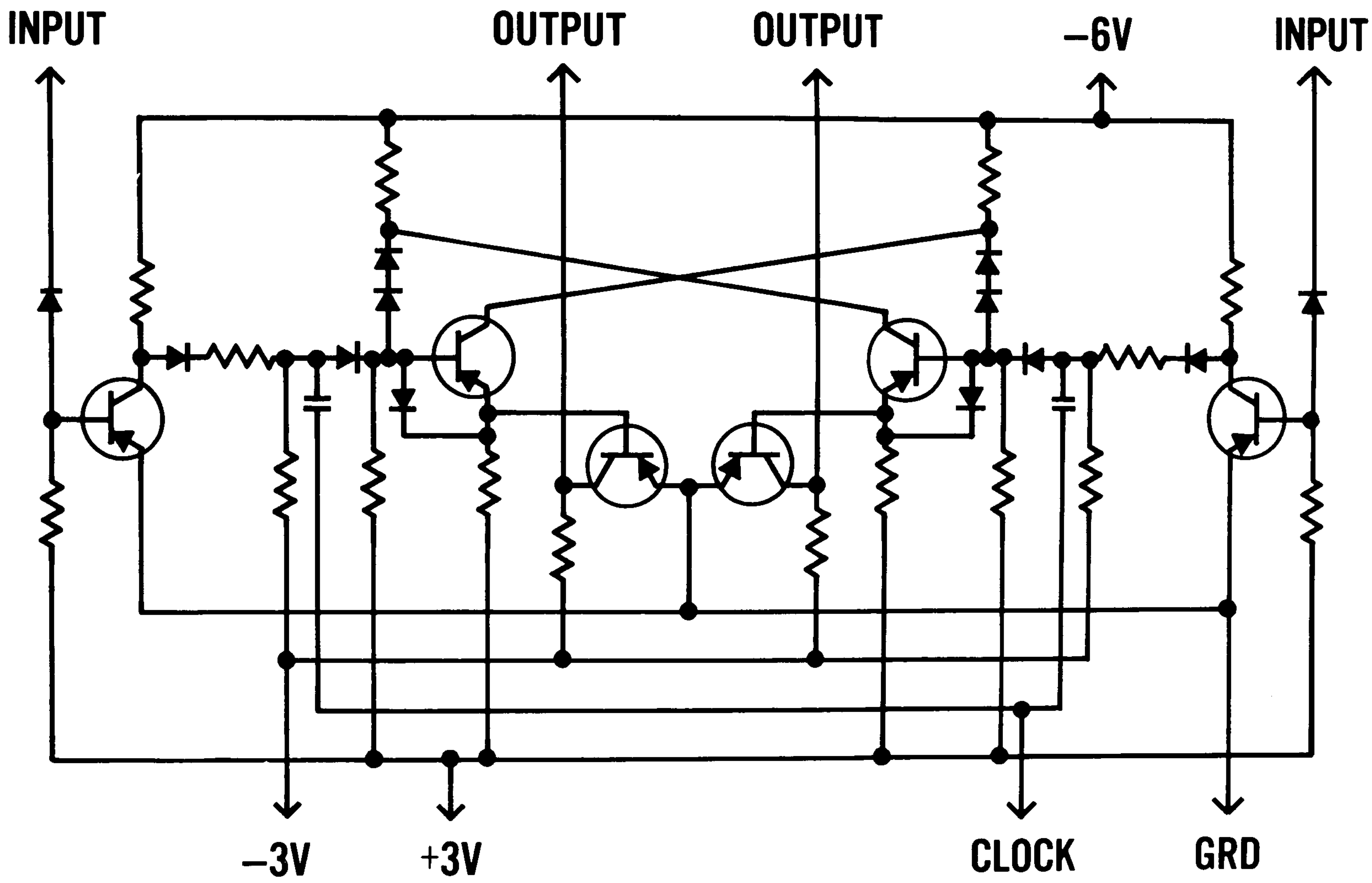

Figure 7 - Command Clock, Flip-Flop Circuit

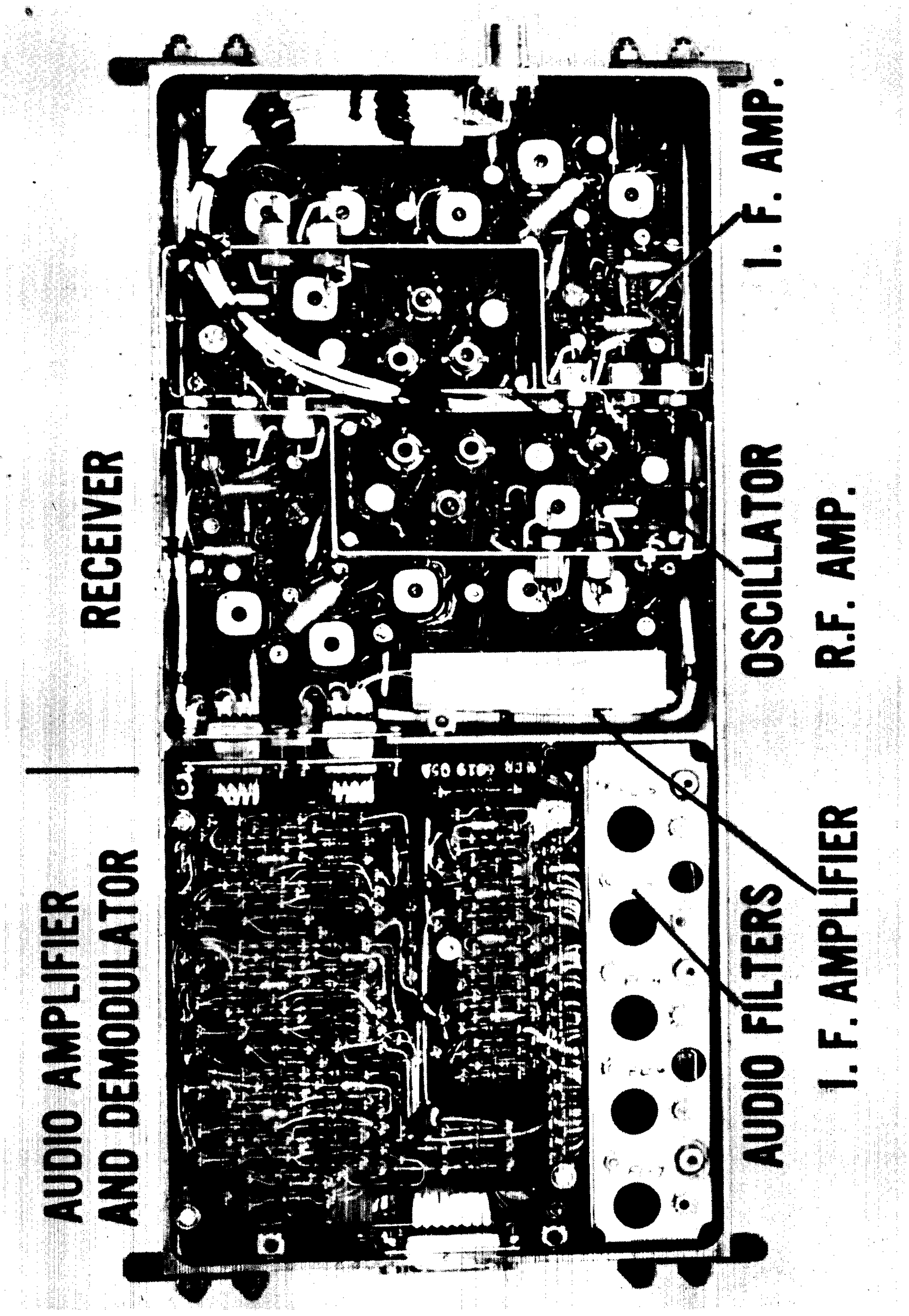

Figure 8 - Clock Receiver Module

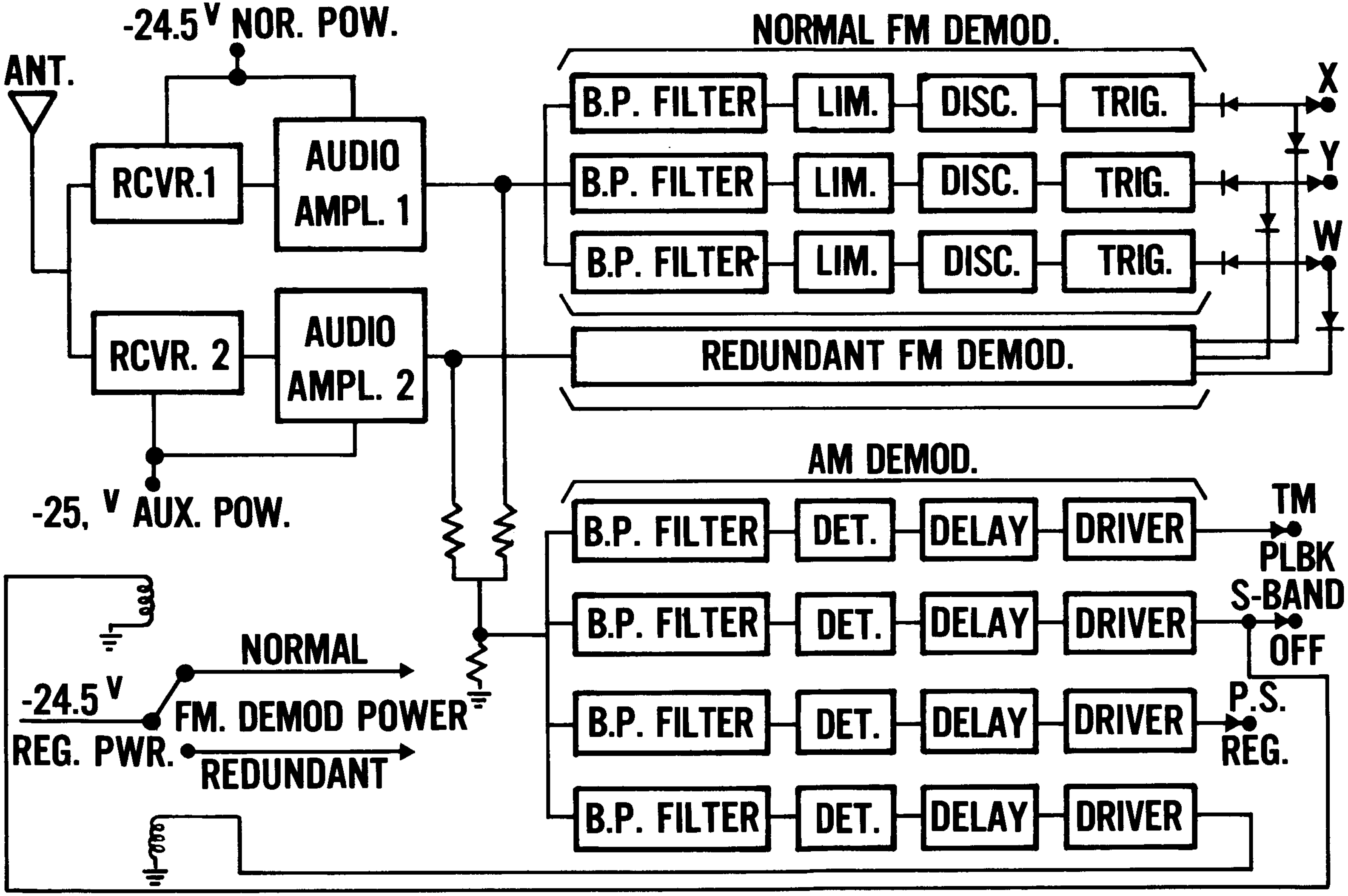

Figure 9 - Nimbus Clock Receiver, Functional Block Diagram

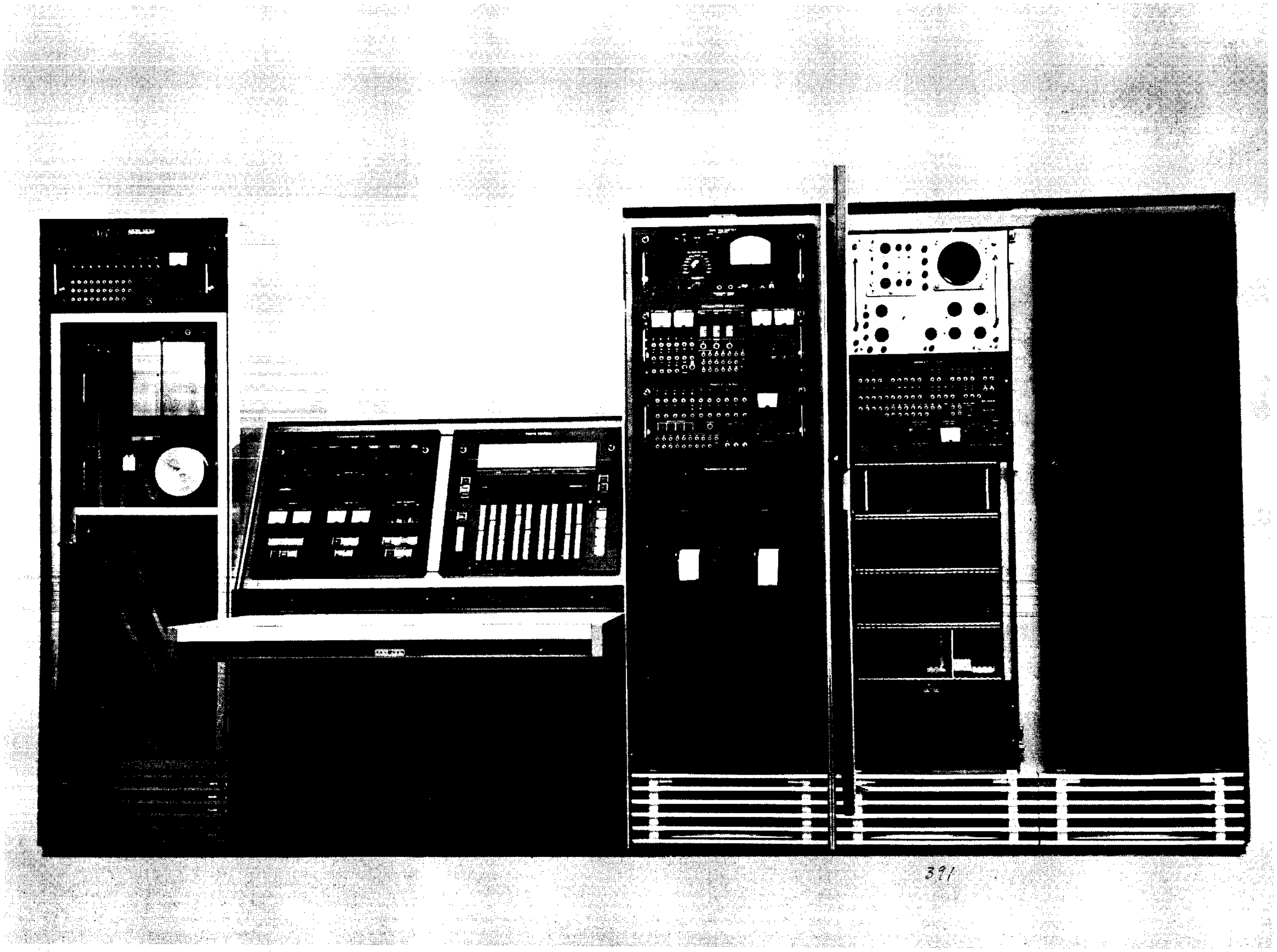

Figure 10 - Command Clock, Ground Station Equipment