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DEVELOPMENT AND PERFORMANCE OF POWER PROCESSOR SYSTEM FOR 12-GIGAHERTZ, 200-WATT AMPLIFIER FOR COMMUNICATIONS TECHNOLOGY SATELLITE

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16. Abstract

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SUMMARY

This report describes the electrical and environmental requirements for a power processor system (PPS) designed to supply the appropriate voltages and currents to a 200-watt traveling wave tube (TWT) for a communication technology satellite. A block diagram of the PPS, the interface requirements between the PPS and spacecraft, the interface requirements between the PPS and 200-watt TWT, and the environmental requirements of the PPS are presented. Also included are discussions of protection circuits, interlocking sequences, and transient requirements. Predictions of the flight performance, based on ground test data, are provided.

INTRODUCTION

The Communications Technology Satellite (CTS), jointly developed by NASA and the Canadian Department of Communications, was launched into a geostationary orbit early in 1976. The launch vehicle, a three-stage Delta model 2914, placed the satellite on station on the equator at 116° west longitude at an altitude of about 40 700 kilometers (22 000 miles). From this position, just west of South America, CTS will broadcast in a newly allocated satellite frequency band (12 GHz) to most of Canada and parts of the United States, including Alaska and Hawaii. With the use of new technology, the CTS transmitting power level will be up to 20 times greater than that of currently operating satellites and will permit television reception and two-way voice communication with relatively inexpensive ground equipment in the areas served. The satellite will be used, in addition to demonstrating new technology, to conduct a number of communication experiments concerned with satisfying national needs by users representing many segments of society. The communication experiments include innovations related to education, medicine, business, emergency services, and radio and television propagation.

The high power transmitter experiment package for this spacecraft consisted of a traveling wave tube (TWT), multistage depressed collector (MDC), a power processor system (PPS), and a variable conductance heat pipe system (VCHPS). This report presents design, development, and ground testing performance of the PPS.

POWER PROCESSOR SYSTEM DESCRIPTION

The PPS was designed to convert and condition the power from 76- and 27.5-volt spacecraft sources into the voltages and currents necessary to operate the 200-watt amplifier. The PPS is required to supply a negative 11.2-kilovolt cathode potential, nine collector voltages proportional to cathode potential, a positive 250-volt anode potential, and a 5-watt cathode heater supply floating at the cathode potential, vacuum ion supply for two ion pumps, 37 measurements for telemetry, interface circuits for 20 commands, system protection, and thermal control heaters.

Figure 1 is a photograph of a transmitter experiment package (TEP). The structure in the foreground is the TWT and MDC; the rectangular structure in the background is the exterior of the PPS. The dimensions of the PPS are 52 centimeters long, 24.1 centimeters wide, and 1.78 centimeters high. The weight of the PPS is 1.13 kilograms. The high voltage cables which interconnect the PPS, TWT, and MDC are the white leads shown extending from the upper right corner of the PPS.

The PPS was constructed with two major compartments as shown in figure 2. The high voltage compartment is shown on the left, and the low voltage compartment is on the right. There are six component boards in the high voltage compartment. The following table lists the boards from left to right:

Board	Function
1	Anode supply (247 V) and ion pump supply (3.3 kV)
2	Collectors 2 (-2.24 kV) and 3 (-3.36 kV)
3	Collectors 4 (-4.48 kV) and 5 (-5.60 kV)
4	Collectors 6 (-6.72 kV) and 7 (-7.84 kV)
5	Collectors 8 (-8.96 kV) and 9 (-10.08 kV)
6	Collector 10 and cathode supply (-11.2 kV) and cathode heater (1.293 A, floating at -11.2 kV)

The box mounted to the partition separating the two compartments contains the attenuator components. The attenuator is an active filter which is designed into the circuit to meet the stringent ripple requirement of the cathode supply and to minimize the amount of stored energy.

The low voltage compartment contains eight component boards. The following table lists the boards from left to right:

Board	Main function
1	Primary low voltage side of cathode heater
2	Primary low voltage side of high voltage parallel inverter
3	Constant current chopper regulator
4	Instrumentation and temperature supplies
5	Internal and preregulator supplies
6	PPS protection circuits
7	Command interface circuits
8	Filters for 76- and 27.5-volt input power

Figure 3 presents a block diagram of the PPS. The spacecraft provides 76- and 27.5-volt power as shown in the upper left corner of the figure. The source for the 76 volts is obtained directly from the spacecraft solar array. The thermal control heaters and the cathode/collector supplies are powered from the 76-volt source. The thermal control heaters are resistive elements which provide a heat source to balance spacecraft temperatures when the PPS is not operating. The cathode/collector supply provides power to nine collector elements and the cathode element.

The 27.5-volt power for the PPS is obtained from a spacecraft converter. The spacecraft converter obtains its power from a solar array or battery system. As shown in the block diagram the cathode heater supply is powered directly from the 27.5-volt source. The anode supply, internal supply, instrumentation supply, and special instrumentation supply are powered from the PPS preregulator.

The special instrumentation supply conditions the power for 12 temperature measurements. The instrumentation supply conditions 6 voltages, 15 currents, 2 radiofrequency power measurements, and a multilevel fault indicator for telemetry. The internal supply conditions power for an ion pump supply, anode supply, and the control logic for the cathode/collector supply.

INTERFACE REQUIREMENTS BETWEEN SPACECRAFT AND POWER PROCESSOR SYSTEM

Electrical Requirements

Table I lists the interface requirements between the spacecraft and PPS. The column on the left specifies the requirement while the column on the right shows the performance characteristics of the flight PPS. The spacecraft thermal system requires that thermal control heaters be turned on whenever the PPS electronics are turned off. This is accomplished with externally mounted strip heaters to the PPS that are interconnected with the PPS logic such that the turnoff of the high voltages will turn on the heaters. (More detailed information is given in the INTERFACE REQUIREMENTS BETWEEN OUTPUT STAGE TUBES AND POWER PROCESSOR SYSTEM section.) To meet the fault clearing requirements, the substitute heaters are fused and the remaining electronic components of the PPS are disconnected by a commandable relay. The PPS relay is also protected by a switching sequence and a PPS interlock, both of which are discussed in detail in the INTERFACE REQUIREMENTS BETWEEN OUTPUT STAGE TUBES AND POWER PROCESSOR SYSTEM section.

During the 2-year mission, the predicted operating voltage range for the 76-volt solar array is from 65 to 87 volts. This voltage, however, can be as high as 91 volts when the spacecraft exits from an eclipse. The voltage variation of the 27.5-volt source is not as severe as the 76-volt source.

Table I shows the power requirements and performance of the PPS; it also shows that the PPS was tested at voltages which exceed the predicted operating levels. There are two power constraints for the 27.5-volt source. They are 1.2 watts or less for special instrumentation and 5.0 watts or less for cathode heater 50-percent-power mode because they are operated from a battery during eclipse. The only power constraint for the 76-volt source is 582 watts maximum during full radiofrequency output operation of the TWT. As indicated in the table, all power requirements were met with the exception of the cathode heater 50 percent power. But since sufficient battery power is available during eclipses, the increased power requirement for the cathode heater is acceptable. This table also includes the voltage range and output impedance for the PPS telemetry circuits, the voltage and current capability of a command pulse, the pulse duration, and the maximum continuous voltage that the spacecraft command could impose on the PPS command interface circuits.

Table II is a list of the telemetry channels conditioned by the PPS. The first column identifies the nomenclature for the telemetry channel and the second shows the range in engineering units for the 0- to 5-volt telemetry signal.

Table III lists the 20 commands that are used to operate the PPS. Power from the 27.5-volt source has to be applied to the PPS before any of the 20 commands are operational. Commands 11 through 20 also require that the "PPS enable" command be transmitted before they are operational. Eleven of the twenty commands perform more than one function. These commands are 3, 4, 6, 11, 12, 13, 14, 15, 16, 17, and 20. Since four of the commands (7, 9, 18, and 19) are failsafe commands, an alternate mode can be selected after certain PPS failures have occurred. (More detail is given in the INTERFACE REQUIREMENTS BETWEEN OUTPUT STAGE TUBES AND POWER PROCESSOR SYSTEM section.)

Environmental Requirements

Table IV presents the sine and random vibration environment in three axes. This table shows the qualification level which is 1.5 times the predicted flight levels. The flight and flight backup hardware were exposed to the predicted flight levels during component testing and to greater than flight levels during spacecraft testing. Table V shows the predicted temperature extremes for the PPS and TWT and the temperature levels to which the PPS was tested for qualification and flight acceptance testing.

INTERFACE REQUIREMENTS BETWEEN OUTPUT STAGE TUBES AND POWER PROCESSOR SYSTEM

Power Processor System Power, Regulation, and Ripple Requirements

The TWT requires a cathode voltage of -11.2 kilovolts. The MDC requires nine high voltages ranging from -2.24 to -11.2 kilovolts and a tenth collector element at ground potential. The cathode supply can be adjusted from -11.0 to 11.6 kilovolts to accommodate the variations of individual output stage tubes (OST). The TWT also requires a positive anode voltage. The anode supply circuit was designed for a voltage adjustment range from 150 to 550 volts. The source of electrons for the TWT is obtained from an indirectly heated cathode.

The power required for the cathode heater is 5 watts. The circuit is a current regulated source that is adjustable from 1.2 to 1.4 amperes for the 100 percent power setting. The cathode heater has five commandable positions which are heater off and four set points.

The cathode heater is operated at 100 percent power when the TWT is in the normal operating mode. The 50 percent power level for the cathode heater is used when the spacecraft is in an eclipse or when the TWT is in the standby mode. The 110 and 120 percent power levels for the cathode heater will be used should the electron emitting surface of the filament start to degrade.

The TWT and MDC are enclosed in a vacuum envelope, and the vacuum is maintained with two vacuum ion pumps, each with a pumping speed of about 0.15×10^{-3} cubic meter per second. The PPS was required to supply a 3.3-kilovolt voltage at a load current of 10 microamperes to each ion pump.

Table VI presents the cathode voltage, collector voltages, anode voltage, the regulation, and ripple requirements. The last three columns in this table show the performance of the flight power processor system. The table also shows the current requirements for the cathode heater supply at the 100 percent power level and the voltage requirements for the ion pump at various load conditions. It can be noted from the performance of the flight PPS during ground testing that all the regulation and ripple requirements were achieved. It can also be noted that the desired power circuit efficiency of 85 percent was exceeded.

Protection Requirements for Traveling Wave Tube and Power Processor System

The four protective circuits employed in the TEP are designed to protect both the TWT and the PPS from damage due to various fault conditions. Two circuits specifically used to protect the OST are the body current and ion pump current protection circuits. These circuits will shut off the high voltage of the PPS when currents are excessive and will not permit a restart of the PPS. The trip level settings for these protective circuits are 10 milliamperes for body current protection and 10 microamperes for the ion pump current protection. These protective circuits can be individually defeated by command.

The main power circuit of the PPS is a current source and current limit supply. Thus, the PPS is inherently protected against instantaneous overloads and arcing conditions. However, for thermal consideration, a separate circuit entitled "0.4-second circuit" protects against sustained high voltage overloads and arcing. This circuit will turn off the high voltage when a fault causes the cathode voltage to fall out of regulation for longer than 0.4 second. A low voltage condition on the 76-volt source will cause the cathode voltage to be out of regulation; thus, this circuit also serves as low voltage protection for the 76-volt source.

The PPS does contain a separate protection circuit for an undervoltage condition in the 27.5-volt supply. This circuit is necessary to insure proper operation and sequencing of the low level logic circuits. The undervoltage circuit acts to shut off the high voltage of the PPS when the voltage of the 27.5-volt supply falls below 20 volts; if the voltage is below 20 volts, this circuit prevents a restart of the PPS. The 27.5-volt undervoltage protection circuit can not be defeated by command.

The PPS does not contain special or separate circuits for protection against overvoltage conditions. This protection is provided by the inherent designs of the individual circuits where conservative design voltage stress levels were used.

Power Processor System and Output Stage Tube Interlock Requirements

The four major PPS and OST interlock requirements are (1) "high voltage on" and "cathode heater 50 percent power," (2) "fault clear" and "cathode heater 50 percent power," (3) "substitute heater" and "PPS disable," and (4) "substitute heater" and "high voltage" interlocks. The high voltages can not be turned on if the cathode heater supply is at 50 percent power. The high voltage can be turned on at other heater power levels without causing any damage. However, if the high voltages were turned on with the cathode heater at 50 percent power, then damage would occur to the cathode heater and to the TWT body.

The fault clear switch and the cathode heater 50 percent power level were interlocked to prevent damage to the contacts of the PPS fault clearing relay. The voltage and current ratings of the relay are not sufficient to enable transfer of the relay under loaded conditions. A switch with this load transfer capability would have increased the PPS weight by 1 pound. Since the spacecraft power system had a relay capable of load transfer and since the PPS switch is capable of voltage isolation (contacts open) and current capacity (contacts closed), the operation of the relays are sequenced so that the spacecraft relay is opened before the PPS relay is opened and the PPS relay is closed before the spacecraft relay is closed.

Since the high voltages are interlocked with the cathode heater 50 percent power level, the transfer of the fault clear relay was interlocked with the cathode heater 50 percent power level to ensure that no current was passing through the contacts when the relay was transferred.

The interlock between the substitute heater and PPS disable was a result of the thermal design of the spacecraft. When the TEP was operating the heat dissipation would range from 40 to 70 watts. The TEP level of dissipation is a function of the amount of radiofrequency power from the OST. When the TEP is not operating an equivalent heat dissipation is required to maintain south panel temperatures at acceptable survival limits. Whenever the TEP is commanded off the thermal control heaters are automatically turned on.

The thermal control heaters were also interlocked with the turnon and turnoff of the high voltage. When the TEP high voltages are off, the TEP dissipation into the south panel of the spacecraft is about 17 watts. This amount of heat dissipation is not sufficient to keep the TEP temperatures above minimum acceptable levels. Thus, the thermal control heaters are kept on until the high voltages are turned on. Anytime the high voltages are turned off the thermal control heaters are automatically turned on.

Figure 4 is a simplified diagram of the PPS command logic. The first ten commands (1 to 10) operate when the 27.5-volt power is available to the PPS. The last ten commands (11 to 20) are interlocked so that a 5-volt signal from internal supply 1 must be available before the commands will operate. The interlock between the fault clear and 50 percent cathode heater power switches is shown on command lines 3 and 4 the second "and" circuit. The "50 percent cathode heater" switch also forms an interlock with the "100, 110, and 120 percent cathode heater" setting. This is shown on command lines 11, 12, and 13 (the second "and" circuit). The "50 percent power level" must be sent before the other power settings will operate. The thermal control heaters are turned on by sending command 9 (PPS disable), command 14 (cathode heater 50 percent power), command 15 (cathode heater off), or command 17 (cathode/collector/anode off).

Failsafe Features of Power Processor System

The PPS does not have redundancy for any of the critical circuits because of a weight limitation. However, there were some critical circuits that were made failsafe with a minimum increase to the overall weight of the PPS. Table VIII shows a list of eight circuits with their respective failsafe feature.

Clamping diodes were installed at the output of the anode supply. If the anode supply should open the circuit in the PPS, then the clamping diodes would keep the anode element in the TWT clamped to ground potential. This will permit operation of the TWT. The loss of the anode supply, however, would degrade the radiofrequency performance of the TWT and shorten the cathode heater life because of ion bombardment. If the TWT anode element is not clamped to ground the anode element charges to the cathode potential and the electron beam ceases. Current limiting resistors were installed in the input and output of the anode supply to prevent a short in the anode circuit from causing a failure in other critical circuits.

Two ion pumps were powered from the PPS ion pump supply. A current limiting resistor was installed in series with each pump so that if a pump were to short to ground the other pump would remain operational. Current limit resistors were also installed in the ion pump circuit which is powered from internal supply 1. Thus, internal supply 1 will remain operational if the ion pump circuit shorts to ground.

The failsafe feature for the preregulator is a relay contact across the regulator. In the event that the regulator fails, the relay contact can be commanded closed and the PPS will remain operational; however, housekeeping voltage variations could cause degradation to the overall performance of the PPS.

The automatic shutdown of high voltage, the body current protection, and the vacuum ion current protection can be enabled or disabled by command. Thus, a failure in any of these circuits can be cleared by disabling the circuit by command.

The attenuator in the cathode supply is an active filter to obtain a 0.01 percent voltage ripple. A series of clamping diodes was installed across the output transistor of the attenuator and another series of clamping diodes was installed across the entire attenuator output. In the event that the output transistor would open, the diodes across the transistor will allow the cathode supply to provide power. However, the voltage ripple would increase from 0.01 to 0.1 percent. The clamping diodes across the entire output of the attenuator also protect the attenuator circuit from high voltage transients during arcing.

The last failsafe feature in table VIII is the use of clamping diodes in the telemetry and control signal circuits. These diodes prevent voltage transients from being transmitted from the high voltage section to the low voltage section.

SALIENT POWER PROCESSOR SYSTEM CIRCUITS

Output Stage Tube Power Supplies

The essential power supplies for operating the OST are the cathode/collector supply, cathode heater supply, anode supply, and the ion pump supply.

Cathode/collector supply. - The cathode/collector supply is the principle supply in the PPS because it processes the power from the 76-volt supply and provides the closely regulated and essentially ripple free high voltages to the cathode of the TWT and the ten collectors in the MDC. The cathode voltage is -11.2 kilovolts with respect to the body of the TWT and the collector voltages are graduated and range from -11.2 (collector 10) to 0 kilovolts (collector 1) in increments of approximately 1.12 kilovolts between adjacent collectors (collectors 2 to 10).

The power processing approach used for this power supply is a two-stage system consisting of a high frequency dc chopper-type switching regulator and a high frequency dc to ac square wave inverter. The inverter has a high voltage transformer with ten high voltage secondary windings. System voltage regulation is obtained in the chopper regulator. The regulator provides a constant 55-volt dc input to the inverter from the 76-volt supply which has a voltage range from 65 to 87 volts.

The regulator is a modified conventional series inductor switching regulator. The modification consists of eliminating the output filter capacitor of the chopper and relying on this capacitance to be supplied by the reflected secondary load capacitance. This modification converts the conventional regulator from a voltage source to a current source. A current source is more desirable for this supply because it limits 76-volt supply current peaks and surges due to startup, high voltage arcs, and load shorts. The current source also minimizes electrical stresses on the power transistors in both the regulator and inverter, thereby enhancing reliability.

Regulation of the dc input to the inverter and the high voltage dc outputs is provided by a regulation technique known as ASDTIC (analog signal to discrete time interval converter). Reference 1 ASDTIC is a report on a high performance analog to digital converter with two feedback control loops. The dc loop sets the dc output level and the ac loop regulates the dc output level on a cycle to cycle basis. The output from ASDTIC is a pulse-width-modulated digital signal that controls the on and off switching times of the power transistors in the regulator.

Implementation of the previous power processing approach into the final design of the PPS is illustrated in the simplified schematic drawing of the PPS cathode/collector supply in figure 5. The following are the power processing sequences for this circuit. The 76-volt dc is filtered by the two-stage filter consisting of L_1, L_2, C_1, C_2, and R_1. This filter is designed to the requirements of Military Standard 461 A, Notice 3, for both audiosusceptibility and conducted interference. Transistors Q_1 and Q_2 are the power transistors of the switching regulator, and transistors Q_1' and Q_2' and transformers T_1 and T_2 are the respective base drive transistors and drive transformers for these power transistors. The power transistors are switched during alternate half cycles of the 10-kilohertz signal that drives the inverter. L_3 and D_1 constitute the series inductor and fly-back diode of the regulator. Efficiency of the circuit is enhanced by the energy recovery diode D_2 and positive current feedback to the bases of transistors Q_1 and Q_2. The positive feedback is obtained from windings on transformers T_1 and T_2. The identical power transistors Q_1, Q_2, Q_3, and Q_4 were selected on the basis of second breakdown screening tests to enhance PPS reliability.

The output voltage of the regulator, a constant 55 volts dc, is applied to the inverter at the center tap of the primary winding of T_3. The inverter power transistors Q_3 and Q_4 conduct on alternate half cycles of the 10-kilohertz drive applied to their bases. The high voltage transformer T_3 has ten secondary windings. The voltage of each secondary winding is a 10-kilohertz, 1.12-kilovolt square wave voltage rectified by the full wave bridge circuit and filtered by the capacitor. The dc voltages are series connected to provide the individual collector voltages and the cathode voltage as shown. The series resistor between windings limits surge currents due to startup and shutdown transients and momentary arcing between collectors. The ac filter in the body circuit is an active filter which provides the low ripple required for the cathode to body voltage. The active filter was used to minimize the amount of stored energy and to reduce filter weight.

The ASDTIC circuit consists of the analog signal processor and the digital signal processor. The dc loop senses the high voltage output by a resistor divider between cathode and body, and the ac loop is obtained by a separate winding on L_3. The analog processor integrates the sum of the ac and dc loop signals. The digital processor compares the integrated signal with a reference voltage in a level detector and produces a pulse width modulated output signal to control the switching of the regulator power transistors.

The digital signals are synchronized to the 10-kilohertz inverter drive through the synchronizing circuit. The peak current sensor input to the digital processor is a protective circuit which limits the 76-volt supply current to a prescribed safe level. The sensor, when activated due to sustained overloads or faults, cuts back on the firing or conducting time of the regulator power transistors. High threshold integrated logic devices are used in the ASDTIC circuitry for high reliability.

The cathode/collector supply is turned on and off by command signals and/or protective circuit signals to the digital processor. The turnoff mechanism is to clamp the collectors of transistors Q_1' and Q_2' to ground which in turn turns off the chopper regulator power transistors Q_1 and Q_2. The 0.4-second circuit is an additional form of protection circuit that will turn off the cathode/collector supply. The 0.4-second circuit senses the output of the integrator circuit and determines whether the high dc voltage is out of regulation for a period of 0.4 second. If these conditions are met, the circuit turns off the cathode/collector supply. The faults which can cause an out of regulation condition are collector to body shorts, cathode to body shorts, and the voltage of the 76-volt source falling below 60 volts. The flight model PPS includes provisions to disable the 0.4-second circuit by command.

Cathode heater supply. - A simplified schematic circuit drawing of the cathode heater supply is shown in figure 6. This circuit is known as a single-ended fly-back type of dc to dc converter and operates at a switching frequency of approximately 30 kilohertz. The circuit is a current regulated system and provides filtered dc power of nominally 5 watts at a constant current of 1.29 amperes to the cathode heater (100 percent heater power).

The circuit is powered from the 27.5-volt supply through the 27.5-volt input filter, L_1, L_2, C_1, C_2, and R_1. The fly-back transformer with a step-down voltage turn ratio is T_1. The switching power transistor Q_1 is controlled by the two-loop ASDTIC regulator control circuit through the drive transistor and transformer of the drive circuit. The dc feedback loop senses output current through transformer T_2 and the ac feedback signal is obtained from secondary winding 5, 6 of transformer T_1. The drive transformer for transistor Q_1 provides positive current feedback to the base to improve the efficiency of this circuit. The output power to the cathode heater can be changed over a range of 50, 100, 110, and 120 percent heater power by commanded operation of relays K_1, K_2, and K_3. Although the cathode heater supply is a low voltage constant current supply, it is connected to the high voltage cathode and therefore floats at the -11.2-kilovolt voltage. Because of this, special high voltage design considerations were given to transformer T_1 and the output filter. These components are physically located in the high voltage compartment of the PPS, and T_1, an encapsulated transformer with a special lead geometry and configuration, is insulated for the cathode potential level. The zener diode CR-2 protects the supply from reflected high voltage transients at the cathode of the TWT.

Anode supply. - The anode supply is illustrated in simplified form in figure 7. Transistor Q_1 is the pass transistor of a linear regulator in series with transformer T_1. The use of a dissipative regulator is acceptable for this supply because the anode load power is practically negligible; the anode current is less than 1-milliampere at its operating voltage of 250 volts dc. The regulator circuit is conventional and uses a control amplifier to control the operating point of the pass transistor Q_1.

The reference sets the output voltage level, and the actual output voltage is sensed across resistor R_2. The control amplifier is a single ended operational amplifier that provides an integrated signal of the input error voltage to control Q_1. Transistor Q_2 provides current limit and short circuit protection for the supply.

The input voltage to transformer T_1 is a 10-kilohertz square wave voltage obtained from a transformer winding in the cathode/collector supply. The operating voltages for the control amplifier and the reference circuit are also obtained from the 10-kilohertz input voltage. The output voltage of the anode is 250 volts dc.

Ion pump supply. - A voltage multiplier configuration is used in the ion pump supply and is shown in figure 8. This is an open loop system with no active regulation in the output circuit, but the 10-kilohertz source that is obtained from the internal power supply is regulated in that supply. The output voltage of T_1 is approximately 500 volts and the 8 times multiplication of the configuration provides an output of 4 kilovolts at no load.

The supply powers two ion pumps as shown. The supply provides an output voltage of 3.3 kilovolts at a 10-microampere current and 2.5 kilovolts at a 25-microampere current. The two pumps are used to maintain the vacuum in the TWT and MDC.

High Voltage Transformer and High Voltage Circuits

The high voltage transformer is a critical component in the cathode/collector supply, and considerable detail was given to its design, fabrication, and testing. A photograph of the final transformer design used in the flight and qualification PPS models is shown in figure 9.

The transformer uses a high permeability cut C-core to minimize core losses at the operating frequency. The windings are wound on a bobbin coil form and a Dacron-Mylar-Dacron insulation is used between windings. The coils are constructed so that each complete secondary winding is wound in a single layer. This technique minimizes interwinding capacity and ac voltage stresses between adjacent windings at the coil ends. Three electrostatic shields are used in the transformer to minimize capacity and equalize voltage gradients between windings and the core.

The design stress levels are 23.62×10^5 volts per meter (60 V/mil) for solid insulation and 3.15×10^5 volts per meter (8 V/mil) for surface insulation and creepage distances. These stress levels determine the amount of insulation required between adjacent windings and windings to the core, lead configuration and spacing, and orientation of the transformer within the PPS structure. Anti-corona balls are used to reduce sharp points in high voltage lead terminations. The entire transformer is vacuum encapsulated with a polyurethane resin.

The potting procedure was carefully planned and controlled to produce a void-free structure with good heat-transfer characteristics. Heat transfer is primarily by conduction through the core to the baseplate with radiation as a secondary mode. Because of this, the means of fastening the transformer to the baseplate is critical to insure a good thermal contact.

The transformer was extensively tested to insure electrical, mechanical, and thermal integrity for high reliability throughout the intended mission. In addition to electrical performance testing, the transformer was subjected to high voltage dielectric tests and high voltage corona tests. Hot spot temperature and thermal gradients were determined by thermal analysis and verified by separate thermal tests. A separate transformer was life tested in a vacuum chamber with programmed thermal cycles.

Telemetry Circuits

The PPS telemetry circuits include current monitors and voltage monitors for high and low voltage circuits, temperature monitors, radiofrequency power monitors, and a fault indicator. Each monitor produces a 0- to 5-volt dc output analog signal. The analog signal is converted to a digital signal in an onboard encoder for transmission from the spacecraft. Each of the previous telemetry monitoring circuits is now discussed.

High voltage current monitor. - High voltage current monitors are used to measure collector currents 2 to 10 and the cathode current. A circuit diagram of the current monitor is shown in figure 10. It consists of a magnetic amplifier operating into a high gain operational amplifier with negative current feedback applied from the operational amplifier output to the magnetic amplifier. The magnetic amplifier uses two half-wave self-saturating magnetic amplifiers operating differentially for common mode rejection in a push-pull configuration from a 10-kilohertz square wave ac supply. Each amplifier is biased for operation in the center of its high gain characteristic curve at zero control signal. The magnetic cores are square loop toroidal scores, and a single turn winding controls each amplifier as illustrated. The net output of the magnetic amplifier is connected to the input of the operational amplifier. The operational amplifier output is connected to a negative feedback winding on the magnetic amplifier and nulls the signal input to the operational amplifier. The magnitude of the feedback signal is a measure of the control current (collector current), and the analog telemetry voltage E_o is developed across R_3 in the feedback loop. The analog output voltage is a linear 0- to 5-volt signal as shown. The single turn control winding is the actual high voltage collector lead and passes through the toroidal cores as shown. This technique prevents breaking the high voltage leads to measure current and increases high voltage circuit reliability.

Low voltage current monitor. - Low voltage current monitors are used to measure 76- and 27.5-volt supply currents and the TWT ion pump current. The monitor uses a standard series type self-saturating magnetic amplifier; the circuit is shown in figure 11. The magnetic amplifier operates at 10 kilohertz from a square wave ac supply. A characteristic of this magnetic amplifier is that it is an equal ampere turns device (i.e., $N_c I_c = N_g I_l$ and $I_l = I_c \frac{N_c}{N_g}$). The output voltage is developed across R_1 by the load current I_l.

This output characteristic is illustrated in figure 11 for the 76-volt supply current monitor where N_c is a single turn winding and I_c (supply current) is 10 amperes. The 27.5-volt supply current monitor uses a seven-turn control winding N_c and the supply current is 1.5 amperes.

Voltage monitors. - The monitored and telemetered voltages of the TEP are the high voltage cathode voltage, collectors 4, 5, and 7 voltages, the anode voltage, and the cathode heater voltage. The high voltage monitors consist of an input high voltage resistance divider and an inverting linear operational amplifier. The circuit for the -11.2-kilovolt cathode voltage monitor is shown in figure 12(a). Figure 12(b) illustrates the circuit for the anode voltage monitor. It consists of an input voltage divider and a noninverting unity gain operational amplifier follower. The zener diodes shown in figures 12(a) and (b) are protective diodes for the spacecraft telemetry system. They serve to limit the voltage to the telemetry system to a safe value of 15 volts, if high voltage faults develop in the PPS or if the high voltage resistors in the input divider should arc over or short out. The cathode heater voltage is obtained from a separate winding (7-8) on the fly-back transformer of the cathode heater supply circuit (fig. 6). The monitor is shown in figure 12(c). Conventional R-C (resistor-capacitor) filtering is used and R_1 and R_2 form an output voltage divider.

The telemetry return wire is a separate and isolated return ground line for the system. Because single-point grounding is used in the PPS, this line is grounded at a spacecraft common ground point along with the return lines for the power busses and the command system.

Radiofrequency power monitors. - Both forward and reflected radiofrequency power are telemetered from the transmitter experiment package (TEP). Radiofrequency diode sensors are used in the OST output wave guides to sense the forward and reflected radiofrequency power. The output from the sensor is a 0- to 0.25-volt dc signal. This signal is amplified to the 5-volt telemetry level by the operational amplifier circuit shown in figure 13. The monitors for both forward and reflected power are essentially the same.

Temperature monitors. - Twelve temperature monitors are used in the TEP to telemeter PPS, MDC, coupler, TWT, and heat pipe temperatures. The circuit is shown in figure 14. Temperature is sensed by thermistors whose resistance changes with temperature. The thermistor is connected in series with a fixed 4.99-kilohm resistor for each temperature measurement as shown. The 12 temperature circuits are powered by a regulated 5-volt dc source, and the telemetry signals are developed across the fixed resistors. The 5-volt source voltage is also telemetered.

Fault indicator. - The PPS telemeters identify three types of faults which can shut down the TEP: (1) an undervoltage condition on the 27.5-volt supply, (2) an excessive TWT body current, and (3) an excessive MDC ion pump current. The circuit diagram for the fault indicator is shown in figure 15. The circuit operates to change the ratio of the output voltage divider in accordance with input fault signals, thereby providing discrete voltage levels for fault identification. With protection circuits activated and no faults present transistors Q_1, Q_2, and Q_3 are off. The output voltage divider consists of resistors R_1 and R_4 in series and the output developed across R_4. The telemetry signal for the no-fault condition is 4.3 volts. An undervoltage fault switches flip flop (FF) 1 and turns on transistor Q_1. The transistor Q_1 shorts out R_4 and the telemetry output for this fault is 0 volts. An excessive body current fault turns on transistor Q_2 and this in turn connects resistors R_2 and R_4 in parallel. The output telemetry signal for this fault is 1.5 volts. In a like manner an excessive ion pump current fault turns on transistor Q_3 which connects resistors R_3 and R_4 in parallel. The telemetry output signal is 3.0 volts.

The "OR" gate G_1 permits identification of only the first fault to occur. The fault indicator is reset by the protection on command. Operational amplifiers U_1 and U_2 are level detectors, and the reference voltage levels to these detectors determine the trip points for the body current and ion pump current. The outputs from the level detectors activate the fault indicator and also provide the trip signals to the protection circuit to shut down the TEP. The shutdown signal for a undervoltage fault is obtained directly in the protection circuit.

Command Drive Circuits With Isolated Grounds

Because of the spacecraft single-point ground requirement adopted for the PPS, it is necessary to use an isolated ground return line for the command system (similar to telemetry system). This can be accomplished by using a pulse transformer or a photoisolator semiconductor switch to interface with the command input system. The latter technique is used in the PPS, and the photoisolator is a Texas Instrument TIL-103 device. The command drive circuits are illustrated in figure 16. Two types of drive circuits are used because some commands must be sent initially to energize the PPS and perform other functions so that the only source voltage available is from the 27.5-volt supply. These command drive circuits are labeled relay drive circuits and are powered from the 27.5-volt source. After the PPS is turned on, an internal supply provides a 5-volt dc source voltage to power the command drive circuits labeled logic drive.

Both types of drive circuits use the TIL-103 photoisolator switch for isolation as shown. The output of the relay drive circuit energizes a latching relay directly. The logic drive types also energize latching relays, but the direct outputs from this drive interface with TTL logic devices, and the outputs of the TTL logic energize the relays.

The TIL-103 photoisolators are activated by a 5-volt, 50-millisecond command pulse. This pulse forward biases the LED diode which in turn turns on the phototransistor switch for the duration of the pulse. The 15-volt zener diode reduces the collector to emitter voltage to within the acceptable limits for this device when operated from the 27.5-volt supply.

FLIGHT ACCEPTANCE TESTING AND PERFORMANCE

Test Program

After the power processor was assembled it was subjected to the following tests as a PPS only:

(1) Electrical acceptance test at ambient conditions
(2) Vibration test
(3) Electrical acceptance test at ambient conditions
(4) Thermal vacuum test
(5) Electrical acceptance test at ambient conditions
(6) Thermal vacuum test (high temperature only)
(7) Electrical acceptance test at ambient conditions

The power processor and OST were integrated into a TEP, and the TEP was subjected to the following tests:

(1) Electrical acceptance test at ambient conditions

(2) Thermal vacuum test

(3) Electrical acceptance test at ambient conditions

The TEP was then integrated into the protoflight spacecraft and subjected to the following spacecraft tests:

(1) Electrical acceptance test at ambient conditions

(2) Vibration and shock tests

(3) Electrical acceptance test at ambient conditions

(4) Thermal vacuum test

(5) Electrical acceptance test at ambient conditions

During the power processor testing and TEP testing the PPS input voltage was set at 65, 76, and 87 volts, and the PPS baseplate temperature was set at 0°, 25°, and 60° C. When the TEP was on the spacecraft the voltage varied from 76 to 84 volts and the PPS baseplate temperature varied from -5° to 56° C.

Measurement Techniques

During the testing of the power processor by itself, the power circuit efficiency, the voltage regulation, and the voltage ripple were monitored. The electrical measurements were made on the anode supply, cathode supply, and the nine collector supplies with voltage and current meters. During the TEP testing, the measurements were taken using the the 0- to 5-volt analog telemetry outputs from the power processor. When the TEP was tested on the spacecraft, the measurements were taken using the 0 to 250 count digital spacecraft telemetry system. This corresponds to a 0.4 percent resolution for the telemetry parameters.

For the TEP testing and spacecraft testing the only electrical measurements possible were the anode supply voltage, cathode supply voltage, and three of the nine collectors voltages. Thus, these were the only voltage regulation calculations that are possible. Direct ripple measurements were not taken once the PPS was integrated with the OST. However, indirect qualitative measurements were taken by examining the radiofrequency output of the OST for spurious interference signals associated with the switching frequency and higher harmonics of the switching frequencies from the PPS.

Power Processor System Power Circuit Efficiency

The power circuit efficiency is calculated by dividing the PPS output power by the

PPS input power and multiplying the quotient by 100. The PPS output power to the OST is determined by summing the power delivered from the nine collector supplies, cathode supply, and cathode heater supply. The input power to the PPS is determined by summing the 76- and 27.5-volt power and subtracting the 7 watts used for PPS telemetry circuits. Table IX shows the power circuit efficiencies calculated for zero radiofrequency drive (about 175 W supplied to OST) and saturated radiofrequency drive (about 470 W supplied to OST). The PPS efficiency at OST saturation ranged from 88.1 to 89.7 percent with the lower efficiency occurring at high temperature and high input voltage, and the higher efficiency occurring at low temperature and low input voltage.

The efficiency for zero OST drive ranged from 82.8 to 83.6 percent for TEP testing and spacecraft thermal vacuum testing. The 75 to 77 percent efficiencies for PPS testing were the result of supplying only 145 watts to a OST simulator when actually the power should have been about 175 watts. The 27.5-volt power input to the PPS does not vary with radiofrequency power output of the OST, while the 76-volt power input to the PPS does vary with radiofrequency power output of the OST. As the radiofrequency power output of the OST increases, the constant power from the 27.5-volt source becomes a small percentage of the input power to the PPS; as a result, the PPS efficiency increases. The PPS efficiency is near 83 percent when the PPS output power is 175 watts instead of 145 watts.

Voltage Regulation

The voltage regulation was calculated by dividing the dc voltage variation by the nominal voltage. The voltage change was determined by examining the various supply voltages at three voltage input conditions and three different temperatures and selecting the ones with the largest voltage variations.

Table X shows the voltage regulation calculations for PPS testing, TEP testing, and spacecraft thermal vacuum testing. The PPS calculations for PPS testing were performed using data obtained with a voltage meter. These calculations range from 0.04 to 0.19 percent. The calculations made for TEP testing used the analog telemetry outputs of the PPS and consequently are not as accurate as the PPS testing calculations. The TEP calculations range from 0.09 to 0.34 percent. The calculations made for the spacecraft thermal vacuum testing are the least accurate because the telemetry signals were not analog but are in 0 to 250 discrete counts. The anode voltage cathode voltage and collector 5 voltage did not vary by a count during testing. However, it was assumed that the worst case variation might have been ±1/2 count. This represents ±1/2 volt variation for the anode supply, ±30 volts for the cathode supply, and ±20 volts for collector 5. When the regulation calculations were made for collector 4 and collector 7 it was assumed that the voltage variation was equivalent to ±1 count variation because the digital spacecraft telemetry system changed by one count during spacecraft testing. This represents ±40 volts for both collectors 4 and 7. Even with this worst case analysis the range of voltage regulation was from 0.2 to 0.9 percent.

Voltage Ripple

The voltage ripple for the PPS was only obtained directly when the PPS was tested with a resistive load. The voltage ripple was calculated by dividing the magnitude of the ac voltage by the magnitude of nominal dc voltage and multiplying by 100. The results of these calculations are shown in table XI. For TEP and spacecraft testing the direct electrical measurements were not taken. However, the indirect measurements indicated an acceptable OST performance over the input voltage and temperature variations.

SUMMARY OF RESULTS

Based on the electrical and environmental tests performed on the PPS during ground testing, the following results were obtained:

1. The desired power circuit efficiency of greater than 85 percent has been achieved over the expected flight operating voltage range of the solar array and the expected flight temperature variations.
2. The voltage regulation and voltage ripple for the PPS is better than the OST requirements over the expected flight voltage and temperature variations.
3. The command circuits, telemetry circuits, control circuits, and protection circuits are capable of satisfactory operation for the expected flight voltage and temperature variations.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 15, 1976,
646-22.

REFERENCES

1. Lalli, V. R.; and Schoenfeld, A. D.: ASDTIC Duty-Cycle Control for Power Converters. IEEE Power Processing and Electronics Specialists Conference Record.

Inst. Electr. Electron. Eng., 1972, pp. 96-102.

2. Miller, Edward F.; Fiala, J. L.; and Hansen, I. G.: Performance Characteristics of the 12 GH_z, 200 Watt Transmitter Experiment Package for CTS. NASA TM X-71773, 1975.

3. Farber, B. F.; et al.: A High Power TWT Power Processing System. IEEE Power Specialists Conference Record. Inst. Electr. Electron. Eng., 1974, pp. 81-90.

4. Farber, B. F.; Schoenfeld, A. D.; and Thollot, P. A.: Power Processing System for a 200 W Communication Satellite Transmitter. Presented at Inst. Electr. Electron. Eng. Int. Conference on Satellite Communication Systems Technology, London, England, April 1975.

TABLE I. - SPACECRAFT REQUIREMENTS AS FUNCTION OF PERFORMANCE

Spacecraft requirement	Power processing system (PPS) performance
Substitute heater	
Voltage, V:	Voltage, V:
76	76
Power, W:	Power, W:
71 to 82	80.64
	(Heater on when PPS load <25 W)
Fault clearing	
Experimental bus cleared if PPS shorts	PPS cleared by relay and substitute heaters fused
Voltage range	
Voltage, V:	
65 to 87 (operate at specification).	PPS tested at 65, 76, and 87 V
87 to 91 (operate not at specification)	
91 to 95 (no damage)	PPS operated at 95 V several times (~ 1 min each)
26.6 to 28.4 (operate at specitifation)	PPS tested at 26, 27.5, and 29 V
24.7 (predicted low)	PPS operated at 20.9 V
30.5 (predicted high)	PPS operated at 36 V
Power	
Power (reference), W:	Power, W:
1.2 (special instrumentation).	1.16
16.8 (after PPS enable command)	16.42
20.2 (cathode heater 50-percent-power mode)	20.64
26.2 (cathode heater 100-percent-power mode)	24.29
28.2 (cathode heater 120-percent-power mode)	25.19
582 (maximum 76-V bus[a])	535
5.0(7.0) (cathode heater[b] 50-percent-power mode)	5.04
6.1(8.1) (cathode heater[b] 50-percent-power mode with special instrumentation)	5.30
Electromagnetic compatibility	
Design to Military Standard 461 A, Notice 1, with Communications Research Control/Lewis Research Center modifications	Transmitter experiment package compatible with spacecraft
Telemetry system	
Range, 0 to 5 V Input impedance, <5 kΩ 480 W from power processor system to output stage tube Eclipse operation	Transmitter experiment package compatible with spacecraft
Command system	
Logic one, 3.8 V at 10 mA Logic zero, 0.1 at 50 μA Maximum voltage, 7 V continuous with 0.5-V pulse lasting 1 msec	PPS compatible with spacecraft command system

[a]From PPS to OST, 480 W.
[b]Eclipse operation.

TABLE II. - POWER PROCESSOR SYSTEM TELEMETRY CHANNEL ALLOCATION LIST

Cathode heater voltage, V dc	0 to 10
Cathode voltage, kV	0 to -15
Beam current, mA	0 to 100
Tube body current, mA	0 to 15
Anode voltage, V dc	0 to 600
Collector 4 voltage, kV	0 to -10
Collector 5 voltage, kV	0 to -10
Collector 7 voltage, kV	0 to -10
Collector 1 current, mA	0 to 15
Collector 2 current, mA	0 to 15
Collector 3 current, mA	0 to 25
Collector 4 current, mA	0 to 25
Collector 5 current, mA	0 to 25
Collector 6 current, mA	0 to 25
Collector 7 current, mA	0 to 25
Collector 8 current, mA	0 to 40
Collector 9 current, mA	0 to 40
Collector 10 current, mA	-10 to 5
Power processor system (PPS) component temperature[a], °C	-55 to 150
PPS baseplate temperature[a], °C	-55 to 100
Traveling wave tube (TWT) body temperature[a], °C	-15 to 150
Multistage depressed collector (MDC) temperature 1[a], °C	25 to 225
MDC temperature 2[a], °C	-15 to 150
Coupler temperature[a], °C	-15 to 150
Reflected radiofrequency power, W	0 to 25
Forward radiofrequency output power, W	0 to 250
Envelope internal pressure, μA (torr)	0 to 10 (10^{-6} to 10^{-8})
Housekeeping bus current, A	0 to 1.5
Experiment bus current, A	0 to 10
Signal conditioning (ref. voltage)[a], V dc	0 to 5
Heat pipe temperature 6[a], °C (°F)	-73 to 79 (-100 to 175)
Heat pipe temperature 1[a], °C (°F)	-73 to 79 (-100 to 175)
Heat pipe temperature 2[a], °C (°F)	-73 to 79 (-100 to 175)
Heat pipe temperature 3[a], °C (°F)	-73 to 79 (-100 to 175)
Heat pipe temperature 4[a], °C (°F)	-73 to 79 (-100 to 175)
Heat pipe temperature 5[a], °C (°F)	66 to 93 (150 to 200)
Shutdown fault indicator (4 discrete voltage (V) levels):	
Normal PPS operation	5.0
Ion pump pressure trip	3.0
Excessive body current	1.5
27.5-V undervoltage trip	0.0

[a]Denotes special instrumentation.

TABLE III. - POWER PROCESSOR SYSTEM (PPS) COMMAND LIST

Command	Description	Function
1	Close transmitter experimental package 76-V relay	Connects TEP to spacecraft 76-V source
2	Open TEP 76-V relay	Disconnects TEP from spacecraft 76-V source
3	PPS enable	Turns on internal and instrumentation supplies
4	PPS disable	Turns off internal instrumentation, cathode/ collector, and anode supplies; turns on substitute heaters
5	Special instrumentation on	Activates special instrumentation supply consisting of 12 temperatures
6	All instrumentation off	Turns off internal and special instrumentation supplies
7	Preregulator bypass	Closes alternate path should preregulator fail
8	Substitute heater off	Disconnects substitute heater from 76-V source
9	High voltage protection on	Enables high voltage protection circuit
10	High voltage protection off	Disables high voltage protection circuit
11	Cathode heater off	Turns off cathode heater, enables high voltage turn on
12	Cathode heater 50 percent	Sets cathode heater at 50 percent power, disables high voltage turn on
13	Cathode heater 100 percent	Sets cathode heater at 100 percent power, enables high voltage turn on
14	Cathode heater 110 percent	Sets cathode heater at 110 percent power, enables high voltage turn on
15	Cathode heater 120 percent	Sets cathode heater at 120 percent power, enables high voltage turn on
16	Cathode collector on	Turns on high voltage supplies to collectors and cathode, and anode supply, and turns off substitute heaters
17	Cathode collector off	Turns off high voltage supplies to collectors, and cathode, and anode supply, and turns on substitute heaters
18	Defeat pressure protection	Disables protection circuit which turns off high voltage during excessive pressure in output stage tube (OST)
19	Defeat body current protection	Disables protection circuit which turns off high voltage during excessive body current in OST
20	Fault indicator reset	Reset fault indicator and reinstated body current and pressure protection

TABLE IV. - QUALIFICATION VIBRATION REQUIREMENTS FOR 1.5 TIMES

PREDICTED FLIGHT LEVELS

(a) Sine input (sweep 2 octaves/min)

Frequency, Hz	X axis (gravities)	Y axis (gravities)	Z axis (gravities)
5 to 14	Ramp from 1.78 to 5.0	--------------------	--------------------
14 to 100	5.0	--------------------	--------------------
5 to 16	--------------------	Ramp from 1.84 to 5.0	--------------------
16 to 40	--------------------	6.0	--------------------
40 to 100	--------------------	10.0	--------------------
5 to 25	--------------------	--------------------	Ramp from 3.0 to 15.0
25 to 70	--------------------	--------------------	15.0
70 to 120	--------------------	--------------------	4.0
120 to 250	--------------------	--------------------	2.3
100 to 250	2.3	2.3	Not applicable
250 to 400	4.5	4.5	4.5
400 to 2000	5.0	5.0	5.0

(b) Random input (duration, 90 sec each axis; overall acceleration, 10.4 gravities rms)

Frequency, Hz	Power spectral density, $(\text{gravities})^2/\text{Hz}$
20 to 300	Ramp from 0.006 to 0.07
300 to 1000	0.07
1000 to 2000	Ramp from 0.07 to 0.035

TABLE V. - PREDICTED THERMAL ENVIRONMENT

Component	Temperature, °C					
	Worst case predicted		Acceptance test		Qualification test	
	Hot	Cold	Hot	Cold	Hot	Cold
Out stage tubes	48	0	53	-5	58	-10
Power processor system	54	0	60	-5	65	-10

TABLE VI. - POWER PROCESSOR SYSTEM REQUIREMENTS AS FUNCTION OF PERFORMANCE

Function	Requirement			Power processor system performance		
	Magnitude, kV[a]	Regulation, percent	Ripple, percent	Magnitude, kV	Regulation, percent	Ripple, percent
Cathode voltage	-11.2	±1	0.01	-11.23	0.3	0.007
Collector:						
1	0	±3	2	0	0	0
2	-2.24	↓	↓	-2.25	.4	.6
3	-3.36			-3.38	.5	.4
4	-4.48			-4.50	.4	.2
5	-5.60			-5.62	.4	.1
6	-6.72			-6.78	.9	.1
7	-7.84			-7.88	.5	.08
8	-8.96			-9.00	.4	.07
9	-10.08			-10.12	.3	.04
10	-11.20			-11.23	.3	.007
Anode voltage	247 V	±3	.5	247 V	.3	.24
Cathode heater (floats at cathode potential)	1.29 A	±1	2	1.293 A	.7	.4
Ion pump	3.3 kV at 10 μA	10	NA[b]	3.9 kV at 0 μA	2.5	NA
	2.5 kV at 25 μA			3.2 kV at 20 μA	2.8	NA
				2.7 kV at 10 μA and one pump shorted	3.0	NA
Power circuit efficiency	>85 percent	NA	NA	89.1 percent	NA	NA

[a]Kilovolts unless stated otherwise.
[b]Not applicable, NA.

TABLE VII. - PROTECTION REQUIREMENTS OF POWER PROCESSOR SYSTEM AS FUNCTION OF PERFORMANCE

Type of protection	Magnitude	Power processor system performance
Excess body current	10 mA	9.8 mA
Excess vacuum ion current	10 mA	10 mA
Low housekeeping voltage	<21 V	<20 V
High voltage protection	NA[a]	Any output can be shorted to any other output without damage

[a]Not applicable, NA.

TABLE VIII. - DESCRIPTION AND IMPLEMENTATION OF FAILSAFE FEATURES

Circuit	Method of implementation
Anode supply	Clamping diodes and current limiting resistors
Ion pump supply	Current limiting resistor
Preregulator bypass	Bypass relay
Automatic shutdown of high voltages	Commanded either to able or disable
Body current protection	Commandable for enable or disable
Vacuum ion current protection	Commandable for enable or disable
Attenuator bypass	Clamping diodes
Signals from high voltage supplies to low voltage circuits	Clamping diodes

TABLE IX. - POWER PROCESSOR SYSTEM

Radiofrequency level	Contract specification, percent	Efficiency, percent		
		Power processor system testing	Transmitter experiment package testing	Spacecraft thermal vacuum testing
Zero	NA[a]	75 to 77	82.8 to 83.6	83.2 to 83.9
Saturation	85	88.5 to 89.9	88.1 to 89.7	88.2 to 89.7

[a]Not applicable, NA.

TABLE X. - POWER PROCESSOR SYSTEM VOLTAGE REGULATIONS

	Nominal voltage, V	Efficiency, percent			
		Power processor system testing	Transmitter experiment package testing	Spacecraft thermal vacuum testing	Contract specification
Collector:					
2	2 246.3	±0.19	-----	-----	±3
3	3 370.4	±.04	-----	-----	
4	4 488.7	±.1	±0.34	±0.9	
5	5 612.4	±.11	±.25	±.35	
6	6 736.4	±.19	-----	-----	
7	7 858.1	±.12	±.20	±.5	
8	8 981.0	±.19	-----	-----	
9	10 099.0	±.16	-----	-----	
Cathode and collector 10	11 214.8	±.17	±.17	±.25	±1
Anode	247.74	±.16	±.09	±.20	±3

TABLE XI. - POWER PROCESSOR SYSTEM VOLTAGE RIPPLE

[For transmitter experiment package and spacecraft thermal vacuum testing, no interference signals were detected at power processor system switching frequencies in radio-frequency output of output stage tube.]

	Efficiency, percent	
	Power processor system	Contract specification
Collector:		
2	0.156	2
3	.191	
4	.208	
5	.213	
6	.217	
7	.208	
8	.223	
9	.394	
Cathode and collector 10	.0089	.01
Anode	.282	.5

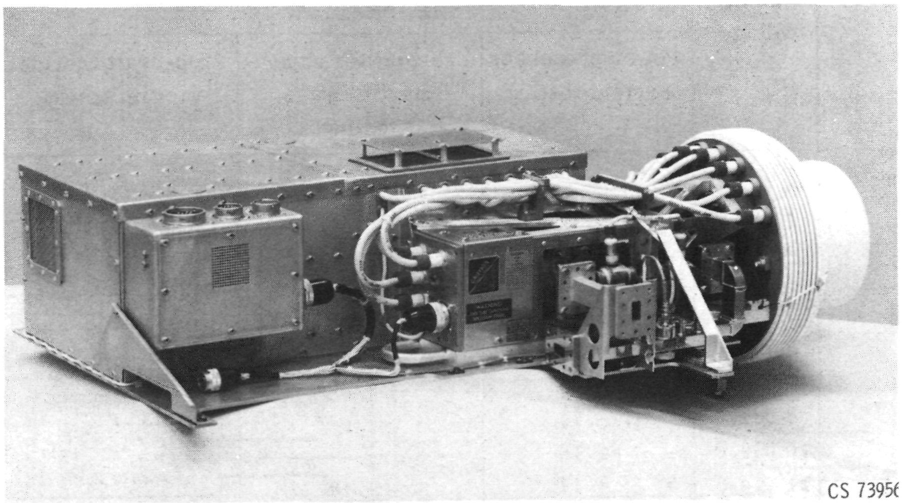


Figure 1. - Transmitter experiment package for Communications Technology Satellite. Radiofrequency output: 200 watts, 12 gigahertz, 30-decibel gain, and 85-megahertz bandwidth. Direct current input: 540 watts. Tube: efficiency, 42 to 48 percent; weight, 13.2 kilograms. Power system: efficiency, 89 percent; weight, 13.3 kilograms.

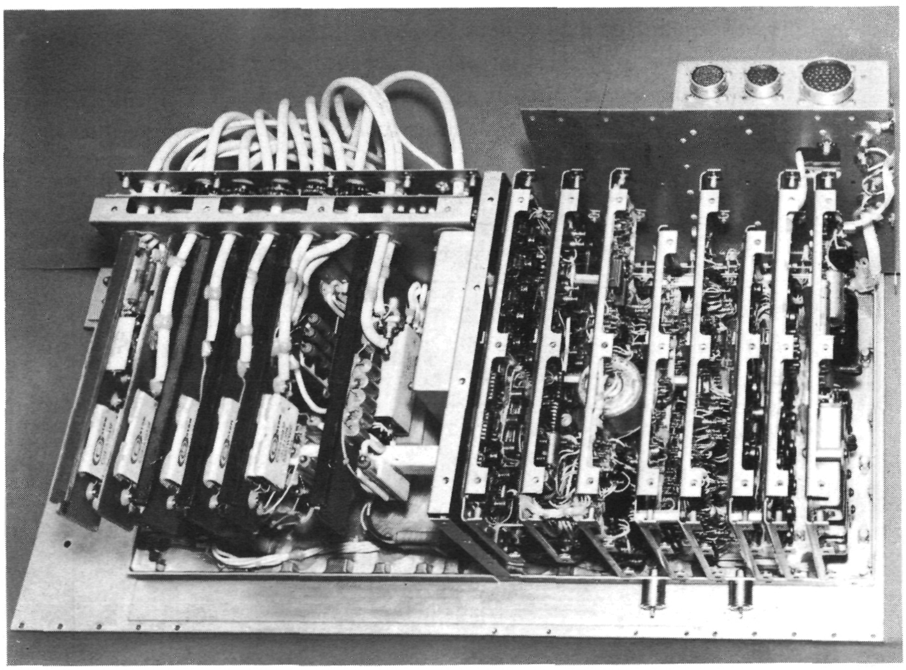


Figure 2. - Power processor system internal configuration.

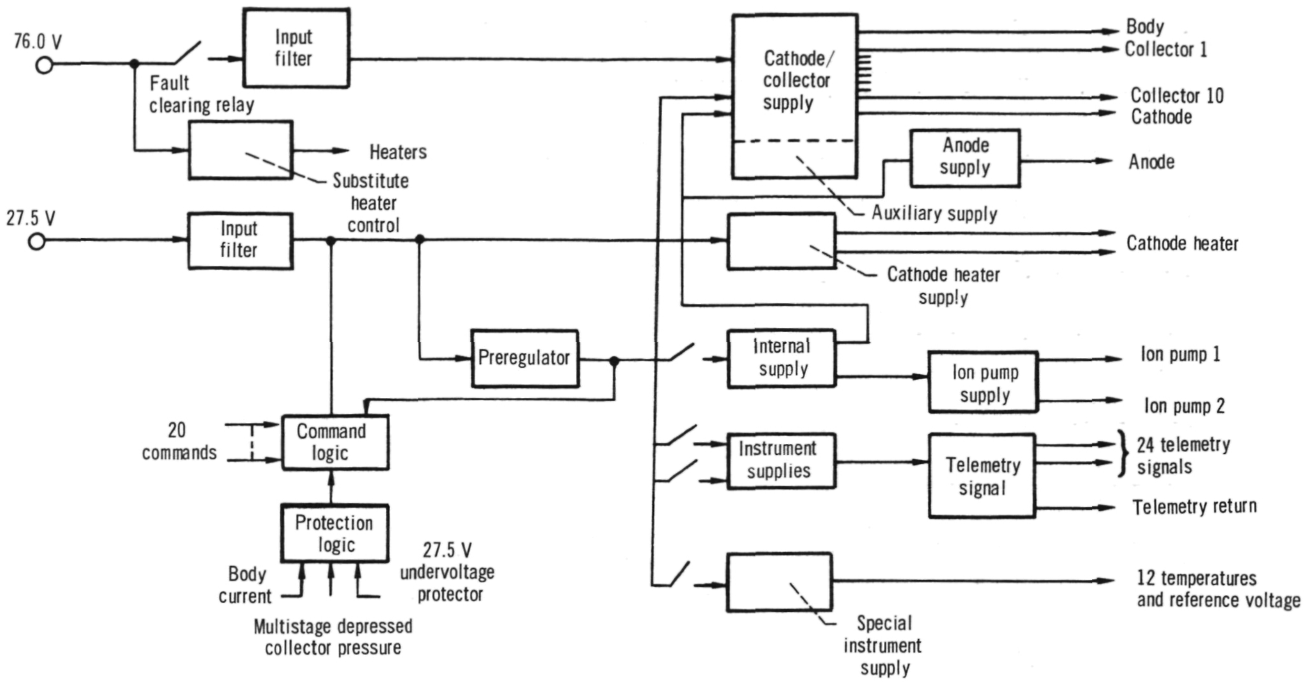


Figure 3. - Block diagram of power system.

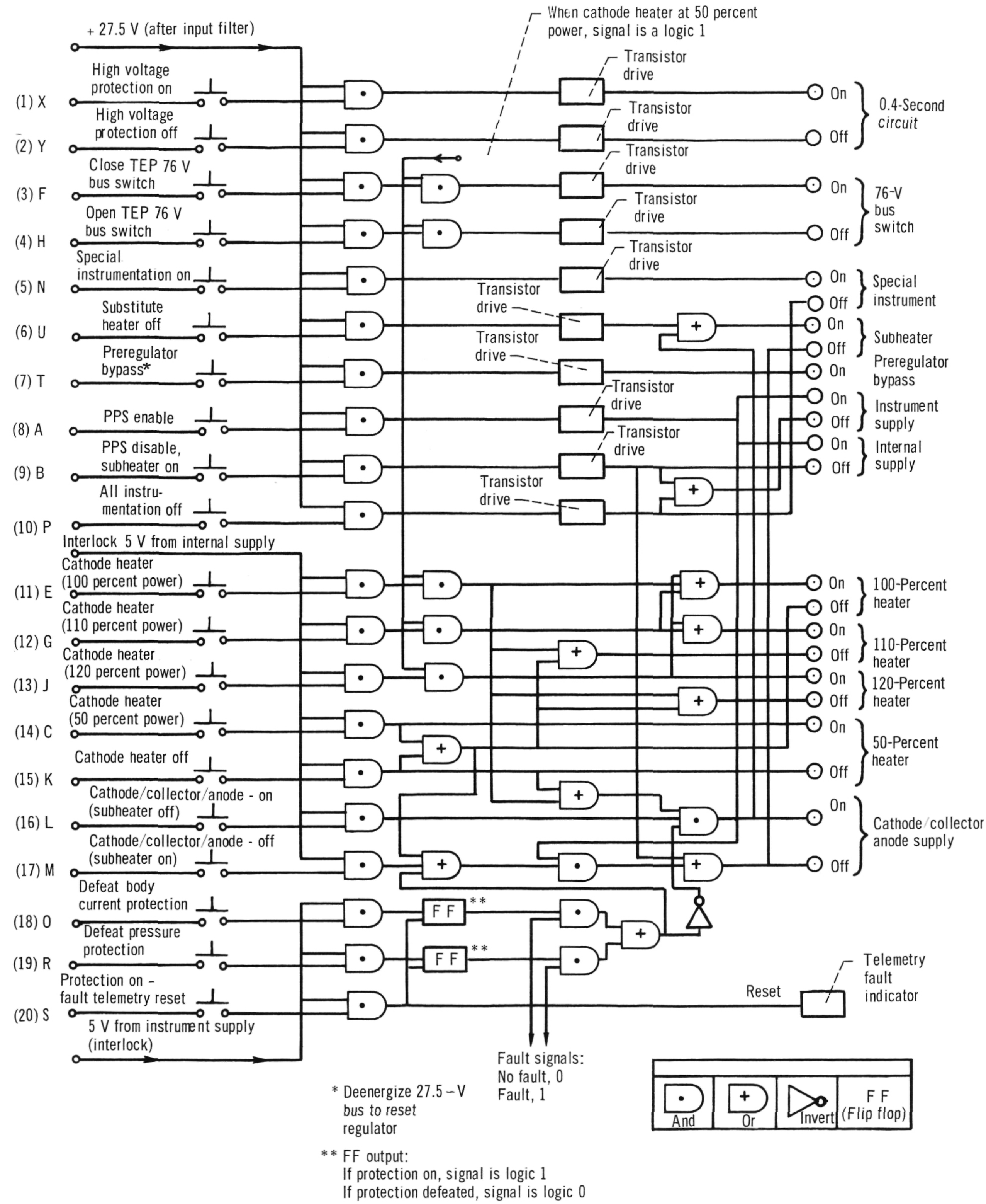


Figure 4. - Simplified command logic drawing for qualification flight PFS - TEP.

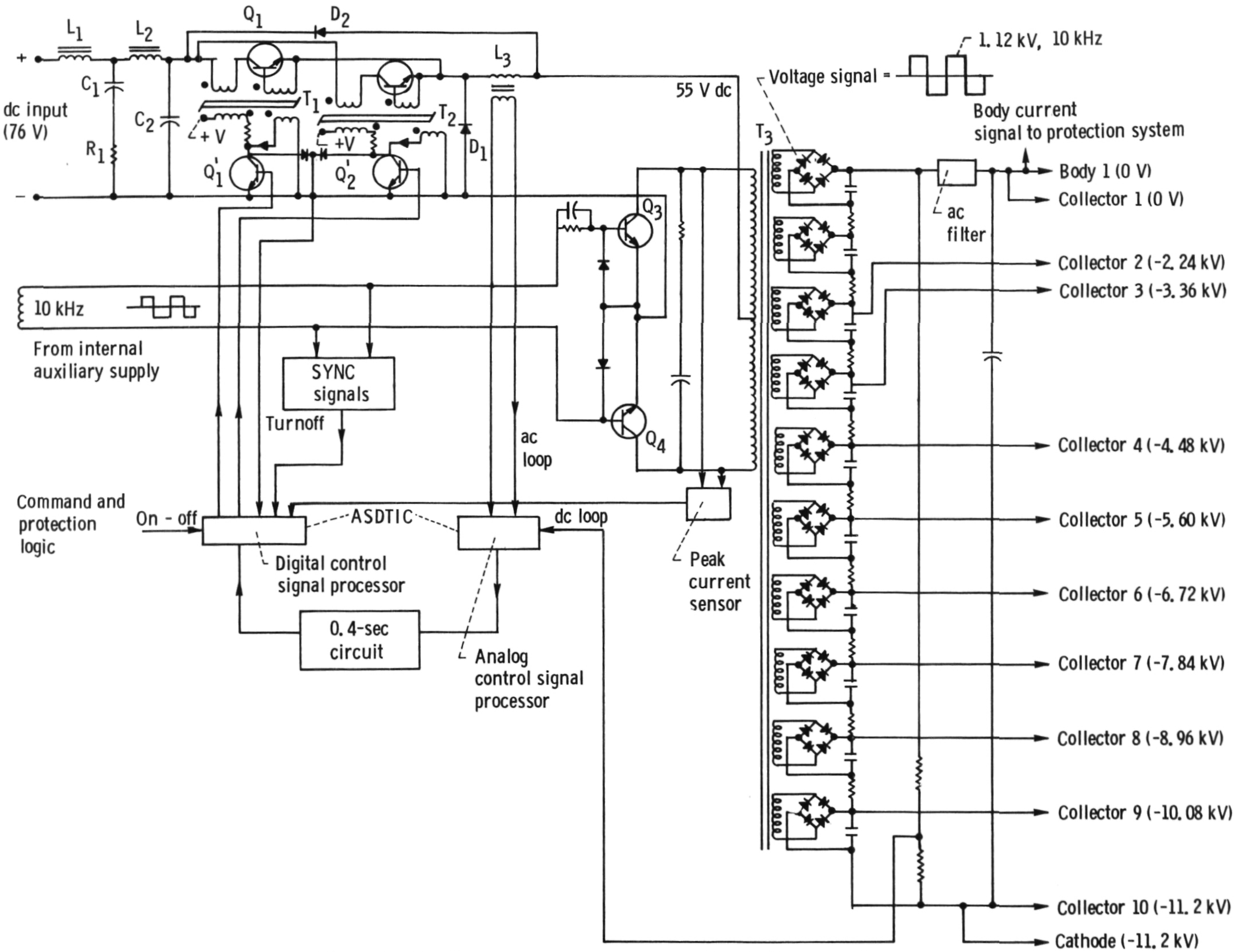


Figure 5. - Simplified power processor system cathode/collector supply.

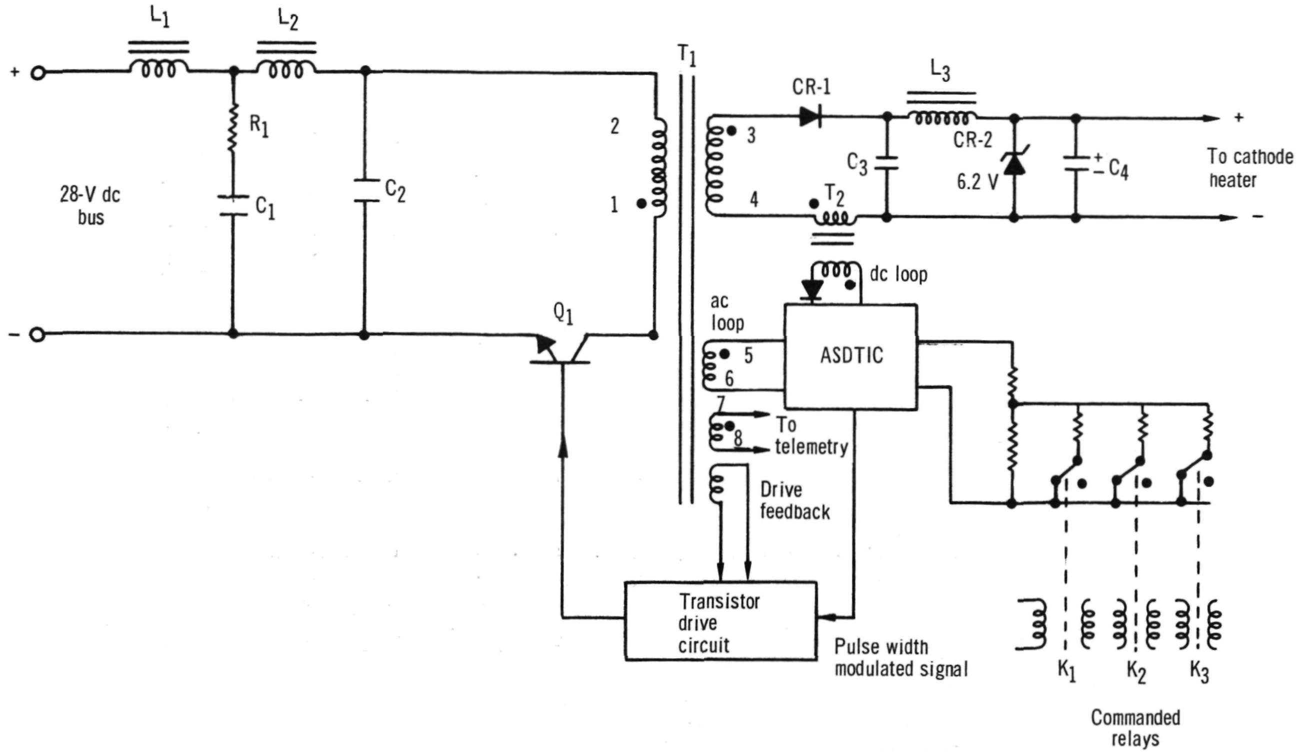


Figure 6. - Simplified power processor system cathode heater supply.

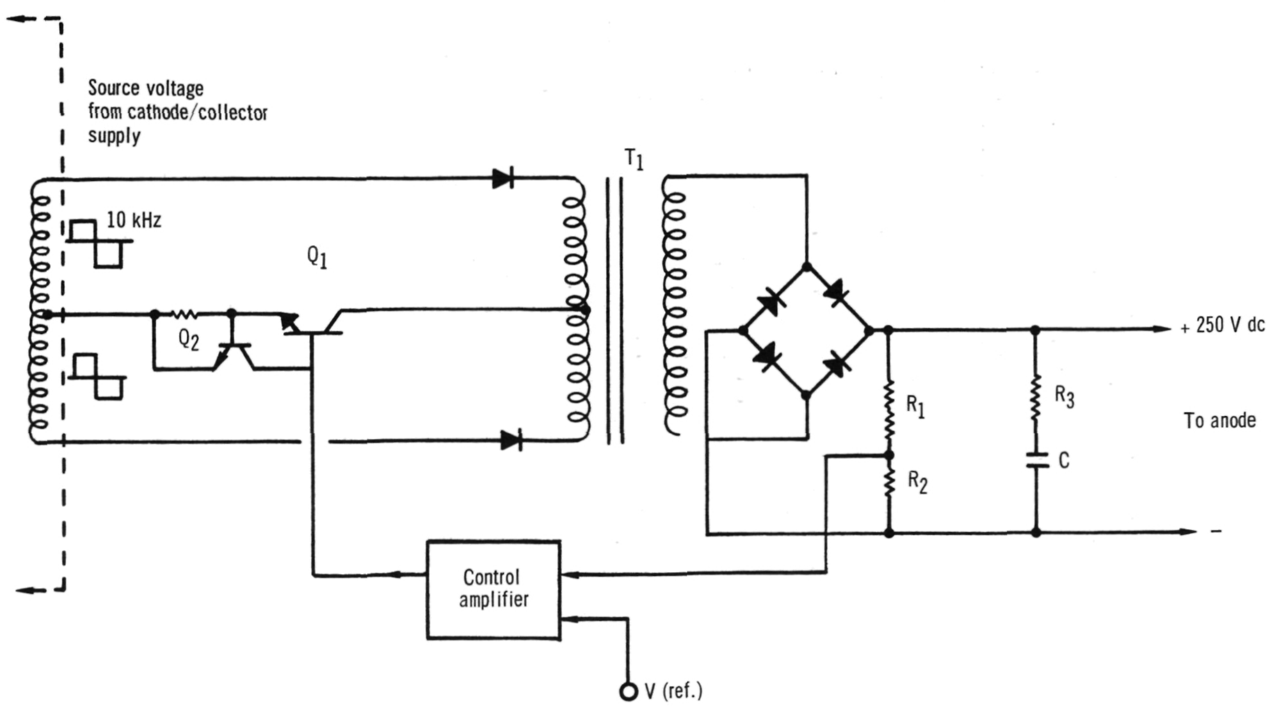


Figure 7. - Anode supply.

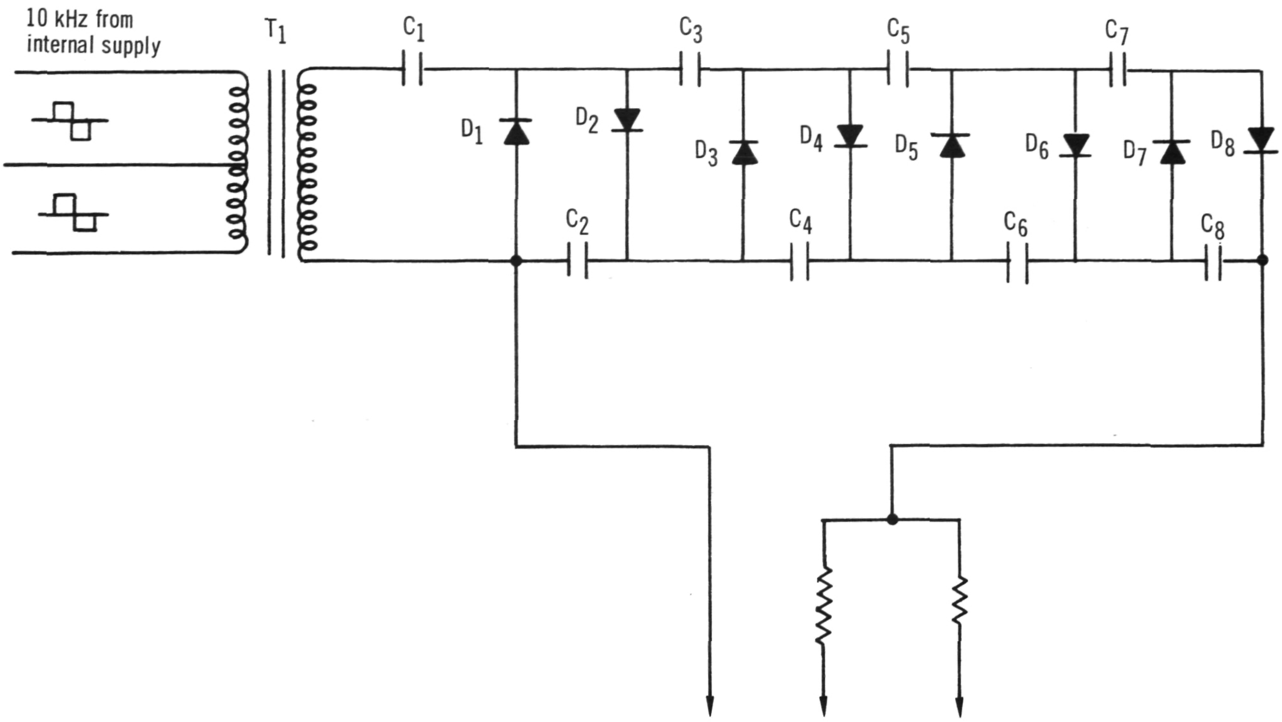


Figure 8. - Ion pump supply.

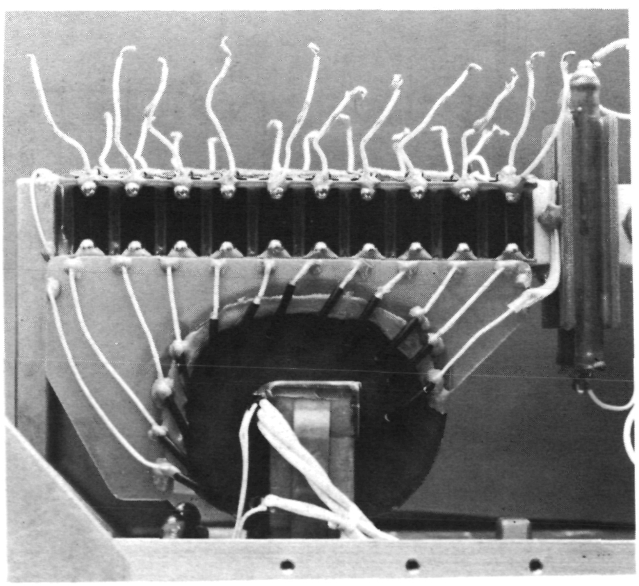


Figure 9. - High voltage transformer.

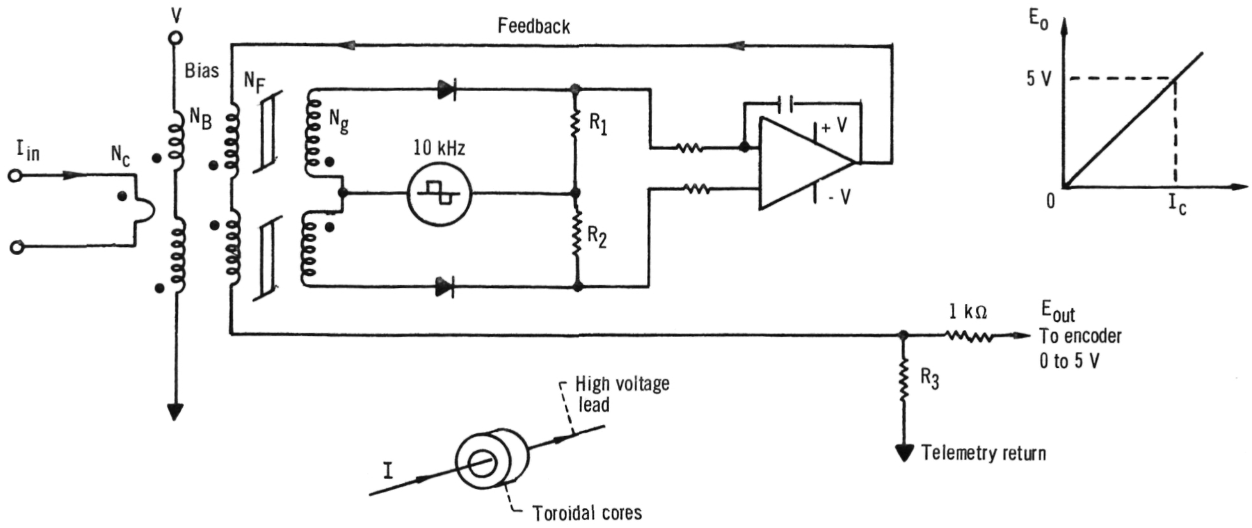


Figure 10. - Current monitor for high voltage circuits.

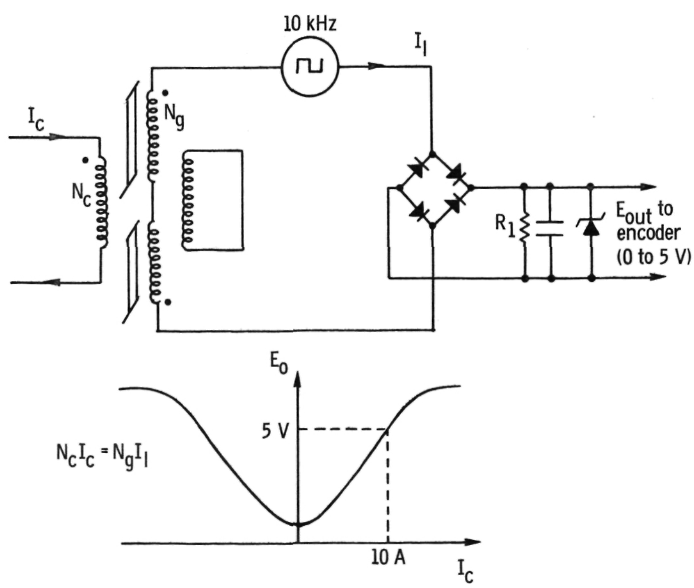
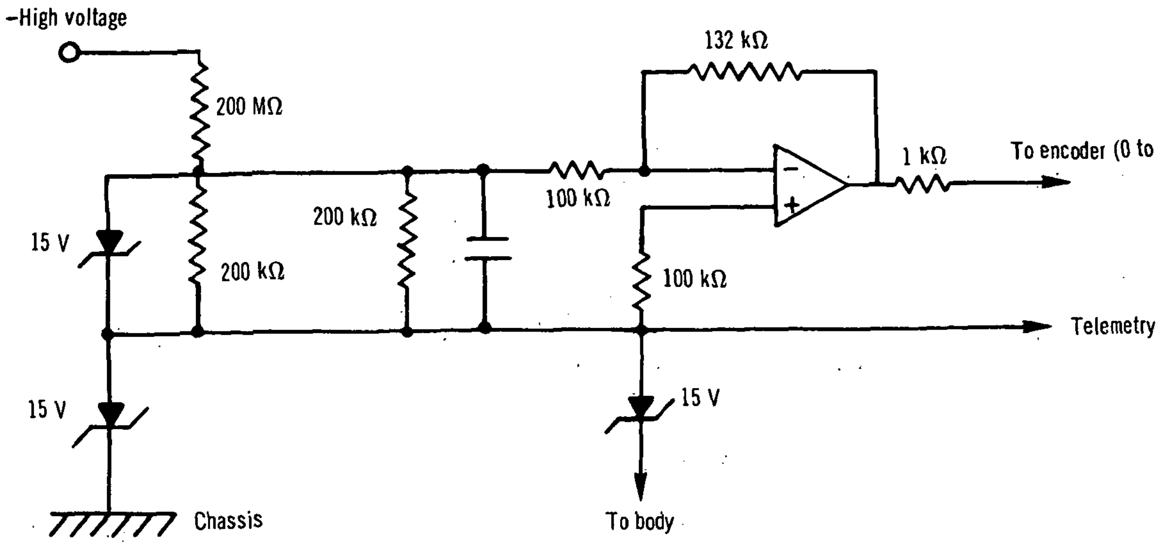
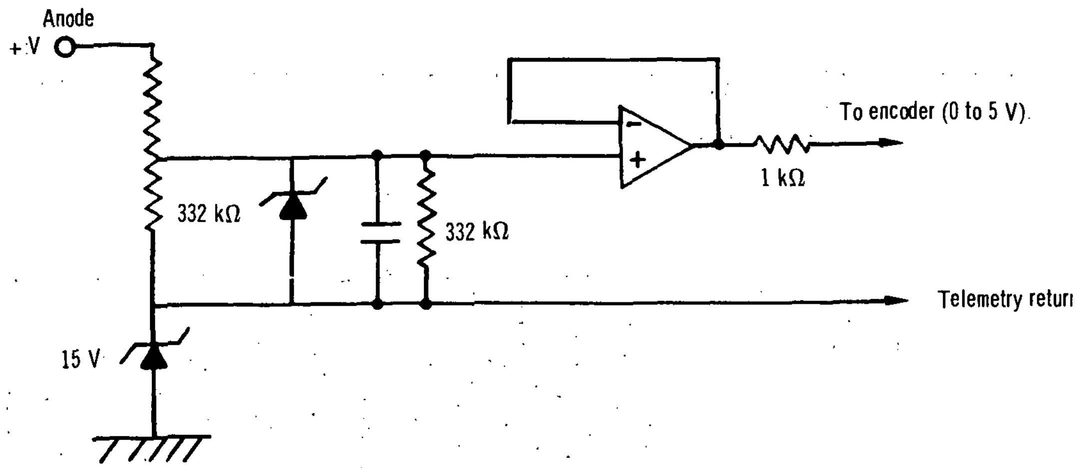


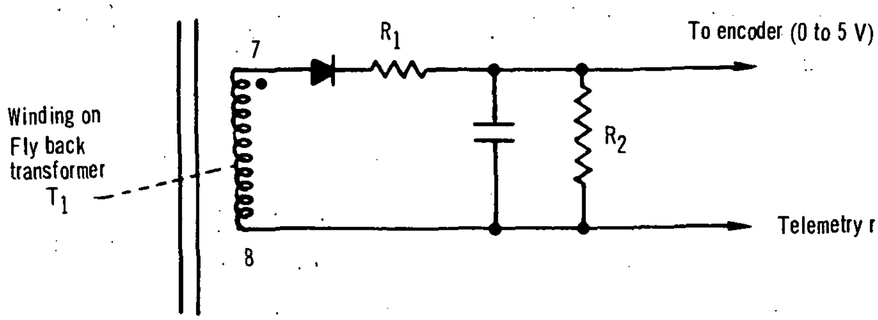
Figure 11. - Current monitor for low voltage circuits.



(a) High voltage monitor.



(b) Anode voltage monitor.



(c) Cathode heater voltage monitor.

Figure 12. - Voltage monitors.

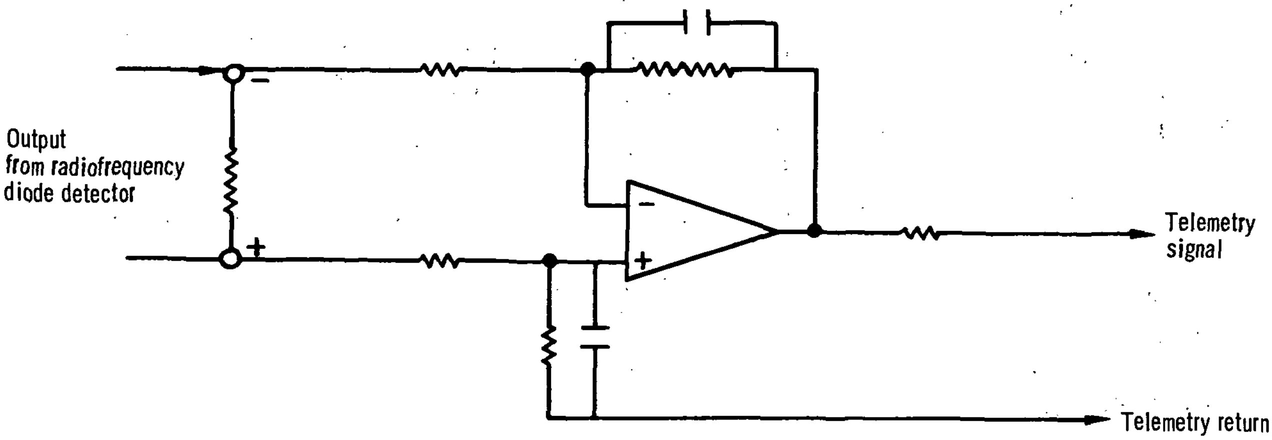


Figure 13. - Radiofrequency power monitor.

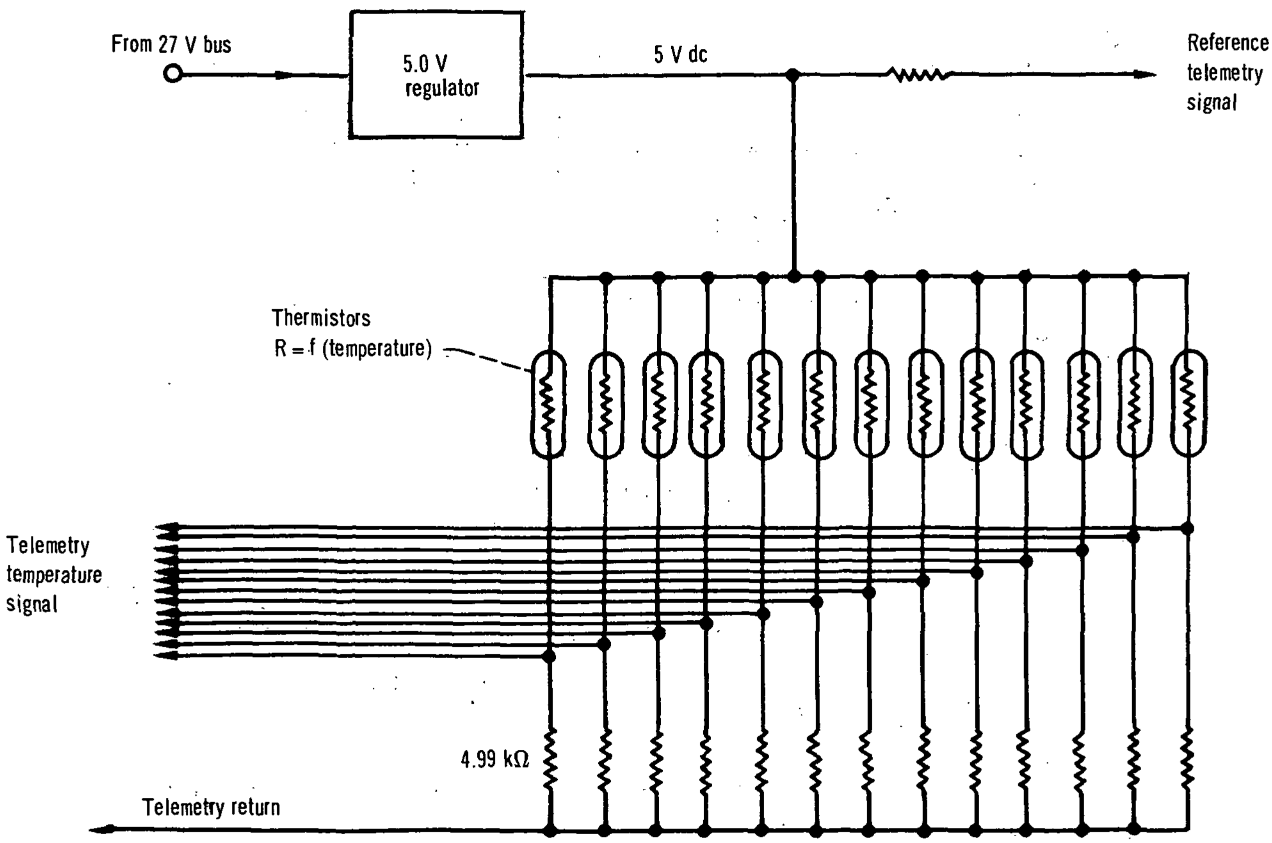


Figure 14. - Temperature monitors.

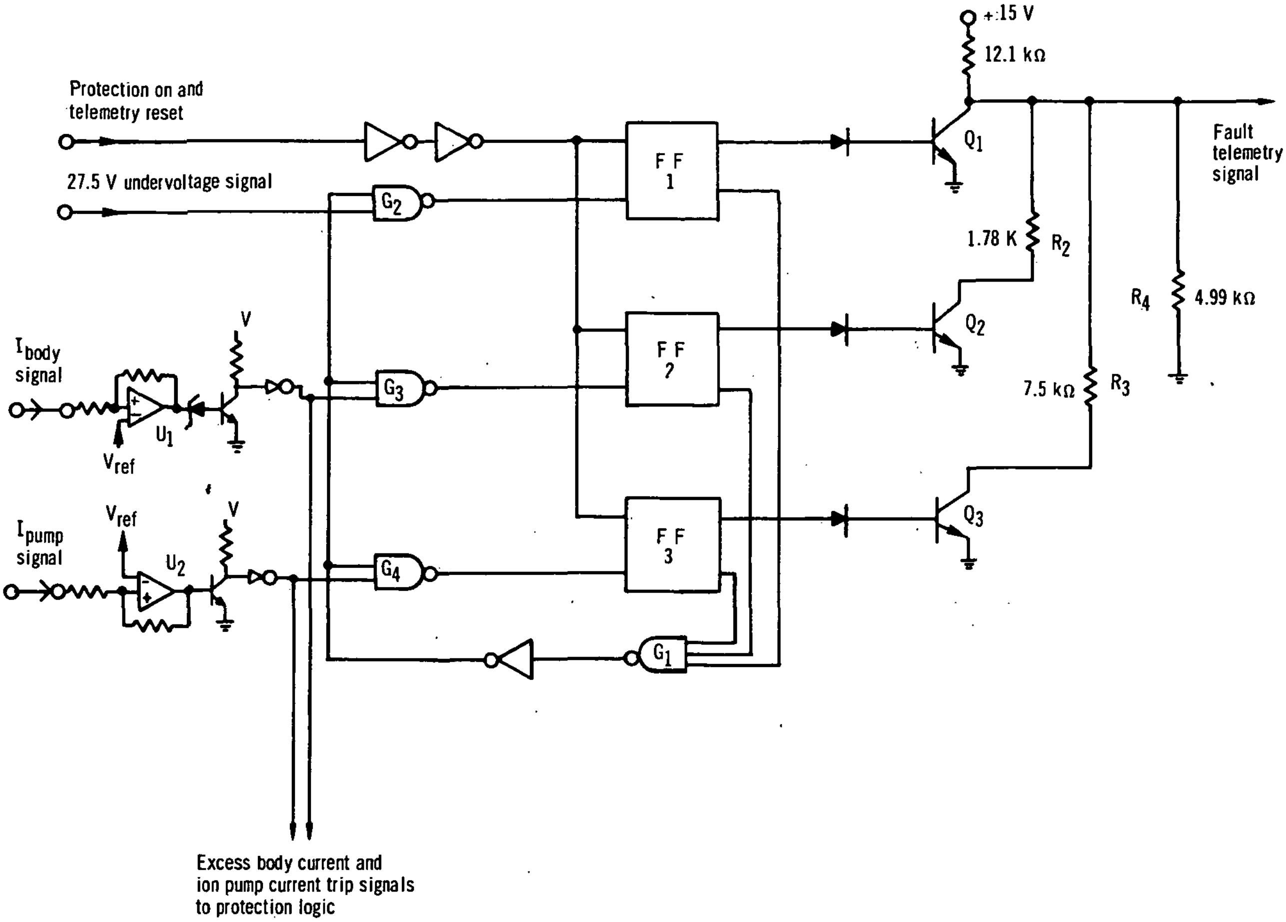


Figure 15. - Fault indicator.

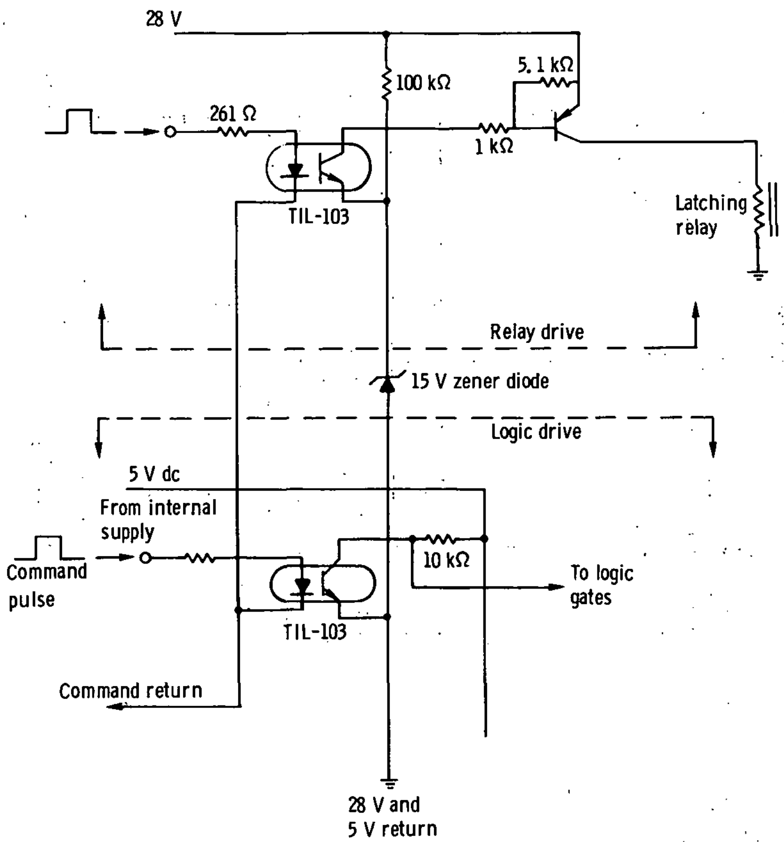


Figure 16. - Command drive circuits.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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