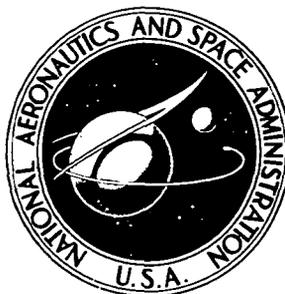


**NASA TECHNICAL  
MEMORANDUM**



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**NASA TM X-3455**

**TEST PROGRAM FOR TRANSMITTER  
EXPERIMENT PACKAGE AND HEAT PIPE  
SYSTEM FOR THE COMMUNICATIONS  
TECHNOLOGY SATELLITE**

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# TEST PROGRAM FOR TRANSMITTER EXPERIMENT PACKAGE AND HEAT PIPE SYSTEM FOR THE COMMUNICATIONS TECHNOLOGY SATELLITE

by James F. DePauw, Karl F. Reader, and John V. Staskus

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## SUMMARY

The Communications Technology Satellite (CTS)<sup>1</sup> program is a joint program of the United States and Canadian Governments. The CTS was launched on a Delta 2914 launch vehicle on January 17, 1976, from NASA Kennedy Space Center, Florida. It was placed in a geosynchronous orbit 35 786 kilometers (22 300 miles) above the equator off the west coast of South America at 116° west longitude.

An important advancement incorporated in CTS that sets it apart from earlier communications satellites is its transmitting power level. The transmitting power of 200 watts is 10 to 20 times higher than the power of satellites now in use. Thus, smaller and less-expensive ground receiving equipment can be used.

This report describes the test program for the 200-watt transmitter experiment package (TEP) and the variable conductance heat pipe system (VCHPS) as components and on the spacecraft in preparation for launch. The test program consisted of qualification tests to demonstrate design adequacy, acceptance tests to expose latent defects in the proposed flight hardware, and development tests to integrate the hardware into systems and to improve confidence in the adequacy of the equipment to perform the mission. The vibration and thermal vacuum tests performed on various system elements are summarized.

The actual test program was not as straightforward as planned because of problems that developed; however, all elements of the TEP/VCHPS were qualified by testing either as complete subsystems or as components.

Although qualification and acceptance tests of advanced communications satellite subsystems are required before flight, they are not sufficient. Supplemental development and confidence testing are needed to provide an early demonstration of compatibility among various systems and confidence in hardware adequacy.

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<sup>1</sup>In Canada, CTS was renamed "Hermes" on May 20, 1976.

## INTRODUCTION

The Communications Technology Satellite (CTS) program is a joint program of the United States and Canadian Governments. Canada developed the spacecraft. NASA provided the high-power transmitting tube for the spacecraft, performed environmental testing, and provided the launch vehicle and launch services. The CTS was launched on a Delta 2914 launch vehicle on January 17, 1976, from NASA Kennedy Space Center, Florida. It was placed in a geosynchronous orbit 35 786 kilometers (22 300 miles) above the equator off the west coast of South America at 116<sup>0</sup> west longitude. The communications experiment time made available by the orbiting spacecraft is shared equally between United States and Canadian user experiments.

A unique advantage of CTS is its 200-watt transmitting power, which is 10 to 20 times the power of satellites now in use. Thus, smaller and less-expensive ground receiving equipment can be used. This is a particularly attractive advantage for service to isolated areas, where other forms of communication are not highly developed.

The development, qualification, and acceptance tests on the 200-watt transmitter experiment package (TEP) and the variable conductance heat pipe system (VCHPS) are described in this report. The TEP and VCHPS were tested both as components and on the spacecraft in preparation for launch.

## DESCRIPTION OF HARDWARE AND SPECIAL TEST PROBLEMS

The TEP/VCHP system and the space it occupies on the spacecraft south panel are shown schematically in figure 1. The TEP is composed of an output stage tube (OST) and a power processing system (PPS). The OST is the 12-gigahertz radiofrequency amplifier capable of 200-watt output. The PPS provides power and control to operate the OST. The VCHPS has its evaporator saddle mounted beneath the OST baseplate so that the heat dissipated by the OST can be transported to a radiator fin mounted external to the spacecraft for rejection to space.

### Output Stage Tube

The OST is shown schematically in figure 2. It is composed of a coupled-cavity, traveling wave tube (TWT) and a multistage depressed collector (MDC). An 850-watt electron beam is produced in the cathode-anode structure of the gun and is focused by permanent magnets down the 0.127-centimeter (0.050-in.) diameter beam hole. A low-level radiofrequency signal is introduced at the input waveguide, where it is propagated through the coupled-cavity, slow-wave structure and interacts with the electron beam.

The input signal is amplified, and a high-level output signal is available at the output waveguide.

After the electron beam passes the radiofrequency output port, it enters the refocusing region where permanent magnets focus the beam to provide controlled beam conditions for entry into the collector. In the collector, the residual kinetic energy of the beam is converted to potential energy as the electrons are slowed by electric fields. Collecting electrons at low velocity reduces the total energy requirement of the OST and improves its efficiency above that of a TWT without an MDC (ref. 1). Table I summarizes some characteristics of the OST. Figure 3 shows an OST in the flight configuration.

### Power Processing System

The PPS provides power and control to the OST by processing power from the spacecraft's 28- and 76-volt direct-current power buses to OST operating voltages. It controls OST operations in response to 22 commands from the spacecraft's command system. It conditions 37 data channels with OST/PPS data and provides 0- to 5-volt signals for input to spacecraft telemetry. It also protects the OST by providing automatic shut-down of the OST in case of low input voltages, excess body current, excess pressure in the tube, arcs, or overloads. The PPS also contains a substitute heater that is turned on to dissipate heat into the TEP baseplate at times when the OST is turned off. This prevents violation of PPS minimum temperature requirements during nonoperational periods. The PPS is shown in figure 4 and the flight configuration hardware in figure 5. A simplified electrical power schematic of the OST/PPS power interface is shown in figure 6. More detail of the PPS is contained in reference 2.

### Heat Pipe System

The VCHP system and its relation to the spacecraft south panel are shown pictorially in figure 7 along with thermal inputs. Figure 8 depicts the CTS spacecraft, with the VCHPS fin shown forward of the south panel.

The VCHPS thermally connects the TEP baseplate with a space radiator subassembly. Effective thermal conductance is varied over a wide range from the full-on design condition to the heat-pipe-off condition. Control over the thermal conductance is achieved passively and does not require a feedback control system. Redundancy is incorporated in the system by using three heat pipes in the heat pipe subassembly, any two of which can transport the total design load of 196 watts.

The heat pipe subassembly consists of three stainless steel pipes, an evaporator saddle under the OST baseplate, condenser saddles on the radiator, and gas reservoirs. The gas-loaded, grooved, arterial heat pipes use methanol as the working fluid. They are described in detail in reference 3. The diametral, homogeneous metal-felt wick and multiple arteries parallel to the heat pipe axis are used as an axial fluid flow wicking system to return the methanol from the condenser sections to the evaporator. Variable conductance is achieved by allowing the noncondensable gas (90 percent nitrogen, 10 percent helium) to expand from a cold, wicked reservoir to reduce the available radiator area under low heat and load conditions. Figure 9 shows the performance characteristics of the VCHPS with one heat pipe failed for equinox and summer solstice conditions. Up to 196 watts can be transported and rejected from the radiator at an evaporator temperature of 50<sup>0</sup> C (122<sup>0</sup> F), and less than 3 watts will be rejected at 28<sup>0</sup> C (82<sup>0</sup> F) or below.

Because of gravity, heat pipes do not function in all VCHPS orientations during ground tests. To overcome this test restriction, the VCHPS evaporator saddle was designed to contain a ground-test coolant tube (fig. 1). Temperature-controlled fluid could be passed through this tube to heat or cool the OST baseplate as needed during ground tests.

### Special Test Problems and Hazards

The TEP testing was challenging because of two inherent features of operation. These were (1) strong radiofrequency fields that were produced by 200 watts of radiofrequency power; and (2) the high voltages present in the TEP, namely, -11.2 and +3.5 kilovolts.

Each test setup conformed to the Lewis Research Center high-voltage-testing safety requirements, which normally included roping off the test area with barricades and installing flashing warning lights. The radiofrequency waveguide systems were checked for radiation leakage after each installation or reconfiguration to ensure safe levels. Special radiofrequency-absorbing material was used when open-loop radiation testing was necessary.

### PHILOSOPHY OF TEST PROGRAM

In the TEP/VCHPS development, tests were conducted on the various subsystems as well as on the assembled spacecraft. Figure 10 indicates the major subsystem elements and the stages at which tests were performed in preparation for spacecraft integration. Most of these tests belonged to one of three categories: (1) qualification tests,

(2) acceptance tests, and (3) development tests. Qualification tests were performed to subject flight-representative hardware to test stress levels in excess of expected flight levels in order to demonstrate design adequacy and some safety margin. Flight acceptance tests were performed on flight-candidate hardware to stress levels above flight levels (but below qualification levels) to expose latent workmanship defects. Development tests were performed in order to gather engineering data to evaluate or improve the design, to determine hardware capabilities, and to demonstrate compatibility among several system elements.

The TEP/VCHP subsystem test program complemented the total spacecraft test program in which the TEP/VCHPS was one element of the super high frequency (SHF) system. At the spacecraft level, a protoflight concept was adopted. No prototype (or qualification) spacecraft was planned. The flight spacecraft with flight components installed would be subjected to a qualification test program and subsequently the same hardware would be flown. The TEP/VCHPS flight hardware would be installed on the protoflight spacecraft for the total system qualification and flight acceptance testing. In addition, the TEP/VCHPS qualification hardware would be qualified on a component basis by testing flight-type hardware to the qualification environment levels.

Table II lists the serial numbers (S/N) of the principal hardware items used in the TEP/VCHPS test program. Figures 11 and 12 are flow charts that show the TEP and VCHPS test programs, respectively, and indicate the categories of development, qualification, and flight acceptance activities. In the interest of readability, only the more significant integration and test activities are shown. Several lesser efforts to overcome specific problems are discussed in detail in the following paragraphs but are not shown in the figures.

At the outset, the program plan was much simpler than the plan that was finally executed. Provisions were originally made for some engineering model hardware upon which to perform development tests and that would support engineering model spacecraft tests. Qualification hardware was included for component qualification tests. Flight and flight backup hardware was included, which, when acceptance tested on a component basis, would be ready for integration on the protoflight spacecraft. In the process of execution, the test program plan was complicated by technical problems and an inability to produce the quantity of usable OST's in the time required. As an example, OST 2025, near the bottom of figure 11, was first flight-acceptance tested as a flight backup. It was then needed to perform thermal vacuum qualification of the OST (since the qualification model was not available). And finally OST 2025 was integrated with the flight backup PPS to become the flight backup TEP.

Another example of a complicating factor can be seen in figure 12. The VCHPS EM001 was subjected to qualification vibration and thermal vacuum testing. It was later realized after qualification vibration testing of the engineering spacecraft that the VCHPS vibration environment was more severe than originally specified. VCHPS qualified status

was then reestablished based on a vibration test on the spacecraft supplemented with individual tests on pieces of the system that had been redesigned.

The test program based on the philosophy just stated, and acknowledging that problems occurred to complicate the testing beyond the original plan, is now described.

## QUALIFICATION TEST PROGRAM

Component qualification tests were performed on hardware representative of flight hardware in order to demonstrate the adequacy of the hardware design. A final system qualification was accomplished with the flight TEP/VCHPS as a subsystem on the proto-flight spacecraft during the spacecraft qualification test program. Both qualification activities are summarized in this section.

### Qualification Requirements

Component qualification vibration requirements are summarized in table III. The same environment was specified for the OST, PPS, TEP, and/or VCHPS when they were tested at the component level. Vibration qualification of the TEP/VCHPS on the spacecraft system level was accomplished on the engineering spacecraft when that spacecraft with representative TEP/VCHPS hardware installed was subjected to a vibration environment 1.5 times the flight environment. The same TEP/VCHPS hardware was required to endure shock on the engineering spacecraft when the pyrotechnic release systems were activated.

Final vibration qualification was required on the protoflight spacecraft with the flight TEP/VCHPS installed. Sinusoidal vibration tests were required at 1.2 times flight level, and random vibration tests were required at 1.5 times flight level. Separate tests were also required that subjected the spacecraft to separation shock of the launch vehicle adapter and the solar array deployment.

Table IV summarizes the qualification and acceptance temperature requirements and the VCHPS thermal dissipations for component and system qualification on the spacecraft. For reference, worst-case flight predictions for temperatures are shown. Since the VCHPS is a nearly constant-temperature device when operating in the range between turn-on and full-on conditions, VCHPS requirements are defined by heat transport capability rather than by temperature.

## Component Qualification of Power Processing System

The PPS (exclusive of the high-voltage output transformer) was qualified on the basis of tests performed on the S/N QF01 unit. The high-voltage transformer in that PPS was of the same design as the flight units but had been potted with a different polyurethane compound. The transformer was qualified as a component on the basis of tests performed on the S/N 003 transformer, which has the same polyurethane as the flight transformers. The high-voltage transformer is shown in figure 13.

Power processing system tests. - The configuration of the PPS (S/N QF01) used for the qualification tests had the following deviations from the flight model:

- (1) Transformer potting material was a different polyurethane.
- (2) Substitute (nonscreened, burned in) parts were used for 12 transistors, 2 capacitors, and 5 logic parts.
- (3) Ion pump voltage was about 2700 volts as compared with 3500 volts on the flight unit because of a minor circuit revision.
- (4) Substitute heater wire routing did not go through the 76-volt bus current sensor.
- (5) Current sensor ranges on collectors 8 and 9 were 0 to 25 milliamperes as compared with 0 to 40 milliamperes on the flight models.
- (6) The high-voltage protection circuitry on QF01 could not be defeated and reinstated by command.

The PPS QF01 was subjected to qualification sine and random vibration testing in three axes. The only failure was a wire that broke at a termination because of a workmanship defect. It was repaired and thermal vacuum testing started. The first attempt at thermal vacuum testing was terminated because the PPS had low efficiency at elevated temperatures. This problem was traced to power transistors that had slower switching speed than required and dissipated more heat than the design allowed. In addition, the thermal design of the transistor installation was marginal. The transistor installation was redesigned and transistors were replaced.

At the time the transistor thermal problem was being investigated, thermocouples had been placed on the high-voltage-output transformer (S/N 008). Transformer temperatures were higher than expected and this was traced to a manufacturing defect. X-ray photographs disclosed that the mating parts of the core and the mounting bracket were not properly aligned. One-half of the core may have been damaged before transformer manufacture. It was at this point that the transformer that started qualification testing in the PPS was replaced by a transformer that had been potted with material other than the flight material. This precipitated the need to qualify the transformer as a component. As a prelude to continuing the PPS qualification, a thermal vacuum confidence test of the PPS was performed in which the PPS transformer baseplate reached equilibrium at 76° C (169° F) at the end of a  $3\frac{1}{2}$ -hour stabilization test. (As shown in table IV, the worst-case flight prediction for the transformer baseplate temperature is 56° C

(133° F), the acceptance value is 60° C (140° F), and the qualification value is 65° C (149° F).)

Qualification testing of the PPS continued with a repeat of the random vibration test in three axes to qualification levels with no anomalies. A thermal vacuum test was conducted over the qualification range of -10° to +65° C (14° to 149° F) transformer base-plate temperature.

To conclude the PPS qualification test program, the PPS was integrated with OST 2025 and a thermal vacuum cycling test was performed. That test concluded with an accumulation of 27 days in vacuum, including 16 thermal cycles between -10° and +60° C (14° to 140° F) plus two thermal cycles between -20° and +60° C (-4° to 140° F). An anomaly occurred during the first attempt to achieve high temperature. The cathode heater current increased to an out-of-specification value. The problem was a workmanship defect in which some terminals had been crimped into circuit boards but had not been soldered. The problem was corrected on PPS QF01 and the thermal cycling test was then completed with no further PPS difficulties.

High-voltage-transformer component tests. - Transformer 003 used for transformer component qualification deviated from flight transformers as follows:

- (1) The leads emerged from the transformer in a different "clocking" than in the flight model.
- (2) The interwinding insulation material was preshrunk before installation.
- (3) The potting material was cracked before the qualification test program was begun.

Transformer 003 component qualification consisted of thermal cycling and prolonged operation at elevated temperature. Periodic corona tests were made to detect deterioration. When the transformer baseplate was at the 60° C (140° F) acceptance value, the temperature of the innermost secondary winding was 104° C (220° F). This is the temperature of the interwinding insulation material. Its published useful life is a temperature-dependent relation that is a straight line on a log-log plot of time versus temperature. Analysis of the predicted time versus temperature of the transformer baseplate during the 2-year mission in space can be equated to 1320 hours at 104° C (220° F) on the innermost winding. The transformer was tested between 104° and 116° C (220° to 240° F) for a time equivalent of over 2000 hours at 104° C (220° F). From this accelerated life test, it was concluded that the insulation system would be adequate for the mission. In addition to the time at temperature, the transformer was cycled from -20° to 110° C (-4° to 230° F) for 17 cycles with no anomalies or increase in corona level.

## Component Qualification of Output Stage Tube

The OST component qualification test consisted of a vibration test of OST 2023 and a thermal vacuum test of OST 2025 as a part of TEP QF01. The thermal vacuum test of OST 2025 was repeated on an OST subsystem.

OST 2023 vibration test. - The configuration of OST 2023 was representative of flight models except for the following deviations:

- (1) The collector jacket had a circumferential weld.
- (2) Some high-voltage leads inside the collector were spliced and welded as a result of insulator replacement.
- (3) The bellows was punctured and welded shut.
- (4) A sever cavity was crimped to secure a loose sever.
- (4) The tube had a radiofrequency short in the output section; therefore, operation was only permitted at 10 watts of output power.

The OST was sine and random vibration tested to qualification levels in three axes. After the first axis qualification sine test, it became apparent that the ion pump support brackets were inadequate. The design was changed and new brackets were installed. The remaining qualification vibration tests were completed and no degradation due to vibration of the OST was noted. A repeat of the first axis test was felt to be unnecessary because it was the least severe environment for the ion pump brackets.

OST 2025 thermal vacuum test. - OST 2025 was identical in configuration to the flight model. It was a flight backup unit and also performed as a vehicle for OST thermal vacuum qualification. It was therefore subjected to flight-acceptance vibration and thermal vacuum testing before qualification thermal vacuum testing as part of TEP QF01. The flight-acceptance program began by subjecting the OST to three thermal cycles over the temperature range  $0^{\circ}$  to  $45^{\circ}$  C ( $32^{\circ}$  to  $113^{\circ}$  F). (Worst-case flight predictions are  $0^{\circ}$  to  $48^{\circ}$  C, or  $32^{\circ}$  to  $118^{\circ}$  F). This was followed by three-axis sine and random vibration testing to flight levels. Following the vibration test, the OST body current increased about 2 milliamperes for saturated-output, center-band-frequency,  $45^{\circ}$  C ( $113^{\circ}$  F) base-plate conditions. Since the OST could still be operated at 4.1 decibels overdrive, no action was taken.

The flight-acceptance thermal vacuum testing was concluded after vibration with one thermal cycle from  $0^{\circ}$  to  $45^{\circ}$  C ( $32^{\circ}$  to  $113^{\circ}$  F), seven thermal cycles from  $0^{\circ}$  to  $48^{\circ}$  C ( $32^{\circ}$  to  $118^{\circ}$  F), and one thermal cycle over the flight acceptance range of  $-5^{\circ}$  to  $53^{\circ}$  C ( $23^{\circ}$  to  $127^{\circ}$  F). No performance degradation due to thermal vacuum testing was observed during these 12 thermal cycles.

After this flight-acceptance testing, the OST was integrated with PPS QF03, and tested in air as a flight backup unit. Upon delivery and integration of the flight hardware to the spacecraft, OST 2025 was removed from PPS QF03 and was integrated with PPS QF01 for TEP qualification thermal vacuum testing.

In the TEP qualification test, OST 2025 could only be operated to power levels of 1 decibel below saturation during hot conditions. This was partially due to the PPS QF01 voltages being set somewhat higher (150 V more cathode-to-anode potential) than they were in the OST flight-acceptance tests. In the TEP thermal vacuum tests, the OST was subjected to an additional 18 thermal cycles. Two of the cycles were over the qualification range of  $-10^{\circ}$  to  $58^{\circ}$  C ( $14^{\circ}$  to  $136^{\circ}$  F). Nine of the cycles were over the worst-case flight prediction range of  $0^{\circ}$  to  $48^{\circ}$  C ( $32^{\circ}$  to  $118^{\circ}$  F). Five of the cycles were from  $0^{\circ}$  to  $45^{\circ}$  C ( $32^{\circ}$  to  $113^{\circ}$  F). Two of the cycles were for  $0^{\circ}$  to  $34^{\circ}$  and  $42^{\circ}$  C ( $32^{\circ}$  to  $93^{\circ}$  and  $108^{\circ}$  F), respectively. No measurable degradation of the OST performance occurred as a result of the TEP thermal vacuum exposure.

Since the OST could not be saturated during hot thermal vacuum conditions, it was decided to return the OST to the contractor for refocusing at elevated temperatures. This technique had been successfully employed in the past when tubes were not able to be saturated at high temperature in a vacuum environment. Upon return, the tube was cycled once through the qualification range  $-10^{\circ}$  to  $58^{\circ}$  C ( $14^{\circ}$  to  $136^{\circ}$  F). No performance degradation was observed.

The tube was then given a "confidence" vibration test to flight-acceptance levels in three axes (random only) to demonstrate the integrity of the epoxy holding on the shunts and magnets that were added during the refocusing operation. After vibration testing, the OST was subjected to one qualification level cycle of  $-10^{\circ}$  to  $58^{\circ}$  C ( $14^{\circ}$  to  $136^{\circ}$  F) and then 16 cycles between the worst-case flight limits of  $0^{\circ}$  and  $48^{\circ}$  C ( $32^{\circ}$  and  $118^{\circ}$  F). No performance degradation of the OST has been observed as a result of this testing.

#### Component Qualification of Variable Conductance Heat Pipe System

The original plan was for the VCHPS (exclusive of its silvered Teflon thermal control finish) to be qualified on the basis of vibration and thermal vacuum tests conducted on the S/N EM001 unit. The silvered Teflon thermal control finish was qualified on the basis of tests performed on coupons. After qualification vibration was completed on S/N EM001, the vibration level in the test specification needed to be increased. Instead of retesting S/N EM001, vibration qualification for the VCHPS was based on the S/N EM002 system, which was on the engineering spacecraft during spacecraft-level qualification vibration testing.

After the qualification of the VCHPS was completed, investigation of spacecraft charging effects on the VCHPS radiator revealed that arc discharges would cause excessive silver to be lost from the silvered Teflon thermal control surface. This effect could be reduced by using electrically conductive adhesive to attach the silvered Teflon to the fin. This adhesive system was qualified on the basis of tests performed on the

flight fin. The previously qualified silvered Teflon-bonded-with-Kapton-tape system remained on the heat pipes, saddles, and reservoir radiators.

After vibration of the S/N EM002 VCHPS on the engineering spacecraft, the pin joints at the ends of the fiberglass struts that supported the fin from the spacecraft forward panel were found to be loose. After redesign, a strut was modified and qualified by a vibration test.

VCHPS EM001 tests. - The S/N EM001 VCHPS had the following deviations from the flight model:

(1) The thermal control system was a Kapton-covered film heater rather than silvered Teflon.

(2) The screen material for the arteries was cut on a 30° rather than a 45° bias.

(3) The arteries were crimped (buckled) in the bend area of the pipes as a result of the 30° bias cut.

(4) A stiffener was added to the design of the reservoir support structure late in the program. It was not present for the S/N EM001 tests.

(5) The struts that connect the VCHPS to the spacecraft forward platform were later redesigned and qualified separately.

The system was sine and random vibration tested in three axes to qualification levels. It was then subjected to thermal vacuum cycling for 18 cycles in which the methanol in the heat pipes was successively frozen and thawed. Postvibration functional testing revealed no performance degradation. Since this heat pipe system did not have silvered Teflon installed, the thermal control finish was qualified by means of the coupon tests summarized here.

Silvered Teflon coupon tests. - The set of two coupons used to qualify the silvered Teflon on a component basis represented materials and techniques used on the heat pipes, saddles, and reservoirs of the flight VCHPS. A rectangular, aluminum, flat-plate sample approximately 13 by 25 centimeters (5 in. by 10 in.) covered with four pieces of 5-centimeter (2-in.) wide silvered Teflon was prepared by the same vacuum bag techniques as were used on the full-size radiator fins provided by the contractor. The second coupon was a 38-centimeter (15-in.) piece of stainless-steel tubing, that was soldered to an aluminum saddle and covered with silvered Teflon by application techniques similar to those for complete systems.

The flat plate was tested for 1301 temperature cycles from -102° to -30° C (-151° to -22° F) and 1265 cycles from -76° to 18° C (-105° to 65° F).

Then the flat plate, the heat pipe, and the saddle coupons were subjected to more than 50 temperature cycles from -155° to +60° C (-247° to 140° F). (Worst-case flight predictions indicate a range of -140° to 60° C (-220° to 140° F.) No physical degradation was apparent.

VCHPS EM002 tests. - The S/N EM002 VCHPS had the following deviations from the flight model:

- (1) The screen material for the arteries was cut on a 30° rather than a 45° bias.
- (2) The arteries were crimped (buckled) in the bend area of the pipes as a result of the 30° bias cut.
- (3) The stiffener to the reservoir support structure was a welded aluminum box section bonded to the structure during the engineering spacecraft vibration tests. The aluminum stiffener had the same section stiffness properties as the fiberglass box section bolted on the flight unit.
- (4) The silvered Teflon was not applied to the radiator with the conductive adhesive system that was qualified later.
- (5) The end fittings on the struts that connect the VCHPS to the spacecraft forward platform were later redesigned and qualified separately.

This heat pipe system was mounted on the engineering spacecraft for the spacecraft test program. After thermal vacuum testing, the engineering model spacecraft with VCHPS EM002 installed was subjected to a mechanical environmental test program consisting of the following tests:

- (1) Low-level sine survey vibration
- (2) Flight-level sine vibration (at least twice on each axis)
- (3) Flight-level random vibration
- (4) Qualification-level sine and random vibration
- (5) Jettisonable body solar array (JBSA) deployment - pyrotechnic shock test
- (6) JBSA alternate release system (JARS) deployment - pyrotechnic shock test

During vibration tests on the spacecraft, it was discovered that the VCHPS (especially the reservoir area) was responding at higher g-levels than predicted. This necessitated the addition of an extra stiffener on the reservoir support structure. These tests also showed that the vibration levels induced in the spacecraft-mounted VCHPS were higher than those to which VCHPS EM001 had been subjected in the component qualification test. Rather than retest VCHPS EM001, the basis for vibration qualification of the VCHPS was elected to be the spacecraft-level tests performed with VCHPS EM002 in place.

After the vibration tests, the VCHPS EM002 was X-rayed and functionally tested at the Lewis Research Center. There were no previbration X-rays available for comparison; however, the interior components of the reservoirs appeared to be intact after testing. The system was able to sustain 300 watts of power into the evaporator, and it was concluded at that time that this system sustained no damage during the test program. (Some time later, after the system was inspected further, it was found that the aluminum end fittings pinned into the fiberglass struts to the spacecraft forward panel were loose. The redesign and qualification of the struts is discussed later in the section Strut tests.)

Radiator fin tests. - Relatively late in the program, tests were run that indicated the radiator thermal control surface may be damaged by charge buildup in space. References 4 and 5 discuss the phenomenon. To reduce silver loss due to spacecraft charging-discharging effects, the silvered Teflon thermal control surface was removed from the

radiator fin of heat pipe system EM002. The silvered Teflon was then replaced by using an electrically conductive silicone adhesive system. (The adhesive system was previously tested by subjecting coupons to thermal vacuum cycling.)

The radiator fin was subjected to one thermal cycle over the qualification range  $-155^{\circ}$  to  $+60^{\circ}$  C ( $-247^{\circ}$  to  $140^{\circ}$  F). It was then subjected to 34 more thermal cycles over the worst-case, flight-predicted temperature range  $-140^{\circ}$  to  $60^{\circ}$  C ( $-220^{\circ}$  to  $140^{\circ}$  F) with no significant physical or optical degradation. After the protoflight spacecraft completed its thermal vacuum cycling, the fin on the spacecraft was replaced with the EM002 fin that had undergone the qualification test.

Strut tests. - After the protoflight spacecraft vibration testing was completed, it was found that the holes in the fiberglass tubing where the tubing and end fittings were pinned were elongated on the flight struts. Reinspection of VCHPS EM002 showed that the same looseness existed. It was caused by bearing failure in the thin-wall fiberglass tubing where the aluminum end fittings were pinned into place. This deficiency was corrected by increasing the thickness of the walls at the ends of the fiberglass tubing. Spare struts were modified for installation on the spacecraft.

One of the EM002 struts was modified for use in a qualification vibration test. The test consisted of Y- and Z-axis sine and random vibration tests at levels 1.5 times the expected flight levels. During vibration tests the struts were loaded with a simulated load that represented the fin, reservoir, and reservoir support loading. No degradation was observed.

### TEP/VCHPS Qualification on Protoflight Spacecraft

Configuration and status. - Before spacecraft installation, the PPS and OST had each received a flight-acceptance vibration test and a thermal vacuum test as individual components. Then the PPS and OST were integrated as a TEP and subjected to a flight-acceptance thermal vacuum test. The VCHPS received flight-acceptance vibration and thermal vacuum tests as an individual component.

Vibration test. - The protoflight spacecraft with the flight TEP/VCHPS installed was subjected to a sinusoidal vibration test in three axes at 1.2 times the expected flight levels and to a random vibration test in three axes at 1.5 times the expected flight levels. The spacecraft was then subjected to a shock test that was conducted by firing the pyrotechnic devices. The only anomaly that was associated with the TEP and VCHPS was the elongated hole in the struts connecting the radiator fin to the spacecraft forward deck. This anomaly was discussed previously.

Thermal vacuum test. - The protoflight spacecraft with the flight TEP/VCHPS installed was subjected to four periods of elevated temperature, three periods of cold

temperature, and eight transitional periods. The TEP was operated at all low-temperature periods, all except one high-temperature period, and all transitional periods.

During the spacecraft testing, the temperatures given in table IV for the system qualification on the protoflight spacecraft were achieved on the TEP and no performance degradation was observed.

## ACCEPTANCE TEST PROGRAM

Flight-acceptance testing was performed on the designated flight hardware to characterize the hardware performance and to expose workmanship deficiencies before the equipment was integrated with the spacecraft. After component-level tests, the hardware was integrated with the protoflight spacecraft, where it remained throughout the spacecraft qualification and flight-acceptance program.

### Acceptance Requirements

The flight-acceptance sine and random vibration tests were conducted in each of three axes. Frequency breakpoints were the same as the qualification values of table II. Acceptance sine vibration was to levels two-thirds of those shown in table II and at a sweep rate of 4 octaves per minute rather than 2 octaves per minute. Acceptance random vibration on each of three axes was 6.8 g's for 45 seconds rather than the 10.4 g's for 90 seconds required for qualification. Component-acceptance temperatures are included in table III.

### Component Acceptance of Power Processing System

The flight PPS was ready for testing before the flight OST was available; consequently, we decided to acceptance test the PPS and OST separately rather than as an integrated TEP as originally planned. At the completion of manufacture, the PPS was subjected to a functional test followed by acceptance vibration testing and two cycles of acceptance thermal vacuum testing. Later when an OST was available, the flight TEP was subjected to three more temperature cycles of thermal vacuum testing before integration with the spacecraft.

## Component Acceptance of Output Stage Tube

The OST amplifier after manufacture was subjected to functional tests to characterize the device as an amplifier. Some video transmission and thermal dissipation tests were also performed. Flight-acceptance vibration testing was performed followed by a thermal vacuum test. The thermal vacuum test could not be completed since the OST had excessive body current at high temperatures. The test was aborted and the OST was refocused at a high temperature. After refocusing, the OST was integrated with the PPS and the TEP was subjected to three temperature cycles of thermal vacuum testing.

A goal was set of about 2000 hours of operation to burn in the OST before launch. Because the OST delivery was late, only 1420 hours had been amassed when the OST was shipped for integration with the spacecraft. Eventually, 1800 hours of operation were accumulated before launch.

## Component Acceptance of Variable Conductance Heat Pipe System

Upon completion of manufacture, the VCHPS received a functional test and a dimensional inspection and X-ray photographs were taken. It was then vibration tested to flight-acceptance levels. The vibration test exposed two minor problems. Ground straps for the reservoir thermal insulation blankets were not well secured and needed better attachment. An improved fastening was thus added to the assembly. Also, the metalized side of one thermal insulation blanket shorted out some temperature sensor terminals. Kapton tape was applied to correct that deficiency.

A flight-acceptance thermal vacuum test was performed in which the VCHPS was cycled over the acceptance temperature range 12 times. Some adhesive bonding that held a temperature sensor harness in place failed, and mechanical tiedowns were added to secure the harness.

After integration of the acceptance-tested VCHPS with the spacecraft, spacecraft charging considerations made it necessary to change to a new silvered Teflon thermal control tape with an electrically conductive adhesive system to bond the tape to the aluminum fin. A redesigned fin assembly was fabricated and qualification tested as described in the section Radiator fin tests. That fin was then flown.

## TEP/VCHPS Acceptance on Protoflight Spacecraft

After the component acceptance test program was completed, the hardware was integrated with the flight spacecraft. The entire system was then qualification tested as described in the section TEP/VCHPS System Qualification on Protoflight Spacecraft.

After the spacecraft qualification effort was completed, the environmental test program was essentially finished as far as the TEP was concerned. All that remained were some spacecraft preflight checks such as functional tests, X-ray of VCHPS reservoirs, EMC tests, compatibility tests with the ground station, solar simulation tests (TEP nonoperational), and static and dynamic spin-balance tests.

## DEVELOPMENT AND INTEGRATION TESTS

Qualification and acceptance tests are performed on flight and flight-representative hardware; consequently, they occur relatively late in the program and well after the design is frozen. Discovering major problems during these tests can result in serious cost and scheduling difficulties. Therefore, development and integration tests of breadboard and engineering model hardware are required to expose system interaction problems or poor system performance in time to affect the final flight configuration design. Life testing is also included in this category since it was not a qualification or acceptance activity but did add to confidence in the hardware design. This section of the report summarizes the major milestones of the development test program.

### Thermal Test of South Panel

The TEP/VCHPS occupies about one-half of the spacecraft south panel, provides the largest heat dissipation and range of heat dissipations on that panel, and includes the unusual thermal characteristics of the VCHPS. Therefore, we decided to perform a thermal system test of the spacecraft south panel. The test article was a thermal mockup that used resistance heaters rather than active components to supply thermal loads. The honeycomb south panel and the VCHPS were engineering model units representative of flight designs. The test was performed in a thermal vacuum chamber. Cold walls and auxiliary heaters simulated the space environment and other boundary conditions of the panel for test. Reference 6 describes the thermal test and its results in detail.

The test results were used to modify the analytical thermal model of that portion of the spacecraft. The fact that the heat pipes deprimed when frozen in the tilted condition used to simulate zero gravity did affect the test profiles of the engineering and proto-flight spacecraft tests which followed.

## Integration of Breadboard Transponder with TEP

The major elements of the SHF transponder-TEP system were integration tested as soon as that hardware was available. The objective was to expose system problems, instability, etc., as well as to characterize the system and demonstrate operation with different types of signals such as single frequencies, video, or high-speed digital data. Early-generation engineering units that functioned as flight units were expected to function were used but were not packaged for spacecraft installation.

The test results did verify the viability of the system design. The combined system was stable and did behave in a predictable manner.

## Interaction of TEP/VCHPS with Preliminary Spacecraft Models

As stated previously, a program decision was made to use a protoflight spacecraft approach in which a complete spacecraft system would be qualified and then that system flown. Testing of that spacecraft model and implications on the TEP/VCHPS were discussed previously. To minimize problems in the protoflight spacecraft activities, some preliminary spacecraft models were built; namely, the dynamic, thermal, and engineering models. The dynamic model contained mass dummies for each of the subsystems like the TEP and was used to evolve a spacecraft structure design and to determine component environmental test levels. The thermal model spacecraft (actually the dynamic model refurbished) contained resistive heaters for most of the components, including the TEP, and was used to test the thermal analysis and design. (The thermal model spacecraft did not include a VCHPS since the requirement for that system had not yet surfaced. The south panel test was actually performed after the thermal model spacecraft test.)

The engineering model spacecraft was the only functional model spacecraft other than the protoflight model spacecraft. It was used for system integration and compatibility tests in air and in thermal vacuum environments. When the spacecraft was being integrated, an operating TEP was made available for mechanical and electrical integration with the spacecraft. Tests to demonstrate compatibility of the TEP command, telemetry, power, and SHF interfaces with the spacecraft were performed. An improved model TEP/VCHPS was supplied before the spacecraft was subjected to thermal vacuum tests. Early integration of these TEP models with the spacecraft and transponder in air validated techniques for handling high-power radiofrequency emissions. Tests verified the need to maintain a radiofrequency seal on waveguide and coaxial cable joints and to have intact the thermal insulation blanket separating the SHF antenna from the transponder system. This need exists because the thermal insulation blanket also serves as a radiofrequency shield to prevent feedback oscillations of the high-gain transponder.

After the compatibility tests in air, the engineering spacecraft with TEP/VCHPS installed underwent thermal vacuum compatibility tests to demonstrate acceptable operation of all systems over a wide temperature range. Heated panels radiatively coupled to the spacecraft provided temperature control. Additional data were obtained to check the thermal analysis and to characterize operation of all systems over a temperature range. A TEP problem that surfaced in this test was that a facility cooling system deficiency would have caused this particular OST collector to overheat beyond its 200° C (392° F) capability. And thus the collector could not be run to thermal equilibrium. Subsequent to production of this OST, processing of OST's had been changed to include bakeout and evacuation of collectors at 300° C (572° F) before the OST was sealed off from the processing vacuum pump. The 300° C (572° F) bakeout later proved to be adequate. In addition, for subsequent spacecraft thermal vacuum testing, the collector cooling system design was improved.

The spacecraft with the TEP/VCHPS installed was subjected to solar simulation testing to demonstrate thermal system suitability under conditions of simulated solar input. A VCHPS problem that became evident in these solar simulation tests was a rapid degradation of the aluminized Mylar wrapped around the radiator support struts. The insulation on later struts was replaced with grounded aluminized Kapton multilayer blankets with the Kapton surface facing outboard.

## LIFE TESTS

There was not enough time or hardware available to perform statistically meaningful life tests before launch. However, we decided to accumulate as many hours as possible on two subsystems before flight in order to provide opportunity for latent failure modes to surface.

### VCHPS Life Test

During the development of the VCHPS, which has stainless steel heat pipes and uses methanol as the working fluid, there was much discussion about the internal gas generation occurring in the aluminum-ammonia heat pipe system of ATS-F (later ATS-6). Long-term chemical reactions and gas generation were believed to be taking place at elevated temperatures, which would reduce pipe heat dissipation capacity. For this reason, a three-pipe set of CTS heat pipes was placed on long-term test. The test set of heat pipes was identical to the flight heat pipes except for external thermal control surfaces. The test was performed at the expected worst-case flight dissipation of 150 watts, in room ambient conditions, and with 1.27-centimeter (0.5-in.) tilt to simu-

late worst-case, zero-gravity operation. At the time of launch, the test had run 9045 hours at temperature with no detectable change in operating conditions. The test was continued after launch, and over 13 000 hours had been accumulated by mid-August 1976.

### OST Life Test

The OST described previously contains an impregnated tungsten cathode to generate an 850-watt electron beam that is focused by permanent magnets down a 0.127-centimeter (0.050-in.) diameter beam hole 18 centimeters (7 in.) long. The beam of electrons is velocity sorted and brought to rest in the collector by nine conical plates at nine different high voltages. Some of the molybdenum plates exceed 1100<sup>o</sup> C (2012<sup>o</sup> F) in operation due to beam impact energy. To expose long-term failure mechanisms, an OST was continuously tested. It had accumulated 5800 hours at the time of launch without detectable change in operation. The test was continued after launch, and 10 500 hours had been accumulated by mid-August 1976.

### CONCLUDING REMARKS

This report documents the test program that was conducted on the transmitter experiment package/variable conductance heat pipe (TEP/VCHP) subsystem of the Communications Technology Satellite (CTS) program. It describes the testing philosophy and the specific tests involved to qualify the TEP/VCHPS design and to acceptance test the flight articles in preparation for spacecraft integration. The spacecraft test program is discussed only insofar as the TEP/VCHPS subsystem is involved. The goal of the test program was to qualify and acceptance test the hardware on a component basis as well as to test the total spacecraft system.

Even though problems occurred and the actual test program was not as straightforward as planned, all elements of the TEP/VCHPS were qualified by testing them either as complete subsystems or as components.

Although qualification and acceptance tests of advanced communications satellite subsystems are required before flight, they are not sufficient. Additional development and confidence testing is required to supplement the qualification and acceptance programs in order to provide an early demonstration of compatibility among various systems and confidence in hardware adequacy.

Lewis Research Center,  
National Aeronautics and Space Administration,  
Cleveland, Ohio, August 12, 1976,  
610-22.

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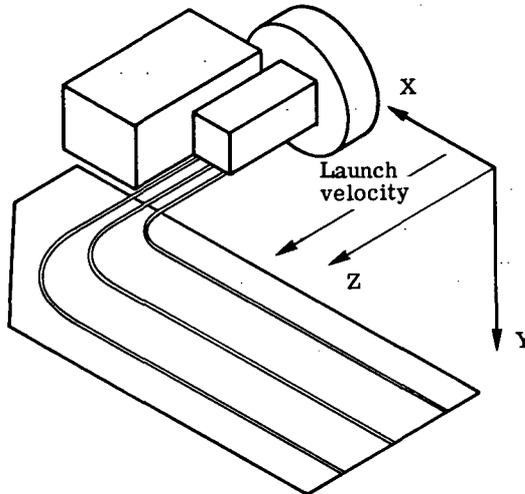
**TABLE I. - NOMINAL PERFORMANCE CHARACTERISTICS  
OF OUTPUT STAGE TUBE**

Center frequency, GHz . . . . .	12.080
Bandwidth, MHz . . . . .	85
Saturated output power across band, W . . . . .	200
Saturated gain, dB . . . . .	30
Efficiency, percent . . . . .	48

**TABLE II. - SERIAL NUMBERS OF PRINCIPAL HARDWARE ITEMS  
IN TEP/VCHPS TEST PROGRAM**

	Development program	Qualification program	Flight-acceptance program
	Serial number (S/N)		
Output stage tube	2005 2019 2020	2023 2025	2022 2025
Power processing system	ETMA1 ETMB1 ETMB2	ETMB2 QF01	QF02 QF03
Variable conductance heat pipe system	EM001 EM002 FM006	EM001 EM002	FM004 FM005

TABLE III. - QUALIFICATION VIBRATION  
 REQUIREMENTS (1.5 TIMES  
 FLIGHT LEVELS)



(a) Sine requirements (sine sweep, 2 octaves/min)

Frequency, Hz	Axis		
	X	Y	Z
	Vibration level, g's		
5-14	≤5.0	----	----
14-100	5.0	----	----
5-16	----	≤6.0	----
16-40	----	6.0	----
40-100	----	10.0	----
5-25	----	----	≤15.0
25-70	----	----	15.0
70-120	----	----	4.0
120-250	----	----	2.3
100-250	2.3	2.3	----
250-400	4.5	4.5	4.5
400-2000	5.0	5.0	5.0

(b) Random requirements

Frequency, Hz	Random vibration, 90 sec each axis (total, 10.4 g's rms)
20-300	+3 dB/octave
300-1000	0.07 (g's) <sup>2</sup> /Hz
1000-2000	-3 dB/octave

TABLE IV. - QUALIFICATION AND ACCEPTANCE THERMAL REQUIREMENTS

	Operating	Temperature						VCHPS dissipation, W
		°C	°F	°C	°F	°C	°F	
		OST baseplate		PPS transformer baseplate		VCHPS radiator		
Worst-case flight predictions	Hot	48	118	56	133	60	140	} 163 ---
	Cold	0	32	0	32	----	----	
	Nonoperating (cold)	-8	18	-7	19	-140	-220	
Component acceptance	Hot	53	127	60	140	60	140	} 196
	Cold	-5	23	-5	23	-140	-220	
	Minimum turn-on	-5	23	-15	5	----	----	
Component qualification	Hot	58	136	65	149	65	149	} 216
	Cold	-10	14	-10	14	-155	-247	
	Minimum turn-on	-10	14	-20	-4	----	----	
System qualification on protoflight spacecraft	Hot	48	118	56	133	----	----	--- --- ---
	Cold	-5	23	-5	23	----	----	
	Minimum turn-on	-5	23	-5	23	----	----	

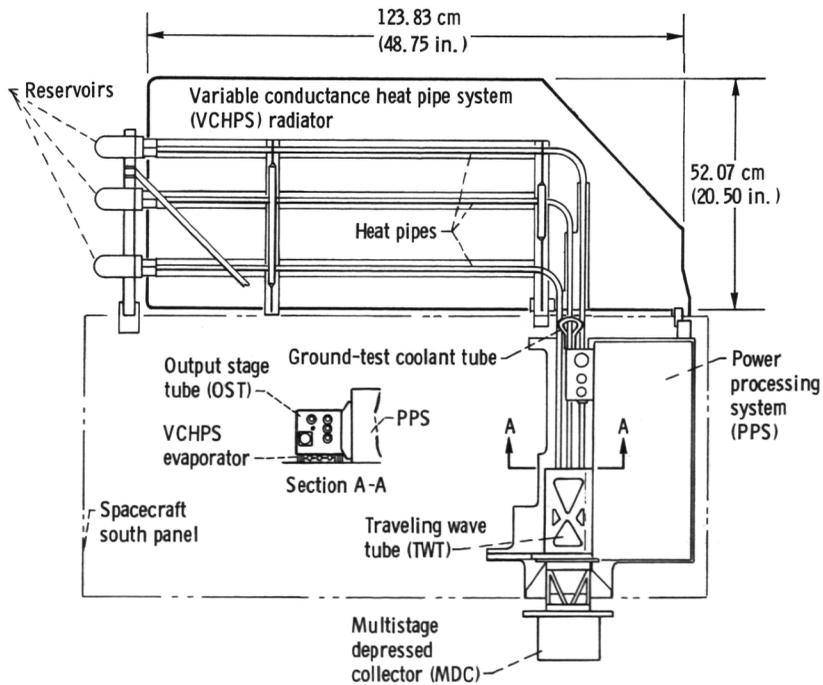


Figure 1. - Transmitter experiment package and variable conductance heat pipe system.

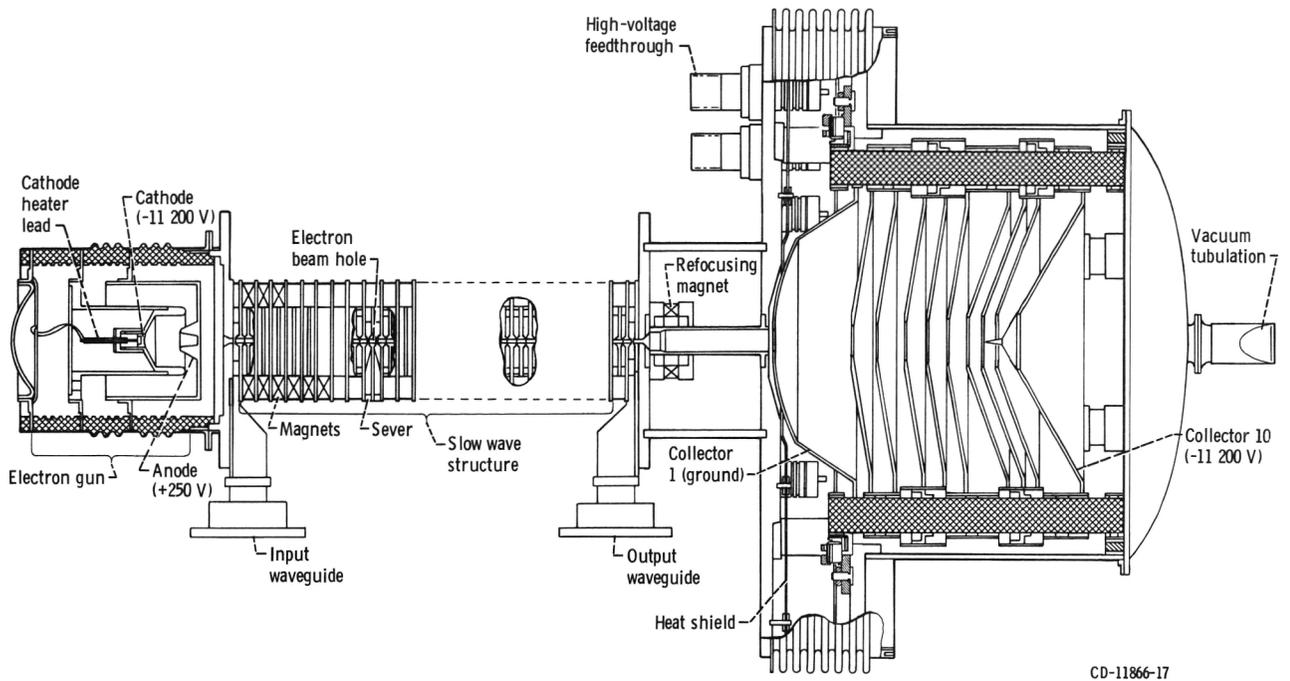


Figure 2. - Coupled-cavity, traveling wave tube with multistage depressed collector.

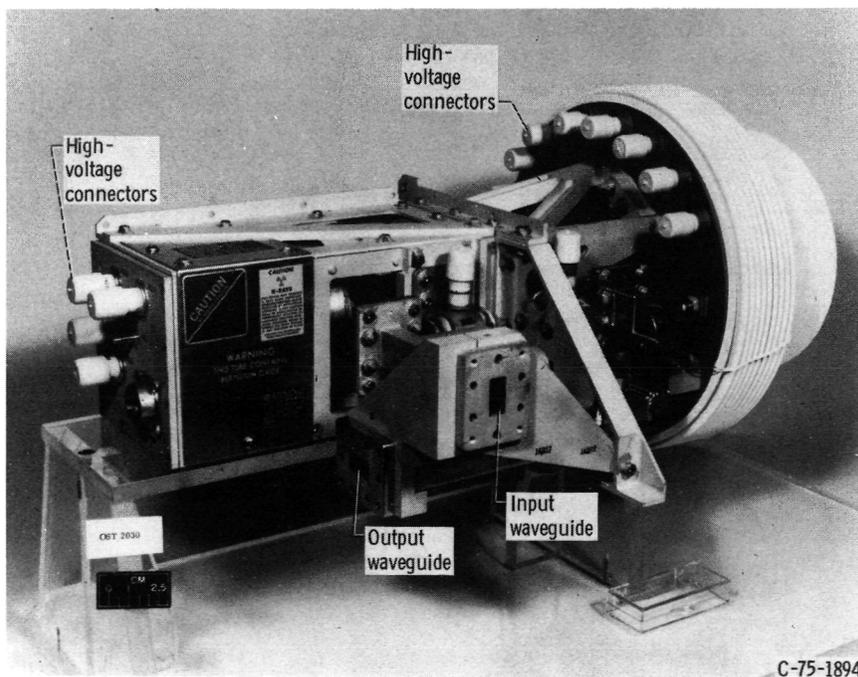


Figure 3. - Output stage tube in flight configuration.

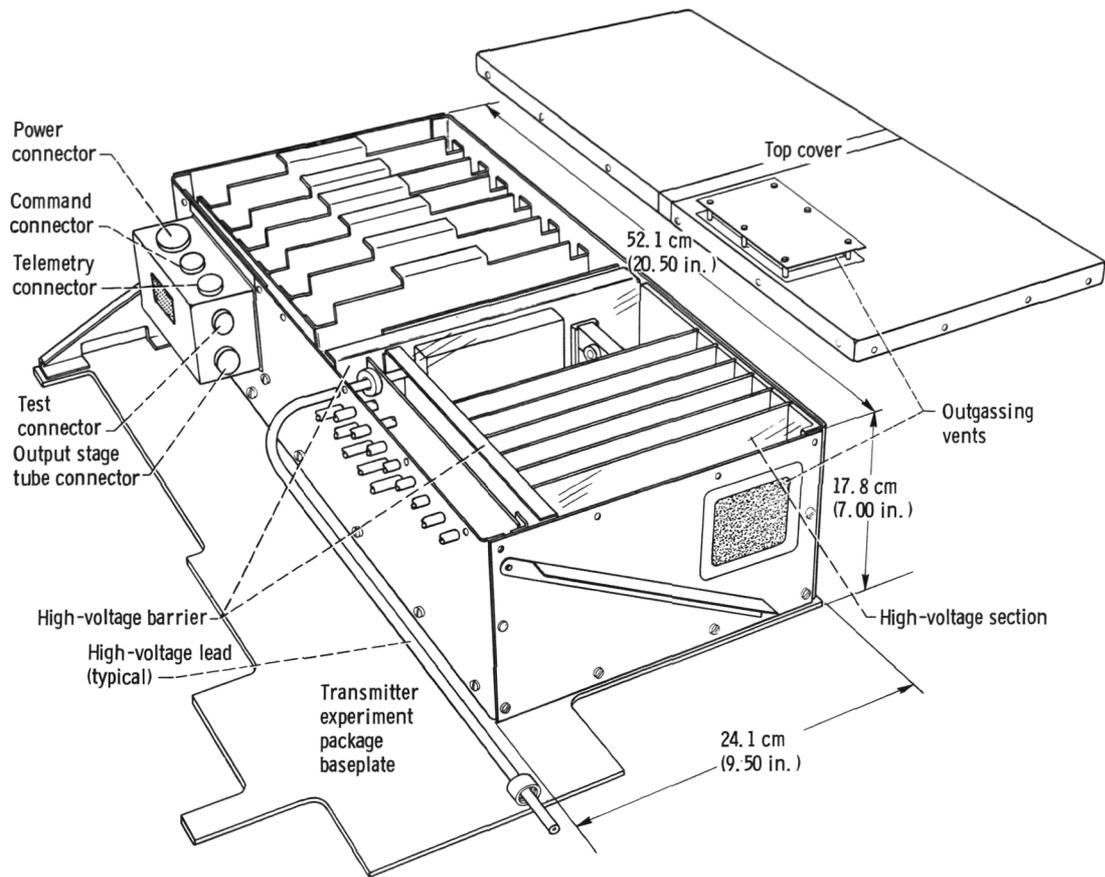


Figure 4 - Power processing system.

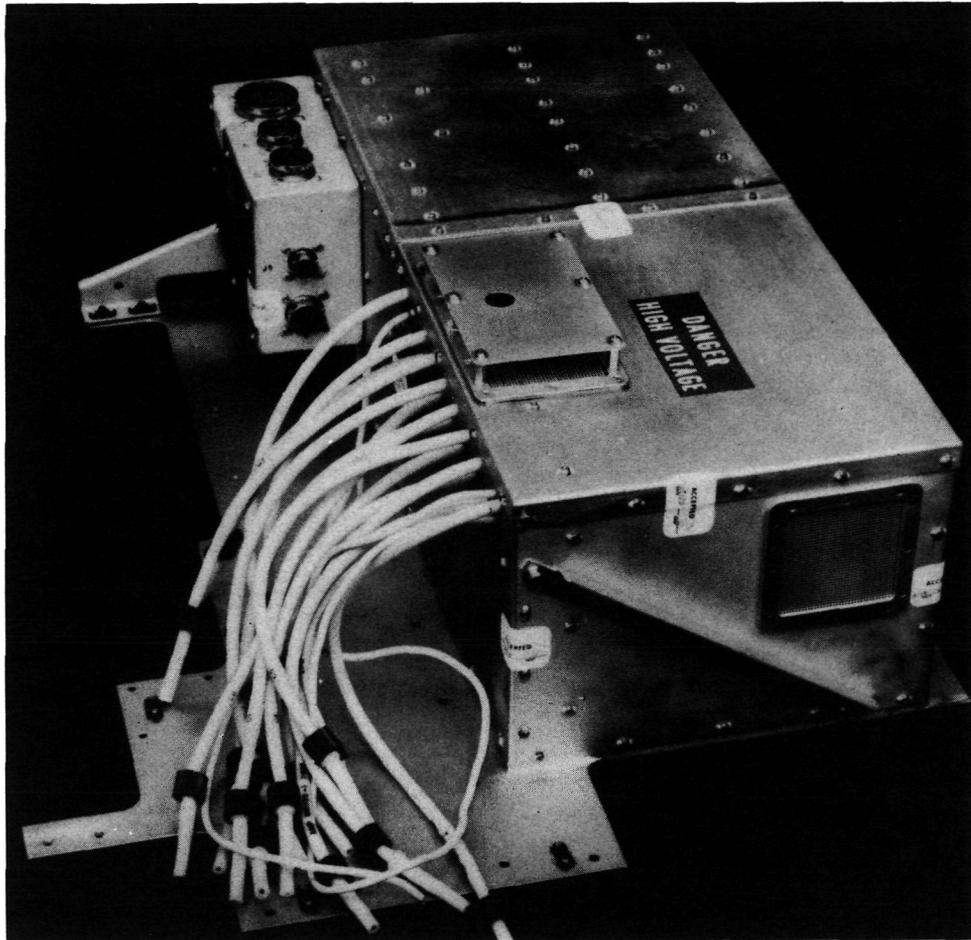


Figure 5. - Power processing system in flight configuration. Nominal power output, 480 watts; efficiency, 89.2 percent; weight, 13.18 kilograms (29.28 lb); voltage inputs, 76 and 27.5; cathode voltage, - 11 200 volts; cathode voltage ripple, 0.006 percent; cathode voltage regulation,  $\pm 0.064$  percent.

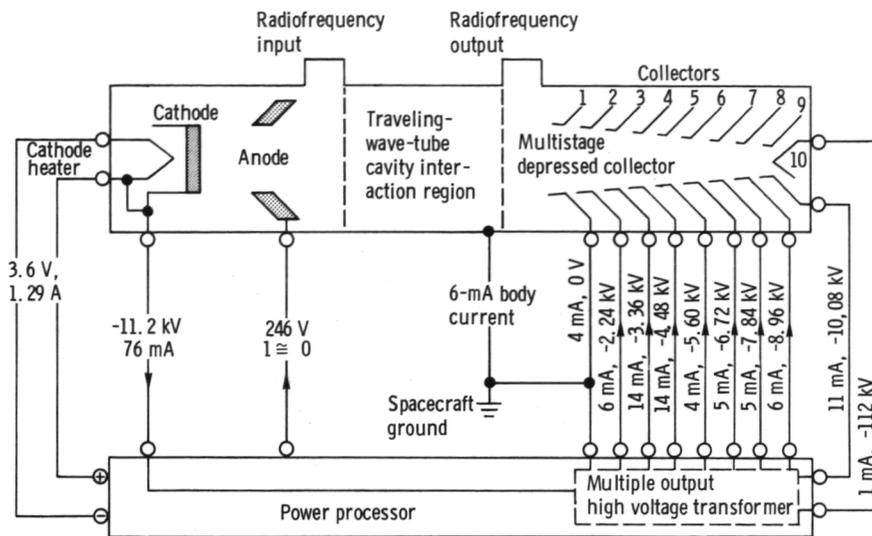


Figure 6. - Power interface between output stage tube and power processing system. (All voltages are with respect to spacecraft ground. Collector currents are typical of operation at center band, saturated.)

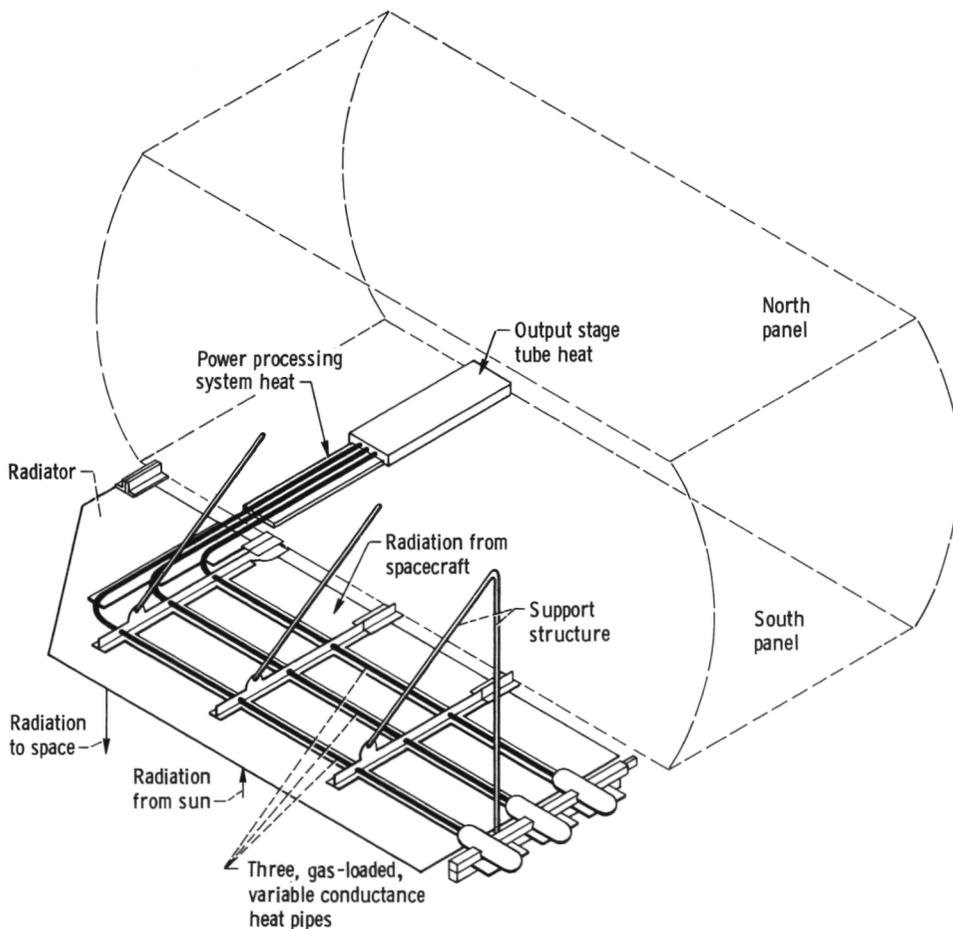


Figure 7. - Variable conductance heat pipe system. (Variable conductance feature thermally disconnects transmitter experiment package during TEP power-down condition.)

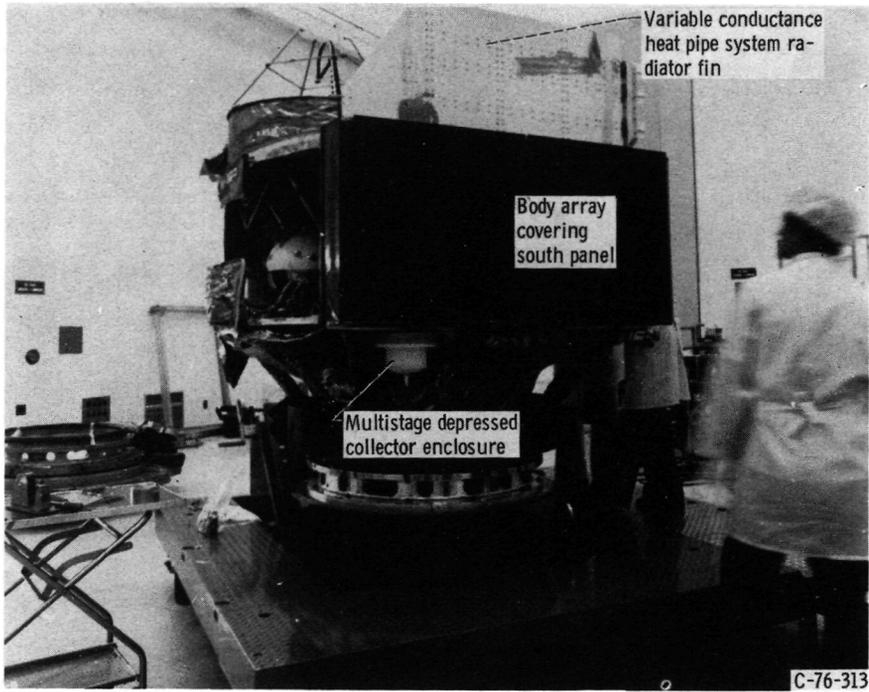


Figure 8. - Communications Technology Satellite spacecraft showing radiator fin.

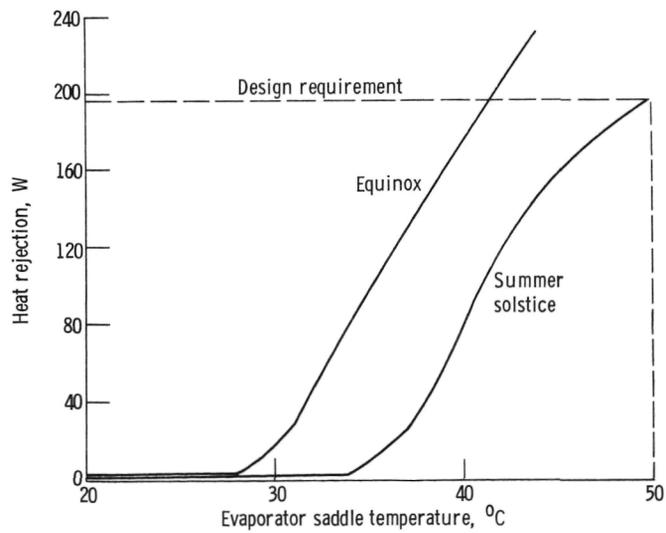


Figure 9. - Variable conductance heat pipe system performance. (One-heat-pipe-failed design conditions.)

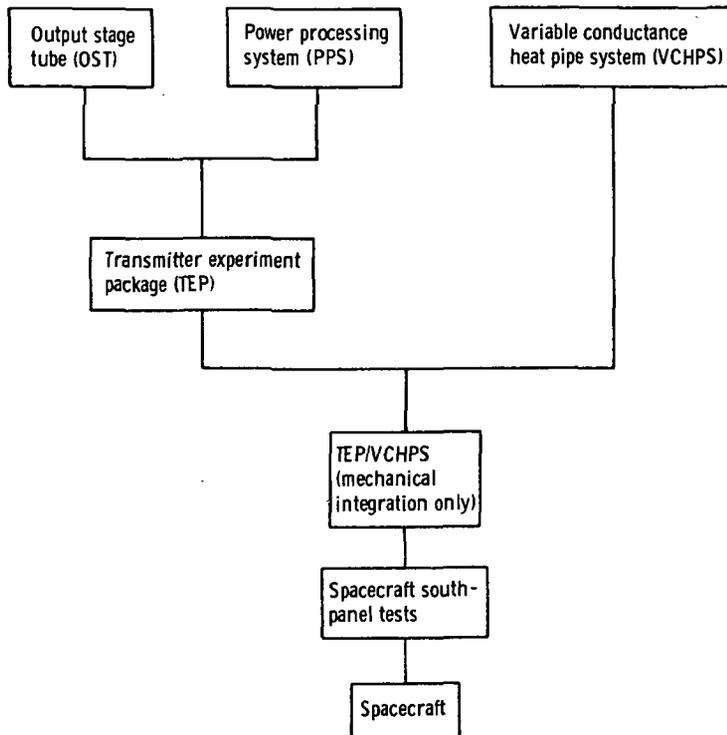


Figure 10. - Stages at which major subassemblies were tested and integrated in preparation for spacecraft integration.

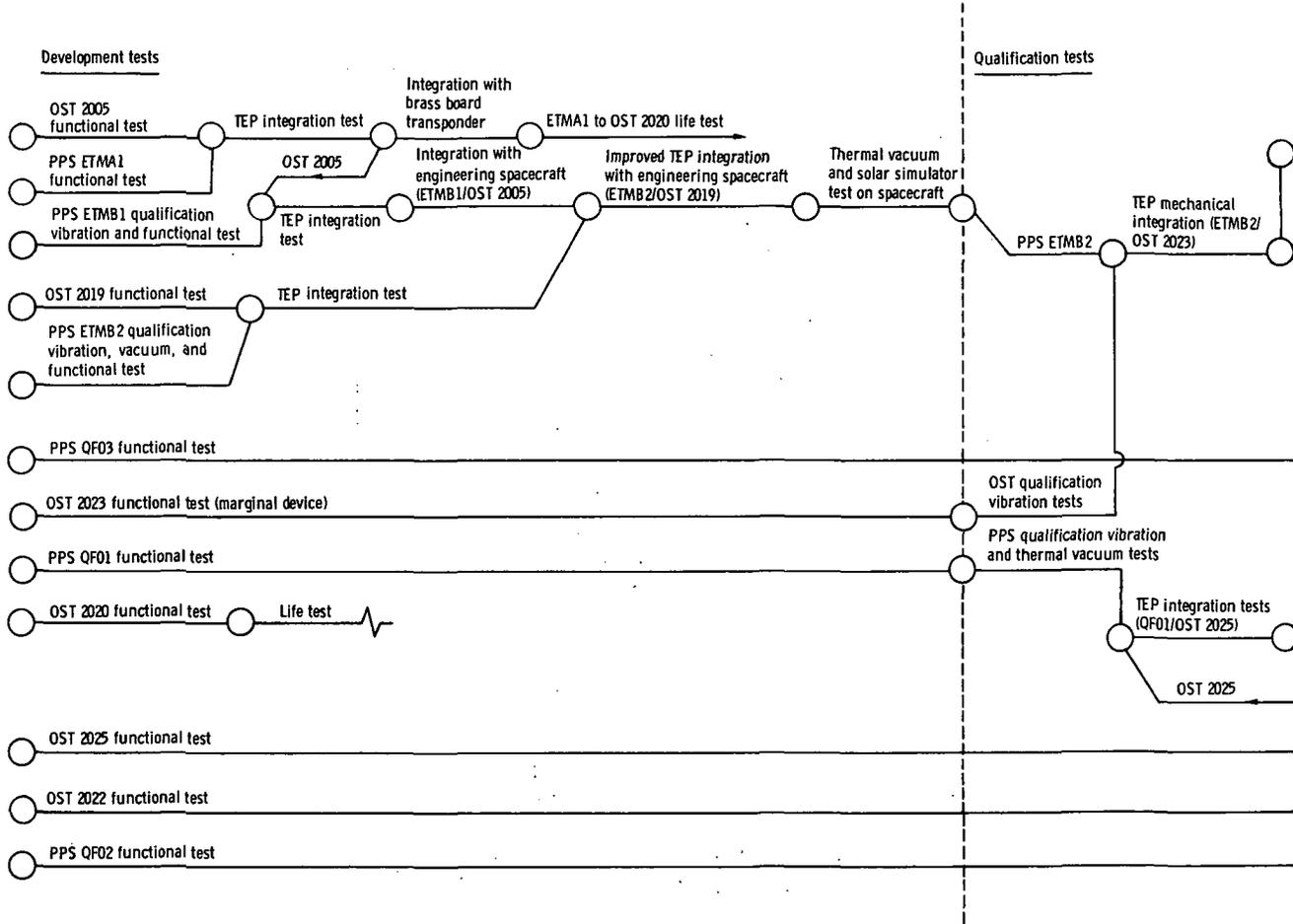
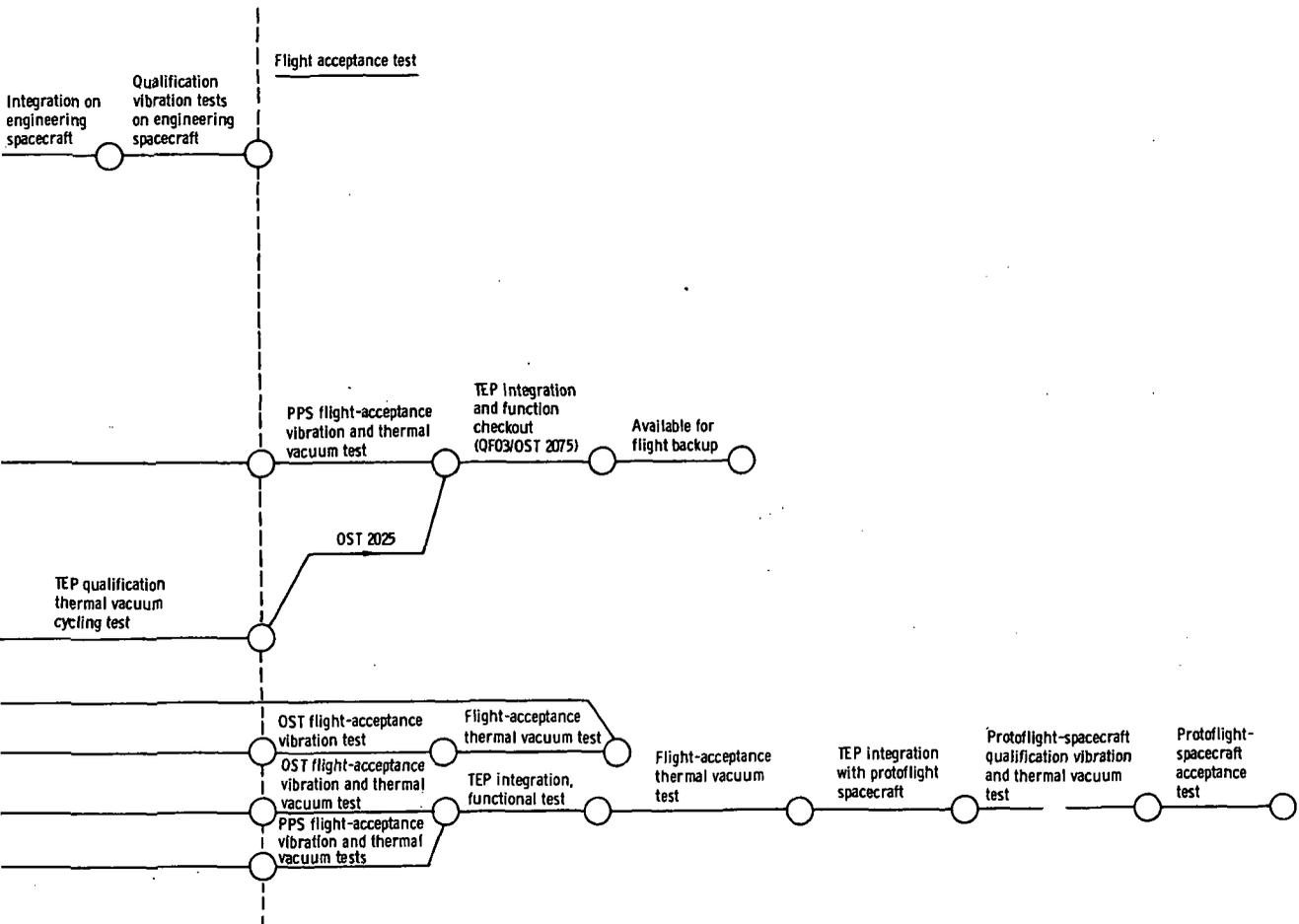


Figure 11. - Transmitter experimen



package test program.

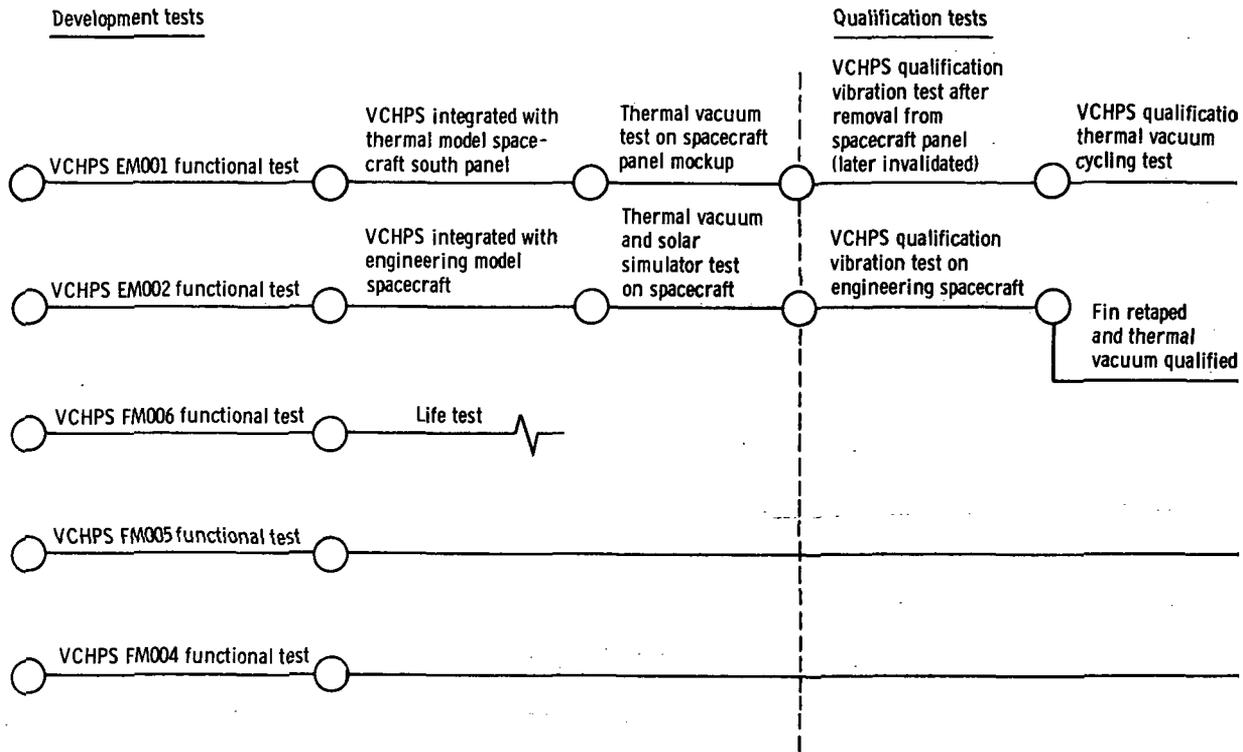
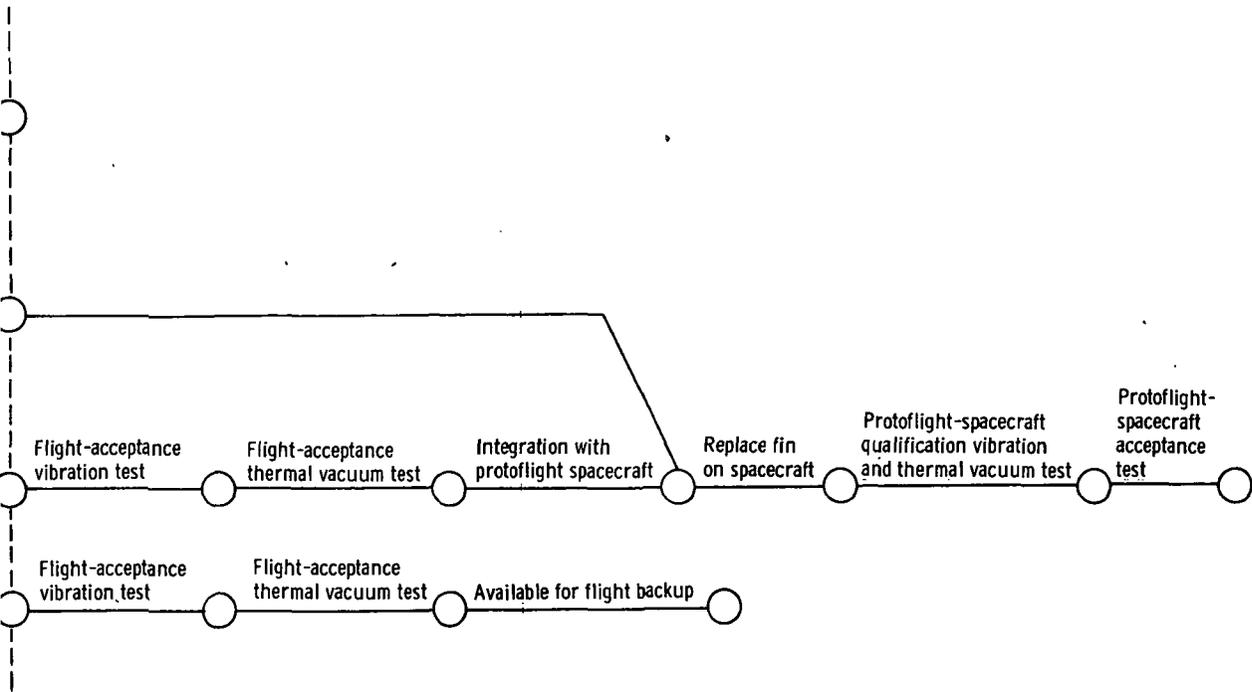


Figure 12. - Variable conductance

Flight acceptance tests



heat pipe system test program.

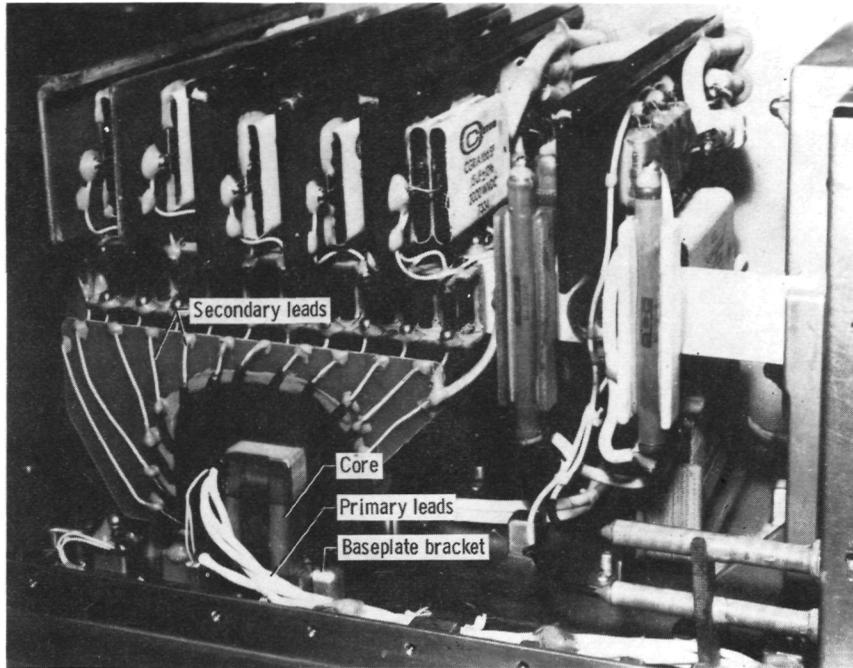


Figure 13. - High-voltage transformer area of power processing system.



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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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