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SNAP 10A FSEM-3 AGENA COMPATIBILITY TEST

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SNAP 10A FSEM-3 AGENA COMPATIBILITY TEST

By

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ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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ABSTRACT

This report summarizes the results of SNAP 10A/Agena developmental testing and final vehicle systems tests. Developmental testing was performed with the SNAP 10A FSEM-3 payload electrical simulator and an Agena Functional Mockup. FSEM-3 was utilized during vehicle systems testing prior to shipment of the Agena to the launch site.

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I. SUMMARY

FSEM-3, an electrical mockup of SNAP 10A, was designed and fabricated by the Atomics International Division of North American Aviation for the purpose of verifying compatibility between the project SNAPSHOT payload and the Lockheed Missiles and Space Corporation Agena spacecraft. It was also utilized for final systems testing of the Agena flight vehicle. Compatibility tests including an Electromagnetic Interference (EMI) investigation were performed with a functional mockup of the program-modified Agena

The Test Program was conducted at LMSC's Sunnyvale facility between May 1964 and February 1965 Compatibility tests consisted of programming the two mockups through a simulated flight sequence of events with the main unregulated power bus maintained at either 28 or 23.5 vdc. The tests with the bus at the lower voltage level were designed to verify that all vehicle and payload equipments could operate within specification limits under conditions bordering on mission failure. Automatic circuitry in the SNAP 10A Nuclear Power Unit (NPU), if enabled, will initiate a failure sequence if the unregulated bus drops below 22 5 plus 0.5 minus 0.0 vdc and does not increase above 24.0 plus 0.5 minus 0 0 vdc within one minute. The failure sequence is completed with ejection of the reactor reflector assembly FSEM-3/FMU testing revealed that incompatibility between the vehicle and the payload existed in the telemetry (TM) signal conditioning circuitry for the converter voltage taps. The original circuit resulted in excessive common mode voltages being presented to the 50-mv submiltiplexer which caused magnetic amplifier instability and incoherent TM data It was also determined that adjacent converter legs could be shorted during TM sampling due to lack of isolation between circuits and a possible make-before-break situation in the submultiplexer commutating relays. Lack of ac isolation between the NPU thermoelectric converter and the vehicle equipments connected to the unregulated bus seriously affected the resolution of the converter impedance measuring device. The vehicle ac impedance of 0.2 to 0.4 ohm shunted the converter impedance resulting in a 5- to 6-mv TM output versus the expected 0- to 50-mv calibration for converter impedance variations of 0 to 3 ohms. An isolation choke was added later to improve the impedance measuring device calibration, and the voltage tap circuits were redesigned for the flight Agena.

EMI tests were conducted in accordance with the general requirements of MIL-E-6051C A 6-db (factor of 2) margin was found to exist between vehicle malfunction and self-generated interference observed on the vehicle plus 28-vdc unregulated and regulated buses. The flight vehicle's radiated EMI signature was obtained during vehicle system testing (VST)

Significant system interactions between the payload simulator and the Agena vehicle were uncovered during VST. Payload resistance thermometers' outputs which saturate the 50-mv submultiplexer magnetic amplifier during the flight test were found to have deleterious effects on adjacent TM channels. The circuits for the NPU converter continuity umbilical monitor shorted the isolation choke preventing prelaunch monitoring of this variable Dynamic interactions between the TM system and the NPU drum and expansion compensator position indicators and converter voltage monitors resulted in apparent erroneous TM readings. Resolutions of these and other problems were achieved before shipment of the Agena vehicle to Vandenberg Air Force Base.

II. SNAP 10 A NPU DESCRIPTION

The SNAP 10A nuclear power unit (NPU) (Figure 1) is a static electrical power system for space applications. Electrical power is generated by using a nuclear reactor as the thermal power source, a liquid-metal heat-transfer fluid, and a thermoelectric converter. The heat-transfer fluid, a mixture of sodium and potassium (NaK), is heated in the reactor core and circulates throughout the converter, heating the hot junction of the thermoelectric elements.

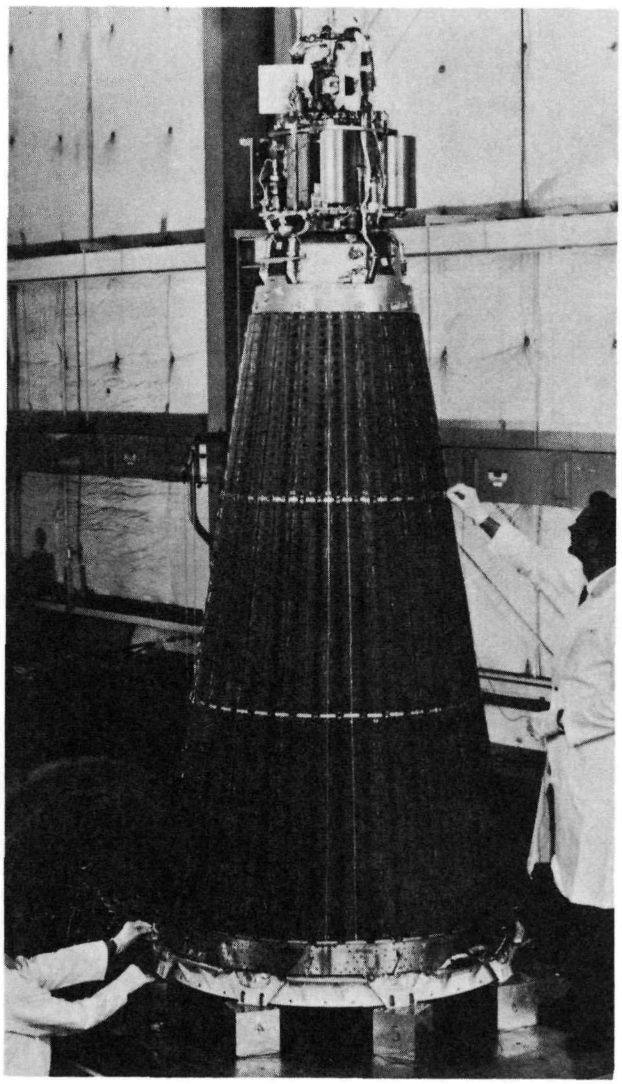

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Figure 1. SNAP 10A Nuclear Power Unit

An aluminum fin located on the cold junction of each element rejects the heat to space. The temperature difference between the radiator and the NaK results in the generation of a voltage and, when connected to a load, electrical power. A dc conduction pump is used to circulate the NaK. Current to the pump is supplied by its own thermoelectric module.

The design objective of the SNAP 10A NPU is to supply a minimum of 500 watts of electrical power for 1 yr in space. Total weight of the system will be approximately 950 lb. Major subsystems of the NPU are the reactor assembly, thermoelectric converter, coolant loop, and control and instrumentation system.

A. REACTOR ASSEMBLY

The reactor assembly consists of the reactor core and reflector assembly. The reactor contains the fuel elements and provisions for passing the NaK through the core. The reflector assembly included the beryllium reflectors, coarse and fine control drums (also fabricated from beryllium), actuators to rotate the fine control drums, and safety devices (Figure 2).

Attenuation of the nuclear radiation emanating from the reactor is accomplished by a radiation shield (Figure 2) located directly beneath the reactor. Sensitive electronic equipment is located within the "shadow" created by placing the shield between the instruments and the source of radiation. The neutron flux is attenuated to a level which presently permits operation of solid-state components for periods of 1 yr. Radiation effects and qualification of SNAP 10A and Agena electrical components in the expected environment constituted a significant effort in the overall flight test program.

B. THERMOELECTRIC CONVERTER

The thermoelectric converter changes the thermal energy to electric power through the use of Ge-Si alloy thermoelectric elements. The NaK flow is divided between 40 parallel tubes arranged axially along the NPU's conical surface (Figure 3). The thermoelectric elements are placed along the length of each tube and are electrically connected in series (Figure 4). This assembly is called a module. The tube modules are electrically interconnected in groups of parallel and series combinations to give an overall open-circuit voltage of approximately 66 volts, with an internal resistance of about 1.9 ohm. The method of connection minimizes the possibility of open-circuited couples causing a system failure. Figure 5 is a schematic of the converter circuit.

Aluminum fin radiators serve as an electrical connection as well as a thermal radiating surface. A clearance gap between each radiator plate is provided. The total radiator area, including gaps, is approximately 65 ft^2.

A thermal shield, used to prevent prestartup NaK freezing, covers the entire converter until the NaK temperature is approximately 275°F, at which time squibs are fired and the thermal shield is ejected, exposing the radiators to space.

C. COOLANT LOOP

The coolant loop consists of the liquid-metal fluid, a dc conduction pump, expansion compensators, and interconnecting piping. The dc conduction pump is energized by a thermoelectric generator operating between NaK heated to the reactor outlet temperature and a cold junction determined by radiator fins. A permanent magnet provides the required magnetic flux.

Two expansion compensators, located on the NaK return lines, regulate NaK pressure and maintain a sufficient quantity of fluid in the system to prevent the formation of voids (Figure 6).

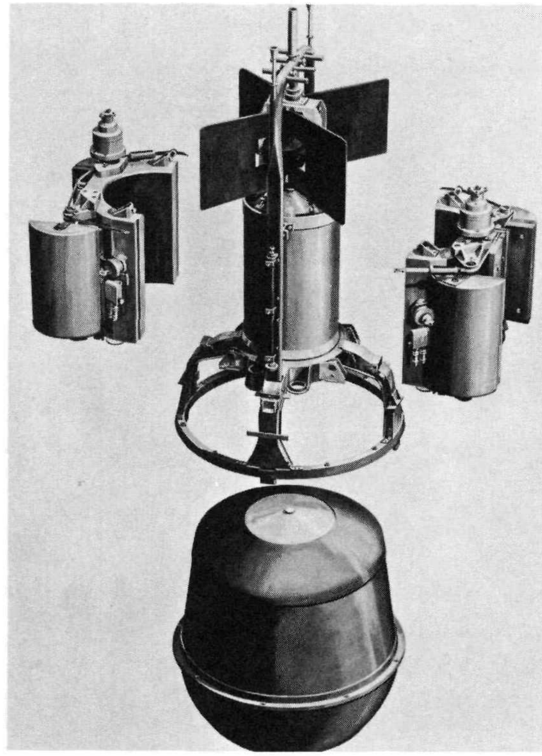

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Figure 2. SNAP 10A Reactor-Reflector-Shield

D. CONTROL AND INSTRUMENTATION

Once the startup sequence is initiated, the control system provides all the logic, timing, and power switching to bring the system to its design point and maintain it for a fixed period of time. The control system is deenergized after steady-state conditions have been attained. The reactor compensates for long-term changes in reactivity by the addition of burnable poisons in the fuel elements.

The reactor is therefore considered to be on passive control after the active control system is deenergized. This is expected to occur about

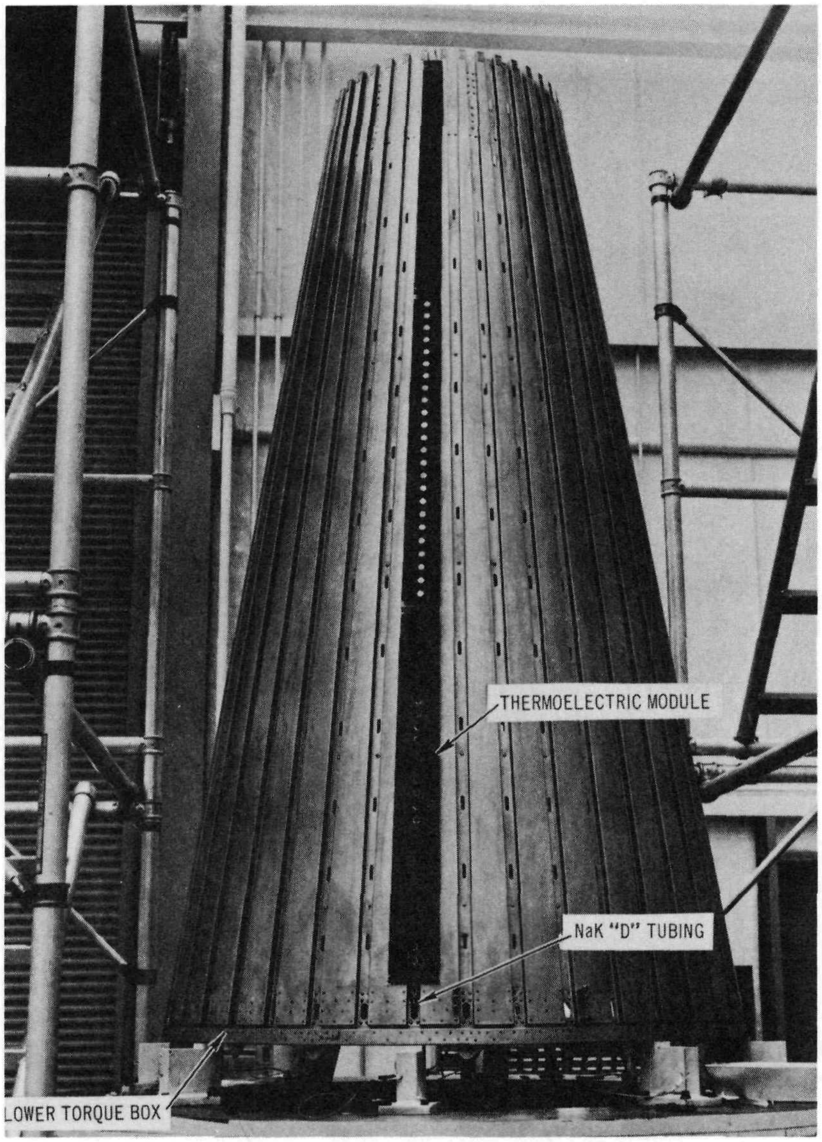

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Figure 3. SNAP 10A Conical Structure

3 days after the initiation of the startup sequence. The control system also automatically initiates the recording of diagnostic information when a system malfunction is present and automatically ejects the reactor reflectors at the end of useful life.

The control system contains an electronic temperature controller, temperature switches, fine-control-drum actuators, relays, timers, voltage sensors, shutdown devices, and other necessary hardware.

An extensive diagnostic instrumentation system monitors important NPU performance and safety variables during all phases of the mission. Parameters measured are as follows:

1) NaK and radiator temperatures

2) NaK flow

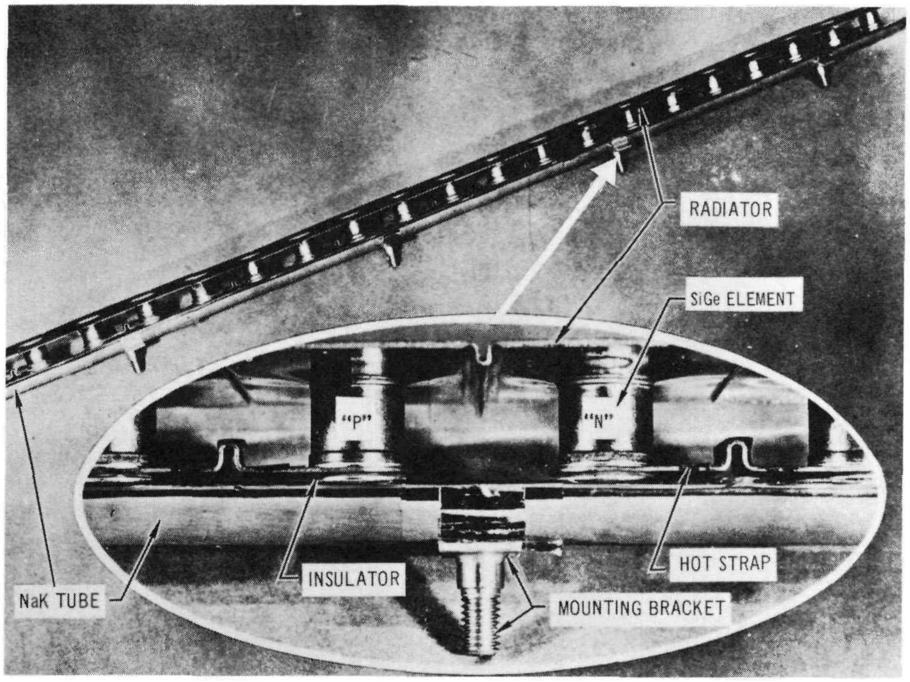

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Figure 4. Thermoelectric Element Assembly

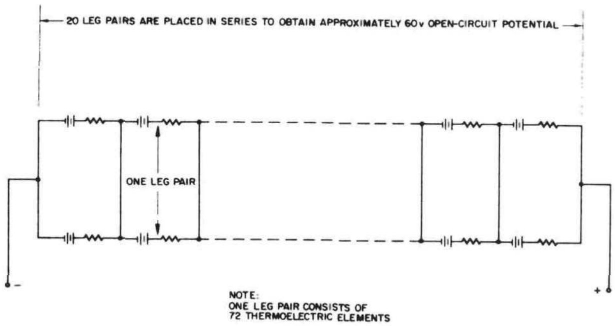

Figure 5. Converter Schematic

3) Converter voltage, current, leakage current and internal impedance

4) Shock and vibration

5) Nuclear radiation

6) Rotary and linear positions which indicate the extent of control-drum insertion (reactivity required) and NaK pressure

7) Contact and switch closures to indicate proper sequencing of the control system and the status of various components.

Over 120 telemetry channels are required to transmit this information. Section III-D discusses the Agena telemetry system used to condition, commutate, and transmit the data.

E. PYROTECHNICS

Squibs are energized by control-system relay switching. Squib-actuated pin pullers perform the required operations, such as releasing the control drums, the thermal shield, and the expansion compensators.

F. SYSTEM OPERATION

The SNAP 10A NPU is placed in orbit by an Atlas/Agena launch vehicle (Figure 7) (see Figure 8 for sequence of operation flow diagram).

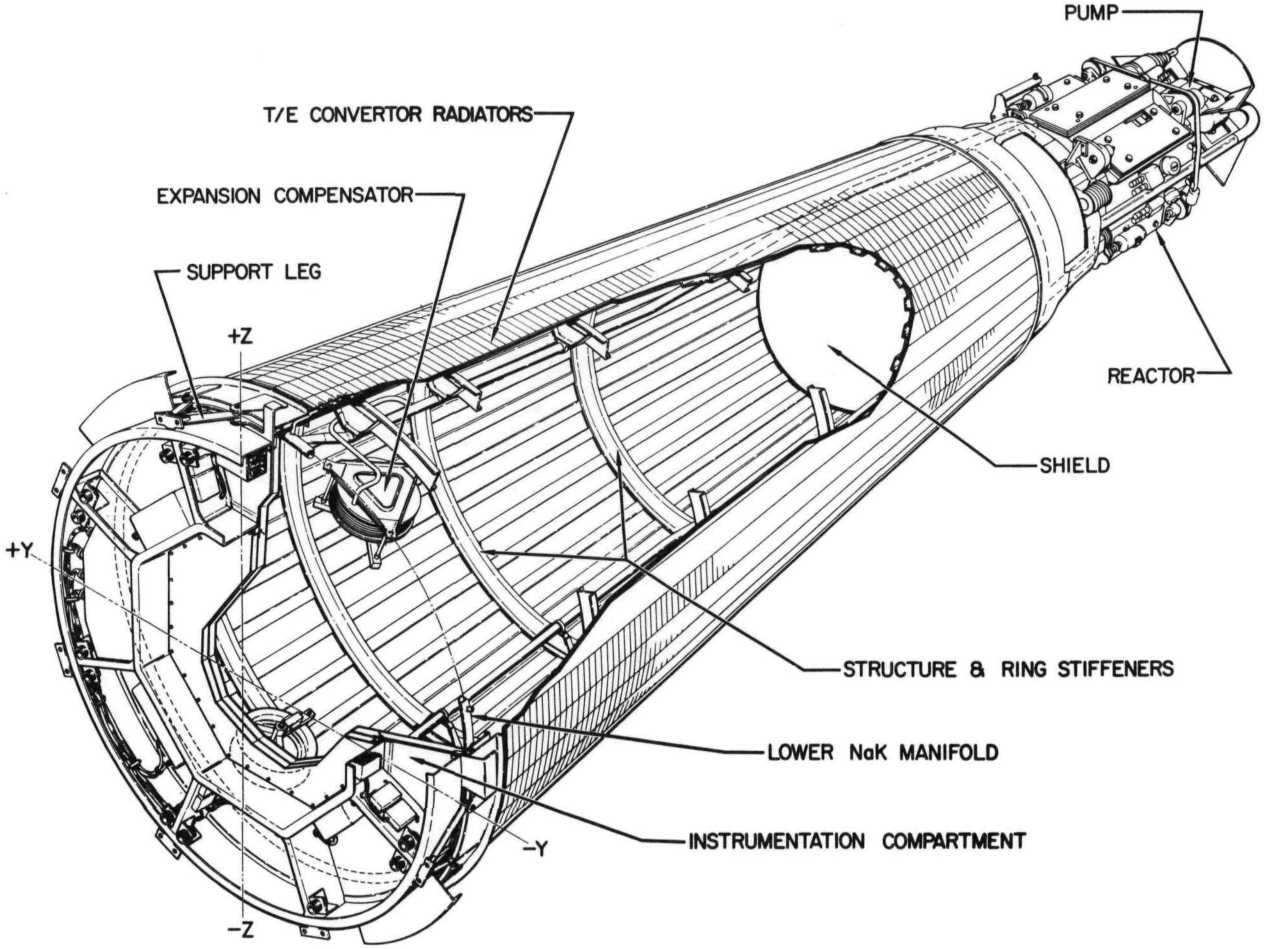

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Figure 6. SNAP 10A System

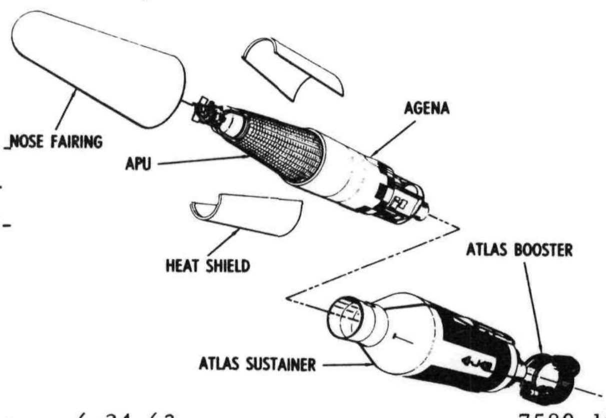

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Figure 7. Vehicle Integration

The NPU remains attached to the Agena, the latter performing the converter power conditioning, telemetry signal conditioning and transmission, command receiving and decoding functions. A more complete description of the NPU-related Agena subsystem is contained in Section III.

After the Agena second burn is completed and the nose fairing is ejected, the NaK compensators are released. Squib firing is initiated by an Agena timer signal. The compensators are maintained in a compressed condition during the period of maximum launch acceleration to prevent mechanical damage.

The NPU startup command is transmitted after the proper orbit has been established. This command energizes the startup relays. Power

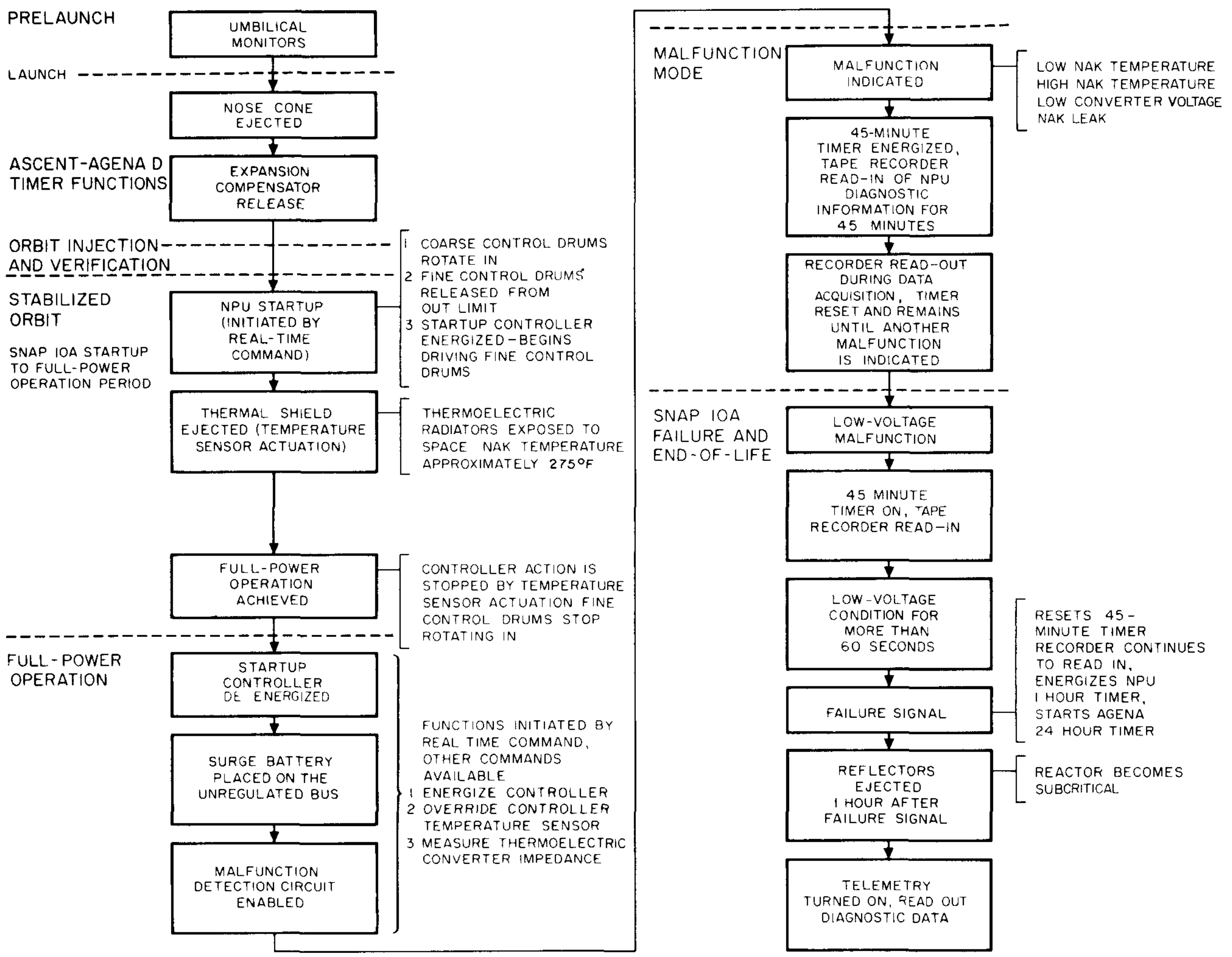

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Figure 8. Flow Diagram, Sequence of Operation

is applied to the reactor temperature controller, and the control-drum squibs are fired. Two coarse-control drums immediately snap to a "full-in" position. The two fine-control drums are rotated slowly toward the "in" position by the controller sequencing and actuator motors. Batteries supply the vehicle and payload with electrical power until useful power is generated by the converter.

Rotating the control drums inward increases the effective reflector thickness. More neutrons are reflected back into the reactor core, increasing the number of neutrons available for initiating uranium fissions. Reactor core and, consequently, NaK outlet temperature increase. When the reactor outlet temperature reaches approximately 275°F, two redundant thermal switches close energizing relays which fire the thermal-shield ejection squibs. The thermal shield, which up to this point has surrounded the entire converter, is ejected and the SNAP system begins radiating heat to space.

The controller and actuators continue to drive the fine-control drums in until the reactor outlet NaK temperature reaches approximately 1000°F. Temperature sensors provide the "off" signal for the controller. The startup control system is then disabled by a real-time command. The reactor will maintain essentially constant operating temperature for the remainder of the mission. Real-time commands are available to turn the controller on and to override the controller temperature sensors to increase the reactor outlet temperature, if necessary.

Other functions which can be initiated by real time command are:

1) Ejection of the reflector assembly

2) Converter impedance test "on and off"— a periodic diagnostic measurement of converter internal impedance

3) Malfunction detection circuit arm

The malfunction-detection circuit arm command enables a logic circuit which provides a signal to the Agena to initiate on-board data recording in the event an off-normal condition exists in the NPU. This command also enables the automatic shutdown circuit. Off-normal conditions which will energize the Agena telemetry and recorder are:

1) Excessively low converter output voltage. Normal range of this parameter is 22.75 to 29 vdc.

2) Low reactor outlet temperature

3) High reactor outlet temperature

4) NaK expansion compensator position. Both compensators must be compressed to initiate malfunction data recording. Abnormal compression of the compensator bellows is indicative of a leak in the coolant loop.

Data are recorded for a period of 45 min after a malfunction is indicated. The recorded information is transmitted to the ground station during real-time data acquisition. A low-voltage condition (converter output less than 22.75 vdc nominal) will provide a malfunction signal. A 1-min timer is energized at the same instant. If the voltage remains below 22.75 vdc for more than 1 min, the automatic shutdown circuit is energized and 1 hr later the reactor reflector is ejected. Ejection is accomplished by melting a fusible link in a band holding the reflector assembly in place. Preloaded springs displace the assembly.

G. REFLECTOR EJECTION

As previously mentioned, the reflector can be ejected by command and by automatic end-of-life shutdown upon loss of NPU output. While on the launch pad, the reflectors also can be ejected through activation of an umbilical signal. A thermally actuated band-release device (TABRD) also is provided as part of the reflector assembly. This safety device is armed when the system temperature is increasing. If the temperature decreases once the safety device is armed, a pin is sheared releasing the retaining band and ejecting the reflectors.

III. NPU/AGENA RELATED FUNCTIONS

The Agena vehicle, in addition to placing the SNAP 10A system in orbit and orienting the two systems with respect to the earth, performs other functions directly related to NPU operations. Agena subsystems directly associated with NPU operation are as follows

1) Electrical power subsystem — all batteries, thermoelectric converter output conditioning, dc/ac inverters, and dc/dc converters

2) Command telemetry

3) Pyrotechnic power

4) Telemetry data signal conditioning, recording, and transmission

5) Umbilical functions

A. ELECTRICAL POWER SUBSYSTEM

The converter output is maintained at nominally 30 vdc by a shunt voltage regulator located in the Agena. A simplified equivalent circuit of the converter is a battery with an open circuit voltage of approximately 66 volts and an internal resistance of about 1.7 ohm. The voltage between the output terminals A and B of Figure 9 is maintained at 30 volts if the combined resistance of the vehicle load and the regulator equals approximately 1.4 ohm. As the vehicle load changes resistance, the regulator resistance also changes maintaining a constant 1 4

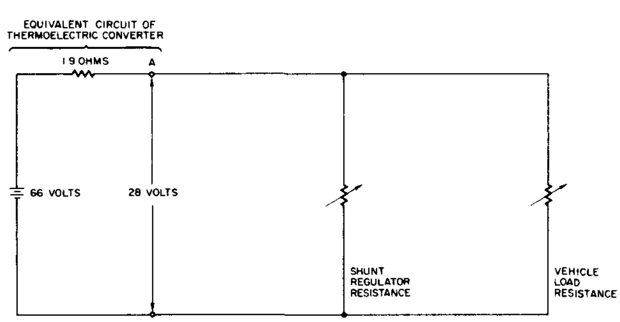


Figure 9. Converter Equivalent Circuit

ohm and the desired line voltage. The numbers used above are nominal values of the expected converter output. The regulator compensates for changes in converter open-circuit voltage or internal resistance.

Figure 10 is a block diagram of the electrical power system including the converter, regulator, batteries, converters, and inverters. SNAP 10A requires five different types of electrical power

1) 22- to 29vdc unregulated — used mainly for control circuitry

2) +28-vdc regulated
3) -28-vdc regulated — diagnostic instrumentation, startup controller

4) 115-volts, 400-cycle ac — diagnostic instrumentation

5) 1.5-vdc — prestartup power for NaK pump

The 22- to 29-vdc power is designated as the unregulated bus and is essentially the converter terminal voltage maintained at the desired level by the above-mentioned shunt regulator. During normal operation the bus voltage is held at 28 vdc plus and minus approximately 2%. When the bus is powered by batteries, the voltage level is about 25 vdc.

The plus and minus 28-volts regulated power is obtained from a dc-to-dc converter which is energized by the unregulated bus. A dc-to-ac inverter changes the converter output (unregulated bus) to 400-cycle, 115-vac.

Figure 10 also shows primary batteries, a surge battery, and failure batteries on the unregulated bus. The primary batteries supply electrical power until sufficient converter output is obtained. The surge battery is switched into the circuit to maintain the unregulated bus

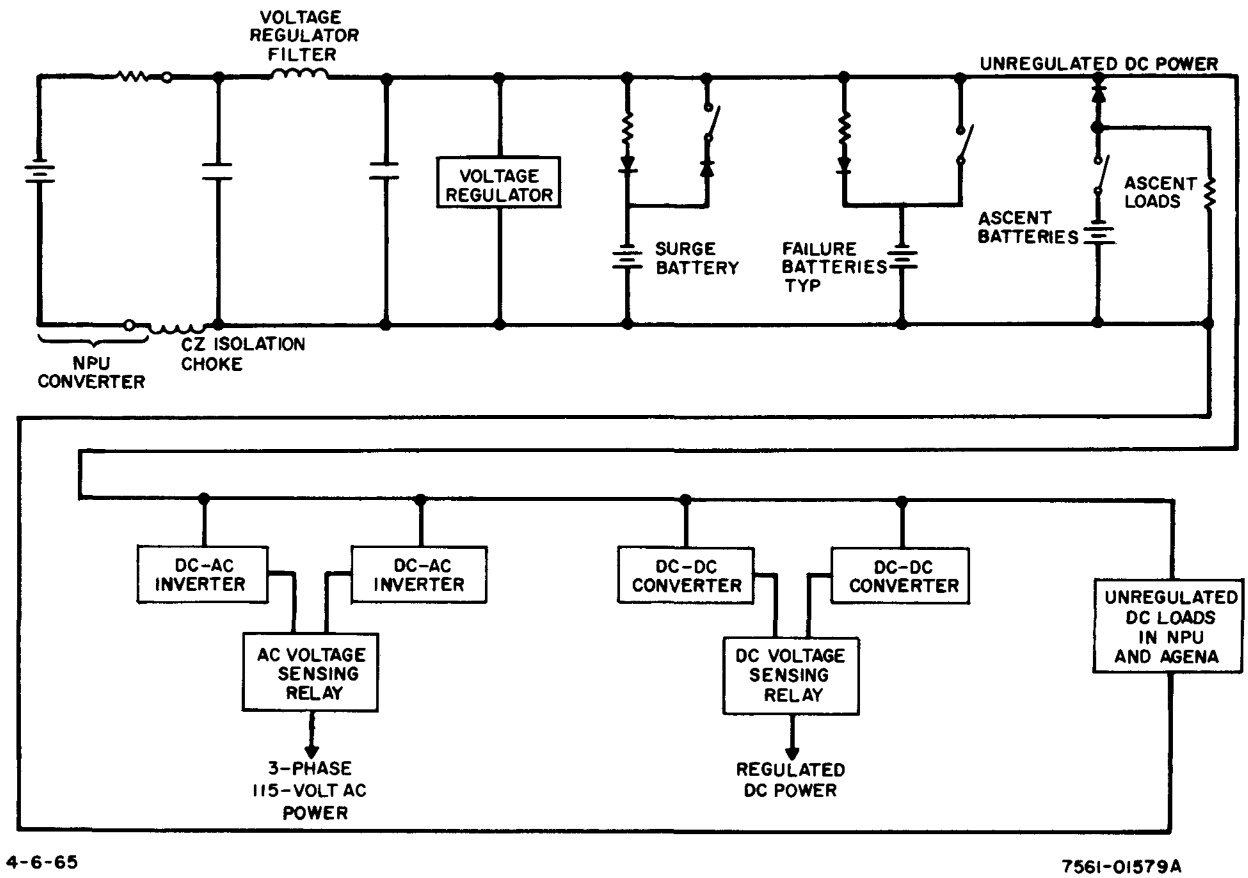


Figure 10. Block Diagram of Electrical Power System

within design limits during periods when the power demand is in excess of the converter output. The surge battery is trickle-charged during normal converter operation.

The failure batteries are connected to the unregulated bus from launch until full power operation is achieved and after a failure signal from the NPU is received in the Agena. The batteries are disconnected from the bus by the same command which connects the surge battery. A single inverter and converter are normally used to supply ac and regulated dc power. A redundant unit is energized when an out-of-spec. converter or inverter output voltage is detected by the sensing relay.

The dc conduction pump used to circulate the NaK is energized by two 1.5-volt batteries until sufficient NaK temperature enables the pump thermoelectric element to supply the required current. A switch, located in the Agena, permits activation of this circuit shortly before launch.

B. COMMAND TELEMETRY SYSTEM

The Agena command system accommodates 32 real-time command signals. The SNAP 10A unit uses the following 11 commands:

1 and 2) NPU startup command – combination of two commands given within a predetermined interval. The first enabling the circuit for execution of the startup signal by the second command.

3 and 4) Reflector eject command – also consists of two interlocking commands. Reflectors are ejected, thereby disabling the reactor.

5) Controller "off" command — disables the reactor startup controller.

6) Controller "on" command — reactivates the startup controller.

7 and 8) Malfunction-detection circuit arm command — enables the NPU malfunction-detection failure logic circuit. (See Section II for operation of this circuit.)

9) Converter impedance test "on" command — a measurement of the thermoelectric converter internal impedance is obtained when this command is exercised.

10) Converter impedance test "off" command — negates the above command and switches the measuring device to the inflight calibration condition.

11) Temperature switch override command — the temperature sensor switch input to the startup controller can be overridden with this command. Initiation of this command presents a simulated low-temperature signal to the controller which causes the controller to rotate the fine control drums in, increasing reactivity and thus raising the reactor temperature.

The command telemetry system receives the ground initiated signal, decodes it, performs the necessary switching functions, and presents at the SNAP 10A/Agena interface a 28-volt pulse. This signal, lasting from 20 to 80 msec, energizes the appropriate relays in the NPU control system. The remaining commands are used by the Agena to control secondary payloads, telemetry links, tape recorders, timers, etc.

An Agena timer signal is provided to release the NaK expansion compensators shortly before the vehicle is injected into orbit.

C. PYROTECHNIC AND DESTRUCT SYSTEM

A separate pyrotechnic battery for energizing squib circuits is located in the Agena. SNAP 10A squibs are fired by operation of the NPU power and control circuits.

D. DATA SIGNAL CONDITIONING~ RECORDING, AND TRANSMISSION

Onboard diagnostic instrumentation used in the SNAP 10A flight-test program is tabulated in Table 1. The Agena contains the multiplexers, transmitters, tape recorders, antenna, and some of the signal conditioning circuits required to complete the data telemetry system. Figure 11 is a block diagram of this system. Three types of signal levels can be accepted by the submultiplexers; outputs between 0 and 20 mv, 0 and 50 mv, and 0 and 5 volts. The millivolt signals are amplified to 0- to 5-volt levels before being further commutated by the control multiplexer. SNAP 10A instrument outputs are conditioned to usable levels either in the NPU instrument compartment or in the Agena. The Agena contains a thermocouple reference junction and junction box which electrically establishes several different "cold" junction temperatures for all the SNAP 10A chromel-constantan thermocouples. Interconnection for obtaining temperature difference measurements also is accomplished in this box. Temperature differences are obtained by measuring the resultant voltage obtained when two thermocouples are placed in series with their generated voltages opposing each other.

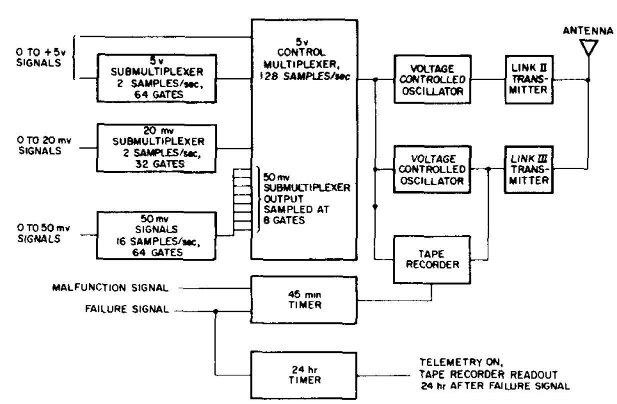


Figure 11. Data Telemetry System

TABLE 1

SNAP 10A DIAGNOSTIC INSTRUMENTATION

Instrumentation	Information Obtained	Simulation of Variable or Instrument on FSEM-3
1. Voltage dividers (VT)	a. Thermoelectric converter output	a. Converter output was simulated by PSM-2. Flight-type dividers were installed
	b. Controller operation	b. Actual controller was installed
2. Voltage taps	a. Converter module outputs	a. Ten resistors were paralleled across the PSM-2 output
	b. NaK flowrate	b. Simulated with a battery and voltage divider circuit
3. Rotary and linear position transducers — variable transformers (PnI)	a. Rotary — Fine control drum position	a. Actual device installed
	b. Linear — Expansion compensator position	b. Actual device was installed. Compensator position simulated by manually moving core of transformer
4. Thermocouples (TC)	a. Pump radiator, reflector surface, thermoelectric radiator, thermal shield, squib, safety device and NaK temperatures	a. Transducers were installed and stimulated with heat guns and resistance heaters
5. Resistance thermometers (RT)	a. Instrument compartment, pump radiator, and NaK temperatures	a. Transducers were installed and stimulated with heat guns and resistance heaters
6. Radiation detectors (ND, RD, ND_o)	a. Reactor neutron flux, instrument compartment fast and thermal neutron and gamma flux	a. Instruments were installed but not stimulated. Fast flux detectors were adjusted to provide on-scale TM readings. ND's and RD were later simulated with voltage divider networks.
7. Accelerometers (AC)	a. Launch shock and vibration	a. Instruments were installed and stimulated by striking sensor
8. Temperature switches (TS)	a. NaK temperatures	a. Simulated with toggle switches. Variable resistors were used for the controller sensors
9. Position switches (PnS)	a. Drum, reflector, expansion compensator, heat shield, and reflector retaining band position	a. Simulated with toggle switches
10. Relay contacts (EvM)	a. Verification of proper control system operation	a. Complete control system was installed and operated in the same manner as the flight system
11. Current shunts (IT)	a. Converter output current	a. Stimulated by PSM-2 output
	b. NaK pump battery current	b. Stimulated by external power supply
12. AC impedance measuring device (CZ)	a. Converter impedance	a. Actual device installed in FSEM-3
13. Converter leakage current measurement	a. Converter current shunted to ground	a. Not installed on FSEM-3

The net voltage output is then multiplexed and transmitted.

Other outputs conditioned by Agena equipment are:

1) Converter leg voltages — 0 to 7 volts conditioned to 0 to 50 mv by voltage dividers.

2) Switch and relay contacts — contact opening and closing in the NPU is conditioned to 1 or 4 volts by voltage dividers located in the Agena.

The PAM-FM telemetry system operates as follows. The 20-mv and 5-volt submultiplexers commutate the conditioned signals at rates of 2 samples per sec. The 50-mv submultiplexer commutates at the rate of 16 samples per sec. The control multiplexer commutates the 0- to 5-volt outputs of the submultiplexers at a rate of 128 samples per sec. The pulse train obtained from the control multiplexer becomes the input to two voltage controlled oscillators. The oscillators output frequencies, which vary with pulse amplitude inputs, in turn frequency-modulate the Link II and III R-F transmitter carrier signals.

Real time and recorded information are transmitted on the same carrier. Redundancy of Link II real time information is obtained by transmitting the same data through the Link III system.

Secondary payload information is acquired from the Link III tape recorder.

E. MALFUNCTION AND FAILURE DATA SYSTEM

After proper startup has been achieved, a real-time command arms the malfunction detection circuit in SNAP 10A. The operation of this circuit is explained in Section II. A malfunction signal is obtained when any of the following conditions exist:

1) Unregulated bus voltage of less than 22.5 + 0.5, -0.0 vdc

2) Excessively low NaK reactor outlet temperature

3) Excessively high NaK reactor outlet temperature

4) Compression of both expansion compensator bellows, due to a NaK leak.

The timer and recorder mentioned in Section II-F are located in the Agena. A SNAP 10A malfunction signal initiates a 45-min timing sequence in the timer. The Link II telemetry system, with the exception of the transmitter, is turned on. The tape recorder records all Link II data for 45 min. The 45-min timing sequence and data recording will continue even though the malfunction signal is removed.

After the 45-min clockout due to a malfunction, the timer must be reset to time zero by real-time command. A low-voltage condition which remains for more than 1 min produces a failure signal. The failure signal, a contact closure originating in the SNAP unit, initiates an irreversible series of events in both the Agena and the NPU. The failure batteries are placed on the unregulated bus, a 24-hr timer is energized, and the 45-min timer is reset to zero and begins another 45-min sequence. The recorder, controlled by the 45-min timer, accumulates Link II data until clockout.

One hour after the failure signal, the reactor reflectors are ejected by the SNAP 10A control system. Clockout of the 24-hr timer results in the Link II telemetry system being turned on and the tape recorder switched to the read-out mode.

F. UMBILICAL FUNCTIONS

The Agena umbilical is used for several SNAP 10A prelaunch monitor and control signals.

The monitors, displayed on a panel in the launch complex, are required to verify that the reactor control drums are in a "full out" (prestartup) position, the reflector assembly is in place, the thermoelectric converter is not damaged, the squib bus is armed, the squib circuit "arm" plug is installed, sufficient current is present in the NaK pump circuit, and the NaK is at a temperature sufficient to prevent it from freezing before the startup command is given.

The squib bus is armed before launch by a signal transmitted through the umbilical. The bus also can be disarmed in the same manner. Ejecting the reactor reflectors and switching the NaK pump battery in and out of the pump circuit can be accomplished through umbilical signals.

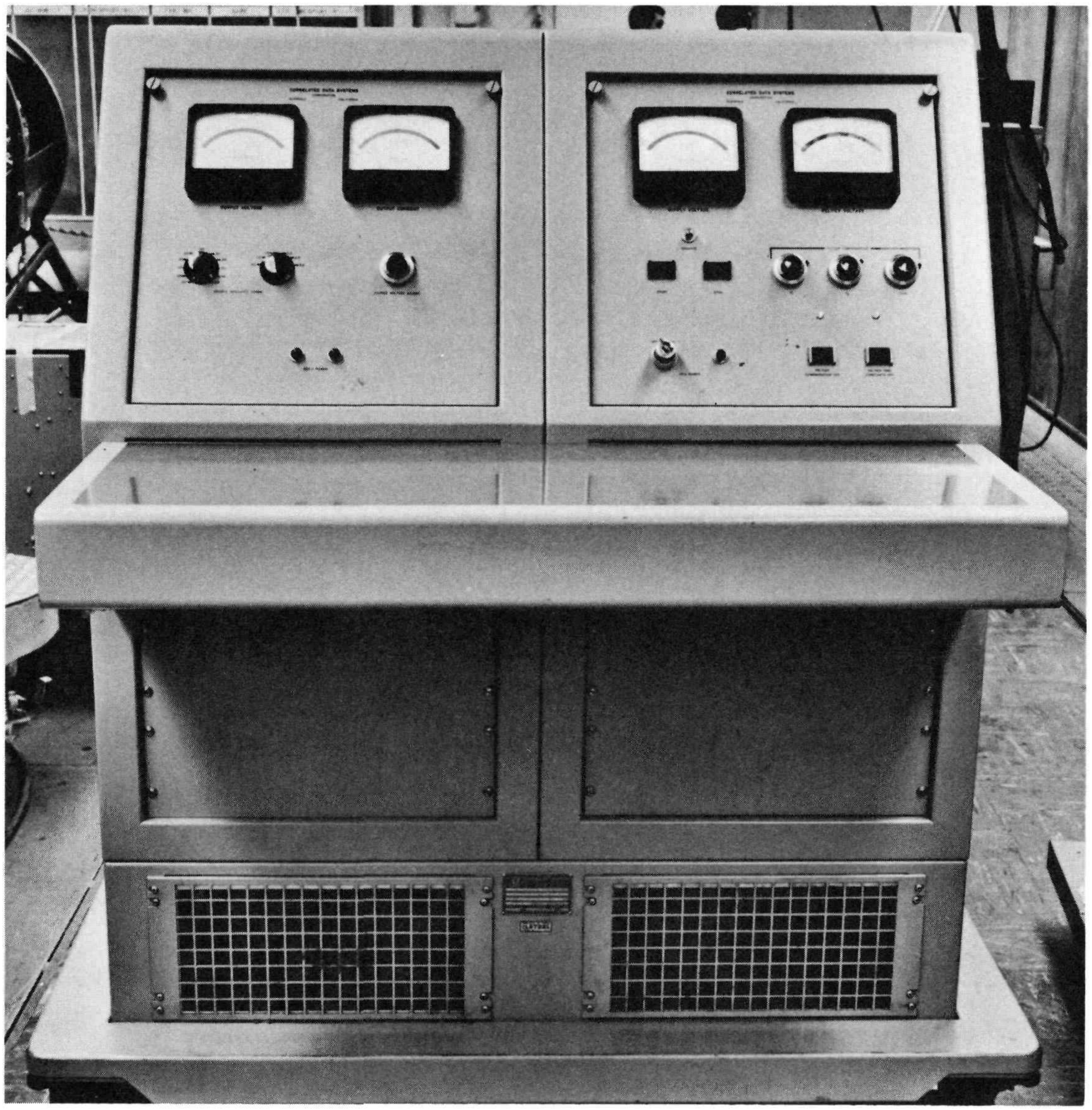


Figure 12. Analog Power Simulator, PSM-2

IV. FSEM-3 SIMULATIONS

FSEM-3 is an electrical mockup of the SNAP 10A nuclear power unit. It was designed to verify the electrical compatibility between the SNAP 10A NPU and Agena vehicle. Since it was not economically and technically feasible to conduct these tests in a thermal, nuclear, and vacuum environment, it was decided that FSEM-3 would contain mass mockups of the reactor assembly, pump, and radiation shield. NaK piping, expansion compensators, pyrotechnics, and thermoelectric converter were omitted. Other test systems and facilities were designed and built to environmentally test the SNAP 10A design. Environmental testing was performed at the AI field facility.

A series of tests was planned utilizing FSEM-3 and an Agena functional mockup. Both vehicles were to contain flight-type electrical equipment. A console was designed to simulate the SNAP 10A thermoelectric converter output. This console was designated PSM-2, Analog Power Simulator (Figure 12).

A. REACTOR ASSEMBLY

As indicated above, the FSEM-3 contained a mass mockup of the reactor and reflector assembly. The only flight-type components of this assembly were the two fine-control-drum actuators and position transducers. The transducers are rotary differential transformers. Demodulators (PNI-1, 2, 3, and 6), located in the instrument compartment, supply power to the sensors and rectify their outputs. The resulting dc analog signal is telemetered to ground stations and is indicative of the amount of reactivity inserted to sustain the fission process in the reactor core.

Drum movement is simulated by a gear train coupling the actuator motor to the transducers. Drum and reflector "in" and "out" limit switches are simulated on FSEM-3 with toggle switches (PnS-1 through 8, and 15 through 18).

B. THERMOELECTRIC CONVERTER

The converter output was simulated with the PSM-2 console. PSM-2 is essentially an ac-to-dc power supply. The output is unregulated, ripple-free dc power. The open circuit voltage, internal resistance, Peltier cooling effect and time constants are provided and are fully adjustable. The following will suffice as an explanation of Peltier cooling and time constants, a detailed discussion being outside the scope of this report.

Current flowing through a thermoelectric element cools the element hot junction. The temperature difference across the element decreases, which in turn lowers the net open-circuit voltage. This property of thermoelectric materials has been used as a cooling technique in many applications. If the current through the converter changes, the cooling effect also changes, though not instantly because of thermal lag. This is the time constant mentioned above.

Simulation of the current path on the shell of the NPU was attained by routing 12-gage wire in series and parallel arrangements in the same manner as the actual converter. This circuit is placed in series with the PSM-2 output. In the flight NPU, proper operation of sections of the converter is verified by tapping the circuit at 10 points and measuring the voltage produced by that section. These voltage taps (VT-3 through 12) are simulated on FSEM-3 by resistors placed across the PSM-2 output. NaK tubing, thermoelectric elements, radiators, and the thermal shield were omitted from FSEM-3.

C. COOLANT LOOP

The entire coolant loop (pump, expansion compensators, NaK fluid and piping) was not installed on FSEM-3. A mass mockup was provided for the pump. Battery power is required to energize the pump from launch until the pump thermoelectric module can produce the required current to keep the NaK flowing. The two batteries are located in the Agena. Wires to conduct this power to the pump were installed and routed in FSEM-3 in accordance with flight system requirements. A shunt (IT-3) used to monitor the current in this circuit was included. NaK flowrate is obtained from taps on the pump. These signals (FT-1 and FT-2) were simulated on FSEM-3 with a battery and resistor network which duplicated the voltage level (0 to 50 and 0 to 20 mv, respectively) and output impedances This simulator also contains toggle switches to simulate thermal switches (TS-3 through 6), a simulated reflector-assembly electrical band-release device, and variable resistors to actuate the controller electronic temperature switches (TS-1 and 2).

Linear position transducers mounted on the NaK expansion compensators were installed in FSEM-3 in the same approximate location as the flight systems, even though the compensators were not included. The two transducers are linear differential transformers. Their outputs are conditioned by two demodulators (PnI-4 and 5) located in the instrument compartment. The instrument was stimulated by manually moving the transducer core.

D. CONTROL AND INSTRUMENTATION

FSEM-3 contained an essentially complete control system With the exception of simulating the reflector eject mechanism and temperature switch sensors, the controller, relay box, control drum actuators, timers, voltage sensors, interconnecting wiring, and operation of the circuitry were in essential electrical agreement with the flight system design as of the date of assembly, approximately September 1963

Table 1 is a list of the diagnostic instruments used in the flight system and shows the information obtained from these devices. The actual instruments mounted on FSEM-3 were flight-type components. Most of the transducers, normally mounted on components omitted from FSEM-3 such as NaK piping, pump radiator, converter radiator fins, and control drums, were mounted in the approximate location of the omitted hardware and in a position which made them accessible from the outside.

Column 3 in Table 1 shows the method of simulation used for the instruments not mounted on FSEM-3, and lists the technique of stimulating the sensors that were installed.

E. PYROTECHNICS

Squib wiring and plugs were installed per flight system requirements. The plugs were mounted in their approximate locations on special brackets. The pin pullers were not used on FSEM-3. Squib simulators were used during compatibility tests.

F. STRUCTURE

Primary flight-design structural components were used in FSEM-3, and included a corrugated titanium converter shell, reactor support assembly, and a flight-system instrument compartment.

FSEM-3 was electrically and mechanically similar to the latest SNAP 10A flight design. Electrical components were either flight-type hardware or sufficiently similar so that valid data concerning the operation of the control, instrumentation, and power systems could be obtained.

V. TEST PLANNING

The requirement for two electrical mockups of the SNAP 10A system for use in combined tests with an Agena Functional Mockup (FMU) was established in December 1961. These mockups were designated Flight System Electrical Mockup 2 and 3 (FSEM-2 and FSEM-3). Compatibility tests performed with FSEM-2 occurred between November 1962 and June 1963. The results of this series of tests were reported in NAA-SR-9893. The FSEM-2/FMU test program was intended to verify compatibility between the SNAPSHOT payload and Agena vehicle electrical systems. FSEM-3, an updated version of FSEM-2, was originally destined for use during Electromagnetic Interference (EMI) tests with the FMU after which it was to be utilized during the flight Agena checkout and systems tests. Subsequent analysis of the FSEM-2 test results prompted Atomics International to request the performance of additional systems tests with an updated FMU before flight vehicle checkout. It was felt that the minimal combined system operation accomplished during the FSEM-2/FMU test program failed to establish confidence in the reliable, compatible operation of the payload and vehicle electrical systems.

The entire FSEM-3/FMU test effort at LMSC's Sunnyvale facility as of December 1963 consisted of the following:

1) Subsystem checkout of FMU and validation of FSEM-3

2) EMI testing in the anechoic chamber

3) Additional systems tests in the Systems Engineering Laboratory (SEL).

The above was scheduled to take place between October 1963 and June 1964. Following the systems tests, FSEM-3 was scheduled to be used during the systems checkout on the flight Agena vehicle.

FSEM-3 was delivered to LMSC on October 14, 1963. However, program schedule redirection occurred during subsystem checkout and all testing ceased. FSEM-3 was placed in storage at LMSC until the test program was reactivated in April 1964. The FSEM-3 schedule was revised as shown in Table 2.

The EMI investigation included the following:

1) Conducted interference compatibility test — a simulated flight sequence of events to verify proper operation of the systems

TABLE 2
FSEM-3 TEST PROGRAM — APRIL 1964

	1964									
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
1. Update FSEM-3 and FMU and Subsystem Checkout	22		5							
2. Integrated Systems Compatibility Tests					15					
3. Electromagnetic Interference Tests							9			
4. Flight Vehicle Systems Tests										15

2) Conducted interference measurements test — measurement of the magnitude and frequency of the conducted EMI present in the vehicle and payload simulator

3) Conducted susceptibility tests (continuous wave and transients) — establish that a 6-db margin exists between a component malfunction which would lead to a mission failure and the vehicle's "normal" conducted EMI environment

4) Radiated interference compatibility tests — a simulated flight sequence of events conducted in an anechoic chamber with the command and data telemetry systems transmitting "open loop"

5) Radiated signature determination with the vehicle and payload simulators in the prelaunch as well as the ascent and orbit configuration

6) Radiated EMI susceptibility tests — to determine if a 6-db margin exists between a system malfunction and the vehicle's self-generated radiated EMI environment

Atomics International defined EMI test requirements in Specification NS10FSM3-00-002, "SNAP 10A FSEM-3 Electromagnetic Interference Test," dated August 2, 1963. The specification requirements called for performing an EMI investigation on FSEM-3 separately before mating it to the Agena. The purpose of this request was to identify possible noise generators and susceptible subsystems prior to system level testing. This test was subsequently performed at AI using FSEM-2A. System level conducted EMI tests were performed at LMSC in the Systems Engineering Laboratory.

The additional systems compatibility tests' plan required the performance of four "successful" Functional Systems Tests; two with the program unregulated bus maintained at its nominal level of 28 vdc and two tests with the bus maintained between 22.5 to 23.5 vdc. A functional test was defined as a simulated flight sequence of events beginning with NPU startup and ending with clockout of the 1-hr reflector ejection timer (ELD), approximately 6000 sec later. A successful test was defined as one where "no component, due to failure, prohibits the normal sequence of operation associated with the primary mission, or where no component, due to failure, limits the capability to monitor system operation primary to the mission."(1) Failures were further classified as primary and secondary. Failures or "out-of-spec" operation of components with secondary importance did not necessitate repeating the systems test. Since mission failure is defined as the point when the unregulated bus remains below 22.75 vdc for greater than 1 min, two tests were performed at the lower bus voltage to verify that all necessary equipments operated properly at the lowest potential expected during the mission.

FSEM-3 and the Agena FMU were updated before the beginning of the systems tests to reflect more accurately the flight systems electrical configuration. Further modifications were made to FSEM-3 before the start of EMI testing for the same reason. Similarity between the flight SNAP unit and FSEM-3 was necessary, of course, to permit reaching valid conclusions from the test results concerning the operation of the flight payloads.

(1) "Test Plan — Proposed Additional SEL Testing Contract AF 04(695)-136" LMSC document dated December 13, 1963

VI. FSEM-3/FMU SUBSYSTEM AND COMPATIBILITY

A. MODIFICATIONS TO FSEM-3 BEFORE SUBSYSTEM CHECKOUT

Changes to the electrical circuits of the SNAP 10A flight systems were incorporated in FSEM-3 as soon as possible without interfering with the test program schedule. FSEM-3 was updated during the first week in May 1964 in preparation for the initiation of subsystem checkout with the FMU. The payload simulator was also modified between the conclusion of systems compatibility tests and the beginning of the conducted EMI investigation.

Additional modifications and repairs were effected on a non-interference basis at various times during the test program.

1. Modifications

While FSEM-3 was in storage at LMSC's Sunnyvale facility, several changes were incorporated into the flight systems. The following list summarizes the updating effort on FSEM-3 which occurred during May 1964:

1) Added controller electronic temperature switches. The sensor simulator was changed from a toggle switch to a variable resistor to provide the proper input to the electronic switches. Capacitor filtering was also added in the controller temperature switch input circuit.

2) Installed converter degradation measuring device transformer.

3) Rewired test plugs to provide a monitoring circuit for the modified one minute/one hour (ESD/ELD) timer. The flight-type timer was installed in November 1964 before checkout of the Agena flight vehicle.

4) Added the external calibration devices for monitoring drum and expansion compensator position indicator outputs and TC and RTD signal levels.

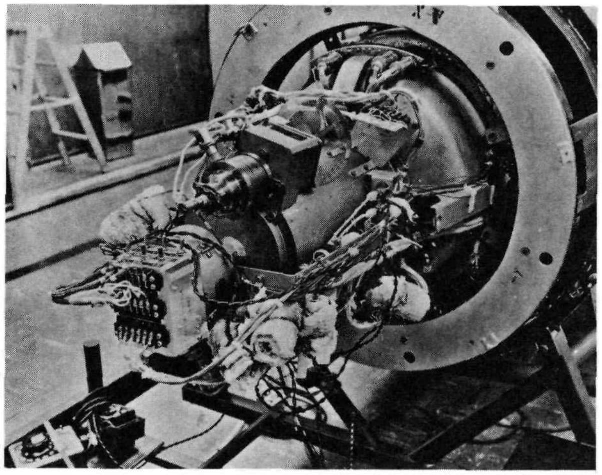
5) Constructed and installed two additional heat-shield harnesses which were used when the heat shield was not installed.

B. SUBSYSTEM TESTING

Subsystem testing and checkout of the Agena functional mockup commenced in late April 1964. The purpose of this effort was to prepare the test vehicle for the combined systems compatibility test program. Subsystem testing terminated on June 25, 1964.

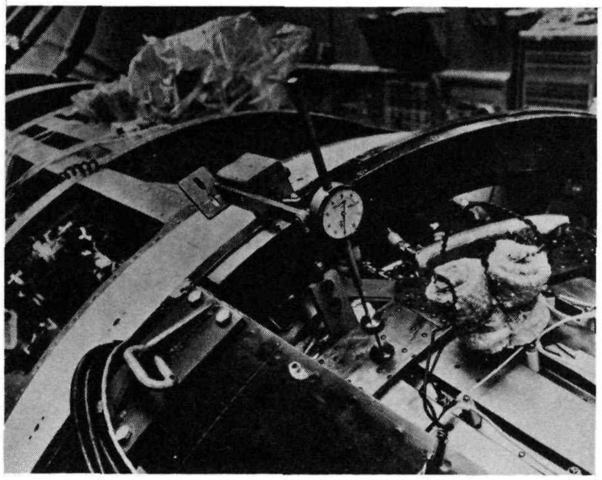
When attempting to mechanically mate the FSEM-3 and FMU, it was found that the FSEM-3 support legs were misaligned and would not mate to the Agena payload adapter ring. The feet were repositioned before the EMI tests. Short circuits in a thermocouple and the reactor neutron leakage flux detector circuit and an open circuited accelerometer cable were the only other problems experienced with the payload simulator during subsystem testing. The FMU power control unit was found to have fused relay contacts and several incorrect wire terminations. Malfunctions in the vehicle power transfer switches, 50-mv submultiplexer gate module, D timer, Timer IV (malfunction/failure timer), dc/dc converter, voltage regulator, and the ac inverters were also observed. All serious problems, to the extent the subsystems were checked, were corrected before the first system run on June 25, 1964.

Additional test aids were installed on FSEM-3 (Figure 13) in preparation for the systems level tests. Special fixtures were installed on the expansion compensator position indicator transducer and the drum position sensor. These devices enabled the test personnel to determine the TM output levels of these instruments from external indications. A precision depth gage was coupled to the expansion compensator sensor shaft (Figure 14). Drum sensor movement was



7561-02614

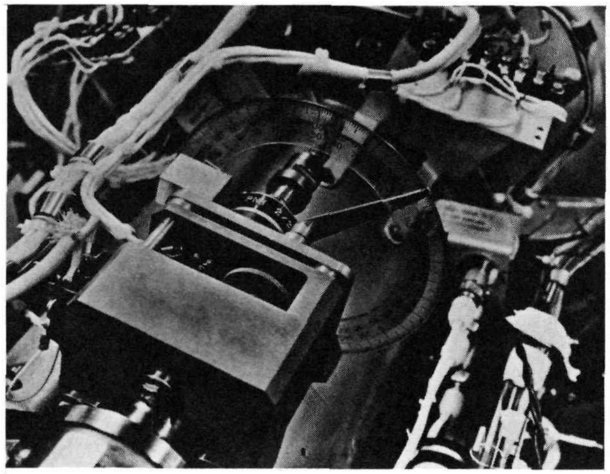
Figure 13. FSEM-3 Reactor Area. Fiberglass Rolls Contain Tubular Heaters and 0.0005-in. Monitoring TC's for FSEM-3 RTD's and TC's



7561-02615

Figure 14. Expansion Compensator Position Indicator External Calibration Device

indicated by displacement of a pointer along a protractor scale. The pointer was connected to the sensor shaft through a gear train (Figure 15). The sensor was not coupled to the actuator motor which enabled the test operators to manually vary the drum position indications throughout their operating range and to predetermined positions.



7561-02616

Figure 15. Drum Position Indicator Calibration Device

Tubular heaters and monitoring thermocouples were connected to approximately 16 FSEM-3 thermocouples (TC's) and resistance temperature detectors (RTD's). The monitoring TC's (0.005-in.-diameter, chromel-constantan) were spot welded to the FSEM-3 sensors in the vicinity of the sensitive active element.

The monitoring TC's were read-out on a Honeywell strip-chart recorder. After correcting for room temperature, the readings were used to predict the TM outputs of the FSEM-3 instruments.

C. INTEGRATED SYSTEMS TESTS

The integrated systems tests commenced on June 25, 1964. The final two simulated flight sequences were performed on September 11, 1964. Data from the final two sequences was analyzed concurrently with the performance of the conducted EMI tests.

1. Check Run No. 1

The NPU sequence of events during the systems tests approximates the data in Figure 8, page 11, Section II-F. Total duration of this test was approximately 1-1/2 hours. An additional startup sequence designated Task II with NPU TM data acquired and reduced from the Link II tape recorder began with the NPU startup command and ended 700 sec later with the simulated SNAP system in a stabilized, full-power condition.

Check run No. 1 was performed to verify that all FMU subsystems and the payload simulator were operating properly before proceeding to the four tests, called Functional Systems Tests, which required successful completion. Numerous problems were found which required a considerable troubleshooting and modification effort. The first Functional test was performed on July 21, 1964 after most of the problems were corrected or identified and deemed non-detrimental or unnecessary for verifying vehicle/payload electrical compatibility.

Figure 16 is a road map showing the actuation of the significant vehicle and payload components and functions as exercised during the Systems Tests.

2. Functional Systems Tests No. 1 and No. 3 (Normal Voltage Tests)

Functional Systems Test No. 1 (FST-1) was performed on July 21, 1964, FST-3 on July 23, 1964. In accordance with the test plan, telemetry data for FST No. 3 was limited to 25 payload TM channels and 15 vehicle data points. All payload and selected vehicle and secondary payload channels were reduced from FST No. 1.

3. Functional Tests No. 2 and No. 4

Performed with the unregulated bus maintained at a nominal 23.5 vdc.

Prior to performing the two "sell" runs, a check run was attempted on July 27, 1964. Vehicle operation was monitored from landline recorders and console indications. Telemetry data was not reduced. The procedure shown in Figure 16 was utilized. Transients on the unregulated bus such as energizing the control drum actuators caused the bus voltage to drop below 22.75 volts, the trip point of the low voltage sensors. Since the reset level of the sensors is about 24.2 volts and the bus was at a maximum level of 23.5 volts, premature failure occurred. It was then decided to perform the low voltage tests at 24.2 volts but since that level was outside the limits specified in the test plan (22.5 to 23.5 vdc), the 23.5 volt level was selected and the test procedure changed to delay arming the malfunction detection circuit until immediately prior to simulating a low voltage malfunction Reset of the low voltage sensors was accomplished before the simulation by raising the bus to approximately 26 volts

Low power output of the TM system transmitter revealed that excessive voltage drops of up to 2.5 volts were present between the vehicle forward distribution point and the aft rack. The drops were reduced to 1 volt by paralleling several wires carrying +28 volts unregulated entering the FMU Power Control Unit and resoldering several electrical connections. The performance of approximately 14 low-voltage systems tests was required mainly due to malfunctions in the 45-min malfunction/failure timer and the Link II tape recorder before two "sell" runs were obtained. The successful tests were both completed on September 11, 1964.

D. SUMMARY OF COMPATIBILITY TEST RESULTS

The FSEM-3/FMU compatibility test effort was designed to investigate the interactions between the payload and vehicle simulators which, by similarity, would determine the degree of compatibility between the SNAPSHOT payload and Agena vehicle. Extensive testing and troubleshooting over a period of 6 months uncovered several unexpected vehicle and payload interactions and equipment deficiencies. Incompatibilities between FSEM-3 and the FMU were relatively few and consisted of the following

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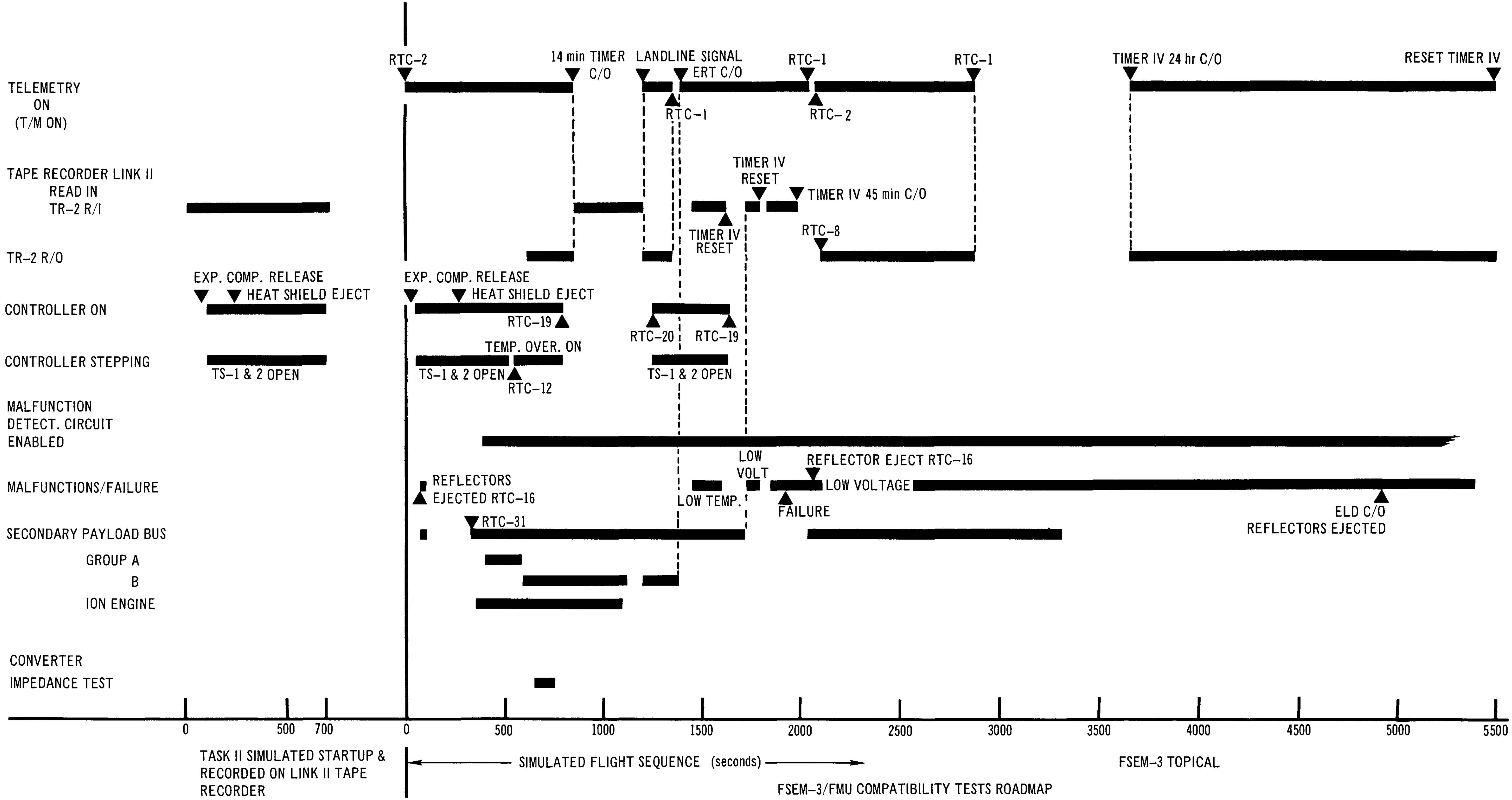

Figure 16. FSEM-3/FMU Compatibility Tests Roadmap

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1) The circuit design of the FMU Type X signal conditioner which conditioned the NPU converter voltage taps from 0 to 7 volts to 0- to 50-mv telemetry signals caused high common mode voltages (up to 30 vdc) to be present on the low-level TM inputs. In addition, it was possible that adjacent converter legs would be shorted out when TM was on due to a make-before-break condition of the 50-mv submultiplexer reed relays. The high common mode voltages caused the submultiplexer magnetic amplifier to oscillate. As a result, 50-mv TM data was noisy, especially the converter voltage tap channels. The converter current shunts in FSEM-3 were incorrectly wired in the positive side of converter circuit which resulted in common mode voltages of 30 vdc being present on these two 50-mv channels. TM data showed level variations of up to 50 to 60% of full scale due to the ringing problem. The flight-type signal conditioner was modified to eliminate all common mode voltages above 0.5 vdc and provided high impedance isolation between converter leg circuits to prevent shorting during TM sampling. The current shunts in FSEM-3 were rewired to place them in the return side of the converter.

Trouble shooting of the TM noise problem was accomplished after the completion of the simulated flight sequences. Corrections made to the signal conditioner were validated on the bench and in the flight vehicle. However, systems tests on the flight vehicle revealed that the 50-mv submultiplexer data was still noisy and further troubleshooting was required. The magnetic amplifier feedback was increased which stabilized the circuit. The problem is discussed further under Flight Vehicle Systems Tests, (Section VIII)

2) The NPU converter impedance measuring (CZ) device operation was found to be affected by the impedance of the vehicle which is in parallel with the thermoelectric converter as shown in Figure 9. The CZ device TM output was between 5 to 6 mv when it should have been reading about 25 to 26 mv which indicated a net impedance of 0.2 to 0.4 ohm. An isolation choke of 5.5 mhy was added to the Agena flight vehicle to increase the AC impedance of the vehicle to 13 to 14 ohms at 400 cps.

Other problems associated with payload circuits which were more a result of incomplete understanding of system interactions rather than incompatibilities include

1) The 24.2-vdc reset level of the low-voltage sensors and the operation of these devices during one of the low voltage tests mentioned previously resulted in a more complete definition of the initiation of mission failure due to low voltage on the unregulated bus. It was found that, should the bus drop below 22.5 + 0.5 - 0.0 vdc and not return to 24.0 + 0.5 - 0.0 vdc within one minute, the reflectors will be ejected 1 hour later.

2) The thermocouple (TC) reference junctions in the Agena are energized from a power supply whose return is connected to the Vehicle Ground Point (VGP). TM data for any TC which utilizes one of these reference junctions will be affected to the point of being unusable should it or a differential TC connected to it short to ground. The differential measurement will also be affected. The effect of grounded TC's on the TM levels was not investigated during FMU testing due to time limitations. A brief test was allowed during the flight Agena systems tests, however, these tests were incomplete in that

they did not provide data to determine the change in output of the differential TC.

3) An apparent anomally which was observed during FMU testing was the high TM values of the drum position demodulators. This problem was explained as a result of troubleshooting performed during flight vehicle systems tests. This problem is discussed in more detail in Table 3. Briefly, the capacitively filtered output of the demodulators, when sampled by a TM gate with an input impedance of 100 k ohms resulted in a time constant of 100 to 150 ms. The gate remains open for only 7.8 ms. Output levels of these devices had previously been checked with a 100-k-load resistor across the output terminals. Due to the transient nature of the output, it was necessary to check the outputs of these devices with a 900-k-load resistor which represents an equivalent average resistance during the 7.8-ms sample period.

4) A minor operations problem was uncovered when it was found that resetting the 1-hour reflector-eject timer would deenergize the secondary payload bus. Launch operations personnel at VAFB were notified of this condition.

In addition to problems associated with payload circuits, several components on the Agena mockup exhibited anomalous behavior.

1) The command system was found to be susceptible to the application of electrical power. Extraneous commands would be sent whenever power was applied to the test vehicle.

2) An unexplained 2-k-ohm resistor was found on the input circuit of the 50-mv submultiplexer magnetic amplifier.

3) The zero calibrate circuit on the same submultiplexer was open circuited instead of being shorted as required.

4) Several reed relay contacts werewelded closed and a short circuit between several TM circuits resulted in burned wires in the 50-mv submultiplexer.

5) The malfunction/failure timer was extremely susceptible to EMI generated by other vehicle equipment especially the Link-II tape recorder. The tape recorder also had mechanical and electrical defects.

6) The control moment gyro (CMG) landline monitors reflected the loading effect of TM sampling.

7) Excessive voltage drops between the forward and aft racks were mentioned earlier under Functional Tests No. 2 and No. 4 results.

8) Difficulty was experienced in identifying data extracted from the Link-II tape recorder. The Link-II recorder does not have an orbital clock indicator as does the Link-III unit and it is mandatory that the quantity of information and the sequence in which it was recorded be known at all times. The tape was erased prior to the systems runs during FMU testing and the flight vehicle checkout effort.

The FSEM-3/FMU compatibility tests in addition to the FSEM-2/FMU tests conducted during the first half of 1963 provided AI and LMSC with sufficient data and experience to conclude that the payload and the Agena vehicle operated together without any serious incompatibility. Repeated programming of the two mockups through simulated flight sequences at normal and off-normal (low voltage) conditions provided a higher degree of confidence in the basic designs of the two units and indicated that the operation of vital power, command and TM functions could be expected during the actual flight tests. Though all equipment on the mockups was not flight-type, the correct performance of units of similar design was accepted as validating the operation of flight articles.

The FSEM-3/FMU test experience later proved to be valuable during the performance of the flight-vehicle systems tests. Some problems reappeared during the later tests such as the noisy 50-mv submultiplexer, CMG monitor anomalies, and timer difficulties all of which were identified and corrected using information and background obtained from the development test effort.

TABLE 3

AGENA VEHICLE 7001/FSEM-3 INCOMPATIBILITIES AND RESOLUTIONS
(Sheet 1 of 4)

Problem	Resolution
1. Excessive noise on 50-mv submultiplexer TM data. This problem was originally thought due to high common mode voltages on several AI TM signals.	1. Increased feedback of magnetic amplifier circuit which decreased rise time of amplifier eliminating oscillations which caused "noisy" TM information.
2. Real time command No. 31 which, in addition to energizing the secondary payload bus, connecting the surge and disconnecting the failure batteries, failed to deenergize the payload ascent instrumentation bus.	2. A potential is generated on the "open" coil of the surge battery transfer switch which holds in the relay coil which energizes the ascent bus. This relay will open if the command is exercised twice. The orbital sequence of events for SNAPSHOT includes this second operation.
3. Payload RTD's which will have outputs in excess of the 50-mv submultiplexer band width will affect the TM gate following the saturated channel to the extent that data will be erroneous.	3. TM gates were reassigned in order to follow the saturated gate with a spare gate.
4. Validation of converter impedance isolation choke indicated that the choke was not effective and the CZ device continued to measure the vehicle impedance in parallel with the NPU converter.	4. The converter continuity measurement in the AGE console created a ground loop which bypassed the choke. The measurement was disconnected during the VST and changes were incorporated in the launch site consoles to prevent a similar occurrence.
5. The drum position demodulators (PnI-1, -2, -3, and -6) TM data levels were up to 10% higher than the levels measured at the payload interface.	5. Interface measurements were originally accomplished by loading the demodulator TM output with a 100-k ohm resistor simulating the TM gate input impedance. Capacitive filtering of the TM output coupled with the 100-k load resulted in a discharge time constant of approximately 100 to 150 ms. The gate is sampled for 7.8 ms. An equivalent impedance of 900 k ohms was calculated from the voltage level obtained 3.5 ms after the gate was open. Correlation of 1 to 2% of full scale was subsequently obtained between TM data and interface levels using the 900-k load impedance. Flight system demodulators were similarly calibrated.

TABLE 3

AGENA VEHICLE 7001/FSEM-3 INCOMPATIBILITIES AND RESOLUTIONS
(Sheet 2 of 4)

Problem	Resolution
6. TM data levels for converter voltage taps VT-1 and -2 were 8 to 10% lower than the values measured at the interface.	6. VT-1 and -2 TM points are monitored on a 0- to 5-vdc single-ended submultiplexer. The ground reference at the submultiplexer gates was approximately 0.4 volt higher in potential than the reference point at the interface. The 0.4-volt difference was caused by the flow of 17.5 amps through the CZ isolation choke, wire, shunt, and plug contact resistance in the converter return circuit. Corrections to flight data will be made based upon the current flow as indicated by IT-2 and the resistance in the converter return circuit between VGP and the interface. Temperature compensation of the resistance is also anticipated.
7. TM data levels for the two expansion compensator position indicators, PnI-4 and -5, were 5 to 6% lower than the values measured at the interface.	7. The cause for this anomally was never discovered but the condition was repeatable. A 10-point calibration, interface level vs TM data value, was performed for each device and the resulting information used to correct flight data. These instruments are bridge circuits with a variable inductance in two legs. Diodes in the bridge cause it to operate on a half cycle of the 400-cps vehicle inverter. The 400-cps inverter uses a Scott T connection and one phase (which is used by PnI-4 and -5) is capacitively coupled to ground. A step-down transformer in the PnI circuit reduces the voltage and apparently isolates the bridge from the power source. Difficulty was experienced during VST with AGE monitoring of the 400-cycle voltage.
8. Umbilical monitors during the preliminary Task X for NaK temperature and pump current showed random fluctuations of ±10% to 20% of full scale and changed levels when TM was switched on and off. The fluctuations diminished to ±5% of full scale during the final systems test.	8. The reason for the varying umbilical signal levels was not determined. TM values for the same transducers did not exhibit these characteristics. It has been assumed that either rework of the guidance module or the addition of grounds at all the Agena dosimeters, both efforts being completed before the final test, were the cause of the improved readings.

TABLE 3

AGENA VEHICLE 7001/FSEM-3 INCOMPATIBILITIES AND RESOLUTIONS
(Sheet 3 of 4)

Problem	Resolution
9. The 45-min portion of Timer IV intermittently clocked out less than 2 min after a malfunction signal was simulated during VST.	9. Pre-Task X vehicle conditioning which included power switching and exercising command functions caused transients which set the magnetic core logic to a point where it would clockout early after a malfunction signal energized Timer IV. Proper operation of the timer occurred if a reset command was exercised prior to the malfunction. The timer will be reset during the flight test prior to enabling the NPU malfunction detection circuit and periodically thereafter.
10. NPU startup controller would clock out 50 sec after switching the source of regulated dc power from one vehicle converter to another.	10. The switching function would momentarily interrupt the regulated dc power to the controller resetting the internal logic to zero time. The first sequence of the controller is 50 sec in duration followed by 150-sec periods until the reactor reaches operating temperature.
11. Inadvertent low-voltage malfunctions occurred during the final systems test which raised doubts as to the validity of simulating the flight NPU converter with PSM-2 settings of 57 volts open circuit and 1.6 ohms internal impedance.	11. The malfunctions and other excessive voltage drops on the unregulated bus during this test were caused by vehicle power demands in excess of the power available from PSM-2 which was about 520 watts at the interface and approximately 500 watts at the Agena forward distribution point. Vehicle power demand at one point was 580 watts. The surge battery simulator which would normally supply the extra power was set at the failure level of 22.75 volts and therefore did not supply current until that level was reached. Analysis of the parameters of the flight converter established the validity of the PSM-2 settings. A separate test was conducted with PSM-2 settings set at the values expected during the flight test (a) after a normal startup, and (b) after 90 days of operation. The PSM-2 parameters were also set to the values used during the preliminary and final Task X's. A flight-type surge battery was installed in the

TABLE 3

AGENA VEHICLE 7001/FSEM-3 INCOMPATIBILITIES AND RESOLUTIONS
(Sheet 4 of 4)

Problem	Resolution
	11. (Continued) vehicle. The vehicle bus was overloaded in the same manner as during Task X without the occurrence of a low-voltage malfunction. The vehicle responded in the predicted manner thereby validating the design of the power system. Power management during the flight was also examined to verify that overloads do not occur.
12. Excessive loss of TM synchronization due to a repeated malfunction in the 20-mv submultiplexer.	12. Loss of synch occurred mostly when the unregulated bus voltage was approximately 23.5 vdc. Voltage at the submultiplexer was near 22 volts which is its lower operating limit. Another unit was installed in the vehicle and was found to operate satisfactorily.
13. The ambient readings of the vehicle radiation dosimeters exceeded specification limits.	13. This condition was corrected by grounding the unregulated bus return to the vehicle structure at the dosimeters. Though ground loops were created, other equipment was not affected.

VII. ELECTROMAGNETIC INTERFERENCE TESTING

EMI tests were performed between September 23 and October 9, 1964. The Agena FMU and FSEM-3 were modified prior to the test effort to more accurately represent the flight systems. The radiated EMI investigation originally scheduled for this period was postponed to commence system checkout of the flight vehicle and to obtain a radiated signature on the actual Agena rather than a mockup. The signature was obtained in the vehicle systems test area.

A. FSEM-3 AND FMU MODIFICATIONS PRIOR TO EMI TESTS

The modifications to update FSEM-3 were completed before the performance of the final two low-voltage integrated systems tests. Changes to FSEM-3 included:

1) Installation of eight fast neutron flux dosimeters

2) Removal of destruct circuit wiring which was deleted from the flight system

3) Deleted wiring to two heat shield squib plugs which were also removed from the flight system

4) Relocated the support legs which mate the payload to the Agena in order to align all bolt holes

5) Removed TC and RTD heaters and monitoring instruments

6) Rewired controller sensor input and test points to agree with the latest flight NPU circuitry

In addition to filtering the FMU malfunction/failure timer input power lines and testing guidance and control subsystem components, LMSC measured Link 2 and 3 transmitter frequency deviations and RF power outputs and the insertion losses of all RF cable paths and switches.

B. EMI TESTS

The conducted EMI investigation consisted of the following tests:

1. Test C-1, Conducted Compatibility, Prelaunch-Ascent Phase

FSEM-3 and the FMU were programmed through a simulated launch and ascent sequence of events. Landline recorders, transient detectors, and oscilloscopes monitored vehicle bus voltages and sensitive circuits. Vehicle operation was evaluated from AGE console lights and meters. High-sensitivity squib simulators were installed in all FSEM-3 pyro circuits except the expansion compensator release circuit which is energized during ascent by the Agena D timer. Standard squib simulators consisting of M-79 squib bridge wires were utilized for this as well as for FMU pyro functions.

2. Test C-2, Conducted Compatibility, Orbit Phase

The mockups were programmed through a simulated orbit sequence of events and the vehicle operation was monitored from AGE indications. Prior to being fired, the high sensitivity squib simulators in FSEM-3 were replaced by the M-79 simulators.

The purpose of tests C-1 and C-2 was to verify that the mockups were not susceptible to self-generated interference.

3. Test C-3, Steady-State Conducted Interference Measurement, Prelaunch-Ascent Phase

The vehicle was returned to the ascent phase at a time when TM Links I, II, and III were on and most of the guidance and control system was active. This condition generated the highest EMI levels during the prelaunch-ascent phase. Measurements of the conducted interference on the unregulated bus and the plus 28-vdc regulated bus were made between 20 cps and 25 mc using three 915501-1 Stoddart current probes in conjunction with NM-40A, URM106, and NM20B Stoddart receivers.

4. Test C-4, Steady-State Conducted Interference Measurement, Orbit Phase

The FMU/FSEM-3 test vehicle was conditioned to the "worst case" orbit configuration which included operating all TM links with the Link-II tape recorder reading-out, flight control system to high gain, secondary payloads Group A on, ion engine on, and NPU impedance test on, in addition to the NPU controller and vehicle equipments normally energized whenever power is supplied to the main power bus. PSM-2 simulated the NPU converter output.

EMI measurements were made of the conducted noise between 20 cps and 25 mc present on the +28 volt regulated and unregulated buses using the same test equipment as in C-3.

5. Tests C-5 and C-6, Steady-State Conducted Susceptibility, Prelaunch Ascent (C-5) and Orbit (C-6) Phases

In two separate efforts, FSEM-3 and the FMU were conditioned to a configuration identical to the C-3 and C-4 tests. White noise was induced on the +28 volt regulated and unregulated bus using a General Radio 1390-A noise generator, a 200B McIntosh amplifier — 200 watts, and a Solar 6220-1 coupling transformer. Discrete frequencies were again monitored with the Stoddart equipment. TM data was recorded for 100 sec with the vehicle operating normally. Noise was then injected for 100 sec on one bus at a time. The amplifier gain was increased to obtain a noise level 6 db higher than the measurements made in C-3 and C-4. This was possible only up to 3 to 10 mc. In attaining the 6 db margin at higher frequencies, the noise level at lower frequencies was much greater than 6 db over the measurement tests though no absolute measurement was made. Oscillograph wave trains of the main multiplexer outputs were analyzed to ascertain the extent of TM susceptibility. Landline monitoring was also used to monitor vehicle performance. Two-hundred seconds of Link-II tape recorder data were recorded and analyzed in the same manner as the real time TM information.

6. Test C-7, Transient Conducted Susceptibility, Orbit Phase

The test vehicle was programmed to an orbit configuration and six switching events were exercised. The events were, TM on and off, ion engine on and off, NPU startup and NPU drum actuators energized. Transient interference was monitored on the +28 volt regulated and unregulated buses using an oscilloscope. The most severe transient (-4 volts) on the unregulated bus was caused by the TM on command. The execution of the NPU startup command resulted in a -4 volt pulse on the regulated bus.

A -8 volt pulse was injected upon each bus at a repetition rate of 1 pps. The vehicle was programmed as follows:

1) TM on, Link-II TR readout — 100 sec without noise injection

2) TM on, Link-II TR readout — 100 sec with pulses injected

3) TM transmitters off, Link-II TR read-in — 100 sec without noise injection

4) TM transmitters off, Link-II TR read-in — 100 sec with pulses injected

Oscillograph records of the Link-II real time and tape recorded main multiplexer wave trains were analyzed to determine the susceptibility of the TM system. Vehicle operation was monitored from landline records and visual indicators.

Transients presented to the malfunction/failure timer due to Link II tape recorder operation were measured to obtain the worst-case condition. The largest spike due to the above was found to be 1 volt. The "TM on" command caused a -10 volt spike to appear on the timer power input. Clockout of the 45-min and 24-hr (fast-clocked to 30 min) portions were then checked while a pulse of -24 volts was imposed on the power input line. Both sections of Timer IV clocked out properly in the presence of the injected interference. The NPU 1-min and 1-hr timers as well as the 3 one-min, orbit, and 14-min timers all functioned properly when pulses of approximately -10 volts were injected on the FMU regulated and unregulated lines.

C. SUMMARY

The EMI tests at LMSC verified that the FSEM-3 and FMU conducted EMI characteristics were compatible and that at least a 6-db margin existed between the self-generated EMI environment and equipment malfunction. It was not possible to verify the 6-db margin at 775 and 1550 kc or above approximately 10 mc. Noise generating equipment limitations prevented the insertion of interference at 775 and 1550 kc at twice the vehicle generated level. The source of these frequencies was not determined but appeared to be associated with the TM system. When attempting to attain a +6-db level at 25 mc, the amplitude of the lower frequencies were significantly greater than +6 db over their measured values causing the Agena dc-dc converter transfer relay to oscillate thereby interrupting regulated dc power.

Qualitative evaluation of TM data was limited to analysis of the main multiplexer wave train. The ambient noise level of the Link-II tape recorder was observed to increase when noise was injected on the regulated and unregulated buses.

Radiated and conducted interference tests were conducted on a payload simulator designated FSEM-2A at Atomics International's field facility. The tests were performed in accordance with MIL-I-26600 procedures (compared to the MIL-E-6051C techniques used at LMSC) to measure the interference generated by the payload and to determine the susceptibility threshold of the system. Continuous wave interference generation and susceptibility was examined over the frequency range of 50 cps to 15 kc and 150 kc to 25 mc. Radiated EMI was investigated between 150 kc and 400 mc. Transient interference generation and susceptibility was also determined. Test results were published in AI report NAA-SR-TDR-10746. NPU radiation detectors and accelerometer amplifiers were found to generate continuous wave interference in excess of MIL-I-26600 requirements. Relay and switch transients also exceeded specification limits. The reset levels of the low-voltage sensors were found to vary when cw interference between 50 and 400 cps at an amplitude of greater than 0.5 volt rms was injected on the unregulated bus. The startup controller timing sequences were reduced from 150 to 50 sec by injecting 15-volt positive pulses of 10 μsec duration on the plus and minus 28-vdc regulated neutral line.

EMI tests at LMSC did not reveal any significant anomalous behavior of the controller or the low-voltage sensors due to self-generated noise. However, the controller was found to clock-out incorrectly 11 out of 155 sequences during the conducted transient and continuous wave susceptibility tests C-4 and C-7. Twenty controller timing malfunctions out of approximately 500 sequences occurred during normal operation of the FMU and the Flight Agena and FSEM-3.

VIII. FLIGHT AGENA SYSTEMS TESTING

Systems testing of the Flight Agena, vehicle 7001, commenced on October 29, 1964, and ended with delivery of 7001 to VAFB on February 17, 1965. Vehicle Systems Test (VST) is the validation and final checkout of the spacecraft prior to shipment to the launch site. FSEM-3 was utilized to simulate the payload and PSM-2 provided simulated converter output power. The final systems run, designated Task X, was performed after all subsystems were individually validated. Task X was similar to the abbreviated flight sequence of events performed during FSEM-3/FMU compatibility tests. Successful completion of Task X leads to "buy-off" of the vehicle by the Air Force. Task X was a more complete simulated mission than the earlier FMU tests and included real-time clockout of both Agena 24-hr timers. The total length of the test was about 32 hr plus setup time.

This section will summarize briefly the test effort as it affected the primary payload and incompatibilities discovered between FSEM-3 and the Agena.

A. MODIFICATIONS TO FSEM-3 PRIOR TO VST

Current limiting resistors were added to FSEM-3 switch circuits utilizing high-temperature wire to update the simulator to the flight-system design. Resistors were added to the flight payloads to prevent a short circuit in the high-temperature wire from aborting the mission. TM data levels were affected slightly but still provided sufficient resolution (1 volt—open, 3 volts minimum — closed) to detect a change of switch status. A flight-type ESD/ELD was also installed. The new timer provided test point indication which was more informative in determining reset status than the older units.

Other changes to the payload simulator were made to support the more rigorous test procedures planned for VST. These changes included:

1) Replacing the RTD sensors with fixed resistors. Known TM outputs for these devices, dependent only on +28-vdc regulated bus voltage and not room temperature and voltage, enabled the AI personnel to evaluate TM data quality and accuracy and to provide on-scale readings for all RTD TM channels.

2) The radiation detectors' RD-1, ND-1, and ND-3 were simulated with voltage divider networks for the same reasons. Output impedances of the actual devices were duplicated.

3) A toggle switch was placed in parallel with one low-voltage sensor TM contact in order to stimulate its TM gate independently of the other sensor. Both TM monitors normally occur essentially simultaneously upon low-voltage malfunction.

4) Designed a mv simulator to stimulate up to 9 TC circuits during Task X in order to evaluate TM quality and to verify proper Agena TC reference junction operation. This same device was used to validate the proper operation of all TM gates on the 20- and 50-mv submultiplexers.

B. TEST SEQUENCE — PAYLOAD CIRCUITS

The following tasks were completed prior to Task X to satisfy the requirements of subsystem testing of the payload and payload associated circuits.

1) Prior to mating, all vehicle interface plug pins which carried primary power including 28 volts for switch closure TM signal conditioning were checked for proper voltage level and polarity

2) All pins which carried 28-volt command pulses were validated

3) Proper operation of the Agena voltage regulator in conjunction with PSM-2 was verified

4) Proper wiring and polarity of all payload analog TM channels was verified by stimulating up to 10 gates at once to different levels using either the mv simulator test aid or similar circuits for 5 volt signals. Visicorder records of the submultiplexer and main multiplexer outputs were utilized in the analysis of this effort.

5) An abbreviated flight sequence was performed to validate FSEM-3 circuitry including control system response, controller operation and proper functioning of all telltales (switch and relay contact closures).

6) TM system accuracy was determined by stimulating 18 payload diagnostic channels and comparing TM input levels measured using breakout boxes against the reduced TM data.

7) Setup for Task X included measuring the output levels of FSEM-3 diagnostic instruments. This information was later used to evaluate TM system operation from reduced TM data.

C. TEST RESULTS

The vehicle 7001 system test effort revealed and provided a resolution or explanations for incompatibilities between the payload and the Agena system not uncovered during development testing between FSEM-3 and the FMU.

Table 3 is a listing of the significant difficulties encountered during VST and their resolutions which were associated with the primary payload.

In addition to the changes in flight-test operations, instrument calibration, etc., generated as a result of the vehicle systems tests, two other significant changes were made to the flight vehicle which necessitated changes in vehicle operation. Concern over the failure of one TM transmitter causing the loss of primary payload information resulted in the use of the Link II and III RF links to transmit Link II real-time data. The three one-min timers associated with the NPU startup, reflector eject and malfunction circuit enable commands were replaced by latching relays due to the EMI susceptibility of the timers. The relays are latched open by the same command which turns off secondary payloads Groups A and B.

A revalidation test was performed after completion of the final Task X on January 8, 1965 to determine if the 20-mv submultiplexer loss-of-synch problem had been corrected. The resolution for the Timer IV problem was determined after the revalidation test. Noise on the unregulated bus due to initial startup of the Ion Engine 200-watt battery charger circuit continued to impose transients and noise on the unregulated bus and, though a cause and correction could not be determined, malfunctions in the operation of other equipment were not observed.

Mean values and standard deviations were calculated by hand from TM data generated during the TM accuracy verification test mentioned in Section B-6. Interface values agreed with reduced data to within ±3% of full scale on all the channels examined. Instruments were selected for this test based on their uniqueness with respect to:

1) Output impedance

2) TC reference junction temperature (0, 32, or 800°F)

3) Multiplexer input (20 mv, 50 mv, 5 volts submultiplexer and 5 volt control multiplexer)

4) Reference of output signal to ground

5) Nature of the signal source (TC, RTD, ND_o, etc.)

FSEM-3 was returned to Atomics International on February 23, 1965.