APOLLO EXTRAVEHICULAR COMMUNICATION TELEMETRY SUBSYSTEM

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Summary The original Apollo Space Suit Communications System (SCC) was designed to accommodate one Extravehicular Astronaut. Early in 1967, NAS.N established a requirement for an extravehicular Communications System (EVCS) which would enable two astronauts to simultaneously explore the lunar surface. Included in this requirement was a telemetry subsystem to monitor the performance of the portable life support system (PLSS), space suit performance and body functions of each astronaut while on the lunar surface.

This paper reviews the EVCS telemetry subsystem design including electrical and functional capability, packaging techniques, reliability and configuration control programs utilized in meeting the stringent requirements of a miniature, high reliability, man-rated electronic system for space applications.

Introduction The Gemini Program developed the initial personal communications required in space exploration with the first system being carried aboard the Gemini IX.

Later, the Apollo Program established initial requirements for a space suit communication system to accommodate an extravehicular astronaut. This requirement was expanded in early 1967 to include the capability for two extravehicular astronauts to explore the lunar surface.

In view of the advanced state of the Apollo design effort, a telecommunications system f that would satisfy the following program and system design constraints was required:

1. No impact on the existing lunar module (LM) communications system design.
2. Continuous telemetry data relayed to earth, simultaneously from each of the two extravehicular astronauts.
3. Meet program scheduled (delivery of flight qualified hardware within sixteen months after receipt of contract)

J.B. Tollison, “The Apollo Extravehicular Communication System”, National Telemetry Conference Proceedings, 1968.

4. Minimum inpact on the existing Portable Life Support System (PLSS)

The system designed to fulfill the above requirements is known as the extra vehicular communications system (EVCS) and consists of a pair of extravehicular communicators (EVC), one for each astronaut. The telemetry portion of the communicators differ in that the subcarriers are 3.9 kHz and 7.35 kHz for EVC-2 and 5.4 kHz and 10.5 kHz for EVC-1. Figure 1 shows an early model of an EVC with its top cover removed. The basic form factor for an EVC was dictated by the available space in the PLSS, including retention of existing mounting provisions. This system was flown on the Apollo 11 Mission.

Size, weight and reliability requirements for this equipment required advances in the state of the art relative to circuitry and fabrication techniques. Utilization of high reliability components required extremely high packing densities. Inasmuch as the EVCS equipment is considered essential to mission success on the lunar surface, great emphasis was placed on reliability and quality control. Co-ordination of the reliability requirements, part procurement, configuration control and traceability was a major effort. The telemetry subsystem portion of the EVCS described below, is indicative of how these requirements were met by Sonex.

General Description The telemetry subsystem is contained in an aluminum chassis having a volume of nine cubic inches and a weight of nine ounces (reference figure 2). Each unit consists of an assembly of signal conditioners, voltage regulators, an electronic commutator, voltage controlled oscillators and warning tone generator. A simplified block diagram of the complete subsystem is shown in figure 3.

Transducer signals from the PLSS, space suit and the astronaut are applied to the active and passive signal conditioners where they are converted to 0 to +5 signals suitable for commutation. The electronic commutator processes the signals, adds a pedestal voltage and then applys the signals to the appropriate VCO.

The output of each VCO is applied to the modulator of the RF transmitter where mixing of the signals with the astronaut’s voice takes place.

The tone generator input signal is received directly from the 0_2 pressure transducer in the astronaut’s space suit. The function of this unit is to alert the astronaut of a loss in 0_2 pressure by keying a 1500 Hz tone generator at a 15 Hz rate.

This emergency audio tone is applied directly to the earphones of the space suit. A warbling tone is much more effective than a continuous tone for recognition.

The regulators are used to supply precise voltages to external transducers.

Electrical Design

Voltage Controlled Oscillator (VCO) The VCO consists of a proprietary hybrid circuit designed by Sonex containing an astable multivibrator, a buffer stage, an output stage and various resistor-diode circuits used for temperature compensation. This circ-dt produces a square wave output with a 50 ± 5% duty cycle. The square wave signal is then applied to a six pole low pass active filter. The filter provides an output signal of approximately three volts peak-to-peak, into a 47K ohm resistor wi.th less than 1% harmonic distortion. AM is less than 5% for ± 7.5% deviation in the VCO frequency.

The VCO output set-up tolerance and amplitude change over the temperature range of 20°F to 140°F was required to be within ± 3. 0% of each other with a design goal of ± 1.5%. Actual worst case measurements from any system indicated a variation of less than 1%.

Electronic Commutator The commutator is an all solid state design with a 30 x 1.5 PAM return to zero output format. MOS devices are used in the input switches and the sequential stepping circuits. The clock circuit employs the same hybrid unit as the VCO's. The output of the clock feeds a level translator which converts the bipolar voltage to a sufficient level for proper MOS transistor operation. The commutator utilizes a pre-regulated DC-DC converter which permits proper operation over an input power range of 14.5 VDC to 20.5 VDC.

Voltage Regulators - 5V (25 ma), 10V (50 ma), 10V (200 ma) All the voltage regulators consist of a monolithic integrated circuit regulator driving a series pass transistor (s). Each type is current limited to less than three times the designed output level in case of accidental transducer shorting. Voltage set-up and regulation is within ±0.5% over the combined temperature extremes and no-load to full load conditions.

Signal Conditioners

a) Active - The active signal conditioner amplifies a differential 30 MV signal from the water differential temperature transducer and a single -ended 300 MV signal from the primary power current transducer to produce two five-volt single ended outputs. This circuit employs monolithic amplifiers with metal film resistors for gain control.

b) Passive - The passive signal conditioner primarily utilizes metal film resistors with 0.25% to 1% accuracy for attenuating high level transducer signals to the normal +5 volt range. The PSC also contains a zener diode network used in translating the battery voltage from the nominal +17 volt level to the normal +5 volt level.

Isolating Circuitry The isolation circuit contains the output transformer of the warning tone generator and two high current rectifier diodes used for reverse voltage protection. One diode is common to all the transducer voltage supplies and a separate one is used in series with the E KG VCO Power Supply.

Mechanical The EVCS telemetry subsystem was designed using a modular approach as illustrated in figure 4.

Due to overall system constraints and high reliability requirements, volumetric efficiency bad to be optimized in order to meet the volume allocation.

Listed below is a table indicating the actual volume, weight and component density of typical subassemblies.

MODULE	VOLUME	WEIGHT	DENSITY (Parts /in^3)
5V and 10V Regulators	.175 in^3	.160 oz.	74
Passive Signal Conditioner	.226 in^3	.176 oz.	75
Active Signal Conditioner	.362 in^3	.318 oz.	110
Tone Generator	.33 in^3	.282 oz.	76
VCO	.38 in^3	.352 oz.	160
Commutator	2.48 in^3	2.2 oz.	40

All major heat producing modules were designed in such a way that the heat producing component fits into a heat sink mounted to the bottom of the system chassis.

Each module is assembled into a “mother board” which electrically interconnects the system. All the modules are physically attached to each other with a solithane compound. This prevents the movement of the individual units when the system is potted. After all the modules are assembled to the “mother board” the assembly is placed into the chassis, care being taken to insure that all heat producing components are seated securely in the heat sinks mounted to the bottom of the chassis. The top cover is then installed and the unit is filled with Scotchcast potting material. The potting is accomplished by vibrating the system while pouring the Scotchcast through an access hole in the top of the cover.

After curing, the system is subjected to an acceptance test where each portion of the system is checked electrically at ambient conditions and at the temperature extremes. The system is then subjected to a random vibration test at 8.63g rms, during which time all performance parameters are monitored. After vibration there is a final electrical performance test at ambient conditions.

Thermodynamic Considerations The stringent size, weight and reliability requirements dictates high packaging densities which made the thermodynamic considerations very critical. To determine if the total heat dissipation in the system would cause problems, a static and dynamic analysis was conducted assuming the system to be essentially isothermal. This provided an early indication of expected temperature rises shown below:

SYSTEM CALCULATIONS

Ambient Temp.	Stabilized Temp.	Rise °F
85°F	130°F	45°F
140°F	170°F	30°F

In order to determine if individual hot spots would occur within the system, each component temperature rise had to be individually calculated. The calculations were based on the mechanical design, location of components, and encapsulating material used. Refer to Appendix A for a typical derivation of component heat rise.

The thermal design approach placed all power dissipating components in metallic heat sinks which were directly connected to the base plate. This heat sinking technique enabled the subassemblies to realize a very small heat rise above the base plate temperature.

The actual temperature rise in the system was within the thermal rating of the individual components. The maximum measured temperature within the system was 168°F versus an allowable temperature of 175°F.

Reliability The EVCS is considered essential to mission success on the lunar surface. As such a reliability goal of .9998 for the Telemetry Subsystem was required to be met as a minimum. One of the methods employed to accomplish this was to apply derating requirements to all components. The criteria for this derating is shown in the following chart:

ELECTRONIC PART	Maximum Operating Point at Percentage of Rated Parameter		
	POWER	CURRENT	VOLTAGE
Transistor	30%	75%	75%
Diode Rectifier	30%	Ip 50% Is 50% If 60%	PIV 50%
Zener Diodes	50%	If 50%	
Resistors -Crabon Comp.	30%		
Metal Film	30%		
Wire Wound 1%	50%		
Transformers] Chokes]		Per winding-50% of wire rating	Voltage Across Each winding 50%
Capacitor Ceramic			50% Continuous Voltage/Rating
Solid Tantalum			80% Voltage/ Rating

Each component selected for the Telemetry Subsystem was thoroughly investigated concerning its performance history, failure modes, qualification status on manned flight programs, etc.

All electrical components were subjected to screening test and power burn-in. Ever integrated circuit, monolithic or hybrid, received a 200% pre -cap visual inspection performed by the vendor and Sonex Quality Personnel.

Components having insufficient failure data or unique to the program, such as transformers, chokes, and hybrid units were subjected to complete qualification tests defined by Sonex.

Configuration Control Configuration control records were kept on every module in every system such that each component and its test data was traceable back to a specific manufacturing lot at each vendor.

Piece part control was maintained on the overall program. This control started at the vendors where each component was serialized to identify it with screening tests, and burn-in data. Serialization also permitted traceability back to the manufacturer's lot numbers of the raw material used in the manufacture of their particular component. Sonex maintained this traceability by utilization of a Traceability Control Record (TCR). The TCR was generated for each major subassembly in the Telemetry Subsystem. Ihe TCR listed all the components and materials used in the applicable subassembly and identified these parts by a minimum of purchase order number, procurement specification number and revision and serial/lot number. The TCR was initiated as parts were pulled from stock for subassembly kits and followed to the point of system assembly. From this point on, traceability was via subassembly type and serial number.

Summary Within a very short procurement cycle and with tight mechanical constraints and high reliability requirements imposed, a telemetry subsystem was designed and built for the Apollo Extra-Vehicular Communications System. As a result of timely delivery, circuit performance, environmental integrity and documentation control, the telemetry subsystem met all the requirements of a highly reliable, qualified man-rated system for use during lunar exploration and subsequent space programs.

Acknowledgement

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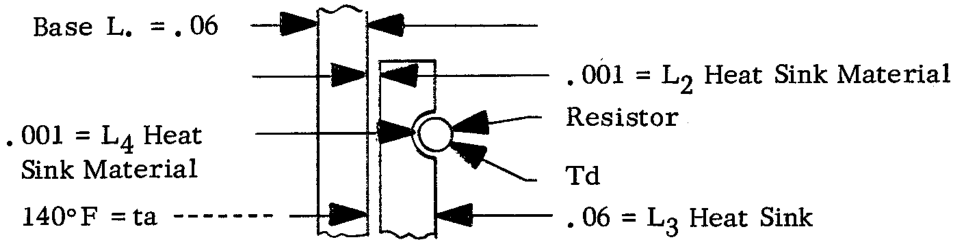
APPENDIX A

Component Thermal Analysis A component thermal analysis was conducted on each part within the EVCS Telemetry Subsystem. The following is a sample of the method used for calculating component heat rise.

Unit = Commutator Power Supply
R 18 = 320 MW dissipation
Q = .320 x 3.413 = 1.09 BTU/hour

The unit will be constructed in the following manner:



Assuming that a steady state condition has been reached, the heat flow through the various materials will be constant for a given temperature and can be expressed as follows:

$$Q = \frac{A\,(Ta - td)}{\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{L_4}{K_4}}$$

Q = BTU/hour
A = Area in Sq. Ft.
L =Thickness of material in inches
ta = 140 °F

L1 = .062
K1 = 1209 = AL
L_2 = .001
K_2 = 12 = Heat Sink Material
L_3 = .062
K_3 = 1209 =A1
L_4 = .001
K_4 = 12 = Heat Sink Material

Component Thermal Analysis

Solving equation for td

$$td = \frac{Q}{A}\left(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{L_4}{K_4}\right) + ta$$

$$td = \frac{10.9 \times 10^{-1}}{2 \times 10^{-4}}\left(\frac{.06}{1209} \times \frac{.001}{12} \times \frac{.06}{1209} \times \frac{.001}{12}\right) + 140$$

$$td = 5.5 \times 10^{-3}(.00026) + 140$$

$$td = 1.43 + 140$$

$$td = 141.43 °F$$

Therefore, it can be seen that the resistor R18 dissipating 320 MW will rise 1.43°F above ambient.

This same procedure was used throughout the EVCS package to determine heat rise in each component part.

It has been determined by actual test that the maximum heat rise in any component within the system was 20°F which is within the reliability derating criteria for the worst case component.

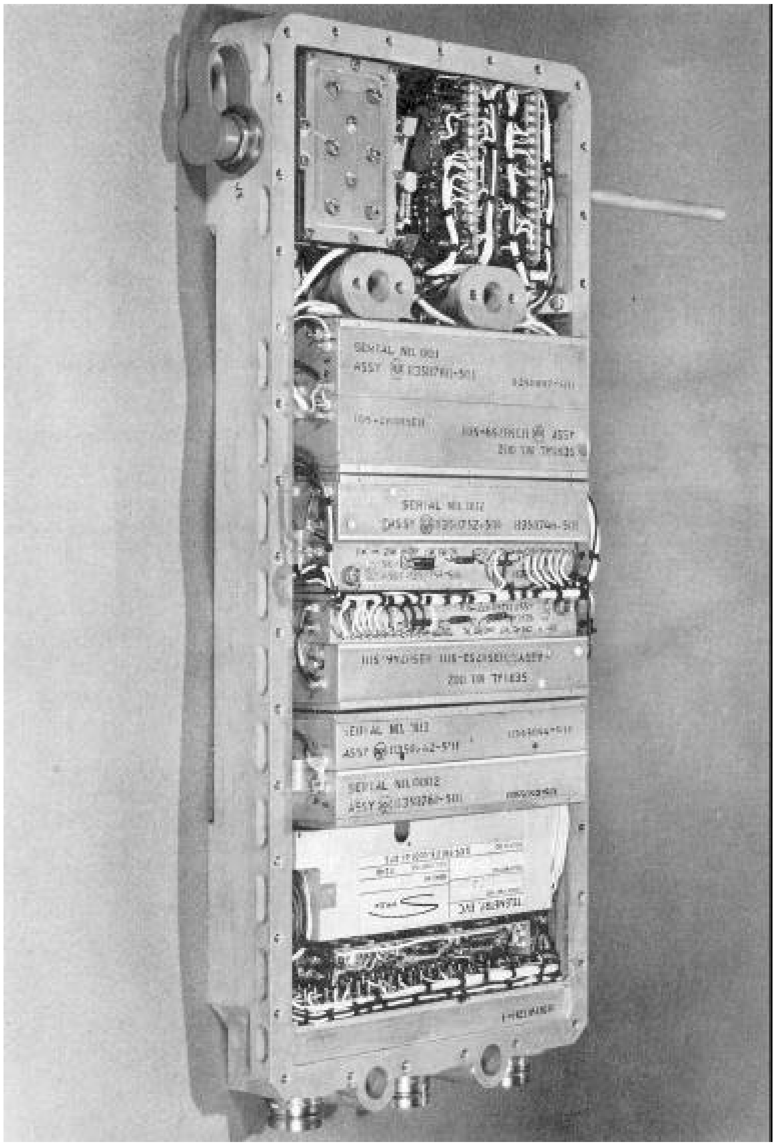


Figure 1 - Extravehicular Communicator Package

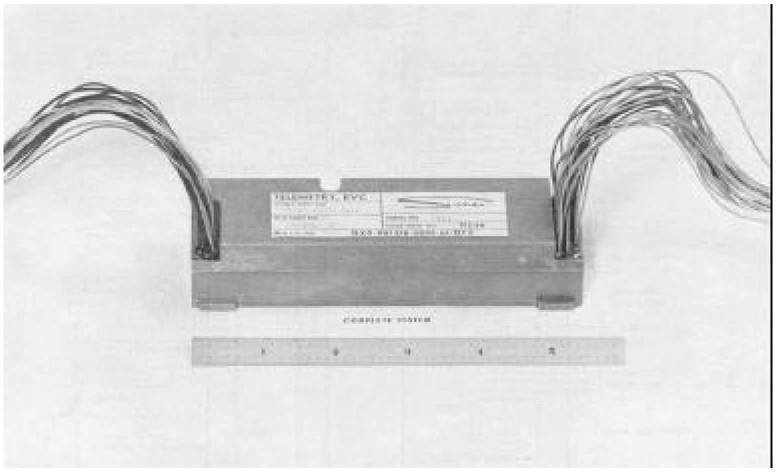


Figure 2 - Apollo EVCS Telemetry Subsystem

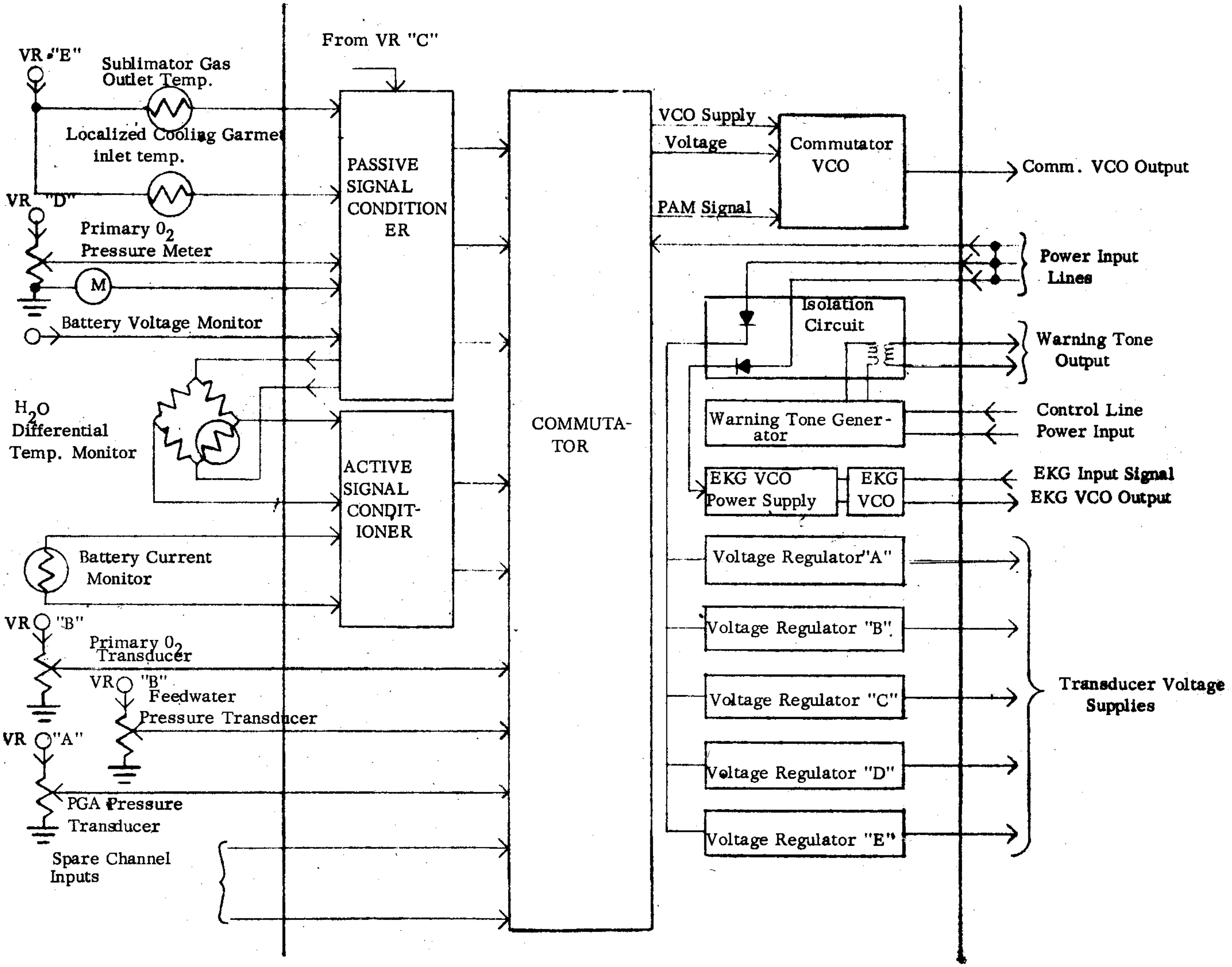


Figure 3 - Block Diagram

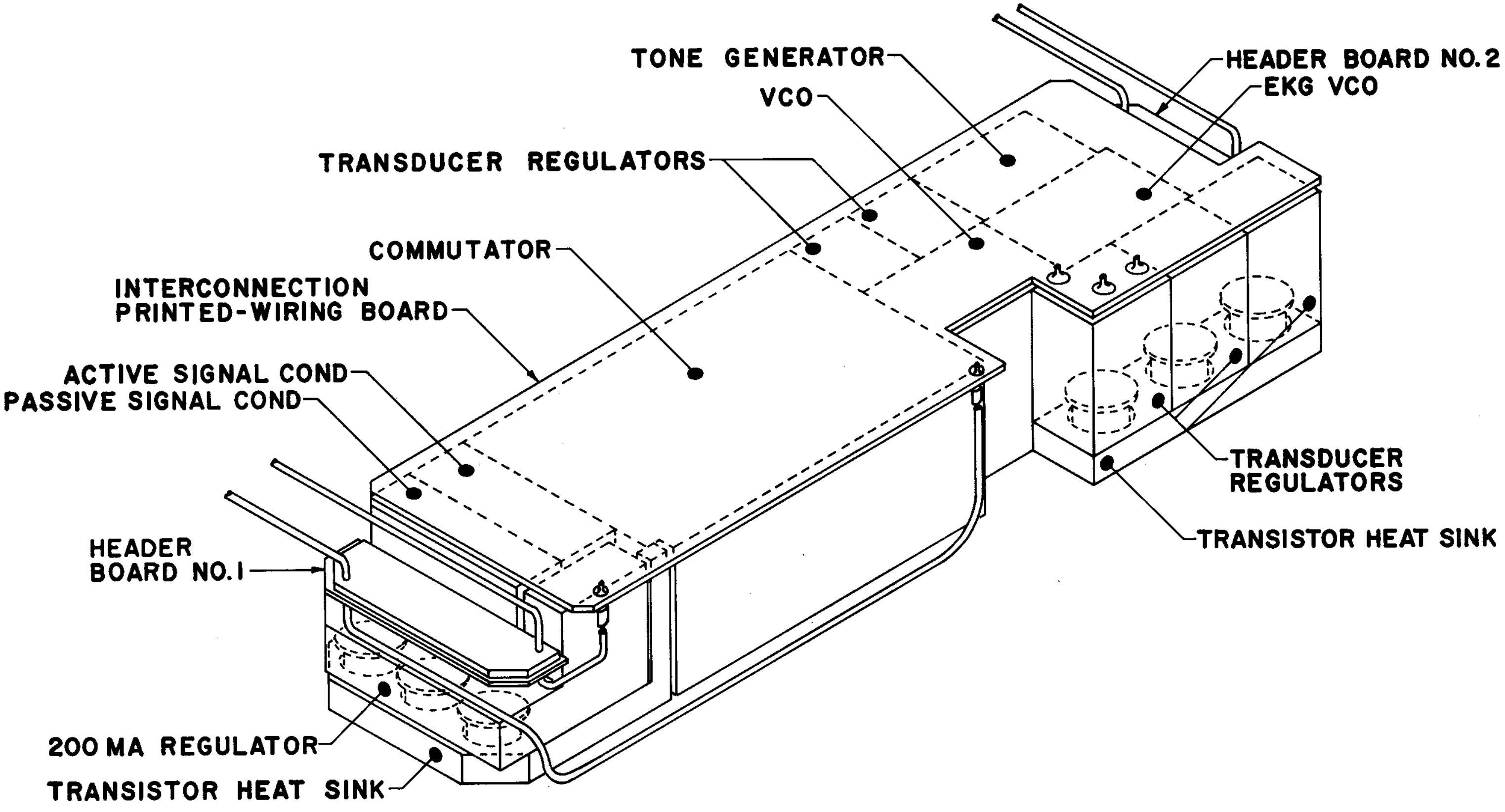


Figure 4 - Telemetry System Assembly