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THE CURRENT MEASUREMENT IN LAUNCH VEHICLE CHECKOUT

by William F. Huseonica

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Kennedy Space Center, Fla.

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ABSTRACT

This technical note discusses electrical system input current measurements as an effective performance evaluation tool during launch vehicle checkout at the launch site. Use of the current shunt as a measuring device to record the desired electrical system load data is described and typical examples of the results obtained through the use of current measurements during the research and development testing of the NASA-CENTAUR space launch vehicle are presented.

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SUMMARY

The current measurement is being used effectively as an evaluation tool in the research and development testing of the NASA-CENTAUR space launch vehicle. Electrical system load profiles on the component level and on the integrated system level are obtained during factory acceptance testing of the launch vehicle with flight hardware. These profiles then serve as fundamental standards when the launch vehicle is received at the launch site. During testing at the launch site, similar electrical system load data are obtained by using a simple measuring device, the current shunt. These data, when compared with the basic load profiles, then guide the analyses of system operation from initial power application to the final launch countdown. In many instances, the current records obtained have provided the conclusive data necessary for isolating a problem or have served as a basic tool in failure analysis whereby the failure mode was duplicated. As a result, more effective use has been made of the engineering effort required for data analysis during launch vehicle checkout.

INTRODUCTION

Preparation of a launch vehicle for flight is accomplished principally by a series of ground tests of increasing complexity culminating in the launch countdown, which demonstrates vehicle flight readiness in the final flight configuration. Data are obtained from each test in this "building block" test program and evaluated to determine functional performance at the canister, the system, and finally at the totally integrated systems level. How well this evaluation can be accomplished is dependent upon the instrumentation used and the experience of the evaluator in comparing actual test results to those which should be obtained for the particular test configuration and environment. Any deviation from the normal must be detected and satisfactorily resolved to guard against a possible flight failure.

The problems most often encountered and the most difficult to resolve are those in which the output of a system exhibits a momentary change of state which cannot readily be identified as being a result of the test configuration or some related test operation. Follow-on evaluation to determine the cause of the problem is often inconclusive and time consuming since failure conditions are difficult to reproduce and usually lead to changes of equipment with many hours devoted to failure analysis at the canister or components levels. To instrument against all failure possibilities is unrealistic; therefore, careful consideration must be given to each vehicle system in order to include instrumentation which proves proper system operation and is also useful in problem evaluation.

Usually, the outputs of vehicle systems are sufficiently monitored by landline or telemetry to determine functional performance during ground tests and actual flight. Experience has shown, however, that initial failure modes can be detected by changes in a system's input without changes necessarily being reflected in the system's output, particularly during the initial stages of a subsystem parameter value change which would ultimately lead to a system malfunction. It is therefore desirable to provide instrumentation to monitor systems inputs, not only to verify proper input parameters, but also to aid in identifying and resolving problems in less time and with less expense than would be required by other means.

DISCUSSION

Power, the Electrical System Parameter

For electrical systems the most pertinent parameter to monitor is power. Any operation requires power and power can be defined within suitable tolerances to satisfy test configuration, environment, and steady state and transient operation. Variations in power supplied to systems are easily detected on the input to the system, and usually some variation is detectable in the output functions. The output or the end function of a system is usually the most important parameter to be monitored since it is a direct measure of performance; however, the monitoring of the end function in each system for predetermined parameters is inadequate for resolving problems associated with system interfacing, operation transients, and extraneous system outputs or for reconstructing failure modes without costly special tests and integrated retesting. The careful monitoring of system input power at selected points in the integrated vehicle provides a means whereby system interaction and system anomalies are readily distinguishable and identified in the event of a problem.

Current, The Most Sensitive Power Parameter

The electrical system parameter measured is actually current rather than power. The current required by a system is usually its most sensitive parameter because the power supplies used during tests and for flight are well regulated to maintain an operating voltage level regardless of the behavior of any one specific system on its output.

The power supply voltages are generally monitored during launch vehicle checkout with a high degree of accuracy. The voltage measurement is a good indicator of static or steady state system input or reflected output conditions, although it is extremely difficult to analyze variations in terms of dynamics of the system with any degree of confidence. The vehicle power supply generally has a constant voltage regulation when operated within its design capacity; therefore, the relationship of voltage variations to power transients is not sufficiently predictable or repeatable to be used in quantitative analysis (see figures 1 and 2). The voltage variations at the power source are dependent on parameters of the power source such as temperature and capacity along with power transient parameters of magnitude and time.

The current measurement with a time base is more directly applicable to system dynamic measurements such as engine movement, valve actuation, solenoid movement, issuance of discrete functions, etc. and when used in conjunction with a voltage measurement of the power

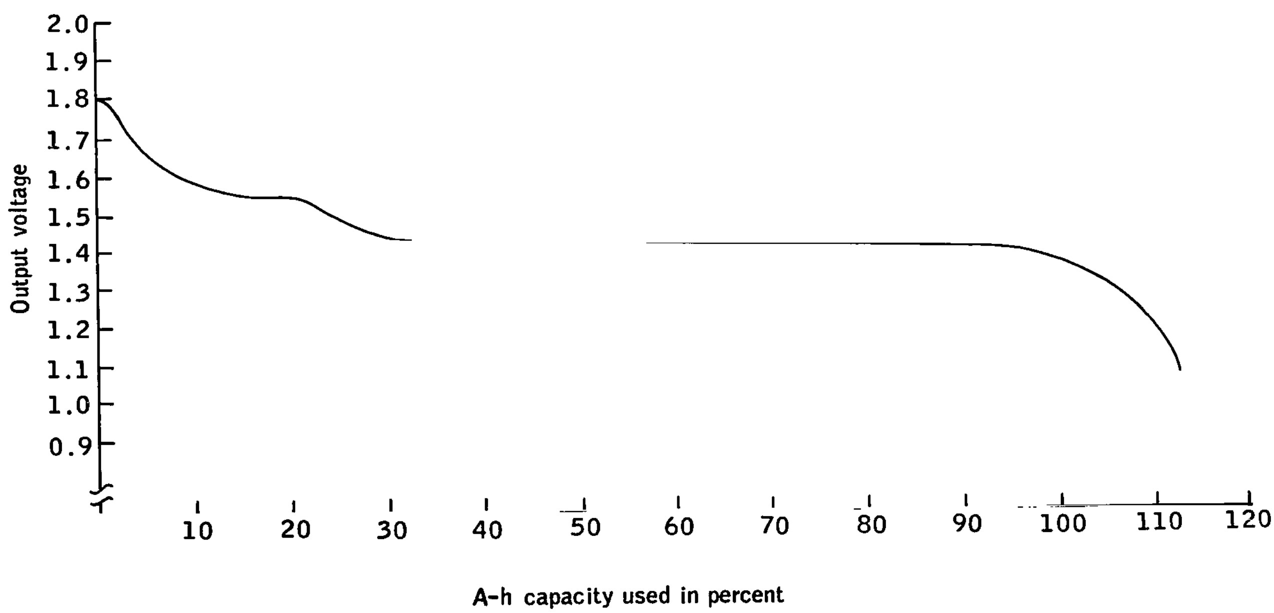


Figure 1. - Output voltage vs A-h capactiy used in silver - zinc cell.

source, is the most useful surveillance measurement obtainable during launch vehicle checkout.

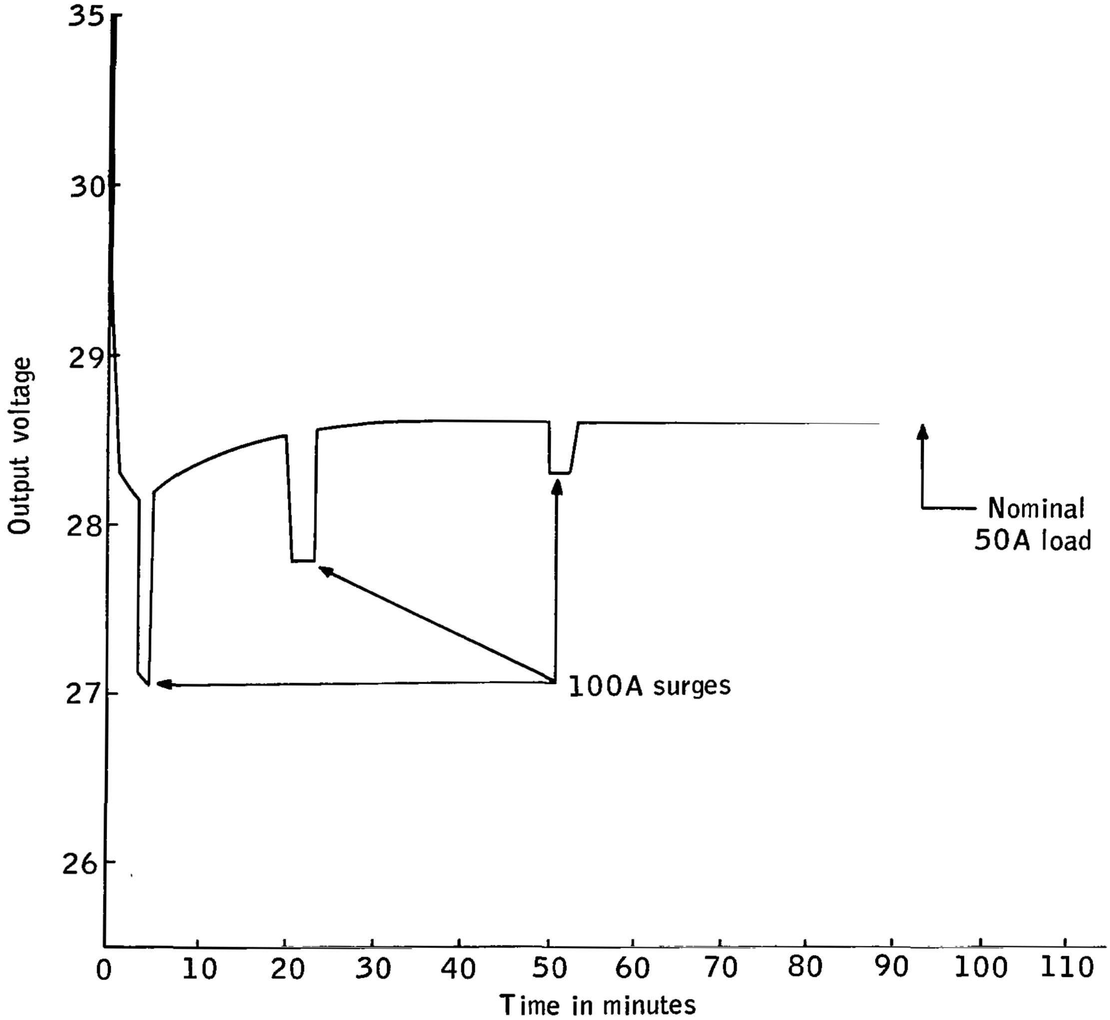


Figure 2. - Effects of time and load variations on output voltage of 100 A-h battery.

System Knowledge Determines Usefulness

The usefulness of the current measurement in launch vehicle checkout is directly related to the evaluator's knowledge of system performance. The current measurement increases this reservoir of knowledge and useful data at little expense. From the component, to the system, to the integrated vehicle the current measurement is the common base line along which the system operational status can be defined and communicated. Intelligent interpretation of the current records requires a knowledge of system performance in terms of the power requirements of a particular component, to the power demands of the system at various changes of state including power parameter excursions. For example, it should be determined what happens to system performance with low voltage, higher voltage, loss or fluctuations of voltage. Knowledge of input requirements with output changes, nominal operating values versus the calculated values, and system operation with changing environment is also required. This knowledge when properly applied has resulted in defining problem areas with a minimum of troubleshooting time expended, and in many cases has led to major design changes in airborne systems and ground support equipment.

APPLICATION AND APPARATUS

The Current Shunt Measurement Configuration

The measurement of power, or more precisely current, is accomplished by incorporating shunts in the electrical system where practical and where data obtained are optimum for system and integrated levels of testing. A typical vehicle electrical system with current shunt instrumentation is shown in figure 3.

The electrical current measurement made by using a current shunt follows the principle that the current amplitude is proportional to the voltage developed across an accurately known resistance placed in series in the power input circuit of a component or system. During the initial phase of the launch vehicle testing, current shunts are placed in each system for monitoring both external and internal power modes of operation. For the internal power mode, the shunts are installed in a test accessory box between the airborne power supply and the airborne system to be monitored. The external power mode of operation is monitored by current shunts installed in the ground power supply circuit to the airborne system (see figure 3). This arrangement allows continuous monitoring in any mode with a correlating redundancy for the initial test phase and, as on CENTAUR, for integrated test phases where the servicing structure remains in place around the vehicle. However, in holding to a philosophy of obtaining and maintaining as complete a flight configuration as possible when the final composite testing begins, the airborne current shunts are removed from the individual systems with the exception of a current shunt used to monitor the airborne power supply output in the internal power mode. The external power mode current measurements are permanently installed in the power distribution terminal boards in the ground

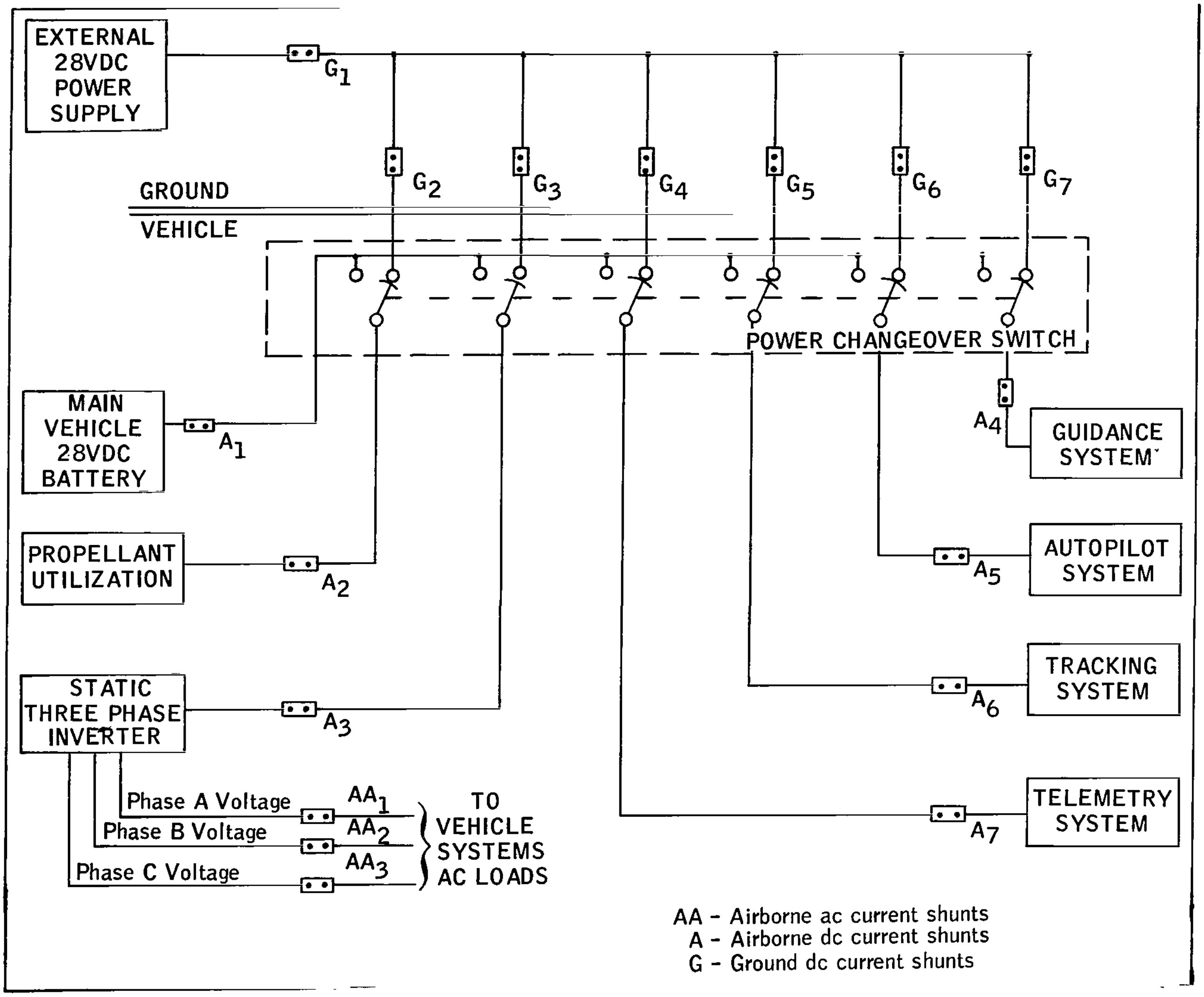
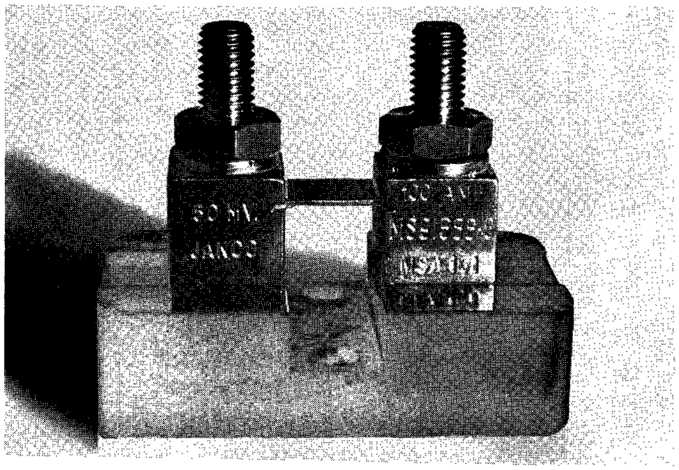


Figure 3. - Simplified diagram of typical electrical system current shunt instrumentation.

Typical Current Shunt Installations

The physical dimensions of a 10 ampere-50 millivolt and a 100 ampere-50 millivolt current shunt are illustrated in figures 4 and 5, while a typical installation of current shunts in the ground support equipment is shown in figure 6. This installation incorporates shunts of various values depending on the system being monitored and has the capability of monitoring 13 systems. The shunt values range from 5 amperes-50 millivolts to 200 amperes-50 millivolts. An installation utilizing a 300 ampere-100 millivolt shunt is shown in figure 7.



1 INCH

Figure 4. - 10A - 50mV current shunt.

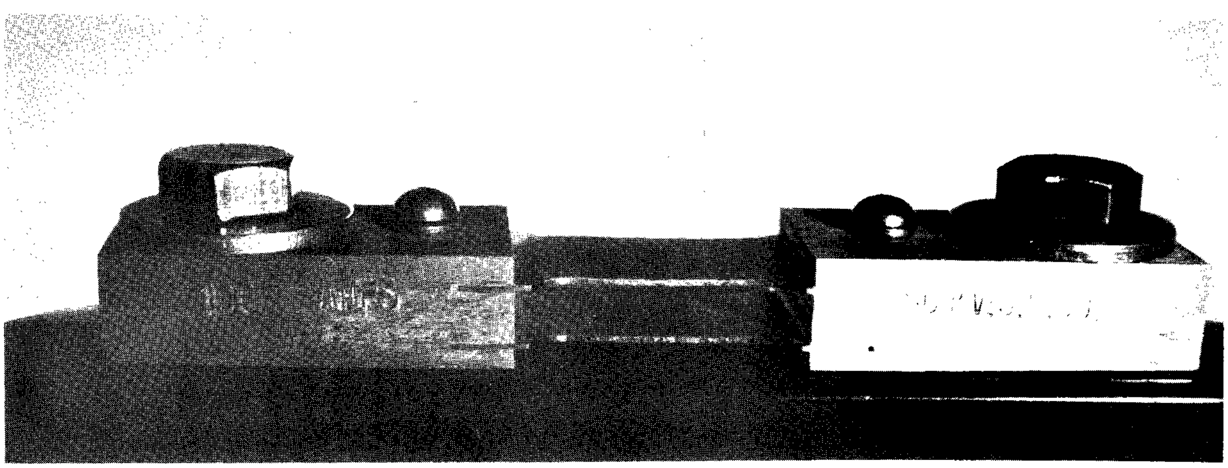


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Figure 5. - 100A - 50mV current shunt.

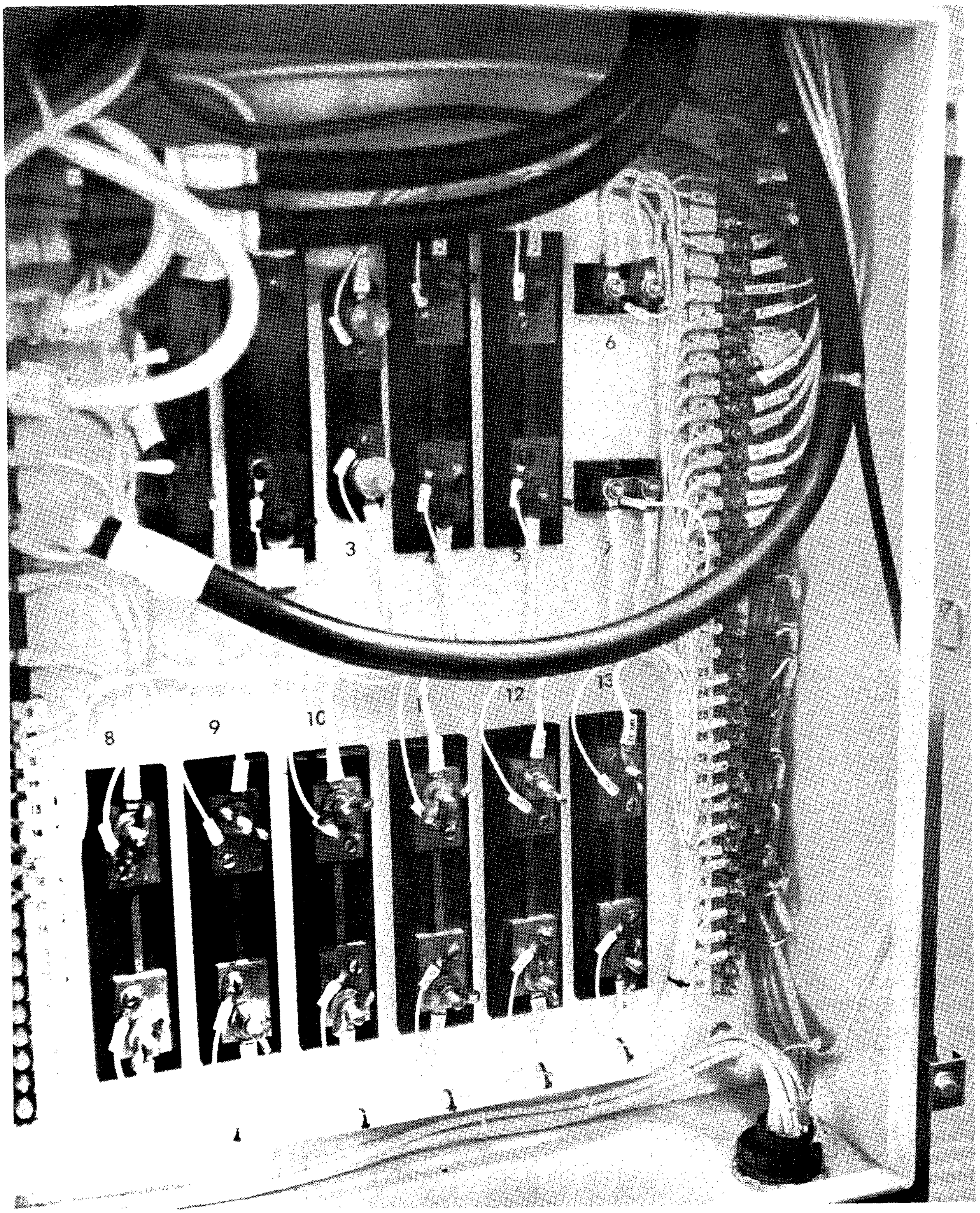

Figure 6. - Typical GSE current shunt installation.

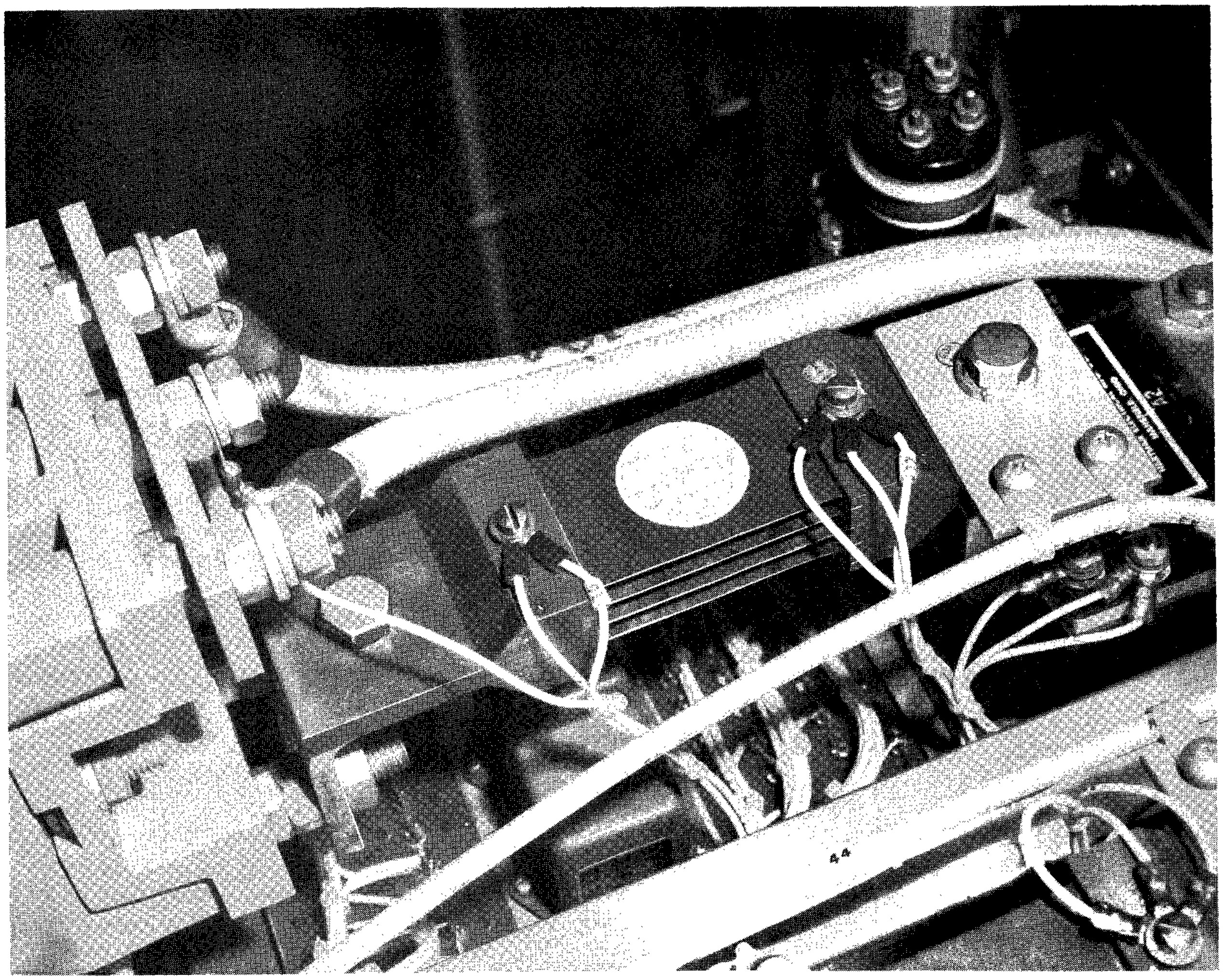

Figure 7. - Typical GSE 300A - 100mV current shunt installation.

Recording Methods

The voltage developed across the current shunt is generally in the 50 to 100 millivolt range and signal amplification may be required for remotely located recorders. Although the airborne system voltage and current measurements can be directly displayed on a galvanometer recorder such as a direct-write oscillograph, the recording of current measurements on magnetic tape with a playback on direct-write recorders at selected time intervals is being used more extensively. The magnetic tape recorders have a higher frequency response capability as well as a great flexibility of playback of anomalous conditions which contain short duration transients. Either method of recording current data has a necessary common time base with all other launch vehicle test data for correlation.

Although the examples presented above are primarily concerned with results obtained from current shunt measurements in dc circuits, ac current shunts are presently being used in static inverter and ground generator output circuits and have produced data as conclusive and valuable as the dc current shunts.

Recorded Current Data

Actual data recordings of anomalous conditions and normal operating current profiles are presented in figures 9 through 17.

Static inverter improperly patched (figure 9). - An output phase of a three phase static inverter was inadvertently patched to one phase of a ground 400 cycle generator to produce the current and voltage record of the inverter and autopilot system shown in figure 9. This condition occurred during preparations for a launch vehicle composite test.

Component failure under excessive temperature conditions (figure 10. - During a guidance system calibration utilizing the airborne three phase static inverter, air conditioning to the launch vehicle electronic equipment area was lost, producing the current and voltage profile shown in figure 10. This profile was duplicated in the laboratory and revealed that a component failed because of the resultant excessive temperature.

Inverter start conditions (figures 11, 12 and 13). - The current profile shown in figure 11 is from a rotary inverter starting with the nominal line impedance used in normal operation. Figure 12 shows the current profile with a high impedance start and a final switch to the nominal operating impedance after two seconds. In contrast, figure 13 illustrates the difference in the start transients of a three phase static inverter. The rotary inverter start current is approximately 400 amperes while static inverter start current is about 20 amperes.

Typical transients (figures 14 and 15). - Nominal starting transients from telemetering packages and a tracking transponder are illustrated in figure 14. Guidance and autopilot transients are shown in figure 15.

Transfer from external to internal power (figures 16 and 17). - The transfer of power from the external to the internal mode on the ATLAS launch vehicle stage is shown in figure 16 with the system currents and the complex power supply current verifying the transfer. The transfer of power from the external to the internal mode on the

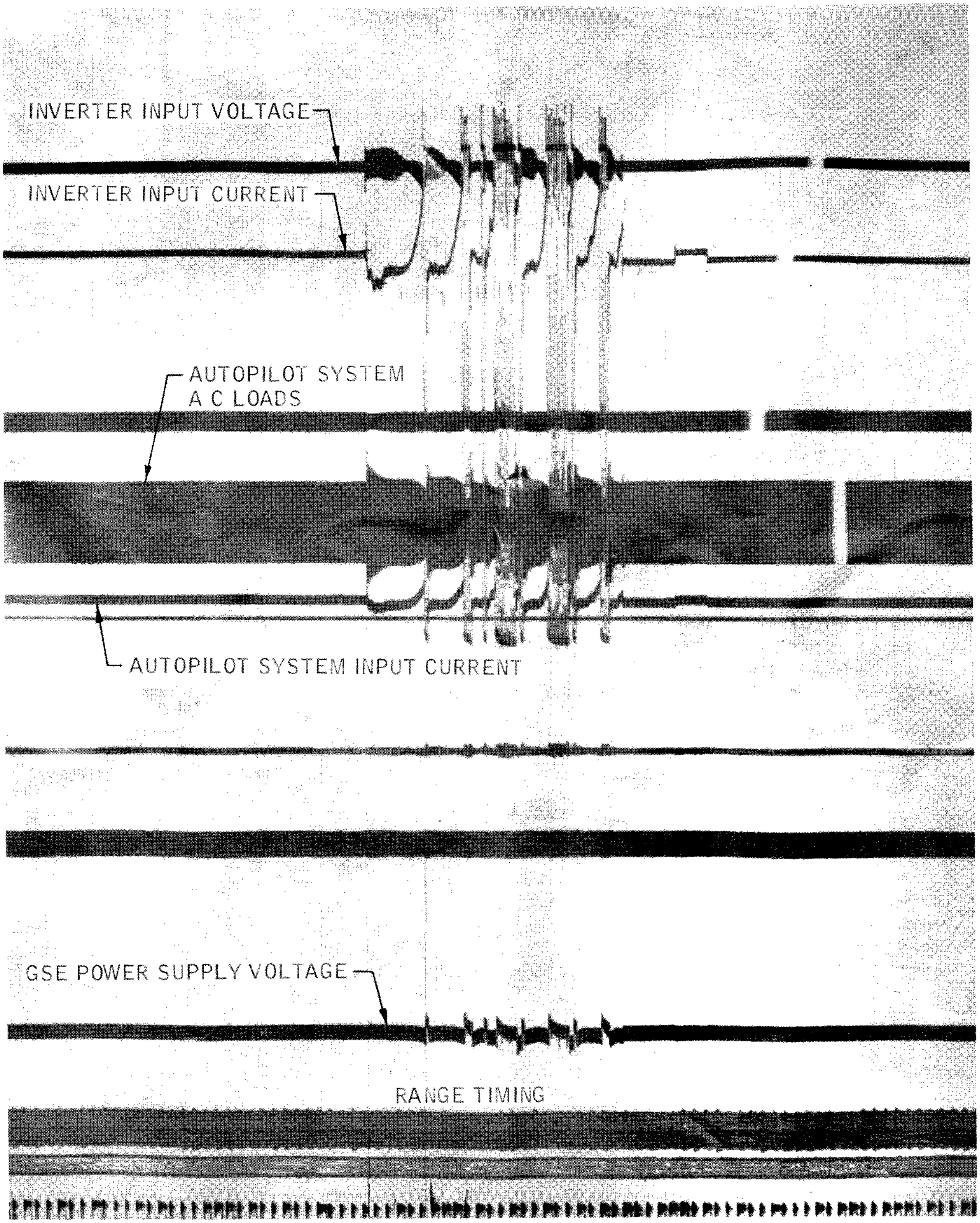

Figure 9. - Data record of improperly patched static inverter.

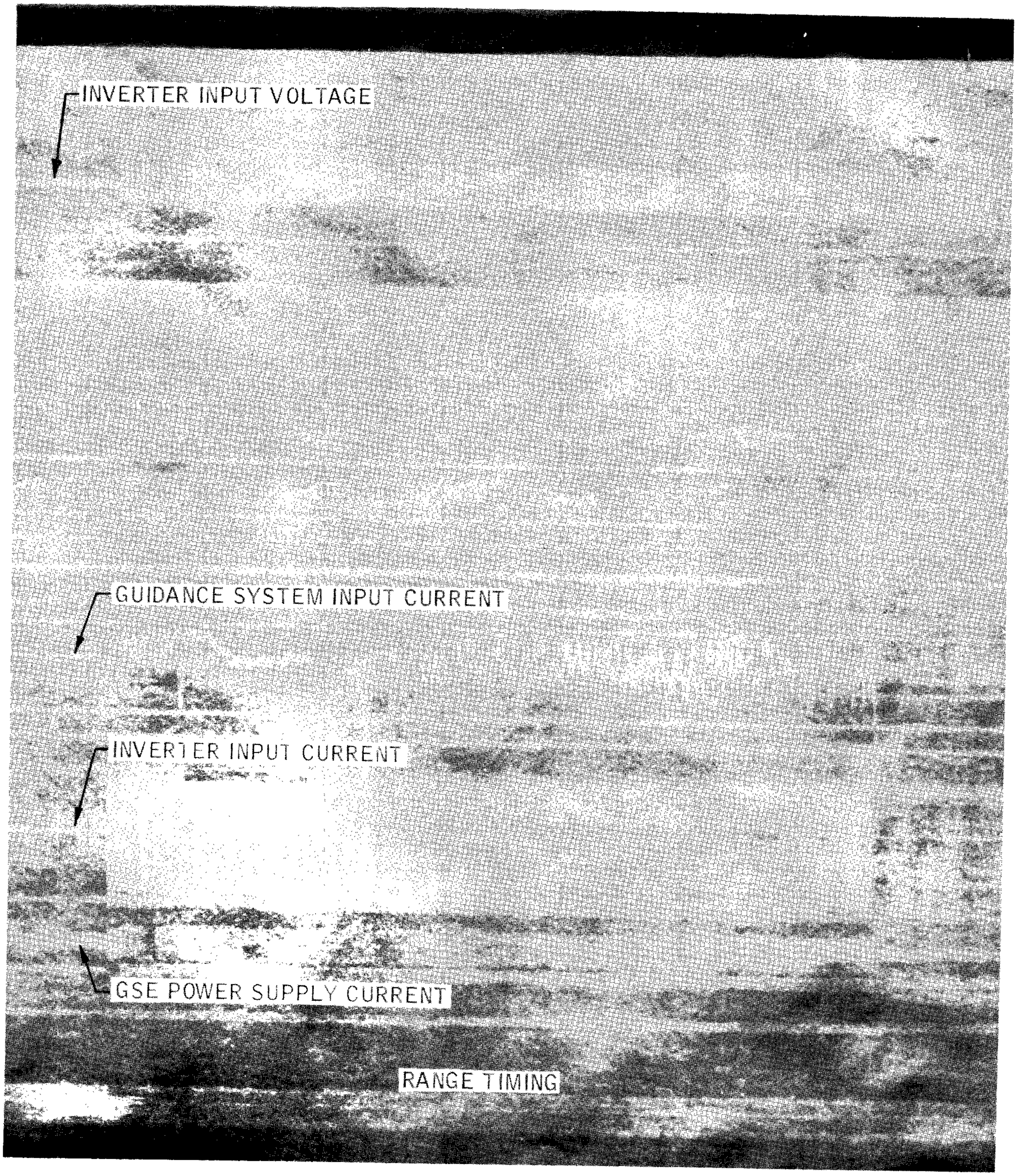

Figure 10. - Data recording of component failure under excessive temperature conditions.

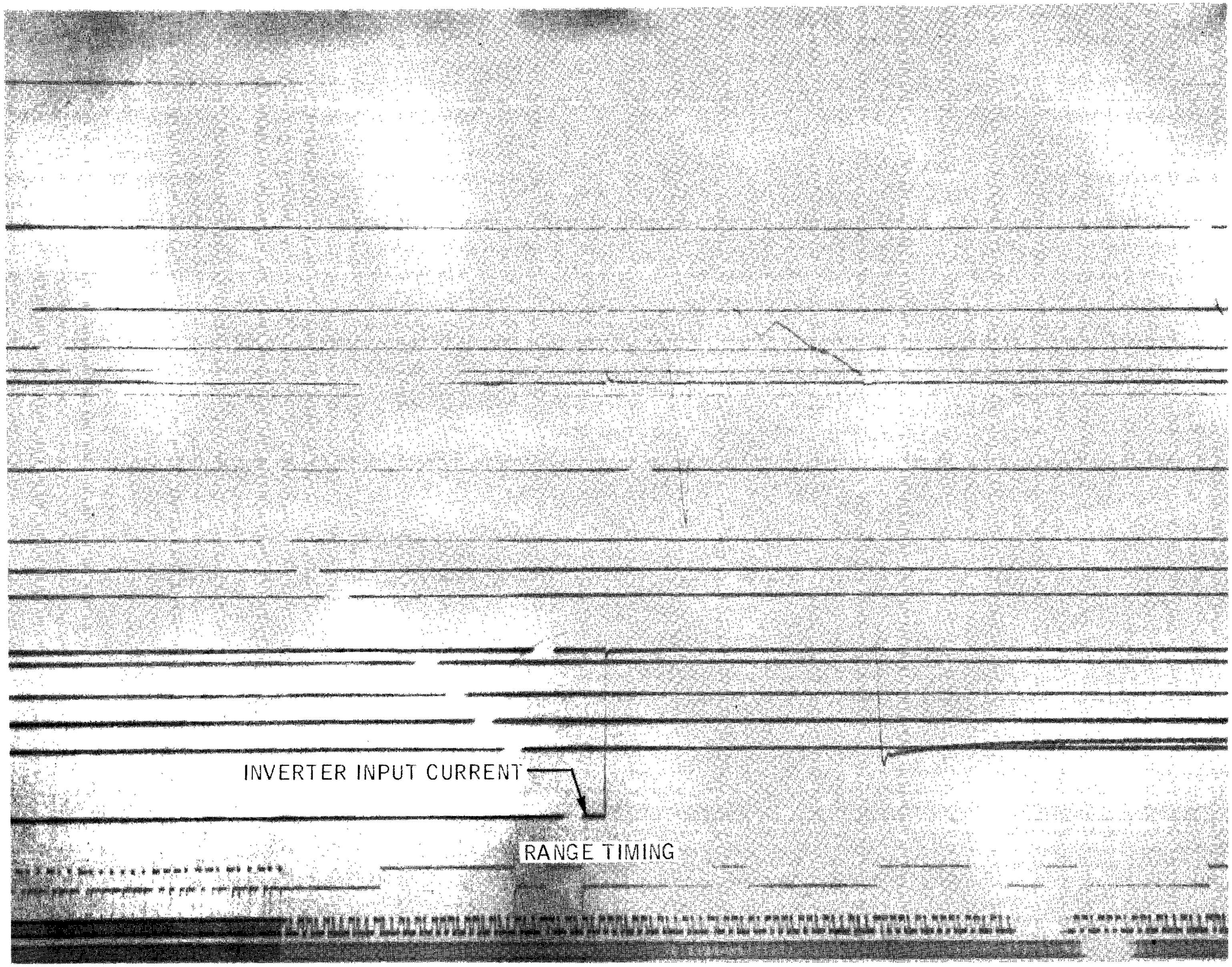

Figure 11. - Current profile of rotary inverter start with nominal impedance.

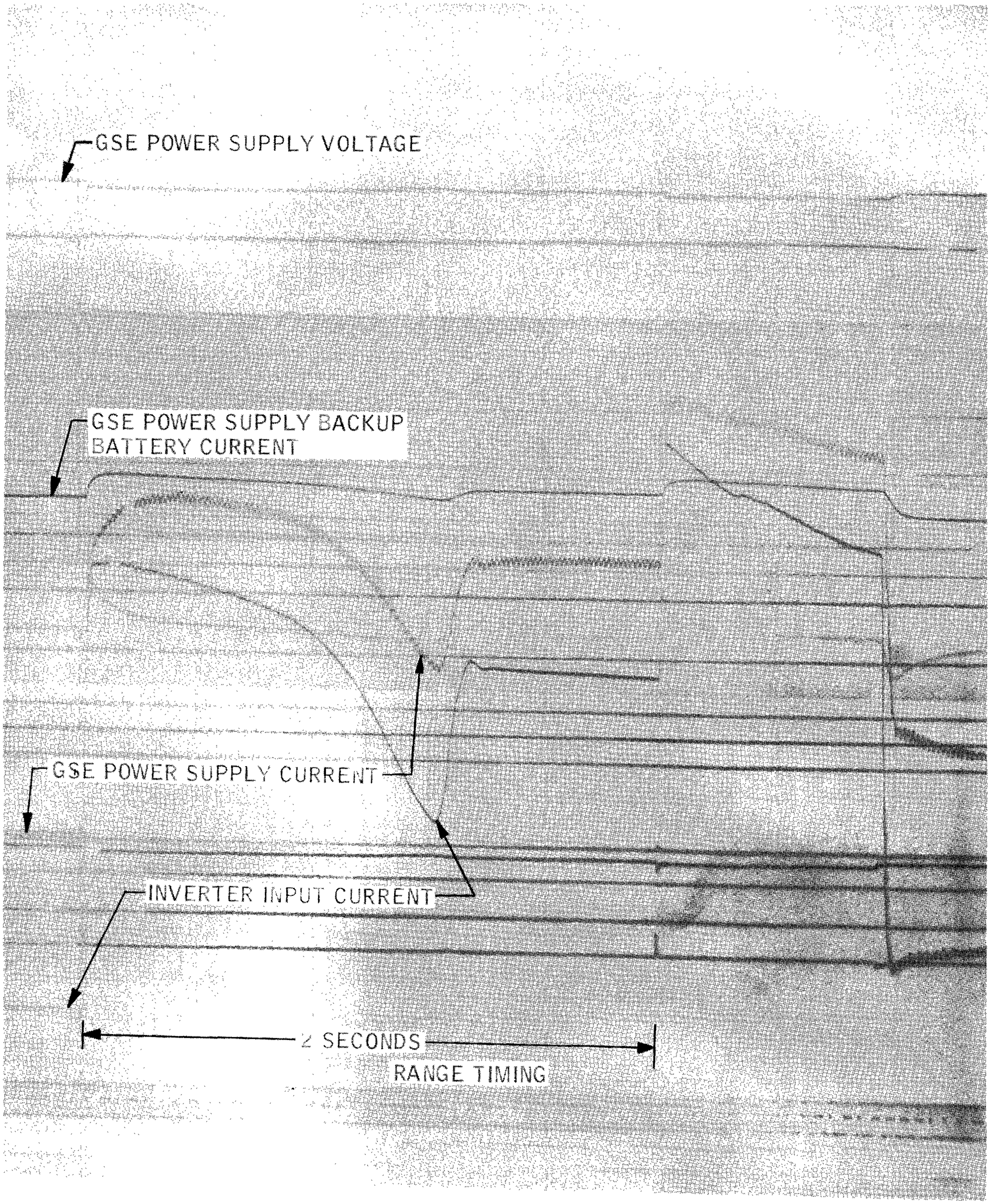

Figure 12. - Current profile of rotary inverter high impedance start with switch to nominal impedance.

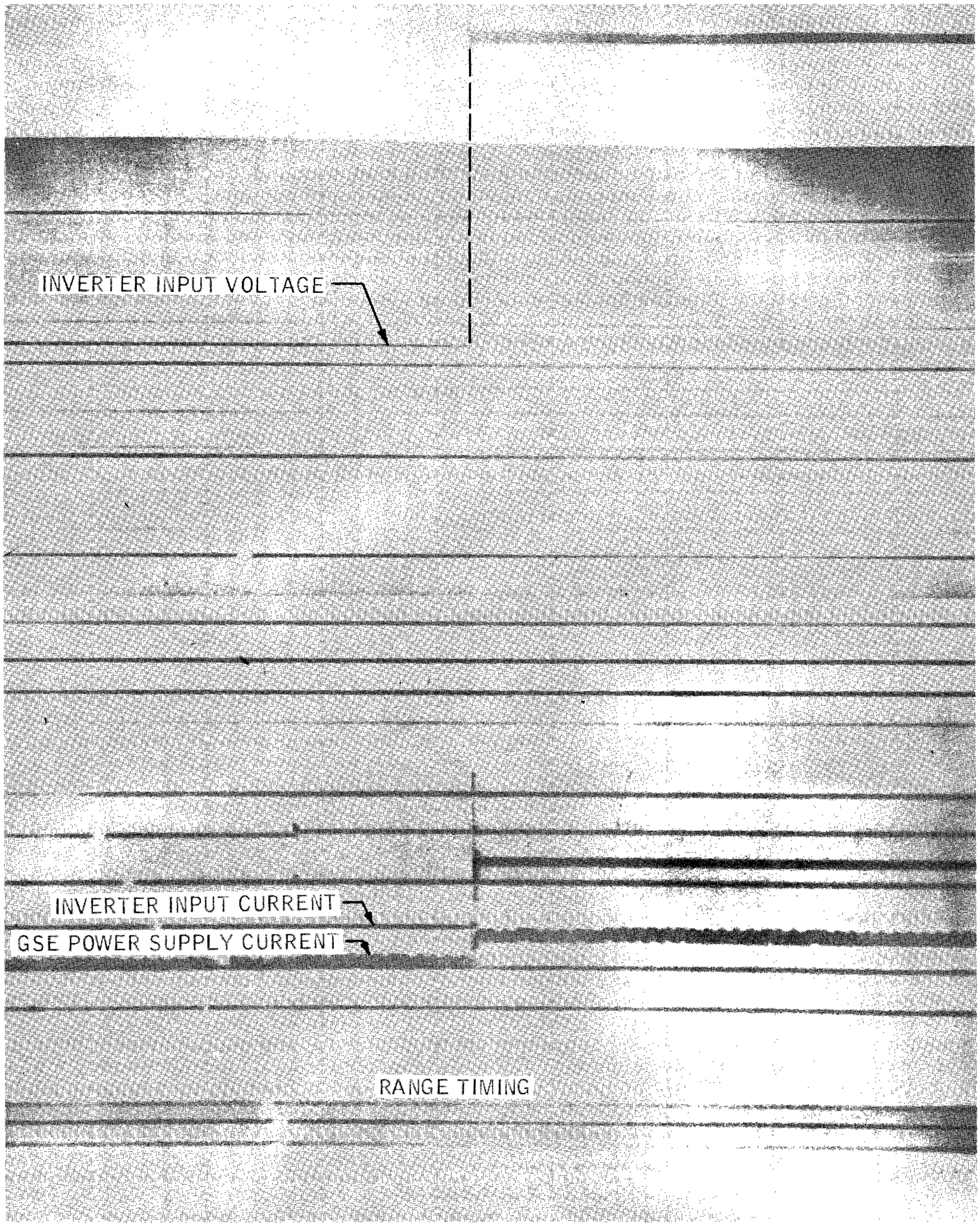

Figure 13. - Current profile of three phase static inverter start.

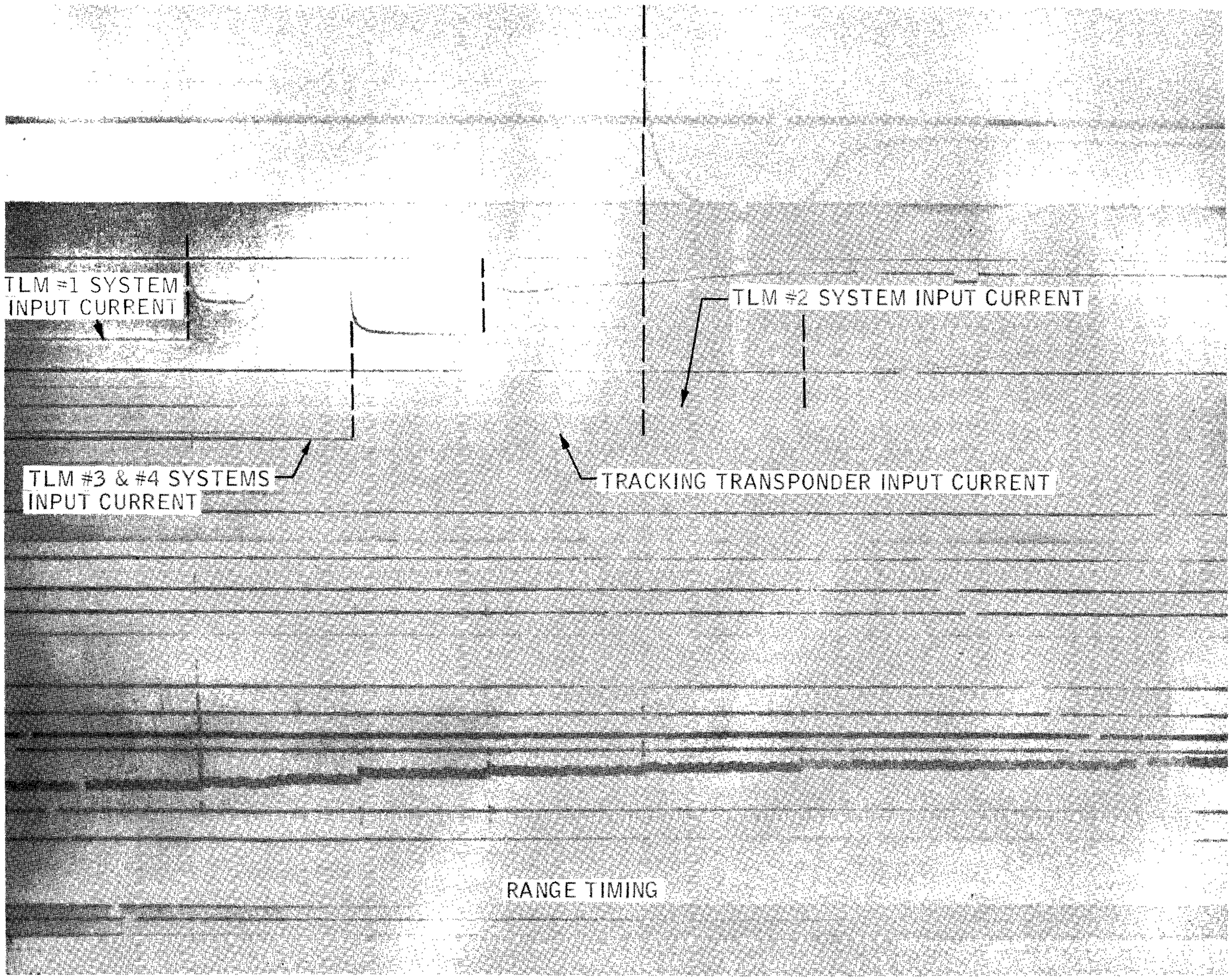

Figure 14. - Telemetry and tracking transponder start transients.

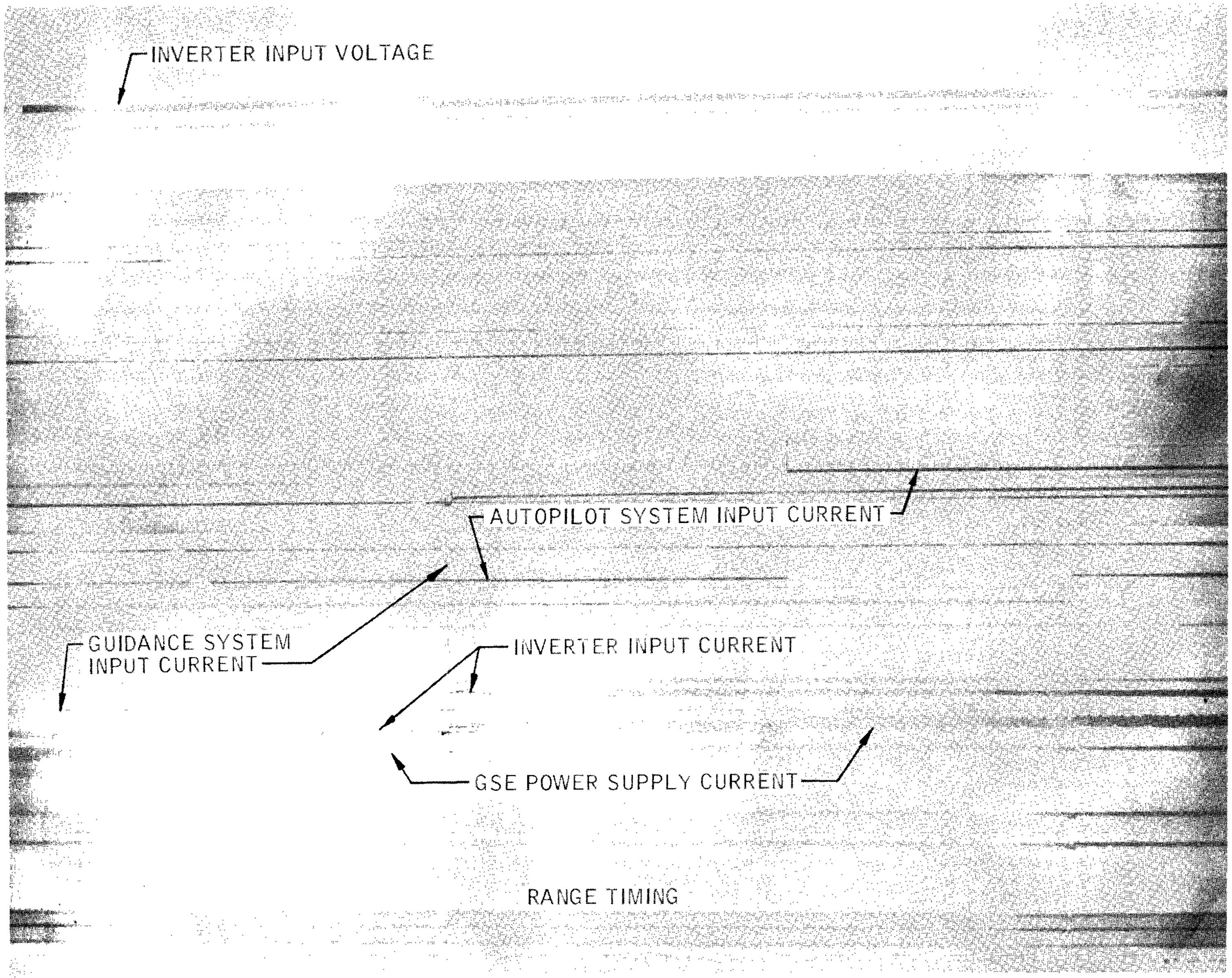

Figure 15. - Guidance and autopilot system start transients.

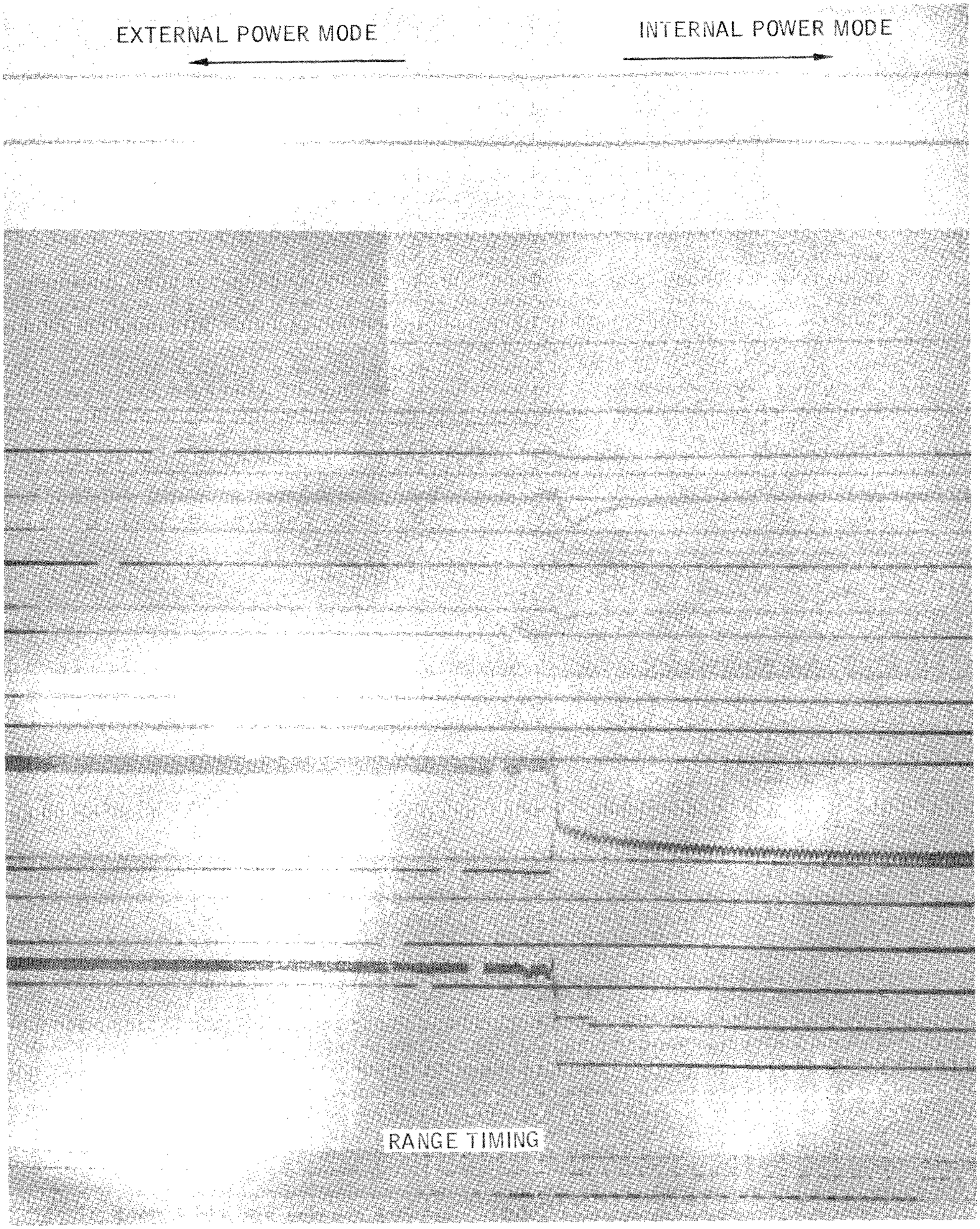

Figure 16. - Data record of ATLAS power transfer.

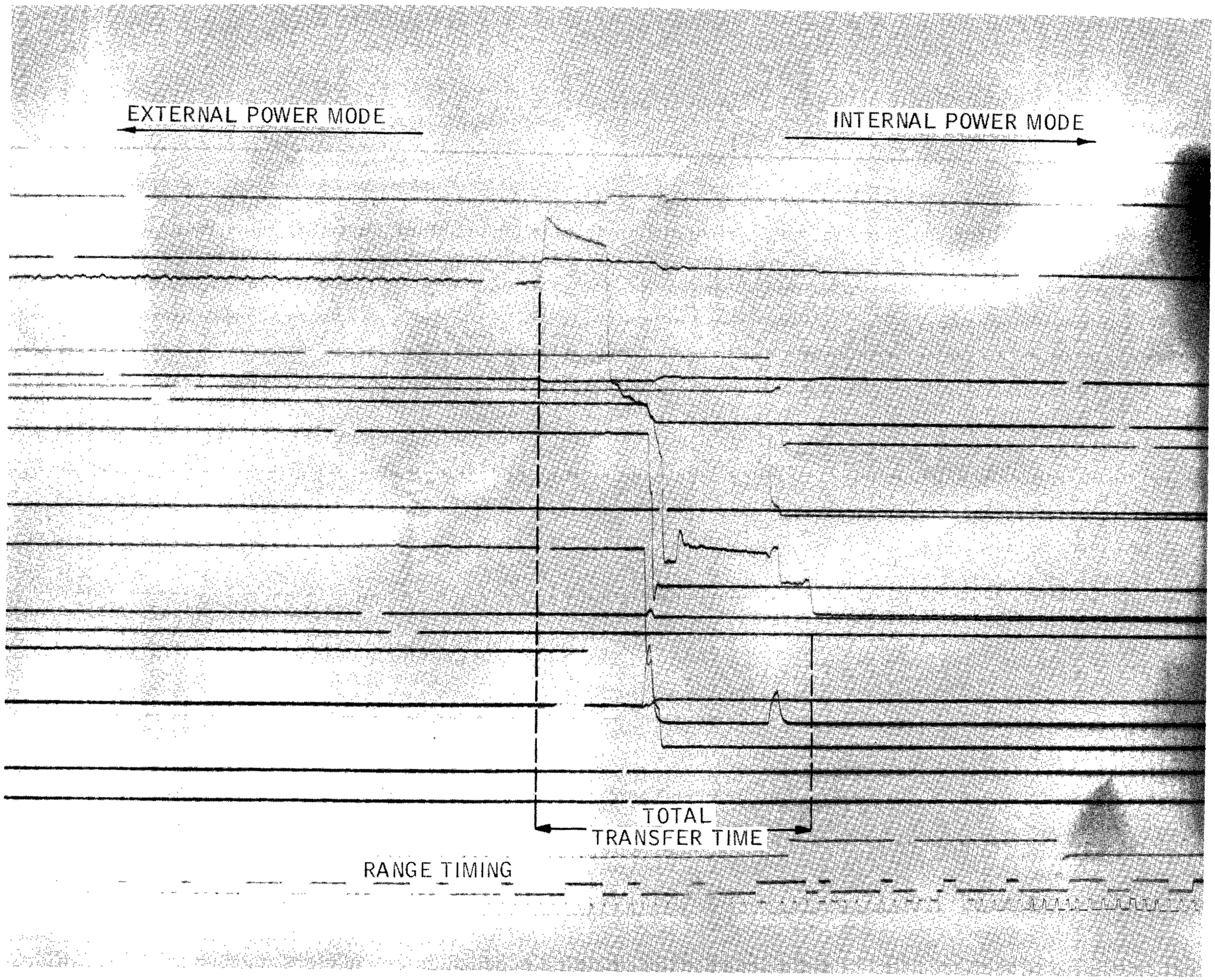

Figure 17. - Data record of CENTAUR power transfer.

CENTAUR vehicle stage is illustrated in figure 17. The CENTAUR power transfer shows more activity because of the greater number of different systems involved. Transfer time parameters can be verified at greater recorder speeds.

Summary of Results

As a part of the overall checkout of the space launch vehicle in preparation for launch, data analysis consumes many hours of engineering effort. The most significant type of data obtained during testing is the data generated by an element which is common to all vehicle systems and ground support equipment and which supports all component, system, and integrated levels of testing. That common element is the electrical power system. The measurement is the current and the measuring device is the current shunt.

John F. Kennedy Space Center
National Aeronautics and Space Administration
Kennedy Space Center, Florida, November 6, 1965.

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