

BELLCOMM, INC.

1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Replacement of Electromechanical
Components by Solid State Components
Case 103

DATE: July 23, 1968
FROM: D. O. Baechler
P. S. Schaenman

MEMORANDUM FOR FILE

Replacing the electromechanical components in space vehicles by solid state devices has the potential advantages of increasing reliability, reducing weight and volume eliminating hazards from arcing across contacts, and, in the long run, reducing costs. This memorandum summarizes the findings of a brief study of techniques for making that replacement. The study was motivated by a request from Dr. George Mueller to determine how one might undertake a program "to replace switches and relays by solid state devices."

Replacing Relays in the Apollo Guidance Computer DSKY

The Display and Keyboard (DSKY) associated with the Apollo Guidance Computer has been the subject of two investigations to determine its convertibility from electromechanical to solid state components. Each DSKY uses 132 relays, 120 of which are of the magnetic latching type and are used to drive electroluminescent display indicators. Thus the three DSKY's in the Apollo spacecraft--two in the CM and one in the LM--use about 400 relays out of a total of about 900 in the CM and LM.

The history of problems with DSKY relays dates back to the Block I design, which used relays that were full crystal can size. The Block II DSKY uses relays which are half crystal can size and were at the leading edge of the relay art at their introduction. The most prevalent relay failures have been:

1. high contact resistance due to contamination,
2. internal shorts due to faulty manufacture and contamination,
3. failure to operate due to wear, broken wires, and bearing contamination.

Numerous attempts to control production and to screen out faulty units have achieved only partial success in terms

of improving yield and eliminating problems. Units which get through the totality of screening processes (at the part, module and DSKY levels) are considered flight worthy.

With this background, AC Electronics, the prime contractor for the PGNCs, proposed to MSC in mid 1966 that the DSKY EL driving relays be replaced with solid state switching. Their initial study indicated that a one-to-one replacement of the Indicator Driver Modules (IDM), which house the latching relays, was feasible using Silicon Controlled Rectifiers (SCR's) as the switching device. This proposal was rejected by MSC and no further work in this area by AC Electronics is known to the authors.

Over the past several years MSC has, however, supported a design feasibility study of a solid state DSKY by MIT/IL. This effort has led to a prototype DSKY which uses transistor switching to drive incandescent display indicators. The EL lamps were replaced because of problems which have been experienced with them in the course of the DSKY development and also to obtain a display device with voltage requirements more compatible with solid state technology.* (EL problems have been associated with sealing, light intensity, and failure rate in Qualification Testing including shock, altitude, and thermal vacuum.) The display indicators in MIT's prototype are fabricated using fiber optics coupled to conventional IL lamps. A segmented IL numeric display indicator was considered but rejected due to fabrication difficulties.

This effort is about completed and an MIT/IL final report should be available within a few months. The prototype DSKY is about the same weight as the relay version but requires roughly ten times the power (approximately 10 watts versus 1 watt). It should be noted that DSKY relays used for guidance and navigation system control functions were not replaced in this MIT/IL prototype. Also, it may be noted that the Data Entry and Display Assembly (DEDA) of the Abort Electronics Assembly used on the LM incorporates EL display indicators (115 V RMS) driven by SCR's.

State of the Art in Replacing Electromechanical Components

There have been a number of commercial, military and NASA projects (outside of Apollo) that have been concerned with replacing electromechanical components such as switches,

*The relays in the basic DSKY switch 250V RMS across the EL lights, thereby eliminating almost all solid state devices except SCR's for consideration as one-to-one replacements for the relays.

relays, and circuit breakers. As background to discussing those projects, we note that each electromechanical component is simply a set of contacts that are operated in response to a signal. A switch, i.e., a mechanical to electrical transducer such as a toggle or push button, responds to a mechanical signal. A relay responds to an electrical signal. A circuit breaker also responds to an electrical signal, usually from an overcurrent sensor.

The primary stumbling block to using solid state relays and circuit breakers is that the solid state device has a voltage drop across its "contacts". In most conventional systems, logic operations are performed by the same contacts that do the power switching and therefore there might be several contacts in series. If these are directly replaced by solid state equivalents, the sum of voltage drops can be such that the circuit will not work. In any particular system, there may be some electromechanical devices that could be directly replaced, but in general, this approach is not feasible.

An approach that does seem feasible is to redesign the system so that all logic is performed at low signal levels using integrated circuits, followed by solid state devices such as SCR's and power transistors for power bus switching and load switching. These high power devices would be constrained from occurring in series, to avoid the accumulation of voltage drops that might occur in conventional systems.

This approach is being used by LTV Aerospace/Dallas, which has been working on various facets of contactless switching since 1962. LTV is presently building a solid state system for power distribution in the A-7B aircraft. This project calls for a complete conventional system and a complete solid state system to be built and compared with one another. They are using an SCR with a 1.5 v forward drop to switch a 115 v, 400 cps, 50 amp, power bus. They use a transistor to switch a 28 vdc bus and specify $V_{CE(SAT)}$ of less than 0.5 v at 10 amps. These devices are controlled by integrated circuits which perform all the logic at a low level.

Several possibilities for replacement of panel switches have been considered by LTV, but LTV has decided against replacing them because:

1. Most potential replacements are not in the production stage and therefore represent a risk.
2. Since these contacts will be switching low level signals, they can be designed to be very reliable.

3. Pilots are accustomed to toggles and push buttons.

However they found that it was necessary to design a buffer between the panel switches and the integrated circuits to eliminate the effect of contact bounce and chatter in applications where the control logic involves timing, latching, counting or memory.

In space applications, the importance of replacing panel switches will depend on whether they have been particularly unreliable and whether further reduction of the possibility of arcing is necessary.

Some of the suggested replacements for panel switches are listed below. These are among the more popular that have recently been studied. The list is not exhaustive.

1. Strain Sensitive Semiconductor. - When strain is applied, the resistance of the semiconductor changes by as much as 30%. Because the resistance is highly sensitive to temperature, compensating circuitry is needed.
2. Variable Capacitance. - Body capacitance changes circuit impedance, actuating the switch. Some problems are that the body capacitance is too low to significantly change the impedance; body capacitance is too variable from person to person; and since only contact is required, there is the chance of accidentally turning it on.
3. Piezoelectric Devices. - At least two designs of piezoelectric signal sources have reached the breadboard stage. LTV and Bell Telephone Laboratories have both designed a laboratory model. LTV's circuit changes state if power is momentarily interrupted. BTL's study of the problem did not proceed to the stage where such problems as the bond between the piezoelectric crystal and the deformable substrate were considered. BTL personnel feel that further study is needed on this problem.

NASA's Electronics Research Center has a study contract with the University of California at Berkeley "to develop new electromechanical devices based on the interaction of the piezoelectric and field effect in appropriate semiconductors." The

charge at the surface of the material is detectable as long as stress is being applied. This technique was discovered by Professor R. Muller and he has licensed Giannini Corporation to develop it. They have not pursued its development.

BTL is also investigating the use of piezoelectric crystals in conjunction with FET's. They are attempting to use the fact that when the piezoelectric crystal is stressed in one direction, the voltage generated is of opposite polarity than when it is stressed in the other direction. This work is in the preliminary stages of research.

4. Photoresponsive Devices. - It may be feasible to use a light emitting semiconductor such as gallium phosphide as a light source to control either a photoresistive material like CdS or a photosensitive transistor. The light source could be broken by a shade controlled by a toggle switch or push button, resulting in isolation of the mechanical and electrical portions of the system while retaining the traditional mechanical devices. The light source would have to be constantly on. This would require approximately 1 mw for each gallium phosphide source with a possibility of reducing this slightly in the future.

Potential for Reliability Improvement

Increased reliability has been mentioned as a probable result of using contactless switching, but this has not always been the case. In May 1963, LTV/Dallas did a conceptual design of a solid state contactless switching system, and its calculated reliability was found to be less than that of a conventional system. This was based on a simple parts count reliability analysis, using failure rate data from MIL Handbook 217; they pointed out that an order of magnitude improvement in reliability of microcircuits was expected by 1964, and that this would result in a more reliable solid state system.

At the present time, LTV's preliminary analysis of the A-7B's solid state power distribution system has borne out their 1963 expectations. In fact, using Texas Instruments, Inc. failure rates, the present calculated reliability is better than was expected, and is better than the electromechanical version. The advantage should continue shifting to solid state devices in the future, but no definitive reliability comparisons have yet been made.

Summary and Conclusion

The state of the art in solid state replacements for electromechanical components can be summarized with the following statements:

1. Relays and circuit breakers can be replaced by transistors and SCR's if the entire system is redesigned.
2. In general, one-for-one replacements are not feasible.
3. Mechanical to electrical transducers can not be replaced by solid state devices until more development work is done on several promising techniques.
4. The relative reliability of conventional and solid state relays, switches and circuit breakers is not well defined, but the advantage should be with solid state implementation in the long run.

The following course of action is recommended for the eventual replacement of electromechanical components by solid state components:

1. A detailed summary of the failure rates and failure modes that have been experienced in the Saturn/Apollo Space Vehicle should be compiled for all electro-mechanical components.
2. A first cut analysis should be performed of the operating time or number of operations that components may experience in some pre-1975 advanced mission such as the Orbital Workshop C. This expected usage data should be compared to data obtained from 1). The intent is to get a gross idea of whether there will be any severe reliability problems if electromechanical components continue to be used in various sub-systems.
3. If 1) or 2) reveal any significant problem areas, NASA should determine whether current research in solid state components is adequate or needs funding in particular areas to eliminate the discovered problems.

4. If not already doing so, OMSF should monitor the LTV power system study and the MIT solid state DSKY study. (Representatives of OART and ERC are already aware of the LTV study.) Study 2) should yield information as to whether any other hardware prototypes are needed. At this time we do not think they are.

5. Designers of new subsystems commissioned by OMSF should be explicitly directed to consider solid state components, and not just choose electromechanical parts because they have always been used before.

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