AN AUTOMATIC ELECTRICAL DISTRIBUTION SYSTEM

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The Automatically Controlled Electrical System (ACES) is a new method of distributing and controlling electrical power. It utilizes remotely controlled power switching and circuit protective devices. Control is exercised through a small general purpose computer using multiplexed control signals. This computer directs the control signals to and from the appropriate system control devices. In addition, it is programmed for automatic control, sequencing and self-checkout functions.

The system offers numerous potential benefits such as:

- Reduced wiring weight and complexity
- Reduced manual supervision
- Lower overall cost
- Less susceptibility to human error
- Fewer bulkhead penetrations
- Simplified maintenance
- Programming of load availability under conditions of low power availability
- Greatly simplified means for system growth and modification

ACES is currently being developed for aircraft and spacecraft applications, but use on submarines and surface ships is also foreseen. The concept may eventually find application in office buildings and industrial plants, particularly continuous process industries.

In an aircraft or spacecraft, the flight crew must be able to exercise control over the electrical system. They must be able to turn loads on and off, and have quick access to the thermal circuit breakers which protect the electrical busses, load switches and thermal circuit breaker panels in the cockpit. In a large aircraft such as a commercial airliner, this requires running heavy electrical power feeders from the generators–located on the engines–to the cockpit, a run of 150 feet or more.

Only 25 percent of the electrical power is used in the cockpit area. The other 75 percent is used in other parts of the vehicle. This power is distributed to the loads by running electrical wires from the electrical busses in the cockpit to each of the loads. This requires many miles of electrical wire. For example, the Concorde (the European-built supersonic transport) has 150 miles of electrical wiring for distribution, control and indication purposes.

A conventional electrical distribution system is shown schematically in Figure 1. Compare this to a system which uses a means of remotely controlling the 75 percent of the power which is not used in the cockpit area. Such a system is shown in Figure 2. Here the electrical power feeders are routed to electric power busses located at electrical "centers of gravity" for various portions of the vehicles. Remotely controlled circuit breakers (RCCBs) are located on the rearward busses. RCCBs are thermal circuit breakers which contain solenoids to open and close them. They are remotely controlled by applying 28 volt power to the control terminals. This requires running a small electrical wire to the cockpit for each RCCB. Since the status of each RCCB must also be known, it is necessary to run a second wire to the cockpit to indicate if the RCCB has tripped. Since these are power carrying wires, they must also be protected by small thermal circuit breakers.

Westinghouse performed a comparative study of the conventional distribution system and the remotely controlled system just described. An airframe company provided information on aircraft loads, load location, wire size and weight, and circuit breaker size and weight for a new transport aircraft design. The results of this study are given in Table 1. Despite the fact that more feet of wire and more thermal circuit breakers were used in the remotely controlled system, there was an overall weight savings of approximately 160 pounds from the use of much smaller wire.

Additional studies were performed to determine what other savings and advantages might be possible from applying other concepts to an electrical distribution system. Multiplexing has long been recognized as a way of reducing the amount of wire required for control purposes. Since remote control was a desireable feature of the system, multiplexing appeared to be a viable concept for further reduction of wire weight.

TABLE I

	Thermal		RCCB	
	Weight Pounds	Cost Dollars	Weight Pounds	Cost Dollars
Load Wire	445.7	28,550*	421.2	29,032*
Thermal Breakers	86.9	7,397	51.2	4,474
RCCBs	—	—	128.7	13,200
Galley Feeder	57.0	1,296**	38.3	1,116**
Bus Feeder	342.0	11,002**	135.0	6,266**
TOTALS	932.4	48,245	774.4	54,088

***An installed load wire cost of $.50 per foot was used.**
****An installed feeder wire cost of $2.00 per foot was used.**

THERMAL BREAKER AND RCCB SYSTEM WEIGHTS AND COSTS

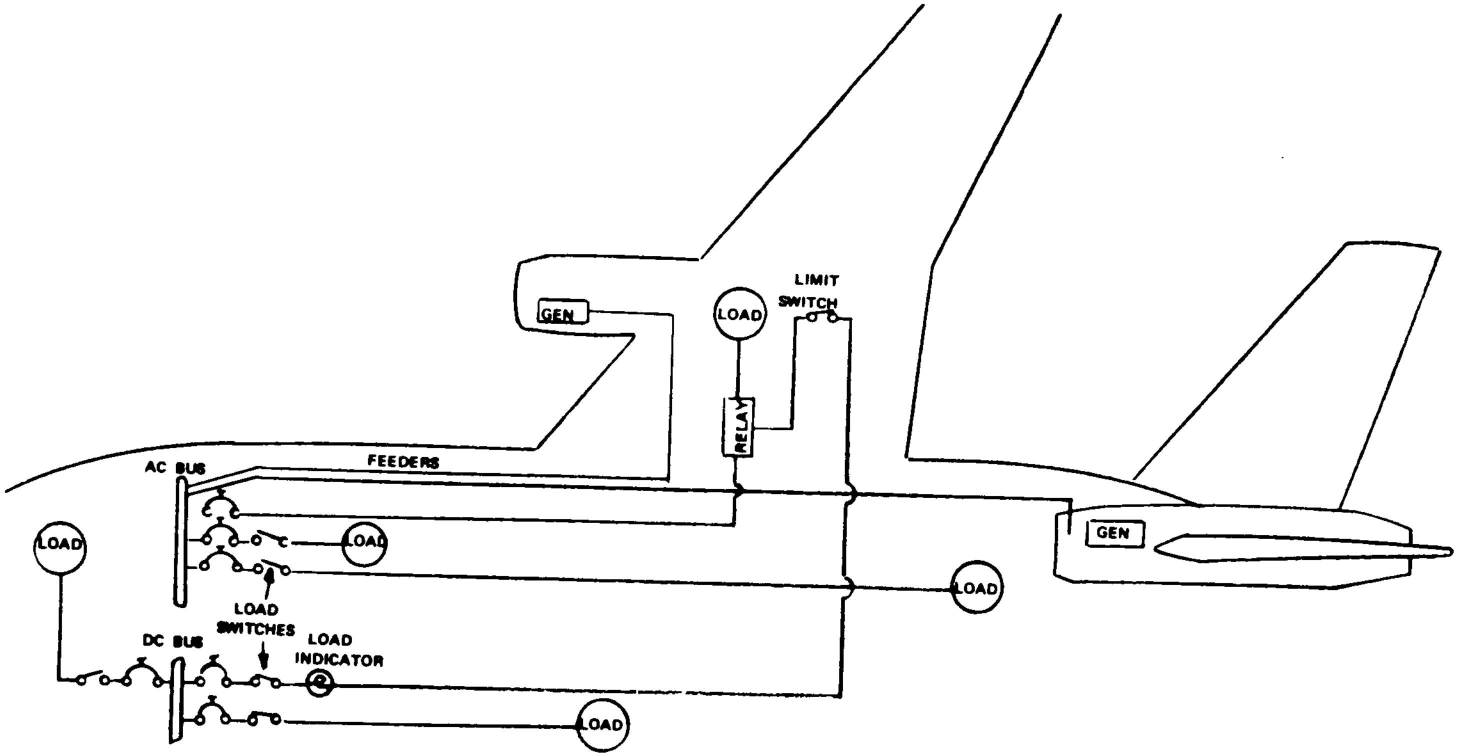

FIGURE 1
CONVENTIONAL ELECTRICAL
DISTRIBUTION SYSTEM

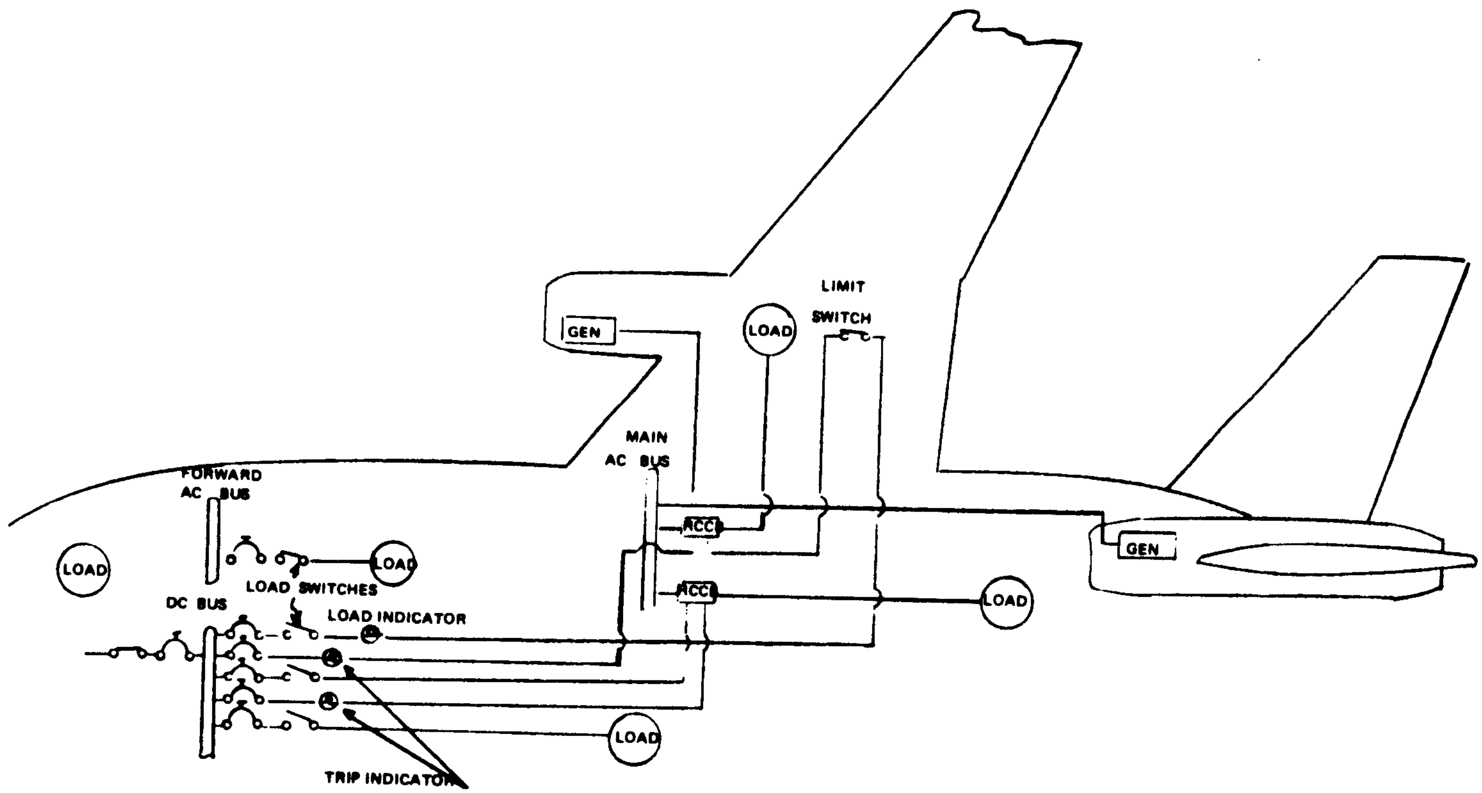

FIGURE 2
RCCB ELECTRICAL
DISTRIBUTION SYSTEM

The U.S. Navy's Solid State Electrical Logic (SOSTEL) concept was also considered. In this concept, mechanical electric-power-switching devices such as thermal circuit breakers, relays and limit switches are replaced by solid state electric-power-switching devices and solid state transducers. As a result, the relay logic conventionally employed for such load control and sequencing functions as extending and retracting the landing gear can be replaced by much more reliable solid state logic. The SOSTEL concept also encompasses the use of solid state remote power controllers which perform both remote load switching and circuit protection functions similar to an RCCB. The transducer signals and control and indication signals for the remote power controllers (RPCs) readily lend themselves to multiplexing.

System features such as self-checkout, sequencing of high inrush current loads and load programming also appeared to be important considerations.

Studies of these concepts and techniques led to the definition of an electrical distribution system concept called the "Automatically Controlled Electrical System", or ACES.

ACES embodies the use of solid state RPCs and solid state transducers insofar as it is economically and technically practical to do so. The use of mechanical switching devices is not precluded since many power levels encountered in aircraft applications cannot yet be practically handled by solid state devices.

A control system schematic is shown in Figure 3. This schematic is somewhat misleading in that the Distribution Control Center (DCC) and the data bus are really in triplet as is shown in Figure 4. The Remote Input/Output (RIO) unit is internally triplicated. Such a configuration allows each computer to be dedicated to its own system and still be capable of assuming the overall computing load if the others fail. Thus, the control system can withstand, at a minimum, two failures without any noticeable effect.

The logic required for load control and sequencing, self-checkout, and load management is contained in the DCC. Signals from transducers and switch/indicator modules (SIMs) are transmitted to the DCC on a multiplexed data bus via RIO units. Logic equations are solved by the computer, and command signals are transmitted on the multiplexed data bus specifying which RPCs are to be turned on or off. The RIOs, which provide the interface between the data bus and the RPCs, "decode" the command signals and route them to the appropriate RPCs which provide the desired load switching functions.

If an overload condition is sensed by an RPC, it provides the circuit protection function by tripping open to prevent damage to the circuit. When it trips open, the RPC transmits an open indication signal to the DCC via an RIO and the data bus. After a pre-programmed time delay, the DCC automatically transmits a reset signal to reclose the RPC. If the fault has cleared, the RPC remains closed and power is restored to the load. If the fault persists after a pre-programmed number of automatic reclosures, the DCC transmits a trip indication signal to the cockpit indicating which RPC has tripped. The RPC remains tripped until manual action is taken to reset. The number of automatic reclosures which may be as few as zero is programmed in the DCC computer for each of the RPCs it controls. So the number of automatic reclosures may be varied depending upon load criticality and other criteria.

Turn-on and turn-off commands are manually provided to the system by SIMs located on the craft's subsystem control panels. The indicator portion of a SIM may be used to indicate if the RPC which that SIM controls has tripped from an overload condition, or to indicate any other occurrence or condition in the system. Manual reset is accomplished by switching the SIM to the "OFF" then back to the "ON" position.

An additional man-system interface is also provided by a data entry and display panel (Figure 5) which is intended to substitute for the capability currently provided by the large thermal circuit breaker panels. This panel provides single point entry and display capability with greatly reduced space and weight requirements.

If a portion of the electrical generating capacity is lost, the system will automatically shed load in accordance with a pre-programmed load priority schedule. This prevents overloading the electrical source. Different load priority schedules are likely to be required for different flight modes. The system software has been designed to handle up to four different load priority schedules which can be selected according to four flight modes.

No analog signals are to be transmitted on the data bus. If analog comparisons are to be made, they will be made on an analog basis in the transducer. Only the fact that a limit has been reached will be transmitted. This, of course, is binary information identical to a switch. Analog control–such as voltage regulation–will be done on an analog basis at the location of the controlled device. Such controllers can actually be smaller and cheaper than A/D-D/A converters. For instance, Figure 6 is a photograph of a voltage regulator for a 90 KVA, 400 Hz, aircraft generator. The logic of the generator control unit is in the DCC. This lack of a requirement for analog transmission on the data bus dramatically lowers data bus rates and alters the word format.

The self-checkout is under software control. Any malfunction of a line replaceable unit is found during control system power up and the location of the unit is indicated on the data entry and display panel. This built-in test is activated every time power is applied to the DCC or upon command of a switch.

Sequencing is accomplished by software control. Simultaneous switching of loads can be restricted to a time sequence of application under software command as to the order and time intervals of application. This sequence also holds for reset of tripped RPCs.

The DCC is a small general purpose military type computer of modular design (Figure 7) and uses standard transistor-transistor-logic (TTL) integrated circuit devices of medium scale integration (MSI) complexity to maximum advantage. It is composed of control, arithmetic, memory and input/output units.

The DCC input/output unit contains a serial data transmission capability for multiplexed communication with the RIOs, a real time clock, and additional input/output mode control. The unit can withstand a data bus short to ground on any one or two busses without damage.

DCC physical specifications are in Table II.

A piece of ground support equipment is the test console which is used to service the DCC. Such a console is shown in Figure 8 with a paper tape program loader. The loader is required for a DCC with an electrically alterable memory, such as plated wire.

The DED, Figure 5, contains a 10 digit keyboard, a numerical display and several switches and indicating lamps. An operator can open or close an RPC by keying in the appropriate RPC address and pressing the "open" or "close" switch. The DCC can be programmed to permit keyboard control of only selected RPCs. If an incorrect address or an address of an RPC not subject to keyboard control is keyed in, the "invalid address" lamp will light.

If an RPC trips, the "RPCs tripped" lamp lights. The addresses of the tripped RPCs can be displayed by switching to the "RPCs trip" mode and pressing the "clear/update" switch.

If the system goes into an automatic load shedding mode, the "loads shed" lamp will light. The addresses of the RPCs controlling the shed loads can be displayed in a manner similar to that for tripped RPCs by switching to the "loads shed" mode.

Each RIO will accommodate up to 64 transducers, SIMs, RPCs, or any combination thereof. Each has 64 command output and 64 status inputs. The control outputs provide signals which activate an RPC or the indicator portion of a SIM. The status accept signals from transducers, limit switches, the switch portion of a SIM and the status indicator output of an RPC.

The key to system operation is the software. The software program is the means of directing the computer hardware and peripheral equipment to accomplish the required control function. Creation of the software is likely to be more closely related to the application than design of the hardware and generally requires a deeper and more extensive understanding of the application. The efficiency of the software, the clarity of use, ease of modification and versatility for new insights into the application is as significant an indication of the extent to which the application is understood as is the design, complexity and size of the hardware.

The software has been written and need not be changed, no matter what the application. Thus, the major portion of the appropriate software has been developed.

This paper has presented a quick look at an automatically controlled electrical system as envisioned by the Aerospace Electrical Division of Westinghouse. It is designed for, but not restricted to, aircraft and spacecraft electrical distribution systems. The modularity, reliability, redundancy, and software make it a leading contender for any automatically controlled electrical system requiring zero-error operation.

TABLE II

	Power (Watts)	Weight (Lbs.)	Size (Cu. In.)
DCC (Military) 8K Memory	68	12	864
DCC (Space) 5.5K Memory	6	4	85
Console (With Tape Reader)	—	—	—
RIO (Including Connectors)	24	5.1	293

DISTRIBUTION CONTROL CENTER SPECIFICATIONS

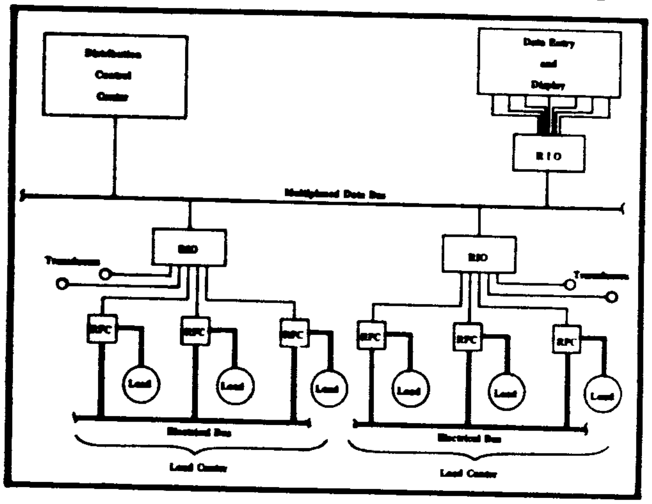

FIGURE 3
SYSTEM SCHEMATIC

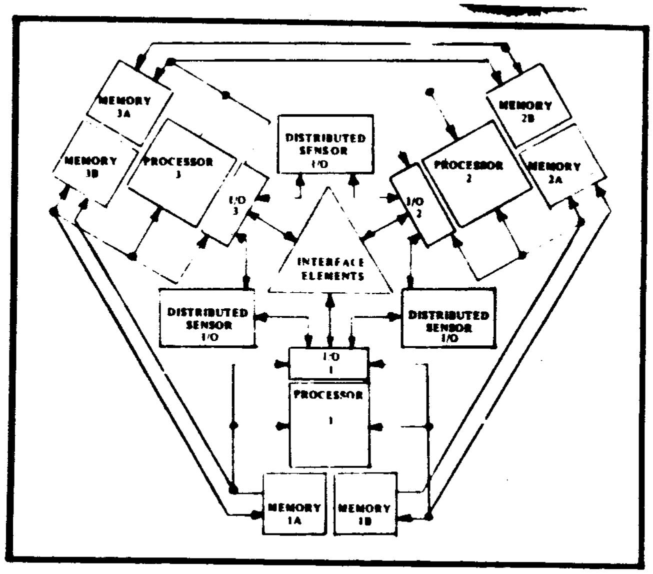

FIGURE 4
ULTRA RELIABLE CONFIGURATION

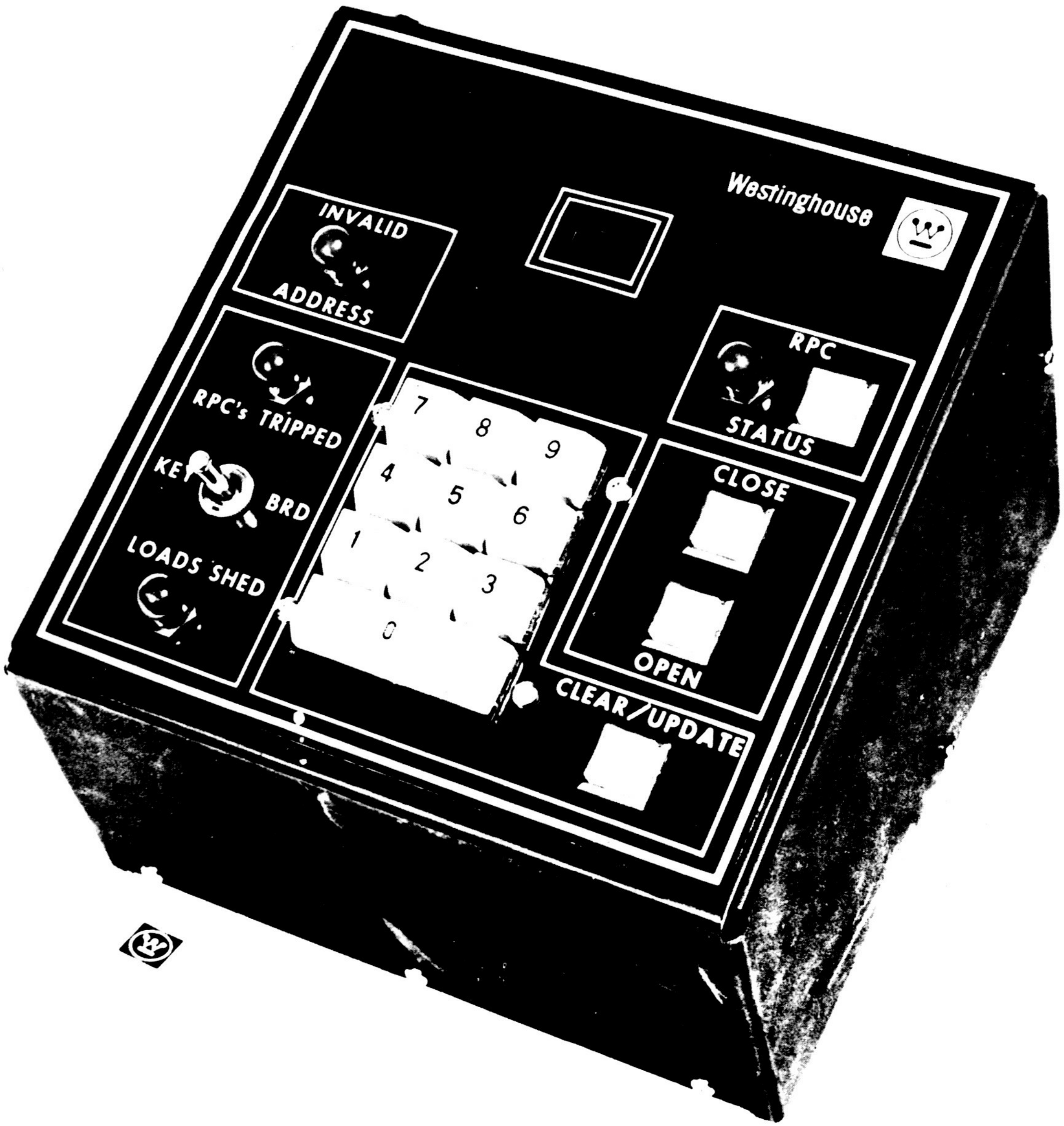

FIGURE 5
DATA ENTRY AND DISPLAY PANEL

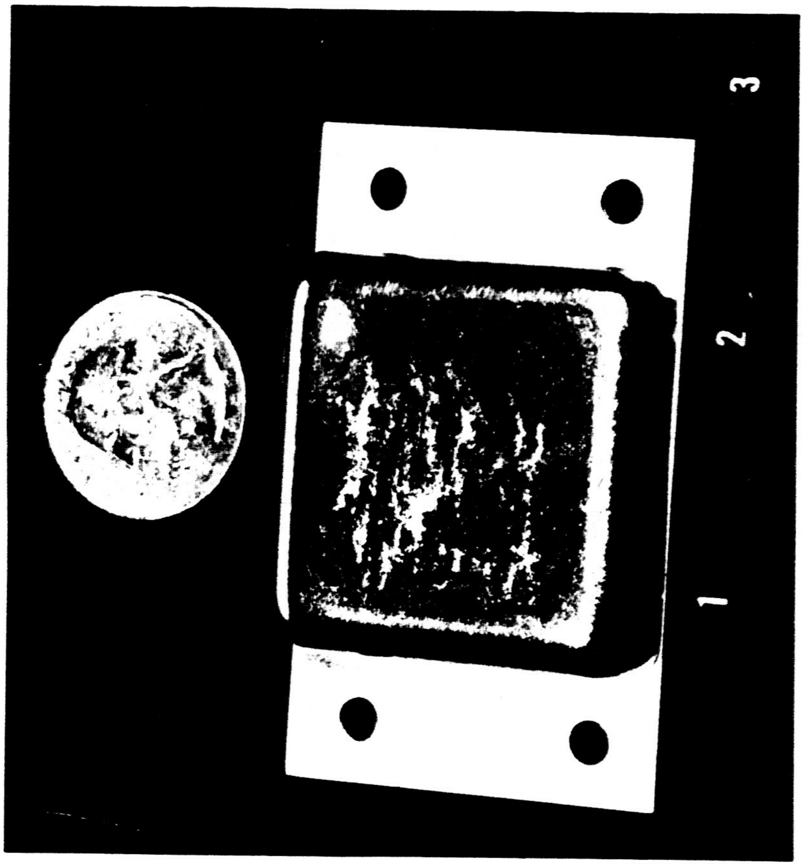

FIGURE 6
HYBRID VOLTAGE REGULATOR

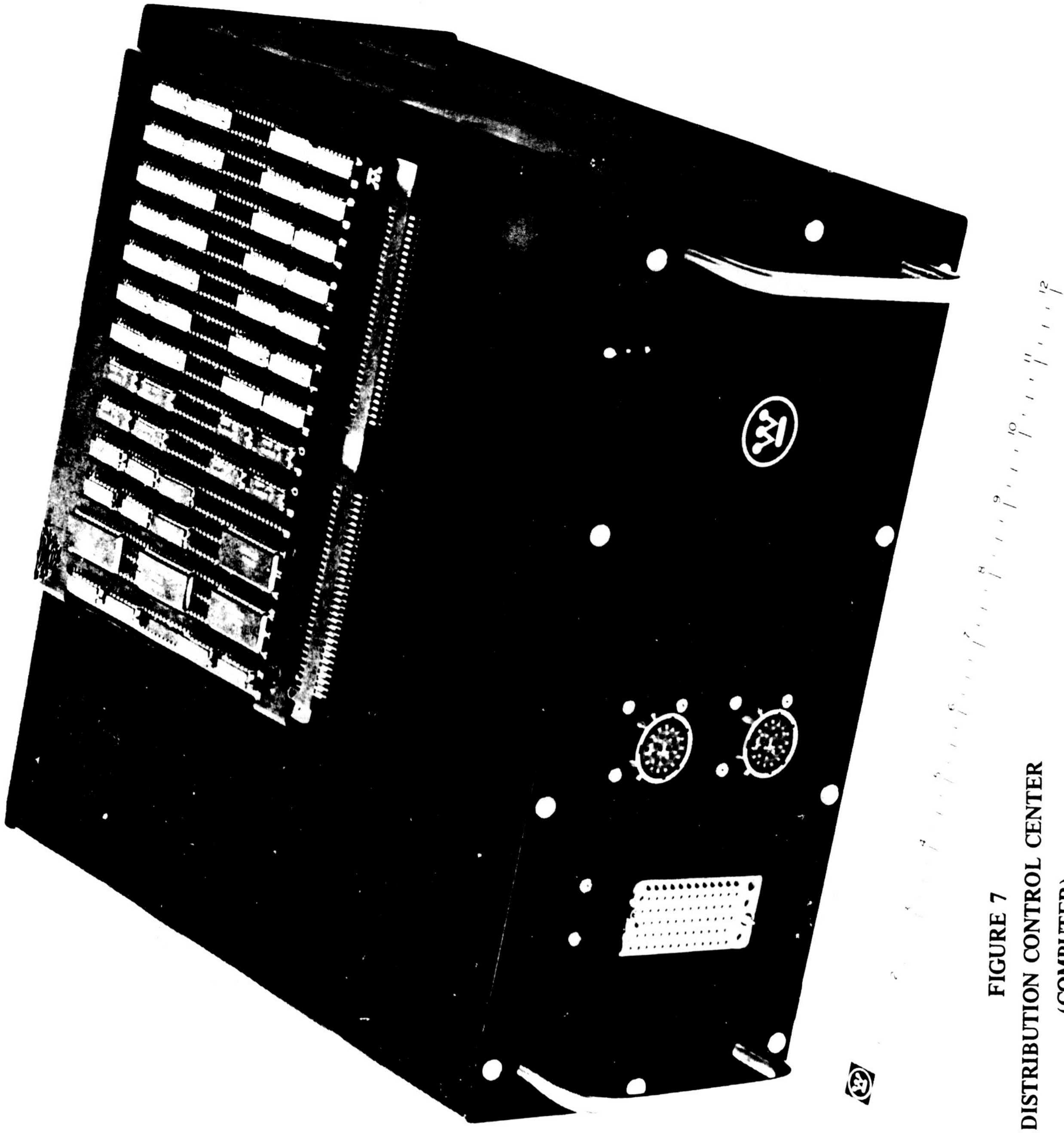

FIGURE 7
DISTRIBUTION CONTROL CENTER
(COMPUTER)

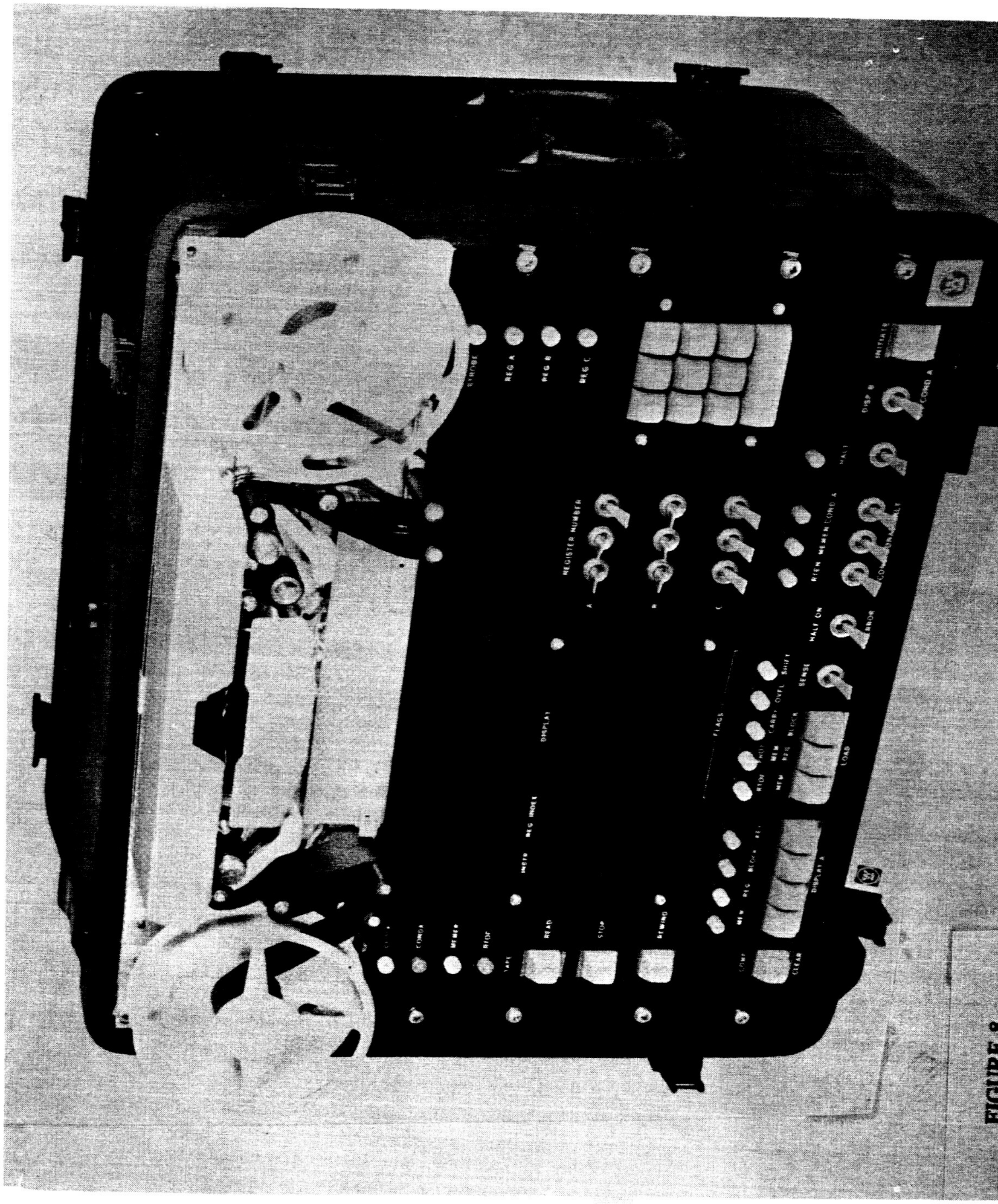

FIGURE 8
DCC TEST CONSOLE