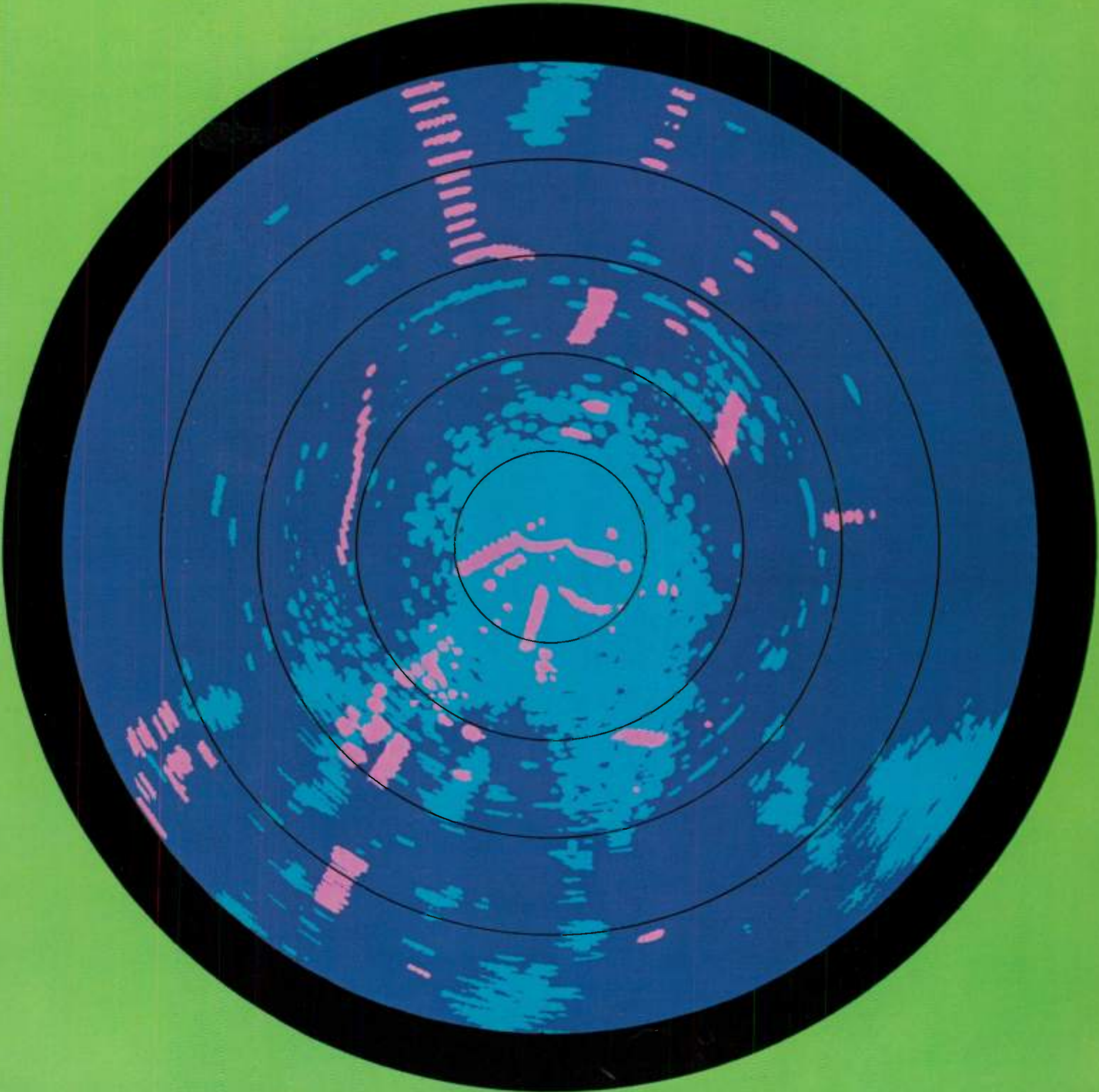
Westinghouse ENGINEER

September 1971



Demonstration Home Blends Imagination with Electricity

Electra 71, an idea home for the 1970s, is designed to show what can be done to improve the quality of life by mixing imagination and electricity. Besides containing many innovative products and systems to make household functions easier and safer, it incorporates an unusual approach to modern building design. It was opened recently at Coral Springs, Florida (Fig. 1).

The team of designers, architects, and engineers studied the functions within a home, examined the needs of a family, and developed living space to meet those needs. The functional study resulted in definition of 11 main centers—entrance, lounge, children's center, adult center, textile care area, interior leisure, food, home utility, exterior leisure, yard, and exterior storage.

The food center illustrates the planning behind each center. More than just a kitchen, it is a grouping of three prewired preplumbed appliance units integrated into a system and designed around a family's habits of preparing various types of meals. Refrigeration is decentralized. A compact quick-food unit (Fig. 2) can be used to prepare snacks or breakfast; along with the dinner unit seen in the background in Fig. 2, it forms a galley for organizing larger meals.

An electronic command post (Fig. 3) in the food center has a television set that lets the housewife watch commercial channels, keep an eye on the children in the swimming-pool and patio area, or check to see who's at the main entrance. She can listen to AM/FM radio as she prepares dinner, tape-record messages for other members of the family, operate the temperature control system for the food center, and, in an emergency, press a button to summon police or firemen.

The air-conditioning system is designed to provide close temperature and humidity control the year around, room by room. It can maintain as much as a 10-degree difference between rooms if desired, and it responds automatically to major load changes to concentrate capacity where needed. The system includes a 5-ton heat pump, a 3-ton heat pump, a Precipitron electrostatic air cleaner, and a deodorizer.

A home security system protects the home against fire, smoke, robbery, and other emergencies. All main doors can be locked from consoles in the food center and the adult-center sleep area.

The adult-center console (Fig. 4) has "his and her" controls to remotely control the security system, drapes, radio, television, reading lights, night lights, and air filter. One end of the adult center has a study area (Fig. 5).

The children's center provides space for study, sleep, and play. It includes an electronic educational console containing a video tape recorder, keyboard, and monitor (Fig. 6).

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Westinghouse ENGINEER
September 1971, Volume 31, Number 5

Subscriptions: United States and possessions, $2.50 per year; all other countries, $3.00 per year. Single copies, 50¢ each.

Mailing address: Westinghouse ENGINEER
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222.

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. Printed in the United States. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

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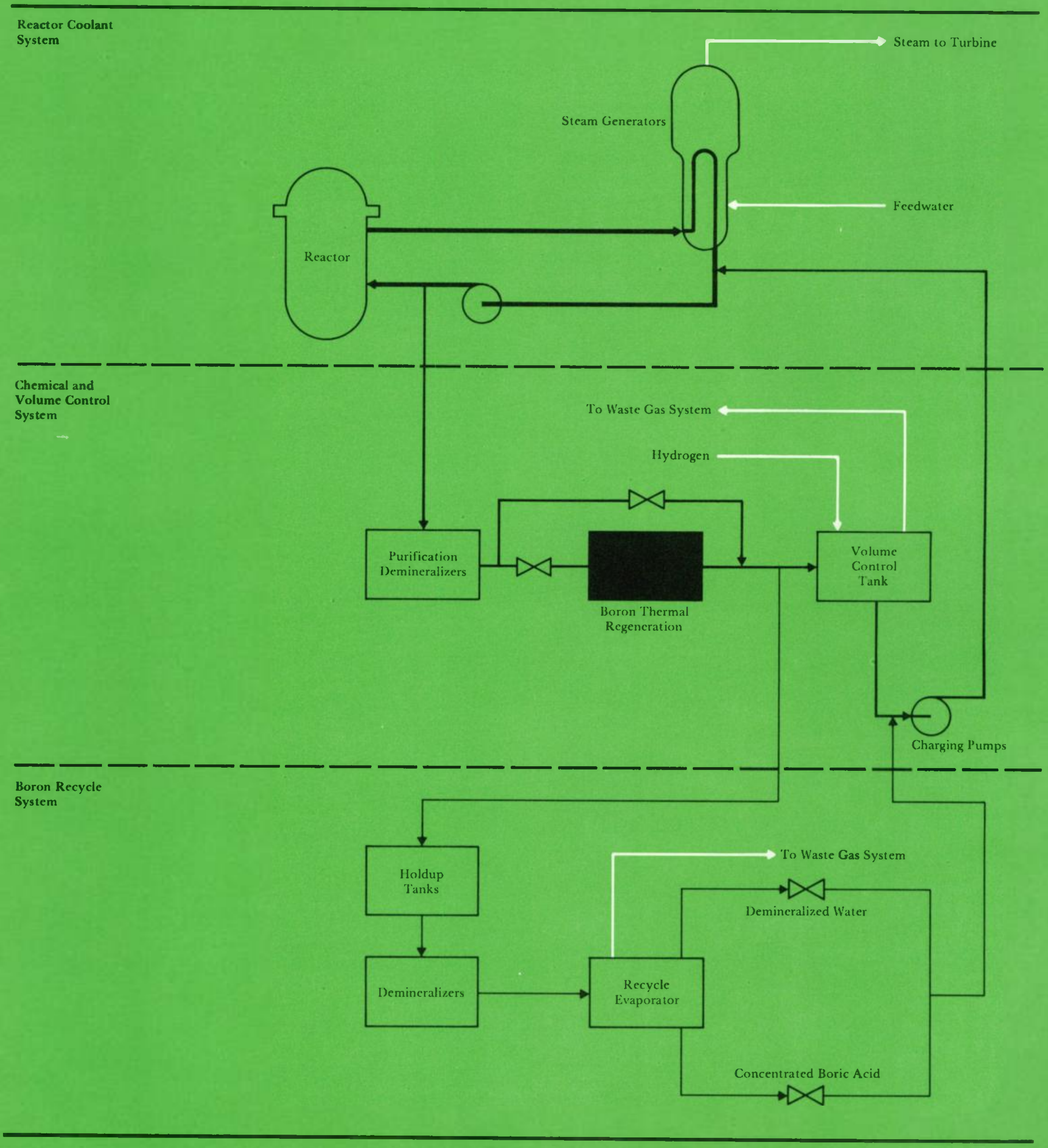
Front Cover: Modern tactical radars use various digital signal processing techniques to extract targets of interest from background interference. The effectiveness of signal processing is illustrated on this month's cover design by artist Tom Ruddy. Multiple scans of video *with* signal processing, which clearly indicate the progress of moving targets, are superimposed over a single scan display of raw video *without* processing. The basic digital processing techniques used in modern tactical radars are described in the article that begins on page 147.

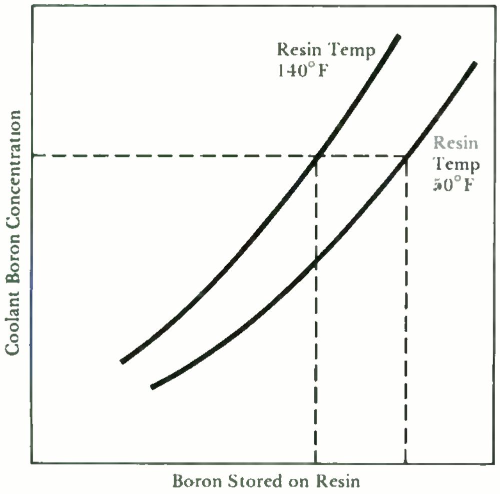
Back Cover: Extra-high-voltage testing laboratory at the Power Circuit Breaker Division, Trafford, Pennsylvania, includes an outdoor section for testing above 765 kV. Its 6400-kV 160-KW/s impulse generator with voltage divider can produce and measure impulses with front times of 1.2 ms and higher. When not in use by Westinghouse divisions, the facility is available on a rental basis.


Reactor Coolant System
Steam to Turbine
Steam Generators
Feedwater
Reactor
Chemical and Volume Control System
To Waste Gas System
Hydrogen
Purification Demineralizers
Boron Thermal Regeneration
Volume Control Tank
Charging Pumps
Boron Recycle System
Holdup Tanks
To Waste Gas System
Demineralized Water
Demineralizers
Recycle Evaporator
Concentrated Boric Acid

New PWR Nuclear Power Plant Systems Reduce Radioactive Releases

H. J. von Hollen
W. A. Webb

Concentration and long-term storage of liquid and gaseous radioactive wastes, rather than dilution and release, are the underlying design principles for today's advanced pressurized water reactor (PWR) to further reduce release of radioactivity to the environment.



1—(*Left*) Heat from the pressurized water reactor is transmitted to steam generators by the reactor coolant system. A side stream from the primary loop is processed by the chemical and volume control system and the boron recycle system to remove ionic and particulate activity and provide for boron control.

2—(*Above*) Coolant boron concentration can be varied by changing resin temperature.

Releases of radioactive products from nuclear power plants to the environment have been carefully controlled and well below plant design levels and AEC requirements. As a result, the exposure to the general public from today's operating pressurized water reactors has been extremely low compared with the normal background level from natural sources.

Even with this excellent performance, the industry continues to monitor reactor experience and to innovate further improvements. An improved Westinghouse system for reducing radioactive releases from PWR plants introduces a basic change in the waste management philosophy applied to nuclear power plants. Where heretofore all nuclear power plants handled liquid and gaseous radioactive wastes on a "dilution and dispersion" basis, the new system concentrates the wastes to manageable quantities for retention within closed plant systems for extended periods of time. In fact, the system has the potential for holding radioactive liquid and gaseous wastes within the plant over its entire operating life.

A key feature of the new design is a basic change in the method of handling boric acid used as chemical shim. Additional modifications to the waste-liquid and waste-gas processing systems have also been made.

Boron Thermal Regeneration

In a pressurized water reactor, fission products that may be released in the event of fuel cladding defects or surface contamination by tramp uranium are initially retained within the reactor coolant loop. Ionic and particulate activities are continually removed by the *chemical and volume control system* (shown in Fig. 1), which demineralizes a side stream from the reactor loop and adds hydrogen to the reactor coolant for corrosion inhibition.

The effect of long-term burnup on core reactivity and the reactivity changes required for load-follow variations are accommodated by changing the boron concentration in the reactor coolant. In previous designs, boron control was provided by the *boron recycle system* (Fig. 1), which consists of holdup tanks, demineralizers, and an evaporator to separate and concentrate boric acid from the reactor coolant stream. The distillate and concentrates from the recycle evaporator are returned to the reactor coolant system as necessary to maintain the desired boric acid concentration.

A principal development in the new PWR design is the incorporation of *boron thermal regeneration* to provide the boron changes in the chemical and volume control system required for load-follow operations. The boron thermal regeneration system is based on the fundamental property of ion-exchange resins that their capacity for storing boric acid varies with temperature and that the process is reversible. Thus, the ion-exchange resin in effect acts as a sponge to soak up or release borate ions as required for operation of the plant. The regeneration equipment is provided as an in-line function within the chemical and volume control system. When boron changes are desired to accommodate load-follow cycles, flow is routed through the boron thermal regeneration equipment; during base-load operation, thermal regeneration is bypassed.

A plot of boron concentration versus resin capacity for the operating temperature range of the system — 50 to 140 degrees F — is shown in Fig. 2. The ion-exchange resins are essentially saturated with boron and their difference in capacity with temperature provides the boron increment for control of load-follow transients. The system is capable of handling boron changes associated with load-follow cycles comparable to those previously accommodated by large evaporators.

A process flow schematic of the boron thermal regeneration equipment is shown in Fig. 3. The equipment includes a series of three heat exchangers to control the temperature of the letdown stream going to the thermal regeneration ion exchangers from 140 degrees F (for boron release to coolant) to 50 degrees F (for

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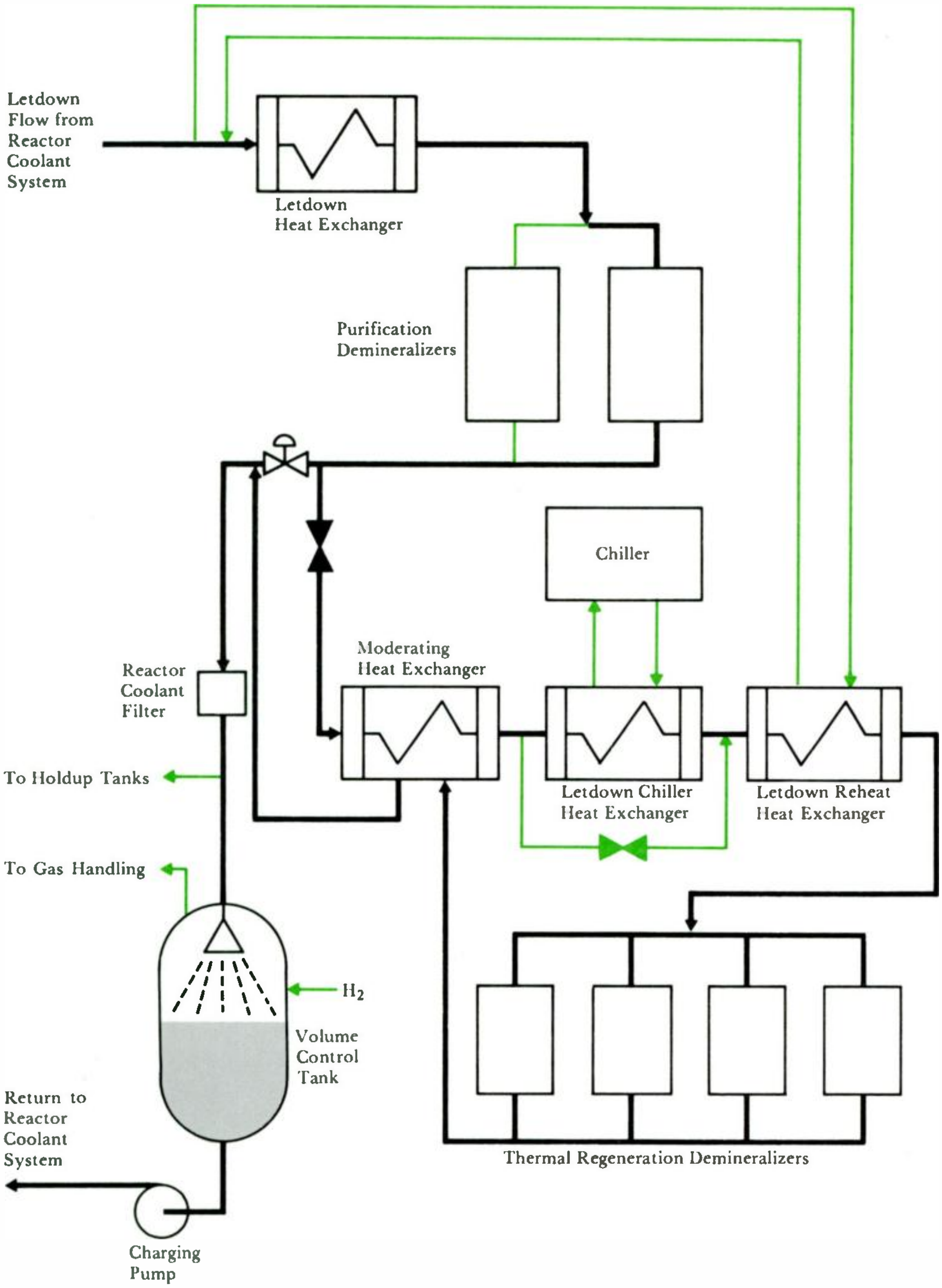


3—The boron thermal regeneration system uses heat exchangers to adjust temperature of coolant stream entering the thermal regeneration demineralizers and thereby control the boron concentration level (Fig. 2).

boron storage on resin). A chiller unit provides cooling through one of the heat exchangers during the boron storage cycle.

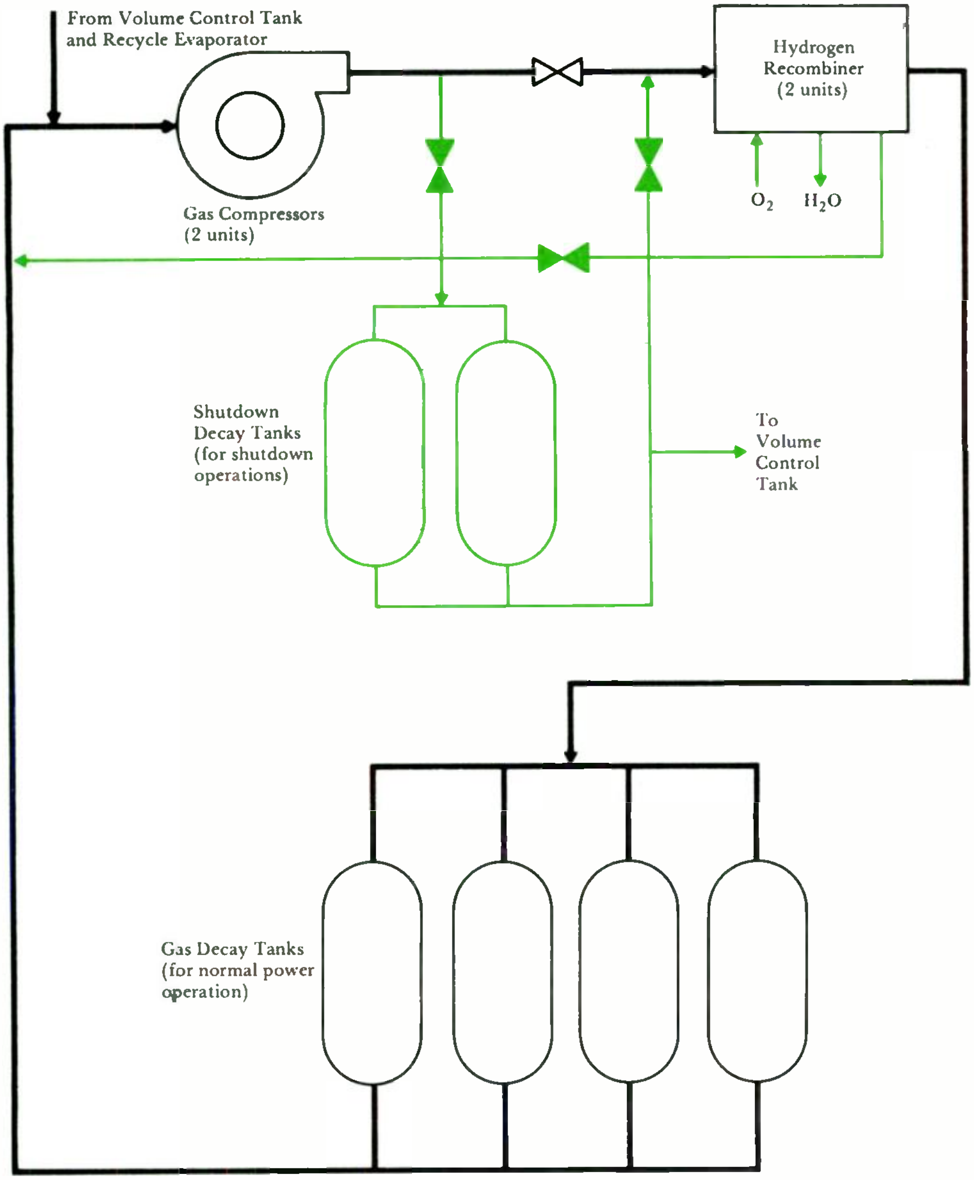
The principal advantage provided by thermal regeneration is the substantial reduction in the amount of coolant that must be processed by the boron recycle system. Since it now only needs to adjust boron level to compensate for long-term fuel depletion, the amount of liquid processed is reduced by a factor of 10 over previous designs using evaporators only.

Waste Gas System

In the event of cladding defects, radioactive gases are released in addition to the ionic activity released to the reactor coolant. These gases remain dissolved in solution and accumulate in the volume control tank in the chemical and volume control system since they are not removed by the ion-exchange resins The principal gases are xenon-133 and krypton-85. The second major change from previous PWR plant systems is the development of a *waste gas system* that concentrates and stores these radioactive gases rather than releasing them to the environment. The system also provides the ability to maintain a significantly lower level of dissolved gases in the reactor coolant system than provided by previous designs.

Since the fission-product gases are retained within the chemical and volume control system, it is possible to provide efficient and continuous removal of fission gases that accumulate in the volume control tank. A continuous purge of hydrogen into the tank transports radioactive gases from the tank to the waste gas system. Residual gases stripped out of solution by the boron recycle evaporators are also collected by this system.

The system shown schematically in Fig. 4 consists of a hydrogen recombiner, compressors, and gas decay tanks to accumulate the fission-product gases. The hydrogen carrier gas is removed by the recombiner, leaving only the small quantities of fission-product gases in storage. The gas decay tanks are filled with nitrogen at essentially atmospheric



4—Waste gas system stores fission gases that accumulate in the volume control tank and the recycle evaporator (Fig. 1).

pressure. Nitrogen is circulated through the waste gas system and provides the diluent for the hydrogen that is burned in the recombiner.

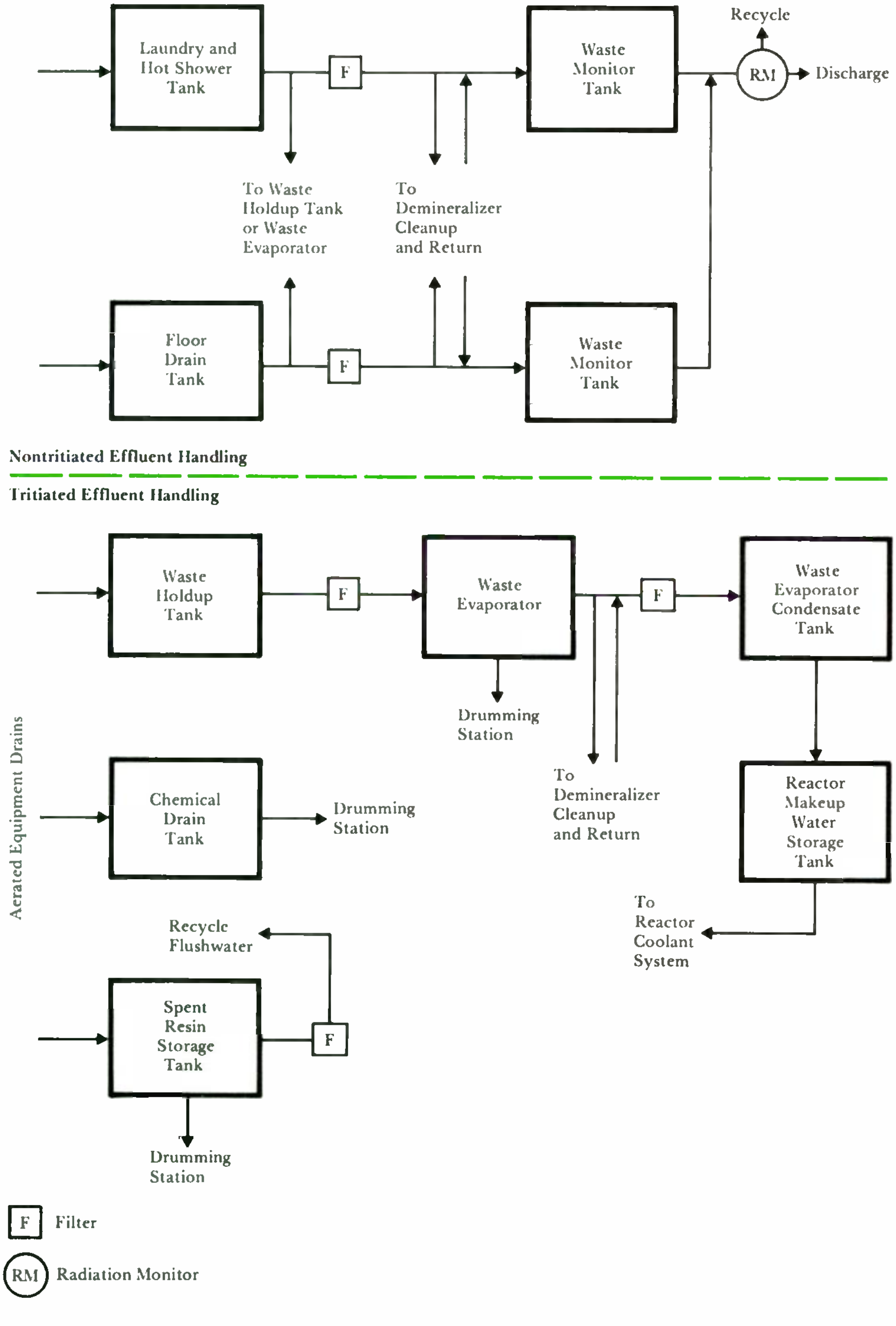
With this system, virtually all of the krypton-85 released to the reactor coolant can be collected and stored.

The bulk of the activity in the gas decay tanks is xenon-133, which has a decay half-life of 5.3 days. The total radioactive gas content in the plant is predominantly xenon-133 when there is defective fuel during power operation. If all the gases are stored for 40 years, and it is conservatively assumed that the plant operates with defective fuel during every cycle, the amount of krypton-85 (with a half-life of 10.7 years) accumulated over the 40-year period will be approximately equal to the xenon-133 present during any fuel cycle with one percent fuel defects. Therefore, the total gaseous activity at the end of 40 years of nuclear power plant operation will be less than twice that present during any fuel cycle with one percent fuel defects.

With this system the concentration of fission-product gases in the reactor coolant system is reduced from previous designs by a factor of about seven. This general reduction in reactor coolant activity substantially reduces the effect of any leakage from the plant.

The waste gas system is provided with sufficient tankage to accumulate all the fission-product gases released to the reactor coolant for the very conservative assumption that the plant will operate with one percent of its fuel failed throughout the design plant life of 40 years. Because the volumetric quantity of radioactive gases is so small, Westinghouse recommends that these gases be continuously stored rather than periodically shipped offsite for disposal.

The storage of this gaseous activity constitutes no additional hazard to the plant operator for two reasons: first, the amount of activity stored with the new design is of the same order of magnitude as with previous designs; second, and more important, the concentration of gases in the reactor coolant system and in the plant process systems is appreciably less than with previous designs.



5—Waste liquid system segregates radioactive and nonradioactive effluents and recycles radioactive water back to the reactor coolant system.

Liquid Waste System

In previous PWR designs, liquid wastes were to be ultimately diluted and discharged, so they were usually collectively gathered. The new liquid waste system is designed to process and recycle radioactive liquids back into the plant systems. Therefore, liquid wastes are now strictly segregated as radioactive and nonradioactive. In this way, tritium can be retained and stored within the plant on a long-term basis.

The general process diagram (Fig. 5) indicates the various process streams. The principal methods for removing any activity present are conventional evaporation, filtration, and ion exchange.

The major impetus to this strict liquid segregation philosophy has been the very high tritium retention experienced with Zircaloy-clad fuel. Because of the lower quantities of tritium released to the reactor coolant, long-term storage of tritiated liquids is feasible. The only discharges from the liquid waste system are those liquids with very low activity for which additional processing is impractical. These effluents are diluted with plant condenser cooling water prior to discharge. The radioactivity collected in the waste evaporators, spent resins, and filters is drummed for offsite disposal.

Conclusion

The systems described have been developed as part of a continuing program to improve PWR plant operation, a program that is based on operating experience and the current emphasis on environmental considerations. The new PWR systems significantly reduce radioactive releases to the environment.

Solid-State Remote Power Controllers for Electrical Systems

D. E. Baker
D. A. Fox
K. C. Shuey

Remote power controllers perform the switching and status-indicating functions in automatically controlled electrical systems. They are reliable hybrid solid-state devices.

Advancing technology creates ever larger and more complex aircraft for commercial and military applications, thereby increasing the amount of electrical utilization equipment powered and controlled by the aircraft electrical system. The consequent increase in complexity of the electrical distribution and protection system cannot long be handled by conventional system designs. Likewise, the system cannot be sufficiently improved by modification of presently available electromechanical switching devices nor by modification of present wiring, fusing, and indication techniques.

As a result, future aircraft electrical systems must be computer controlled through solid-state static switching devices to provide continuous monitoring of all system parameters and to control all loads for optimum performance. Solid-state switching devices have inherent capabilities that allow more load control than is possible with electromechanical devices. Among those capabilities are control of load current rise and fall, close-tolerance load protection, load switching from control signals of very low power, and maximum limiting of load and fault currents.

Besides aircraft, other advanced vehicles for space, marine, and land applications will require such automatically controlled electrical systems and static switches. Moreover, the systems can be advantageous in some industrial applications, such as control of process lines that require extreme reliability.

Remote Power Controllers

The Westinghouse Aerospace Electrical Division is developing static switches as part of its Automatically Controlled Electrical System (ACES). The main functions of ACES are load and bus switching for equal load distribution among the generators to optimize efficiency; automatic load removal and indication according to priorities to prevent overloads due to engine or generator failures; visual display of the status (on or off) of any load; visual display and automatic reset of any static switch that has tripped out due to overloads; automatic location of failed equipment or wiring; display of essential system parameters such as ac and dc voltage, total load, and load per generator; and automatic switchover to emergency power sources.[1]

The static switches are known as remote power controllers (RPCs) because they can be controlled by a central computer. They incorporate built-in overload protection, remote trip indication, and remote on-off-reset capabilities.

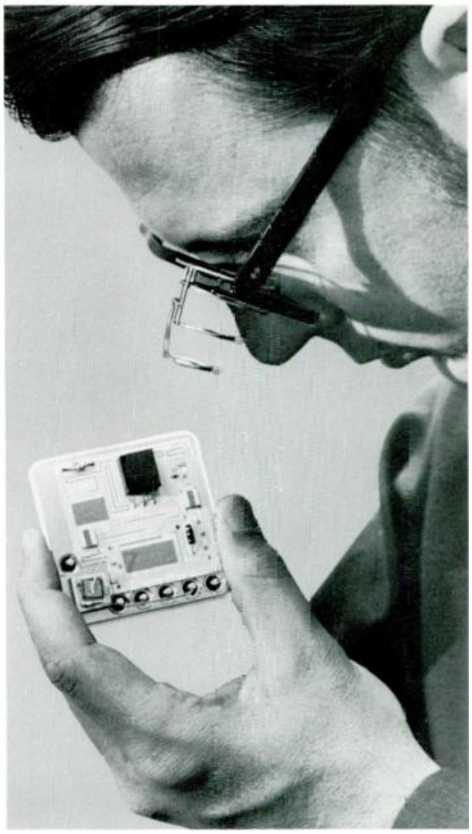
RPCs are currently being developed to meet preliminary airframe manufacturers' specifications and military specifications. The designs of 1-, 2-, 3-, 5-, 7.5-, and 10-ampere ac and dc RPCs are nearly complete. Those ratings cover most aircraft load requirements. The 1- and 2-ampere units could control lamps; the 10-ampere device could control motors.

Size and weight of each RPC are minimized by use of hybrid circuit manufacturing techniques. A first-generation 2-ampere dc prototype has been produced and evaluated (Fig. 1). Hybrid packaging techniques are being advanced to accommodate high-power circuitry. Second-generation 5-ampere ac prototypes are presently being produced, and the continuing development will reach 35-ampere units in 1972 and go on into the 75- to 150-ampere range. The larger devices will be used for control of main power buses.

Advantages of RPCs

In addition to the advantage of allowing automatic control of the electrical system, the RPC offers many not so obvious advantages in total system performance.

First, and one of the most important, is the temperature stability of the RPC's protective characteristics. Typically, it is from three to five times better than



1—Remote power controller (RPC) is a hybrid solid-state switching circuit that turns distribution-system loads on or off in response to control signals. It also opens the circuit on overloads and indicates its status to the central controller. This one is a 2-ampere current-limiting dc prototype built to prove the feasibility of packaging microelectronic circuits with power semiconductors.

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that of thermally activated electromechanical protective breakers.

Moreover, contact life of an RPC is at least a thousand times that possible with comparably rated mechanical contacts. (Typical mechanical relay contacts are capable of up to 50,000 operations.) Every time mechanical contacts make or break, metal transfer changes the characteristics of the device; toward the end of a relay's life, unpredictable changes occur in the contacts. Since RPC contacts are solid-state, arcing and metal transfer are impossible. Therefore, consistent contact operation prevails for the life of the RPC.

Such long contact life fits RPCs for applications that are not possible with electromechanical devices. For example, light dimming could be done directly (either ac or dc) by controlling an RPC to adjust the duty cycle of the lamp power. The ACES computer could be programmed to do the controlling automatically. The arrangement would be more efficient than a mechanical or resistor voltage-dropping method. Radio-frequency interference would not be a problem because it would be minimized by the RPC's controllable rate of turn-on and turn-off, without need of filtering. (More on that later.) Similar applications could be in such subsystems as speed controllers and temperature controllers for defogging and deicing.

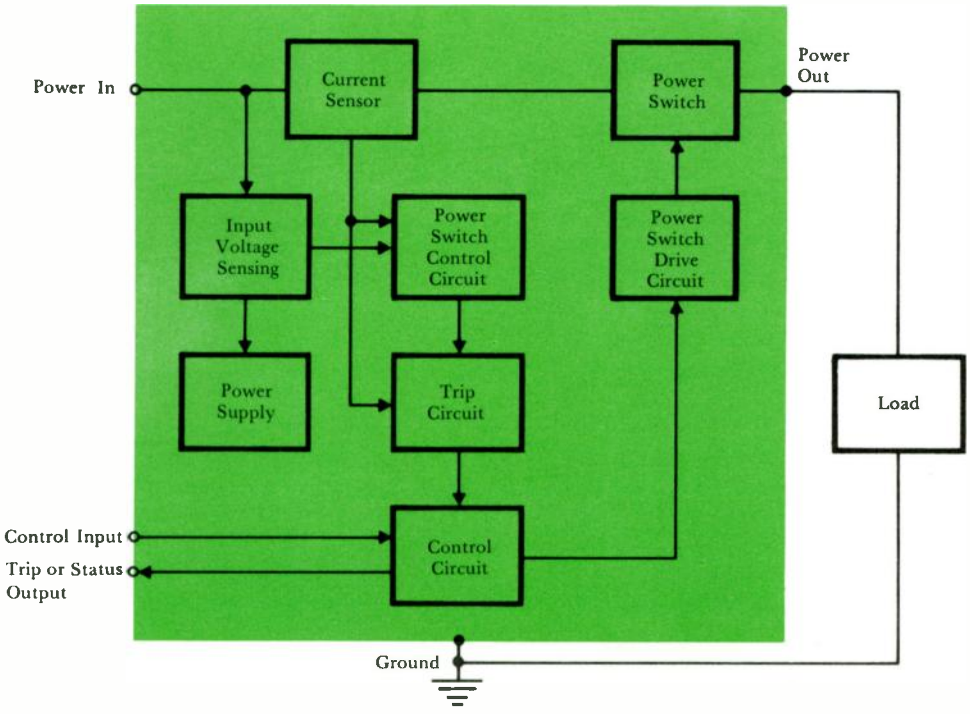
RPCs have little susceptibility to mechanical disturbances such as vibration and shock. Those disturbances are common in aircraft, and they can cause contact bounce or instability in electromechanical devices. Contact bounce and inductive coil transients in electromechanical devices are the main contributors to radio-frequency interference, which limits the use of those devices. RPCs, however, have pure resistive control inputs, eliminating the inductive coil transients.

The extremely short rise time of current through the electromechanical relay contacts on closure also creates considerable radio-frequency interference, especially with large loads. In dc RPCs, rise time and fall time can be controlled to any desired level, so radio-frequency interference is smaller than it is with electromechanical relays—even without filtering—regardless of the size of load being switched. For ac devices, turn-on and turn-off is done at the zero voltage and zero current crossover points respectively to minimize r-f interference.

The dc RPCs can be designed to current-limit during fault or overload conditions. That feature allows wiring to be sized for the load without need for oversized wiring to handle large surge currents; it would result in a significant weight saving in the aircraft wiring, because there would be from 500 to 2000 RPCs on a typical airplane and because the loads would be physically far away from the RPCs. The extremely fast trip-out times (2.5 milliseconds maximum) of ac RPCs for large fault currents allow a similar saving in wire size and weight. Moreover, due to the current limiting of dc RPCs, the fast trip-out times of ac RPCs, and the controlled rise and fall times, the quality of the ACES system power is much superior to that of a conventional system's power.

The large power gains attainable with RPCs allow control of all sizes of loads with only a few milliwatts of control signal power, a feature not readily attainable with electromechanical relays. The control input can easily provide any desired amount of hysteresis between turn-on and turn-off voltage levels, another characteristic that cannot be had in electromechanical devices. In fact, the dropout level of many electromechanical relays can be as low as 0.5 volt while the pickup point is 12 to 15 volts under certain temperature conditions.

Finally, the response times of RPCs are an order of magnitude faster (in the 0.2 to 1 millisecond range) than the fastest electromechanical power devices. If the need arises and radio-frequency interference is not a problem, RPCs can easily be made several orders of magnitude faster (10 to 20 microseconds) than the



2—(*Left*) Functional diagram of an ac RPC is typical of both ac and dc units.

3—(*Right*) Typical contact drops for dc current-limiting RPCs. The devices are in full saturation until load current reaches 140 percent of rated current; they then limit current regardless of load impedance. That level of current limiting is maintained for all supply voltage levels, even during overvoltages (above 30 volts) including 80-volt transients. If an overload persists more than 2 to 3 seconds, the RPC trips out and latches open until reset.

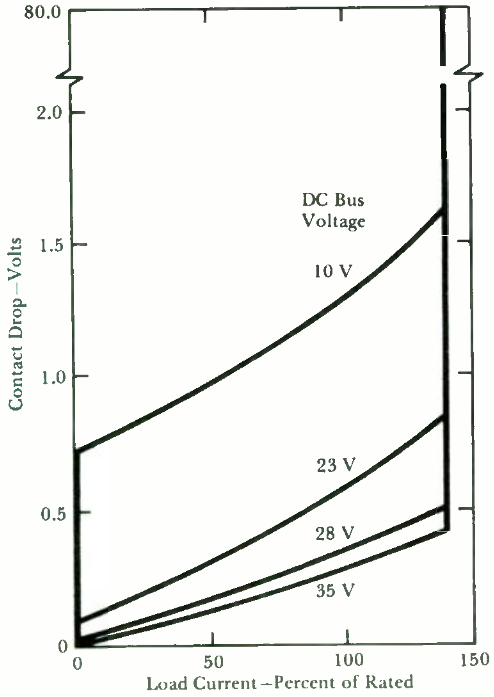
best electromechanical units available.

Along with all these advantages of RPCs, there are still a few drawbacks. For example, contact drop, although more stable, cannot be made as low as that of electromechanical units. Typically, contact drops for dc RPCs are 0.3 to 0.4 volt and for ac RPCs are 1.0 to 1.2 volts; contact drop for electromechanical relays is usually less than 0.1 volt. Also, semiconductor devices are limited to operating temperatures of 125 degrees C or 200 degrees C, for thyristors and transistors respectively.

Efficiency is 96 percent or more for most RPCs, which is comparable to that of electromechanical devices. New circuit techniques are being developed to reduce contact drop and increase efficiency even further.

Control Characteristics

As mentioned before, one of the advantages of RPCs over conventional relays is their low requirement for control power. The coil of a conventional relay may require from 1 watt (for small crystal can relays) to 15 watts (for large circuit breakers), so several kilowatts are needed to control all the relays on a large jet aircraft. The RPC, on the other hand, can be controlled by a very small amount of power, down to microwatts; the same application, then, would require milliwatts instead of kilowatts.



However, the low control levels possible with RPCs could create a problem, because the noise susceptibility of a circuit increases as its impedance increases. In the hostile environment of a jet aircraft, noise (such as voltage spikes and radio-frequency interference) is a constant problem.

A relay coil is insensitive to electrical noise at any power level, being essentially a low-pass resistive-inductive filter. The best way to make an RPC noise-immune is to filter its control input with a low-pass resistive-capacitive filter, which can be made much smaller and lighter than the coil of a relay and still provide the same noise protection.

Additional noise protection can be provided by hysteresis in the control circuit. If the hysteresis is greater than the amount of noise present, false triggering of the control inputs is prevented. In the RPC, the desired amount of hysteresis is provided by appropriate feedback in the control circuits.

There are two schools of thought as to the best voltage and impedance levels for controlling RPCs. The first is the result of an attempt to interface directly with the logic circuits of a control computer. This method requires a control signal of 5 volts at an impedance of 500 ohms. Control power is, thus, 50 milliwatts, which is far above the minimum required by the most sensitive voltage sensors that could be used inside the RPC.

Our belief, however, is that use of 28-volt control signals is better because of the severity of the transients present in an aircraft electrical system. One major airframe manufacturer has gone to the expense of developing logic circuits that can operate directly from a 28-volt source and not be damaged by transients up to 600 volts.

The control circuit of an RPC has several functions (Fig. 2). It must accept control signals, it may be required to accept a reset signal, and it must transmit a status or trip signal.

The first function (control) is analogous to the coil of a relay. The RPC turns on when the control signal is present and turns off when it is removed. If an overload trip occurs, the RPC can be turned on again by removing and reapplying the control signal or by merely applying the optional reset signal. The RPC must be made trip-free so that continuous application of the reset signal will not defeat the trip circuit, which might damage the power switching device or the aircraft wiring.

The output of an RPC may be a trip indication or a status signal. The trip indication is activated only when the RPC has tripped off from an overload. Actuating the reset or removing the control signal removes the trip signal. The status signal indicates whether the RPC is on or off, independent of the control input or power on the bus. It is very useful for fast computer check-out of all the RPCs on an aircraft before any power is applied to them.

There are four possible combinations of hot-wire or grounding signals for both control and indication. Each has certain advantages but, in an ACES system, the hot-wire control and grounding status indication is the best. Hot-wire control can provide enough power to operate the grounding status signal even without bus power applied to the RPC. As mentioned before, it allows computer check-out of the interconnecting wiring for all RPCs on the aircraft before every flight. Also, hot-wire control has the advantage that a control wire fault to ground does not accidentally turn on the RPC; it is the most fail-safe method.

On some electrical systems, it may be desirable to electrically isolate the control inputs from the power switch to prevent ground-loop currents, which can cause noise problems. With a conventional relay, isolation from control to power contacts can be obtained by careful insulation of the control coil. In an RPC, it is more difficult. Optical isolators such as light-emitting diodes and phototransistors can be used, but their characteristics vary greatly over the required temperature range, causing changes in the input control characteristics. The best method of isolation appears to be use of magnetic circuits just as in a relay. An isolator can be built with a minimum of magnetic material by using a high-frequency oscillator at very low power levels. It has fast response and operates directly from the control signal without additional power.

DC Devices

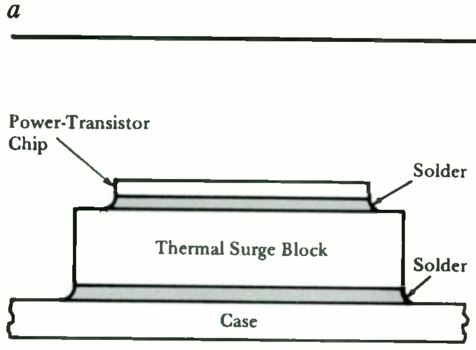
The transistor is the best device for dc RPC power stages. Transistors can have low saturation voltage drops (less than the required 0.5 volt) and relatively high current capabilities. They are also capable of controlled rates of turn-on and turn-off and can limit current for overload and inrush conditions.

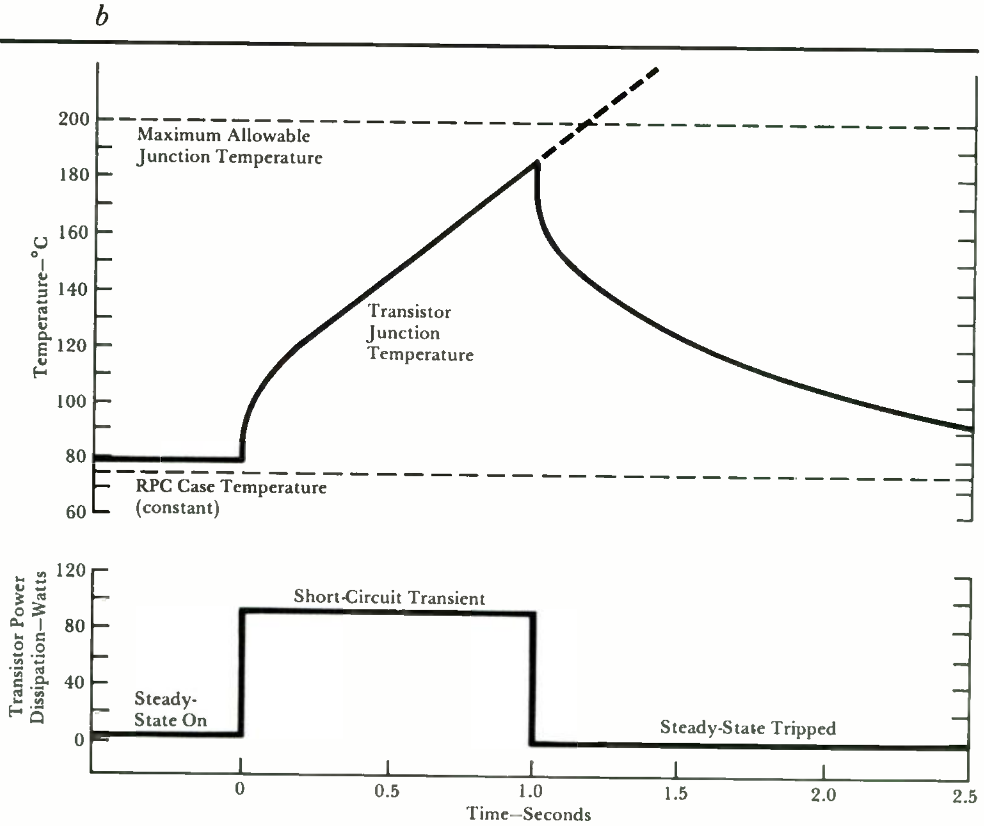
The biggest disadvantage of transistors for the switching element is the requirement for continuous base drive current when the RPC is on. The worst-case gain of power transistors is typically ten. Therefore, the power transistor must be driven with a current equal to at least 10 percent of the load current. One of the most difficult circuit design problems of the power stage is to supply this relatively large current efficiently. The design must be such that the RPC does not drop out of conduction, under full load, for input voltage levels as low as 10 volts while maintaining the highest possible efficiency at the normal input voltage level of 28 volts. Further, the design must be such that overload current (1.5 times rated current for current-limiting devices and 10 times for non-current-limiting devices) can be carried without sacrifice in efficiency at nominal input voltage and load current levels. Overdriving the power transistor above the nominal requirements would solve those problems, but the sacrifice in efficiency would be intolerable.

The circuit configuration that was developed meets all of the necessary requirements and has an efficiency of 98 to 99 percent, including transistor saturation loss. Performance of dc current-limiting RPCs is shown in Fig. 3.

Current limiting is done by a 50-millivolt load current sensor and an operational amplifier driving the power stage in a closed-loop control configuration. To protect the power transistors and to provide the best quality of system power, response time of the current-limiting RPC to an overload must be fast. The desired speed along with the nonlinearities of the power transistors and the inductive, capacitive, and resistive loads that must be handled create a control loop stability problem during current limiting. Simple stabilizing techniques have been found that give the RPC a response time of 10 to 20 microseconds while giving a high-quality dc current during current limiting. Typical ripple levels are less than 2 percent for any degree or type of overload. Hence, the quality of the system power is unaffected during an overload condition.

System transients are absorbed by current-limiting dc RPCs. Although that action greatly improves the power quality to the utilization load, it places a severe stress on the power transistor during an overvoltage transient. Nevertheless, we have developed circuits that can handle the transients in RPCs rated up to 35 amperes, as shown in Fig. 3.





4—Power switch of the dc RPC dissipates more heat during a short circuit than could be carried away safely if it were mounted on the hybrid-circuit substrate; therefore, it is mounted on a thermal surge block attached directly to the case *(a)*. The initial rise of transistor junction temperature *(b)* is abrupt because of the thermal impedance of the transistor chip; its constant rate of rise thereafter is due to the high specific heat of the surge block.

AC Devices

An ac RPC is diagrammed in Fig. 2. It is self-powered through an ac-to-dc convertor. To eliminate radio-frequency interference and increase load capability, zero crossover switching is required. To accomplish it, a control circuit continually senses within ± 4 volts of crossover when the power switch is off and produces a logic signal correspondingly. After the control input is received, the next crossover signal energizes the driver circuit, turning the power switch on. The power switch returns to the nonconducting state at zero current crossover after removal of the control signal or after an internally generated overcurrent trip signal is received.

The basic ac solid-state power switch can be designed with many different techniques, depending only on the specification to be met. For normal aircraft and aerospace applications, the electrical requirements are: rated voltage 115/200 volts ac, single-phase or three-phase; rated current 1 to 35 amperes; frequency 400 Hz; and resistive, inductive, or capacitive load.

Several semiconductor devices could be used for the switching element to meet those requirements, but the thyristor is the best because of its high blocking voltage and its ability to withstand high surge current with no additional drive requirement.

To minimize power dissipation, weight, and size, the thyristors are connected in an inverse parallel configuration. That configuration minimizes the contact voltage drop, the number of power semiconductors, and the power dissipation.

For the inverse parallel configuration, thyristors must be selected to block the full generator voltage when in the "off" mode. A controller operating in a 115/200-volt system requires thyristors with voltage rating of approximately 600 volts to assure that no malfunction will occur during transient overvoltages.

Because natural commutation is used to turn the ac RPC off, each thyristor must be capable of sustaining a full half cycle of fault current. Specifications call for the controller to operate from a low-impedance source that can supply extremely high fault currents, ranging up to 3000 amperes. To sustain a surge current of that magnitude, a thyristor rated for 200 to 300 amperes must be used. Therefore, it is the controller surge rating that determines the size of thyristor to be used, not the steady-state rating.

The trip circuit must perform two functions—protect the wiring to the load controlled by the RPC and protect the power bus from overcurrent transients. Therefore, it is designed to trip within one cycle on fault currents greater than 1000 times rated current; on lesser currents, its trip curve closely approximates the overload capability of the wire that it protects.

Hybrid Devices

Although the performance of RPCs is superior to that of electromechanical relays, their size, weight, and cost are also important factors that must be evaluated before any electromechanical relay can be replaced by an RPC. Those factors rule out the packaged semiconductors and passive elements used for most solid-state equipment today. RPCs must be built with a hybrid or monolithic approach to be competitive in size, weight, and cost.

The hybrid approach employs unpackaged components mounted on a ceramic substrate that has a resistor-conductor pattern to eliminate the need for discrete resistors and interconnecting wiring. The assembly is packaged as a unit. This packaging approach will reduce part handling, decrease cost, and reduce size and weight. We have undertaken a program, in coordination with the Westinghouse Semiconductor Division and the Aerospace and Electronic Systems Division, that will result in a highly automated manufacturing system to accomplish those objectives.

The 2-ampere current-limiting dc RPC fabricated in the first phase of that program is self-powered from the 28-volt bus. For it, the basic packaging approach was to mount the low-power components (both discrete and chip) on a thin-film substrate thermally isolated from the power transistor chip. That substrate is 20- to 24-mil alumina with a layer of resistor material and a layer of conductor material deposited on it. The resistor-conductor pattern is formed by a two-stage photoresist etching process, and resistors are trimmed to tolerance by high-temperature baking. Discrete and hybrid components, including transistors, integrated circuits, diodes, capacitors, and resistors, are attached with solder or gold paste. Interconnections between chip terminals and the substrate pattern are made by thermocompression-bonded gold wires of 0.001-inch diameter.

The power switch of this RPC dissipates approximately 2 watts under normal conditions and up to 90 watts for 1 second during current limiting. For that level of dissipation, normal hybrid chip-mounting techniques cannot be used; instead, the power chip is mounted on a beryllia thermal surge block soldered directly to the case of the RPC (Fig. 4).

Conclusion

Construction of the prototype power controllers has proved the feasibility of hybrid packaging. The success of those devices and the performance of other more advanced breadboard devices (ac and dc) have proved our basic design concepts and will make possible a complete line of RPCs by 1972. Manufacturing costs will be lowered by relatively high-volume production techniques, such as batch fabrication, laser resistor trimming, and use of hybrid-oriented semiconductors, to bring prices into the range competitive with electromechanical relays.

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Coordinating Protective-Device Settings Can Result in Large Dollar Savings

S. Edward Franklin

Power disruption from breakdowns in electrical distribution systems can be minimized by regular studies to determine available short-circuit current and protective-device settings, followed by resetting as required for proper selective operation.

Industry's rapid increase in kilowatt-hours used per man-hour invested in production has put a great economic premium on automatically restoring power flow in an optimum manner after a system fault. Moreover, the same rapid growth in system capacity (with larger sources, transformers, substations, and feeders) is continuously lowering system impedances and increasing the fault current available during a short circuit. One result is the possibility of greater economic loss from more extensive outages.

A distribution system—the complex of buswork, insulation, cables, terminals, switches, circuit breakers, fuses, and other devices—is usually designed for flexible and selective power routing to optimize power flow after a fault. That is, if electrical insulation fails at some point in the system, or if some other misoperation causes a loss of energy flow through a desired routing, enough devices should be in the system to permit opening only the faulted section and thus permit maximum utility of the rest of the distribution system.

Even when the system has devices for such selective power routing, however, the desired automatic isolation of the faulted section occurs only if proper choices and settings have been made for the fuses, circuit breaker trips, relays, and other protective current sensors in the system. Many plants have never had available fault currents calculated and protective-device settings coordinated; they are sitting ducks for costly trouble. Moreover, many systems initially coordinated have grown through urgent necessity, with additional supply transformers, feeders, and devices added, without taking time for coordination. In both situations, the large investment in protective equipment and system design to reduce the extent of shutdown is often wasted.

However, the situation can be corrected. Proper choices, settings, and coordination of devices minimize costly production loss and downtime. They are determined by plant studies, and then the required field settings of relays and breakers are made.

At the same time, relays and breakers can be cleaned, repaired, adjusted, and checked for precise operation.

In addition to minimizing plant downtime costs, additional important benefits are obtained from performing a plant study: the plant's "one-line" power diagram is checked for validity and upgraded if necessary; the plant maintenance and engineering personnel's knowledge of their distribution system and equipment is upgraded, as is their training in emergency troubleshooting; and important needs and priorities in electrical capital equipment are determined.

The Trauma of Downtime

Estimates of the cost of downtime that can (and regularly does) result from loss of power in the United States and other countries are shown in Table I. The figures are drawn from my own plant experience; other engineers may experience higher or lower cost figures.

Downtime costs decrease as the relative degree of selectivity improves; that is, with success in limiting the loss of power to the smallest possible portion of the distribution system (Fig. 1). The costs also depend on the *amount* of downtime, which is directly related to the care used in making device settings that permit prompt reenergizing. An improper device choice or setting can cause a feeder breaker or fuse to open a circuit and shut down a department on just normal inrush or rated currents.

Some assumptions used to arrive at the dollar figures in the table are:

1) Cost of the lost man-hours averages $2.90 per hour.

2) The minimum average of one hour lost per person during shutdown results from general confusion and dramatic interest. The loss is greater if the shutdown is severe enough that employes have to be sent home (and sometimes still paid).

3) There is a definite cost in profit loss from production that is either lost or can only be made up on overtime. This cost is assumed as 10 percent of the net sale price of the product that would have been produced during the lost time. Sale price is assumed to be five times labor and overhead cost.

4) Cost of overhead associated with the lost direct labor is 50 percent of the direct labor cost.

5) Cost of searching out and repairing the fault, including cost of maintenance men and electricians, is $75 per hour per 100 production men, including overhead.

Moreover, there is a definite cost for lost goodwill when production is lost. It is at least one percent of the lost sales dollars, but, for the sake of rounding off, it was not included in the figures.

Distribution-System Devices

Disconnects are studied for coordination only if they are in the main incoming line or a principal feeder and only when motor-operated within the order of 1 to 2 seconds, which is in the common operating time range of relays and other protective devices. In the system of Fig. 1, for example, both lines serve the plant, so disconnects *L1* and *L2* are normally closed and *T* is normally open. If a fault occurs on Line *1*, proper coordination generally would be: breaker *B1* must open before *L1* opens; *T* must close before *B1* closes.

Operation of disconnects in the heat of the battle to restore power to a lost production line, under pressured judgment, can produce disastrous improper

1—The selective limiting of power loss through proper coordination of protective devices in a plant distribution system is illustrated by this simplified diagram. If there is an electrical fault in the first assembly department, for example, Device *1* should open before any of the others, thereby limiting the outage to the one department, which employs only 100 people. Estimated costs of various shutdowns in such a plant (employing up to 5000 people) are listed in Table I.

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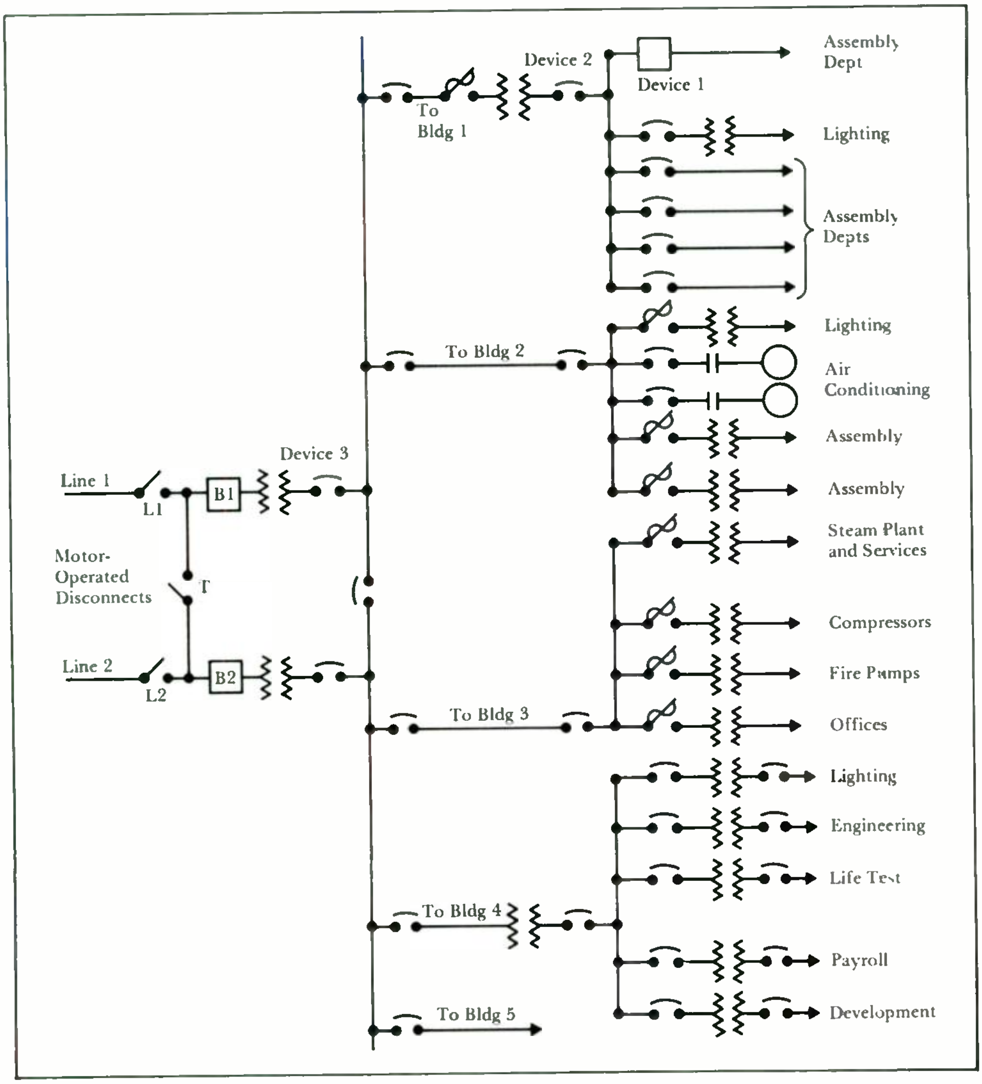
Table I—Estimated Downtime Costs

Relative Degree of Selectivity and Coordination		*Number of Workers Affected*	*Length of Time Down (hours)*	*Estimated Cost of Shutdown*
Good	Only one department down.	100	1	$ 750
		100	4	3,000
		100	8	6,000
	Several departments down.	500	1	3,750
		500	4	15,000
		500	8	30,000
Poor	Whole plant down.	1,000	1	7,500
		1,000	4	30,000
		1,000	8	60,000
	Whole plant down.	5,000	1	37,500
		5,000	4	150,000
		5,000	8	300,000



switching operations such as switching an emergency supply to a short-circuit section. Therefore, any possibility of serious major errors through manual misoperation of disconnects should be removed by use of key-type positive sequential interlocking.

Fuses interrupt the flow of current to a faulted or overloaded section of the distribution system by melting. Plots of their characteristics provide a basic set of curves used in coordinating fuses with other system devices (Fig. 2). Fuses are also rated with time/current plots below which there is no deterioration of the element from partial melting.

Circuit breakers are of several types, but the function of all is to interrupt the flow of current through themselves. One finds old as well as newer types on a system. Their clearing (opening) times vary depending on design, vintage, and size and are important in coordination. The clearing times given here are time intervals after the trip mechanisms have been actuated and are not adjustable once the breaker is manufactured.

Older oil circuit breakers of ratings up through 34.5 kV generally clear their faults in six to ten cycles. Low-voltage molded-case air circuit breakers clear in about two cycles or less. Larger air and oil breakers, 600 V through 69 kV, clear in eight cycles or less. Higher-voltage breakers for transmission systems of 115 kV through 765 kV clear in three cycles or less.

Additional and adjustable time intervals are needed to coordinate one device with another. They are provided by separate electro- or electronic-mechanical breaker timing mechanisms called overcurrent trips or by separate relays (current sensors).

Some old (1930-1940) oil circuit breakers cannot provide coordination adjustment because they do not have overcurrent tripping mechanisms. Other older ones have direct-acting internal current-transformer and trip coils with no time-delay mechanism and, thus, only minimum-trip adjustments. Characteristics of such a breaker are illustrated by the curve for Device *1*, Fig. 3.

Air circuit breakers of the molded-case type (600 volts and below) have relatively low current ratings. They contain integral magnetic instantaneous (one-cycle) trips of solenoid clapper type or a combination of magnetic and slower-operating thermal bimetal trips.

Larger low-voltage (600 volts) air circuit breakers rated for high current (800 amperes to 3200 amperes and higher) may be of direct-acting series coil trip type, in which overcurrent flows directly through heavy integral series current-solenoid coils. The coils sense current magnitudes directly, and armature trip devices inside them actuate the breaker trip latch mechanisms after delay times (in the order of magnitude of 0.02 to 10 seconds) inversely related to the sensed overcurrents (Fig. 2). This inverse timing delay is controlled by dashpot restraint devices fastened mechanically to the tripping latch actuator. The direct-acting inverse-trip-time devices also include overriding instantaneous magnetic trips that function at higher overcurrent. Instantaneous tripping points are illustrated by the vertical portions of the breaker curves in Figs. 2, 3, and 4.

Air breakers having integral solid-state sensors (no heavy solenoid coils) can also be obtained. The sensors work from proportionally lower breaker pole currents taken from integral current-transformer secondaries. They have time-delay adjustments, and their trip curves are similar to those of relays.

An inverse trip function different from those discussed above is illustrated by Curve *A*, Fig. 4, which is a relay overcurrent operating curve. Most high-voltage air and oil circuit breakers use separate remotely mounted relays for coordination as discussed in the next paragraph.

Relays are electromechanical or solid-state current or impedance sensing devices mounted in the power circuit. They close a mechanical or electronic contact after sensing a preset proportional value of current or line impedance (from the secondaries of current and voltage transformers) for a preset time. They are made in a wide variety of types, with different time/current curves such as those in Fig. 3. The relay's output contact (or, in a solid-state relay, the switching function) is used to feed tripping energy from a battery or external ac voltage source to the circuit breaker shunt trip coil to trip the breaker latch mechanism. The relay is so chosen as to coordinate its trip-time characteristics with those of other protective devices in the system.

Some relays are designed to selectively sense overcurrent flowing in one direction and to be insensitive to current in the other direction; they are called reverse current relays. Others are designed to sense impedances of lines or equipment and to actuate when the impedance gets below a value that would permit too heavy a current to flow.

Differential relays sense the difference between current going into and coming out of a piece of heavy equipment such as a transformer or generator. They are set sensitively (for example, at 10 percent of the equipment's rated current) and are not coordinated with other parts of the system. They are connected to trip devices so as to isolate faulted equipment from the system quickly.

Other devices such as motor-operated voltage regulators, automatically switched capacitor banks, tap-changing-under-load transformers, and regulators also may have to be considered.

In some plants with significant paralleled generation and large rotating loads, the selectivity aspect of coordination may have to be tied in with protection to system stability. This protection involves further device tripping time limits, and possibly load shedding, imposed by such system stability criteria as preventing the generators or synchronous motors from pulling out of step with the purchased power system due to transient power swings.[1, 2]

Effects of Additions and Changes

When electrical insulation fails, the magnitude of the resulting fault current depends on the system supply capacity (kVA), system voltage, connected motor types and loads, and impedances of the system conductors, transformers, and reactors. Those fault current determinants are specific quantitative factors used in calculations for device settings. A change in any one or a combination of them can significantly upset proper protective device coordination.

For example, addition of any significant power-supply transformer changes the fault current and hence the time of opening of associated breakers or fuses. Additions or changes of feeder cables, either to improve voltage regulation or just to provide additional current for plant loads, alters the system impedances and directly affects the fault current magnitude to be cleared. It also affects the selective timing of operation of the various protective devices. Moreover, if the power company changes its system capacity to feed the plant, the system impedances and the consequent available fault current and trip timing can change.

Any gross change of system base voltage (e.g. from 66 kV to 115 kV), or a tie between two parts of the system with a voltage transformation, changes the device-coordination parameters. A significant motor addition can contribute more feedback fault current during a fault, requiring a change of device settings.

For these reasons, coordination studies and settings almost always need to be continuously updated to maintain the selectivity that limits the area of a shutdown, and the cost, during a fault.

Coordinating Device Settings

The main steps in determining coordinated settings for selective clearing of faults are:

1) Determining the operating philosophy of the electrical system and plant being served;

2) Determining the presence of protective devices that can provide selectivity;

3) Compiling information about the rated continuous current values of cables, transformers, motors, and other circuit elements, including National Electric Code requirements;

4) Making a new system short-circuit study (or an updated one) to determine the overcurrents and fault currents that are possible; and

5) Designating values and settings for the protective devices.

Operating Philosophy—Usually, the im-

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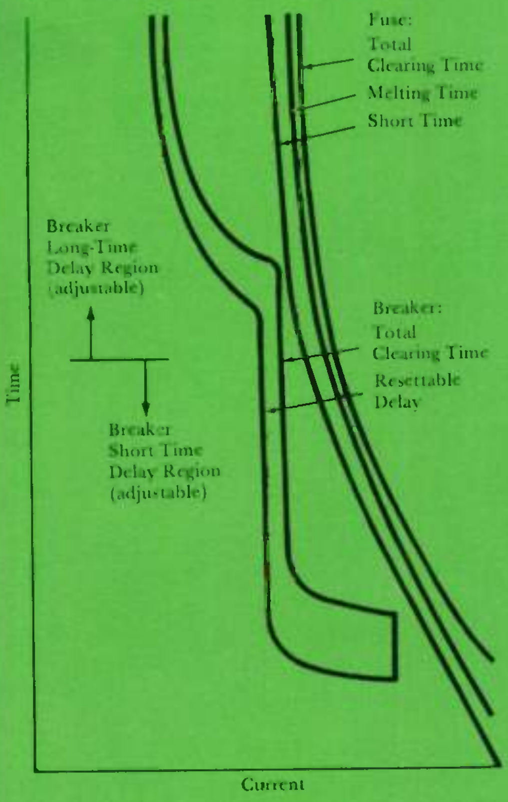

2—Typical performance curves illustrate a fuse coordinated with a low-voltage air circuit breaker for selective operation. Two of the fuse curves show times required to melt and to clear the resulting arc (plotted as functions of current); the short-time curve shows the effect of preloading.

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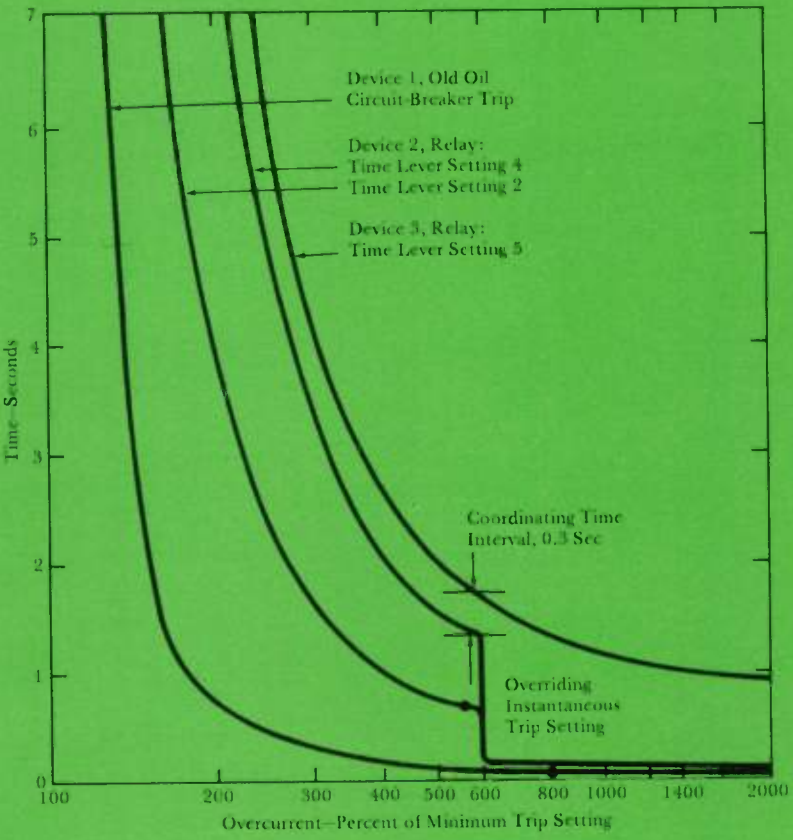

3—These typical curves show the times required for a breaker and two relays to trip and interrupt fault current. Time is plotted against overcurrent as percent of minimum trip setting. ("Minimum trip setting" is also known as "sensitive trip setting" or, for relays, "minimum pickup value.") The curves are for properly coordinated devices, as indicated by the coordinating time interval of 0.3 second between Devices 2 and 3.

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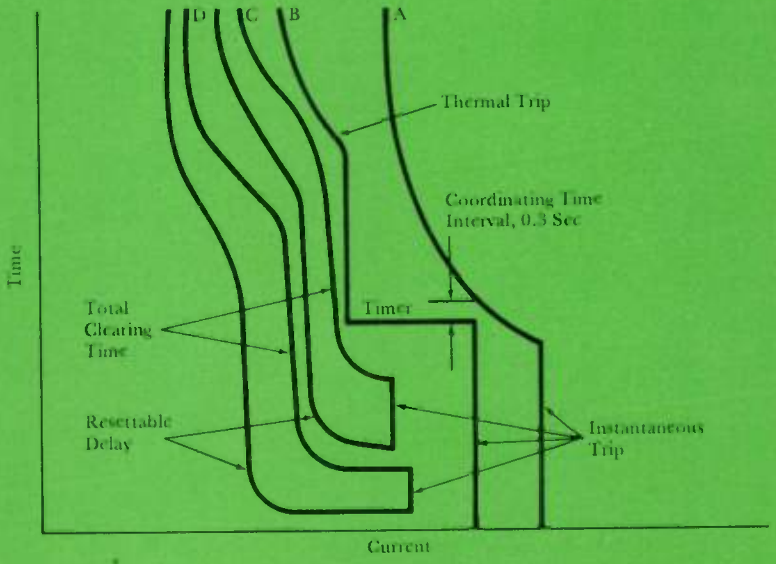

4—Coordinated tripping curves for four different devices. *A* is a conventional overcurrent relay, *B* is a special relay with an auxiliary timer to permit starting a large motor without tripping the branch breaker feeding the motor, and *C* and *D* are typical low-voltage air circuit breakers with integral series trip devices. Device *B* is specially designed to coordinate between Devices *A* and *C*.

mediate goal is to clear faults as quickly as possible to minimize arc damage to the equipment directly involved. At the same time, the parts of the distribution system not directly involved must be "held in" until the farther-out devices have cleared the circuit in trouble. That combination is selectivity. But in some plants, continuity of certain critical processes is more important than prevention of distribution equipment damage.

The cost of downtime must be evaluated against special situations. Consider, for example, the acute losses resulting when power loss cuts off the oxygen supply to large batches of antibiotic cultures, or causes melts of steel to harden in process, or causes an explosion from untimely shutdown of a chemical process. Such loads deserve high continuous service priority in the selectivity setting process. Further, the costs of downtime and product loss must be balanced against the costs of reduction in life of cable insulation through stressing the electrical system for more milliseconds in the hope that the fault may clear itself before opening the backup device and losing more of the system.

Are the Devices There?—Obviously, one can only coordinate settings for fault-clearance devices that are in the distribution system. Most systems have oil circuit breakers and air circuit breakers with relays controlling their opening times and current trip values. However, even if there are only transformer primary and secondary fuses and small low-voltage air circuit breakers, thought and sometimes simple calculations can give selectivity and less downtime in the event of a fault.

Rated Current Values—Devices must be set to pass the maximum rated continuous load currents and still thermally protect the transformers, cables, motors, and other equipment involved. National Electric Code requirements should be met with respect to protection.[3]

Data that must be gathered in the field include motor inrush and acceleration time figures and other cable and load-distribution data. An up-to-date one-line diagram should be prepared; it is invaluable for quickly locating proper switching for emergency corrections. Often that diagram is as valuable a fall-out of the study as are the proper settings.

Feeder or machine full-load ratings, short-term inrush or overload currents to transformers and machines, duty cycle limits for restarting, and time for acceleration to rated speeds must be determined to permit minimum settings that do not interfere with the desired current values.

Motors or transformers should not cause the feeder circuit to trip just because they are repeatedly started within their permissible duty cycles or ratings. This requires consideration of inrush currents, in motors as high as five to eight times their rating and sometimes lasting more than 10 seconds. In transformers, short-time energizing excitation currents are sometimes as high as ten times the rating.

Short-Circuit Study—When the rated values have been arrived at, each protective device's ability to handle overcurrents and the fault current going through it at the time of its opening must be considered. The fault current to be considered in each circuit-opening case must then be calculated for assumed short circuits of all three phases, and in some cases phase-to-phase and phase-to-ground (when the distribution system permits ground currents). These fault calculations must be considered for assumed fault locations close to the main supply, at intermediate points out toward the utilization transformer, and on the load side of the utilization transformer.

From the moment it begins, a fault current flowing through cables, equipment, and protective devices is "watched" by the appropriate current sensing devices, which integrate the rms fault current with respect to time. According to their predesigned time/current transfer functions and their preset adjustments (coordination settings), they decide *selectively* when to energize their circuit-breaker opening mechanisms or when to melt and clear their fault currents.

Fault current can be considered as the sum of three transient and one steady-state components of current. The decaying magnetic fluxes in the source generators and rotating machines in the plant determine the exponential decay rates of the current values of the substransient and transient components. The syste reactance and resistance compc determine the dc transient and synchronous current quantities.[4]

The determinants and factors needed in calculating fault currents are: power supply capacity (or source impedances) from the power company and any plant-generated capacity, bus impedances, transformer or reactor impedances, cable impedances, system voltages, grounding schemes, and types and sizes of motor on the system that can contribute "fe back" power to the fault during the early milliseconds. A large part of a coordination study is the obtaining of data and the calculating of these impedances.

When the fault currents have been calculated, the interrupting capacities of the devices that are going to clear the faults may also be checked (if not recently done) to see if the devices would suffer damage or would remain functional after a fault. (Interrupting capacity is maximum rms amperes or kVA that a circuit breaker or fuse can safely interrupt.)

Device-Setting Coordination Study and Recommendations—The next step is to obtain the various time/current plots of tripping or arc-clearing characteristics for the protective devices being considered. Then the coordinated device settings can be determined.

Device Coordinating Criteria

Rated Current Flow—All devices should pass rated full-load currents and rated inrush or accelerating currents within the equipment ratings. Rated current values are given by manufacturers and are further codified in the National Electric Code.

Minimum Settings—Devices should be triggered to open on minimum settings at predetermined values. "Minimum settings" are the chosen minimum breaker trip, relay pickup, or fuse melt requirements. They should conform with the National Electric Code requirements and also should satisfy any other equipment protective requirements such as those of especially important loads.

To set a protective device to open on current values above a desired minimum overcurrent, while still permitting rated rrent to pass in a cable, a minimum g should be made at 110 percent of the cable rating (ampacity), or as otherwise stated by the National Electric Code and/or specific customer requirements. For a cable feeding a large motor requiring multiple starts within the motor rating, this circuit protective device setting may have to be considerably higher than 110 percent of the feeder supplying the motor, causing a significant problem coordinating with the next backup up of devices and requiring a larger cable. Often the larger motor circuit devices must be specially designed or modified for coordination.

Minimum settings of a fuse are determined simply in the choice of the link size. The curve for clearing time becomes asymptotic to the current value at which the fuse would pass current indefinitely without melting (Fig. 2). For a fuse on the primary side of a transformer, it is common to pick a link value between 140 and 150 percent of the transformer current rating, though individual cases vary. The fuse must never blow for normal expected inrush currents to the transformer.

Selective Tripping—Selectivity between two or more devices should be achieved at minimum setting and at all higher overcurrent values. Generally, those devices nearest the fault should trip first. Selectivity is achieved when only the device or devices necessary to isolate the faulted section operate and all other devices remain closed to supply power to the rest of the system. If this does not happen in the set time, the next device in the series nearer the power source should trip and clear the fault, thus providing backup protection.

For such positive selective tripping between two devices, there must be a coordinating minimum time interval between their respective time/current tripping curves (Fig. 3). This interval (commonly 0.3 to 0.5 second) makes available the minimum time needed for the first device to clear before the backup device is unnecessarily tripped, and it is long enough to negate an accumulation of minor errors in the relay and device

Conducting a Relay-Coordinating Study*

A study starts with an assumed fault placed on the load side of the farthest-out device (Location *A* and Device *1* in the diagram, which is part of Fig. 1). The minimum trip setting of Device *1* is determined by using 110 percent of the rated ampacity of the cable feeder. Dividing the calculated fault current by that minimum trip setting gives the percent of minimum-trip-setting current passing through the device during the fault (for example, 800 percent). Next, the actual fault-sensing time corresponding to the 800 percent is noted on the curve as 0.1 second (Device *1*, Fig. 3).

An end device would normally be set to clear in the shortest possible time for the calculated fault being considered, and 0.1 second is considered a short time. However, we must add to this fault-sensing time the inherent breaker fault-clearing time of 0.133 second (eight cycles), giving a total clearing time of 0.233 second.

To choose the selective-trip coordinating setting for the next breaker or other device farther in toward the source (Device *2*), the same fault current (minus feedback from the assembly departments) is assumed. The minimum pickup current setting for Device *2*, a relay, should already have been set to protect the bus that it feeds on the basis of National Electric Code recommendations. With that setting undisturbed, the characteristic relay curves are checked to see what adjustable time-lever (delay) setting is to be used. A selective-trip (additional) time interval between Device *1* and Device *2* of about 0.3 to 0.5 second is desired. Since this device is a relay with time-delay adjustment available, its time lever is set at Position *2* to give 0.65 second trip time for the fault current occasioned by the fault at Location *A*. It is assumed that this fault has produced 560% of the relay's minimum setting. (See Fig. 3, Device *2*.)

This set time interval between the tripping of Devices *1* and *2* is what allows Device *1* (only one department) to trip out selectively, leaving Device *2* closed.

The next significant device farther in toward the source (Device *3*), with its settings undisturbed, is then evaluated to see what it would do on the same fault current conditions. The time-delay device is set to allow another 0.3-second minimum margin of clearing time between Devices *3* and *2*. Since Device *3* is feeding more branch loads than the first devices considered, its minimum pickup current setting would be higher than that for Device *1* or *2*. Therefore, for the same fault current at Location *A*, it would not see as high a *percentage* overcurrent above its minimum setting, and it would selectively coordinate by taking more time to trip out, thus letting Device *2* clear first and not shutting down all or half the plant.

Perhaps, however, as a special problem, the third device considered would be Device *2A* or *2B*, with its minimum trip setting for rated bus current the same as Device *2*. The device sees the same percentage overcurrent as does Device *2*, and it would trip out in the same time as Device *2* unless its time-lever interval or dashpot time delay is adjusted for a longer time. The necessary adjustment is made.

The next step (still considering phase-to-phase or three-phase faults) is to assume a fault at Location *B* with the trial settings just made. This different fault location provides a larger short-circuit current for Devices *2* and *3* and only motor-feedback fault current through Device *1*. The minimum pickup current settings for Devices *2* and *3* are considered as being undisturbed, and their curves are inspected to see if the higher fault-current value will permit the devices to trip selectively without changing time-lever or dashpot settings. If the trip curves for Devices *2* and *3* drawn on the same percentage overcurrent base maintain the minimum 0.3-second interval over their whole range, the devices will coordinate for any fault current value. (Device *1* for this assumed fault does not have to coordinate with Devices *2* and *3*.)

If, however, the coordinated differential clearing time interval between Devices *2* and *3* is not achieved within their adjustable limits, the problem is corrected by replacing one of the devices.

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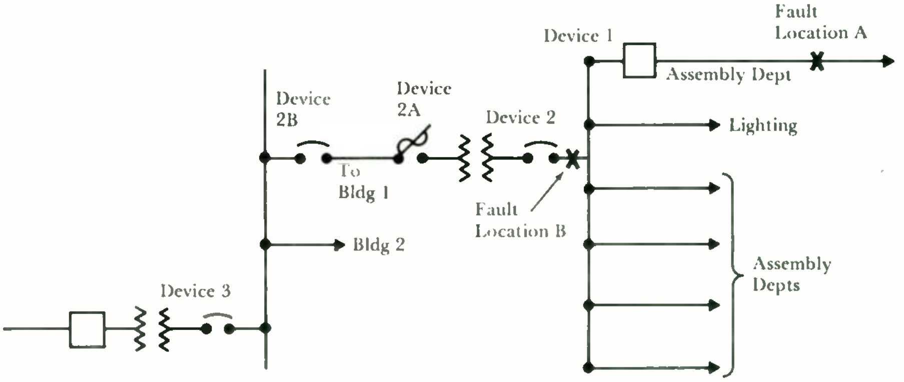
*This is a simplified description of a coordination study, so it assumes the use of hand calculations. When the digital computer is used, the logic differs somewhat but the same results are achieved.



opening times. If the backup device trips first, selectivity is lost. These minimum clearing time intervals between the two devices must exist over the full range of time/current curves for both; that is, when the equivalent current values of the two devices are superimposed, the curves should not cross but should maintain a minimum time interval between them for all current values.

For selectivity between two similar devices in series, the minimum pickup or melt current (proportional to the current-transformer primary trip current, in the case of the relay, or the fuse link rating) of the two devices may be set at different values. Or the time-lever (relay delay) adjustments may be set differently, a long-delay fuse link used, or both.

Many molded-case low-voltage air circuit breakers are nonadjustable thermal types set to trip in about 1½ hours at 125 percent of the thermal trip rating, and with magnetic trips adjustable over wide ranges. The larger open types are available with minimum current settings that can be set for up to 200 percent of rated breaker frame current.[5] Still larger and higher-voltage feeder air circuit breakers and oil circuit breakers normally have current transformers to step the primary current down to smaller current values. These reduced currents are fed into protective relays or into their own inherent low-current trip units. The relays are normally set for minimum pickup value as discussed above.

Ground Current—Selectivity in ground current fault protection should be attained, when the system permits ground current flow. Distribution systems are commonly grounded by "solid," "resistance," or "reactance" ground connections. Grounding lowers the voltage stresses across the insulation of the system, particularly during faults. When grounding is used, relaying is commonly installed for rapid clearing of ground faults. Ground currents, of course, flow during such faults, and they are also calculated in a fault current study. The minimum setting, however, is only 10 to 20 percent or less of the rated current for the feeder, because significant unbalanced neutral currents do not normally flow without ground faults, assuming a grounded system.

General—The suggested coordination criteria and values in this section satisfy the general requirements. Once set for steady-state system conditions, coordination of the fault-current clearing system must be further checked on the possibility that the settings may have to be compromised or even device changes recommended. (See *Conducting a Relay-Coordination Study*, page 145.)

When the Electric Service Division supplies the service, it provides a final analysis and report with recommendations (particularly problem areas). The desired coordinated settings are then made. This is also a good occasion to check each relay for reliability and clean or repair it if necessary, greatly decreasing the probability of costly shutdowns.

Computers Can Help

The calculating procedures involved in short-circuit and device coordination studies can be time consuming on larger systems. Even medium size or smaller systems often need many alternate short-circuit calculations, not just one for a given bus. Some critical buses may have multiple "feeder-out" contingencies; hand calculation of those contingencies is very laborious, so often a thorough job has not been done.

Consequently, digital computer programming has been developed and refined. For large systems and even many smaller ones, it is more economical and accurate than the laborious manual methods or even use of an analytic network calculating board. In most system studies, the Electric Service Division uses the digital computer and relay programs of the Westinghouse Advanced Systems Technology Group.

Only the individual system impedance and distribution system circuitry and load peculiarities need to be processed and fed into the computer for each study: impedance data are programmed for orderly internal computing; coordinating techniques, rules, and conditions for both ground faults and phase faults may be programmed in advance; and time/current curves for standard relays and circuit-breaker trips are already programmed into the computer. Also, much more useful short-circuit data and relay coordination calculations are likely to be performed on a computer than by hand calculations, since the computer does this rapidly and cheerfully. Of course, small short-circuit and relay-coordination studies may be calculated manually.

Another advantage of computer calculation is that it is much easier to recheck later modification to the system and to update the coordination and settings because the original data are already recorded on individual data cards and available for the computer.

Moreover, programs are available from the Advanced Systems Technology Group for services other than the short-circuit and relay coordination studies. They provide results, often from the same input data, on various types of problems; they are applicable to electric utilities and to industrial and commercial building power systems. The programs include load forecasting and load analysis, installed reserve evaluation, production costing, unit selection, economic dispatch, stability studies, switching surge studies, switching surge and lightning surge line design, transmission economic analysis, loss formula and load flow calculation, network equivalents and secondary network analysis, distribution system planning, and reliability analysis of distribution and transmission systems.

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[2] C. J. Baldwin and R. T. Byerly, "Improved Digital Simulation for Analyzing Power System Disturbances," *Westinghouse ENGINEER*, July 1969, pp. 109-16.

[3] *National Electric Code*, National Fire Protective Association, Boston, Mass.

[4] *Electrical Transmission and Distribution Reference Book*, Westinghouse Electric Corporation, East Pittsburgh, Pa.

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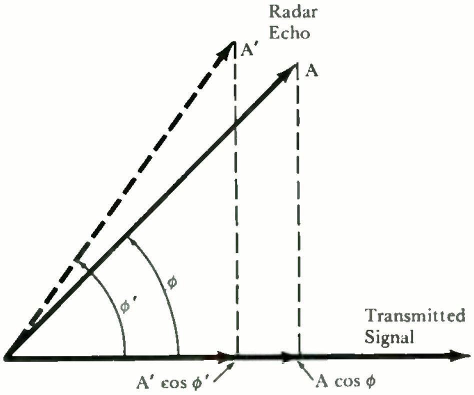
Digital Techniques Advance Tactical Radar

R. A. Linder
J. W. Taylor, Jr.

Digital signal processing techniques have greatly improved the performance of tactical radars by providing practical implementations of system concepts that were impractical in analog form. For example, the digital implementation of a moving target indicator (DMTI) allows complete flexibility in the choice of variable interpulse spacing, multiple pulse comparison, pulse weighting, and processing bandwidth—a flexibility that was not feasible in analog form. In addition to improved system performance, the digital implementation has eliminated the reliability and maintenance problems that were common to the analog versions, thereby producing outstanding on-line equipment availability. At the same time, the system volume, weight, and cost are reduced. Because of these advantages, digital techniques have also been used to implement pulse compression, limiting, video integration, and most other signal processing techniques utilized in modern tactical radar.



1—The in-phase component of the radar echo ($A \cos \phi$) is measured by the receiver synchronous detector. If the target moves between successive transmissions, the magnitude of the in-phase component of the echo ($A' \cos \phi'$) changes accordingly.

Most tactical radars operate in an environment where undesired echoes from clutter (ground, sea, weather, chaff) and undesired signals from other radiating sources often exceed target echoes and, if not eliminated, would completely obliterate the radar display. Therefore, this interference must be eliminated with such techniques as moving target indicators and pulse coding to permit targets of interest to be extracted from background interference.

In the past, most tactical radar systems have implemented these signal processing techniques with analog circuitry. However, analog radars have always had several fundamental limitations, the major ones being hardware complexity, instabilities, and difficulty of maintenance. Fortunately, technological advances in the area of low-cost integrated digital circuitry have made practical the use of digital techniques to implement the various signal processing functions required. In fact, digital signal processing is not only practical, it is essential to meet today's tactical requirements of light weight, small volume, high mobility, high availability, and optimum system performance at reasonable cost.

Throughout the discussion that follows, radars of low pulse-repetition frequency will be assumed; they have sufficient time interval between similar transmissions to prevent ambiguity as to which transmission created the echo. Because of the disparity between the radar cross-section of targets of interest and that of ground clutter, periods of several milliseconds between transmissions in the same direction are required to avoid problems with echoes from ground clutter at longer range than the targets of interest.

Moving Target Detection

The use of moving target indicators (MTI) to discriminate between radar echoes from moving targets and those from fixed or very slowly moving clutter is not new. In the conventional analog MTI system, a synchronous detector measures the in-phase component of the echo. The voltage output of the synchronous detector at any instant of time is represented by $A \cos \phi$ (Fig. 1), where A is amplitude of the echo and ϕ is its phase relative to the signal transmitted. The detector output is applied to an ultrasonic delay line, where it is delayed one interpulse period, and subtracted from the undelayed output of the detector during the next interpulse period (Fig. 2a).

Because of the radar beamwidth, echoes are received from a number of successive transmissions while the target is within the beamwidth. Under ideal conditions, fixed-target clutter echoes have little phase difference between successive radar returns and therefore cancel in the subtraction process. On the other hand, a target with some radial velocity with respect to the radar causes a phase shift between successive returns; thus, the echoes of moving targets do not cancel and therefore yield an output for the radar display.

Although analog MTI systems have been used for a number of years, their success has been limited. Matching gain and bandpass characteristics (gain and phase versus frequency) of the delayed and undelayed analog channels, and controlling absolute delay time, places severe limitations on the maximum cancellation ratios obtainable (approximately 30 dB) in an operational environment. Automatic gain-control circuitry and oven-controlled temperature for the delay line are necessary, at the very least, if any reasonable performance is to be realized.

The on-line availability of analog systems has been generally poor. Their suppression of clutter echoes is good when tuned up but deteriorates rapidly with time. Further, most analog MTIs suppress not only clutter echoes but also echoes from desired targets at specific velocities, known as "blind" velocities. Thus, their effective contribution to radar system performance has at best been limited.

The digital MTI approach (DMTI) eliminates those inherent disadvantages of the analog version. DMTI has both the flexibility and the stability required

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to greatly improve performance in operational radar systems.

Digital MTI

In a simple two-pulse digital canceller (Fig. 2b), the radar receiver's synchronous detector output is sampled by an analog-to-digital (A/D) converter at least once per pulse width. Ideally, sampling should be done twice per radar pulse width to insure that a sample occurs when the echo pulse is very close to maximum amplitude. This sampling provides a series of digital words at discrete range intervals (Fig. 3), each of which represents the phase and amplitude of the received information at that particular range.

The most important system timing relationship in a DMTI system is that between the transmitter pulse and the sample control of the A/D converter. Once the echo information has been digitized, timing stability is no longer important because all further processing is handled in binary arithmetic form.

The A/D converter output for each range interval is sent to a digital store. After one interpulse period, the stored digital words are read out in time sequence and, for a two-pulse canceller, are digitally subtracted from the current A/D converter output for the corresponding range interval. Thus, the digital store has introduced a delayed digital word for each range increment analogous to the delay line of the analog canceller. The DMTI output can either be used in digital form for further data processing or converted back to analog form by a digital-to-analog (D/A) converter for a PPI (plan position indicator) display.

From a hardware standpoint, the A/D converter is the most critical circuit in the DMTI for a tactical application. A Westinghouse-developed mil-spec A/D converter is shown in Fig. 4. It converts a 12-bit word at a 0.5-MHz word rate.

The other hardware item of interest is the digital memory. The type of memory used varies from one system to another, depending upon the individual system requirements. Such devices as integrated shift registers, magnetic core, integrated scratch pad, and other memory devices must be considered as possible candidates. Most of the systems today, however, use MOS (metal oxide semiconductor) shift registers as the memory element. These provide the most cost-effective solution for the implementation of functions such as DMTI, which do not require a random access capability.

The MOS memory shown in Fig. 5 is expandable from 3408 to 27,264 bits of storage, depending upon the amount needed for a particular application.* Plug-in submodules provide the expansion feature, which indicates the flexibility of a digital approach. Each TO-5 can of memory contains 426 bits, which operate up to a 4-MHz rate. The memory operating rate is locked to the A/D sample rate and can be varied widely in a digital system.

DMTI Improvement Factor—The degree of suppression of echoes from slowly moving objects (reduction of their signal-to-noise ratio) is termed the *MTI Improvement Factor*. In a digital canceller it depends on the number of bits of resolution in the A/D conversion. The system noise level is typically adjusted to 50 to 100 percent† of the amplitude corresponding to the least significant bit (LSB). Each additional bit added to the system extends the dynamic range and the potential MTI Improvement Factor by 6 dB, since each bit doubles the echo voltage that can be accommodated. For example, the maximum signal-to-noise ratio that a 12-bit A/D converter can accept (±2047 LSB) is 66 dB (rms noise = LSB).

The least significant bit residue is noise-like in character, and subsequent video integration yields the same improvement in target detectability as would be obtained in the presence of thermal noise. In practice, the number of bits is chosen to provide somewhat more MTI

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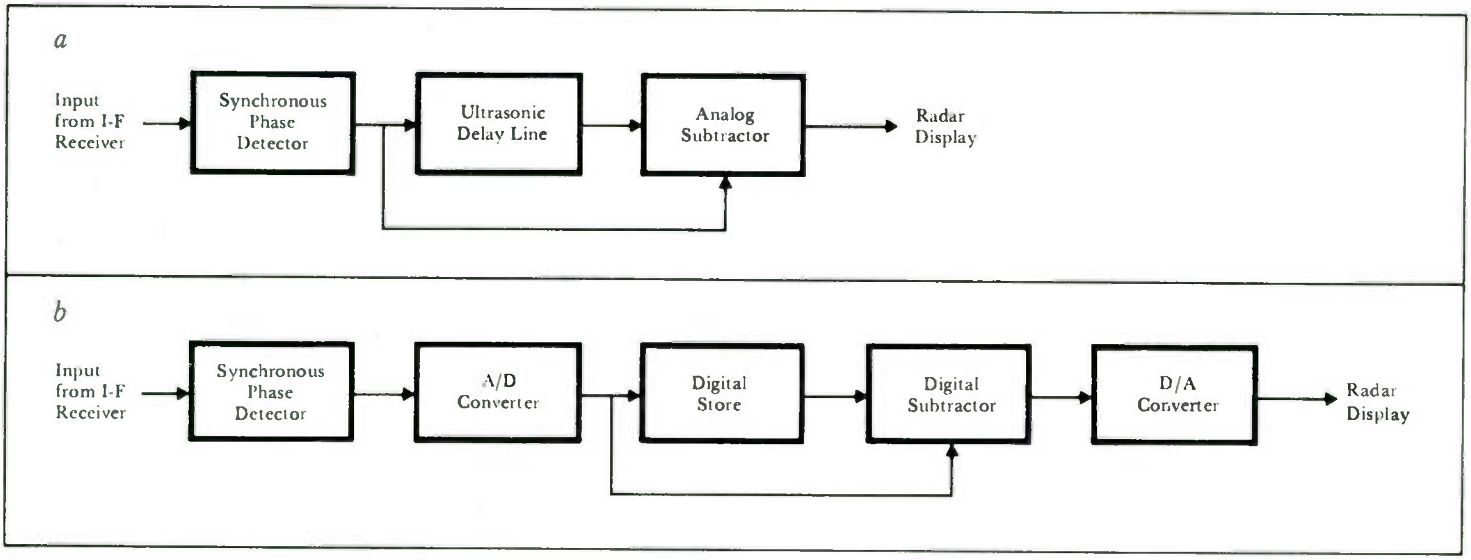

Improvement Factor that the limitations that result from other radar system parameters. Typically, in systems of today, the number of bits varies from 7 to 12.

DMTI Velocity Response

From a performance standpoint, the fundamental characteristics of the MTI velocity response concern the rejection notch around zero velocity and the velocity passband regions for moving targets.

The received clutter spectrum from fixed targets has some finite width due to environmental conditions, such as the fluttering of foliage in the wind, and to the rotary scanning movement of the radar antenna, as shown in Fig. 6a. The ideal canceller rejection notch is the inverse of this clutter-plus-noise spectrum, with sensitivity building up to maximum outside the clutter spectrum range and holding throughout all higher target velocities of interest (Fig. 6b). Unfortunately, the velocity response of a simple two-pulse canceller is not nearly as steep as desired, as shown in Fig. 6c. Moreover, if the interpulse period is constant, the system is "blind"[‡] at zero velocity and at multiples of target radial velocities that cause an echo phase shift of 360 degrees between successive radar transmissions.

The velocity response of a simple two-pulse canceller generally provides inadequate slope (6 dB/octave) in the rejection notch at low velocity. Since a digital system can hold information for any length of time, it is easy to pass the output of the canceller through a second canceller to provide a steeper (12 dB/octave) clutter rejection notch (Fig. 6c, three-pulse curve).

In digital circuitry, the double canceller is implemented as an equivalent three-pulse comparison canceller. Rather than perform two separate difference calculations, the second of which would use a result of the first, stored values and the incoming value are used in a single computation:

$$[(A-B)-(B-C)] = A-2B+C.$$

Thus, the subtractor becomes a processor performing the computation $A-2B+C$, where A, B, and C are successive digital samples from the same range intervals. This procedure minimizes computation time and only unprocessed information need be stored.

In a similar manner, four-pulse cancellation is implemented by storing three previous radar periods (B, C, D) and performing the computation $A-3B+3C-D$ to provide an 18 dB/octave clutter rejection notch. However, the use of higher order cancellers requires some sacrifice in impulse response, which makes the system more vulnerable to pulse interference from other radars or jammers. Each particular system requirement, therefore, must be closely examined to determine the optimum canceller configuration with regard to both velocity and impulse response.

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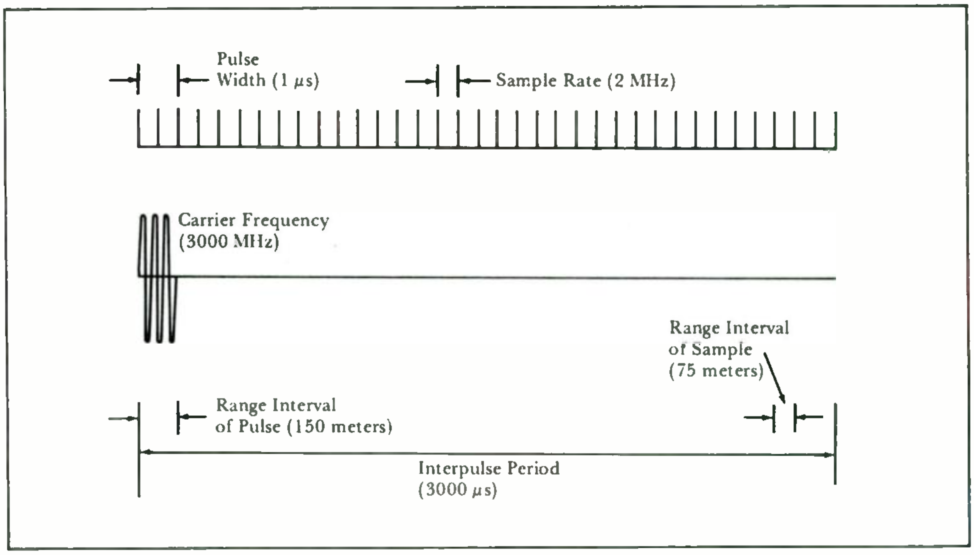

2—In its simplest form, a moving target indicator (MTI) consists of circuitry for detecting the in-phase component of the radar echo, delaying it one interpulse period, and subtracting it from the next echo. Block diagrams are shown for the analog (*a*) and digital (*b*) versions of a two-pulse MTI.

3—Typical timing relationships are shown for a simple two-pulse digital canceller for a tactical search radar.

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[*] The total number of bits of digital storage (B_t) required for multiple-pulse cancellers is determined in the following manner:

$$B_t = \frac{12.3 \times R \times B_w \times (N\text{-}1)}{S_r}$$

where R is instrumented range in nautical miles, S_r is sample rate in microseconds, B_w is bits per word, and N is number of pulses in canceller.

For example, if the following system is assumed:

$R = 80$ nautical miles,
$S_r = 2\,\mu s$,
$B_w = 12$ bits, and
$N = 4$ pulses,

then the total number of bits of digital storage required is:

$$B_t = 17{,}712.$$

[†] Although in the conversion of the echo sample into a digital number, a maximum error of one-half amplitude increment can occur, the rms error is 5 dB lower (LSB/ $\sqrt{12}$). As the level of rms system noise is raised above half the least significant bit (LSB/2), the effect of this error on detectability rapidly falls from 1.3 dB to a negligible amount.

[‡] "Blind" velocities are found by the relationship:

$$V_B = \frac{n\,\lambda}{1.03\,T}$$

where V_B is blind velocity in knots, λ is wavelength in millimeters, T is interpulse period in milliseconds, and n is any positive integer (1, 2, 3...).

For example, if:

$\lambda = 300$ mm (frequency = 1 GHz), and
$T = 1$ ms (PRF = 1 KHz),

then $V_B = 291$ ($n = 1$), 582 ($n = 2$), 873 ($n = 3$)...knots.

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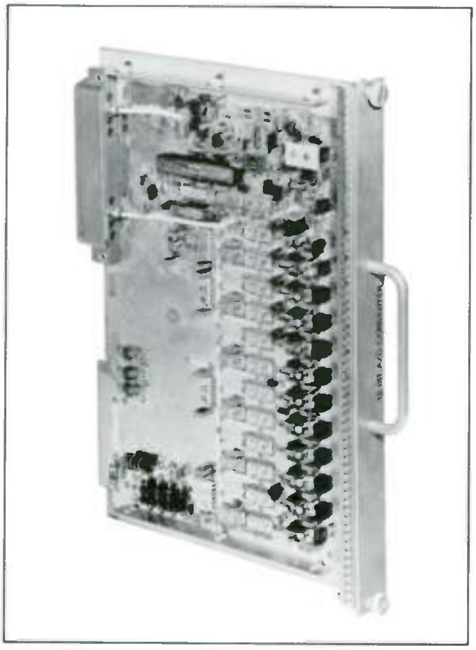

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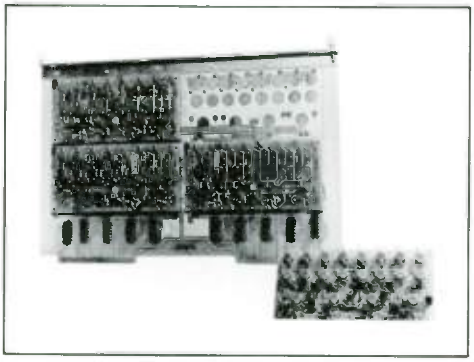

4—This analog-to-digital converter provides a 12-bit word at 0.5-MHz word rate.

5—Digital metal oxide semiconductor (MOS) memory is expandable from 3408 to 27,264 bits.

6—(*Right*) Moving target indicator velocity responses are shown: (*a*) typical clutter spectrum created by antenna rotation; (*b*) ideal MTI signal-to-noise enhancement; (*c*) typical MTI velocity responses with fixed PRF.

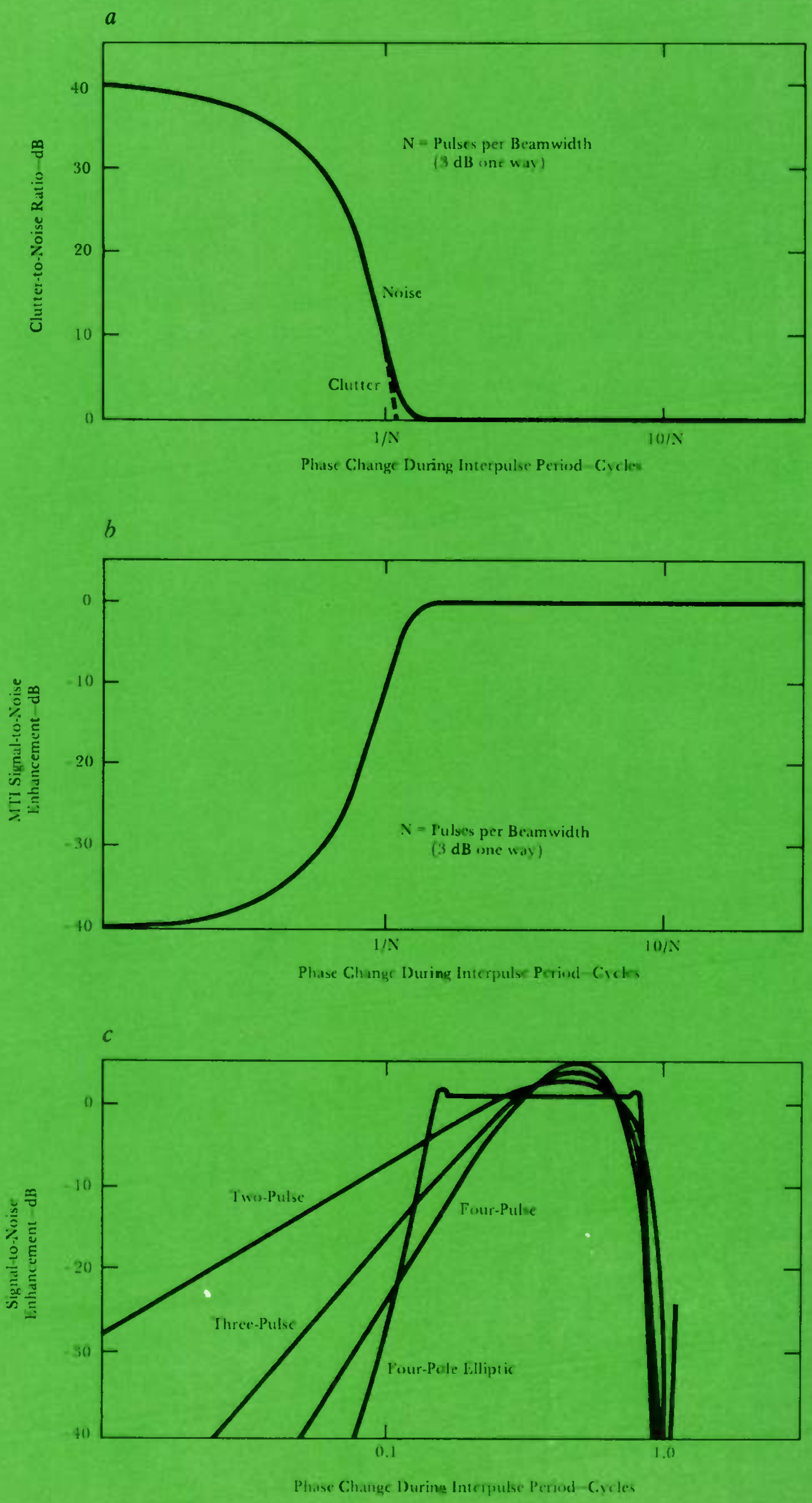

Table I—Variable Interpulse Period Program with Fixed Weighting Coefficients (see Fig. 7)

16-Pulse Echo Sequence	Interpulse Period (percent of avg.) 1-2, 2-3, ...etc.	Weighting Coefficients for Each Computation #1	#2	. . .	. . .	#16
1	78.70	−1.000				
2	79.37	3.000	−1.000			
3	82.81	−3.000	3.000			
4	88.73	1.000	−3.000			
5	97.33		1.000			
6	107.43					
7	114.78				Same for All	
8	119.46					
9	121.47					
10	120.80					
11	117.46					
12	111.44					
13	102.75					
14	92.74					
15	85.39					
16	80.71					−1.000
(17)	78.70					3.000
(18)	79.37					−3.000
(19)	82.81					1.000

Table II—Variable Interpulse Period Program with Variable Weighting Coefficients (see Fig. 7)

8-Pulse Echo Sequence	Interpulse Period (percent of avg.) 1-2, 2-3, ...etc.	Weighting Coefficients for Each Computation #1	. . .	#6	#7	#8
1	137.61	−0.8750	Same for #1-#6			
2	124.70	2.8125				
3	112.98	−3.0625				
4	102.42	1.1250				
5	92.80					
6	84.12			−0.8750		
7	75.22			2.8125	−1.1250	
8	69.08			−3.0625	3.3125	−1.7500
(9)	137.61			1.1250	−2.6875	3.2500
(10)	124.70				0.5000	−2.2500
(11)	112.98					0.7500

Feedback may also be employed in digital cancellers, much more predictably than in analog, to vary the shape of the velocity response. The feedback flattens the peaks of the velocity response (Fig. 6c, four-pole elliptic filter) and provides control of the width of the clutter notch, although it has little effect on its steepness. Again, as in the higher order cancellers, feedback imposes a sacrifice in impulse response and therefore its use is somewhat limited. Feedback is a complex subject which is beyond the scope of this article.

Elimination of Blind Velocities—Blind velocities can be eliminated by varying the interpulse period. For an analog canceller, either a separate delay line or a trimmer delay line is required for each specific interpulse period. Both hardware cost and the difficulty of adjustment have prevented the use of more than two or three interpulse periods in analog MTIs, so efforts to eliminate blind velocities were severely restricted; many regions of severe insensitivity, if not complete blindness, remained.

Since digital storage imposes no restriction on interpulse period, several interpulse periods can be used and thus a vast improvement in smoothing the velocity response is possible. Unfortunately, there is also a penalty associated with variable interpulse periods (VIP). In a simple two-pulse canceller, a change in interpulse period has no degrading effect because each pulse-to-pulse comparison is an independent computation. However, for a three-pulse canceller, a change in interpulse period degrades the slope of the clutter notch response. Notch degradation continues to become more severe as the number of pulses in the canceller increases.

Clutter notch degradation can be avoided by making only very gradual changes in interpulse period, but this is generally impractical because of the limited time in which the VIP sequence must be completed. To ensure the detec-

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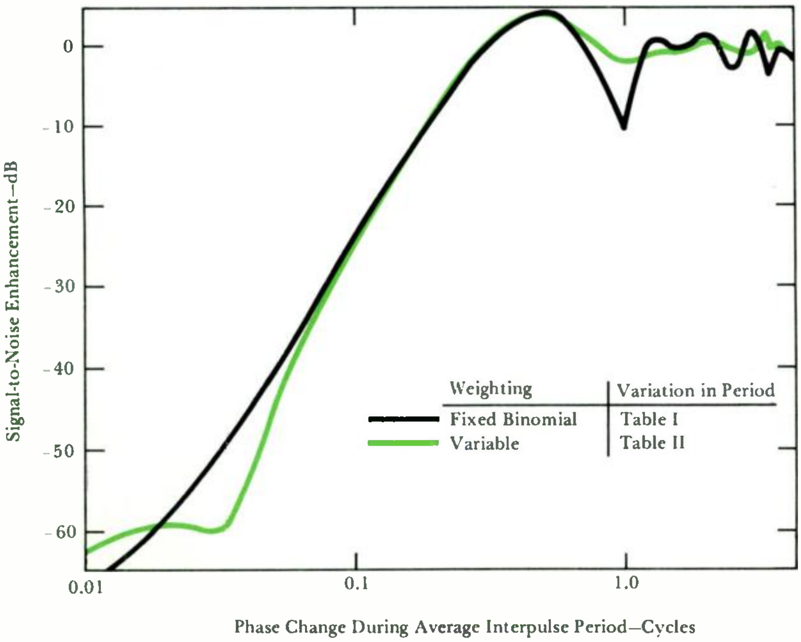

7—DMTI velocity response for a four-pulse canceller with variable interpulse period, with and without variable weighting.

tion of a desired target, the VIP sequence must be completed within the time that the radar beam scans over the target (dwell time). If the radar must detect not only the presence of the target but its location to a fraction of a beam-width, several VIP sequences must be completed during target dwell time; otherwise, the echo will be strongest when the interpulse period is optimum, not when the antenna beam is centered on the target. The VIP cycle used (Table I) for the fixed binomial response curve in Fig. 7 is about as gradual as most radar dwell times can tolerate. The pattern of deviations from average interpulse period is a parabolic approximation to a 16-pulse sinusoidal variation.

Actually, the insensitivity at the first 360-degree phase change could have been substantially reduced with even wider deviation in interpulse period than the ±20 percent used. However, wider deviation would have caused excessive notch degradation.

Digital implementation of cascading cancellers ($A - 3B + 3C - D$ for a four-pulse canceller) is mathematically equivalent to binomial weighting of the pulses. However, digital MTI, unlike its analog predecessor, permits not only flexibility in choice of interpulse period but also flexibility in pulse weighting. Variable weighting, achievable with mathematical precision, can provide the target detection benefits of VIP without sacrificing the shape of the clutter notch. It permits a steep clutter notch with four or more pulses in the canceller without imposing impossible restrictions on how the interpulse period can be varied. This variable interpulse period and weighting (VIPAW) technique has provided a major improvement in MTI performance.

The mathematical derivation for choosing the weighting factors will not be shown here, but the values tabulated in Table II were used to produce the variable-weighting curve in Fig. 7, and they illustrate the extent to which variable weighting can improve velocity response. It nearly doubles the width of the clutter rejection notch at some selected level (−59 dB in this case), providing much better capability for rejecting low-velocity clutter; simultaneously, it virtually eliminates the insensitivity to moving targets at the first 360-degree phase change. These benefits have been achieved with a sequence of *only eight interpulse periods* and the simple binary-weight coefficients shown in Table II.

Coded-Pulse Anticlutter System

It is apparent that the advent of low-cost digital circuitry has revolutionized the implementation of the MTI function in modern radars. As a result, similar digital techniques are being used to implement many other signal processing functions associated with the MTI process. This trend toward digital signal processing will continue in the years ahead.

Another system function that has been implemented with digital techniques is phase coding of the transmitted pulse. The combination of hard limiting with phase coding provides an excellent CFAR (constant false alarm rate) system against noise, distributed clutter (weather and chaff), electronic countermeasures, and uncoded-pulse interference. The receiver destroys all amplitude information by limiting and distinguishes between desired target echoes and the interference solely by correlating the echo phase pattern with the transmitted phase pattern. The overall combination of DMTI and CFAR pulse decoding gives excellent performance against all types of clutter. When this is followed by a digital video integrator and threshold, a very low output false alarm rate is obtained, providing essentially a "black and white" PPI display. The digital output can also be used for further data processing if desired.

Digital phase coding consists of dividing the transmitted pulse into N equal segments, each with one of several possible phase states, 0 or 180 degrees for example. The duration of each segment matches the timing clock and the A/D sampling interval. The example shown in Fig. 8 is a seven-segment Barker code, with a phase sequence of 1110010, where $1 = 0$ and $0 = 180$ degrees. A point target creates an echo in seven adjacent range cells of the MTI, matching the phase pattern of the transmitted pulse and adding up in the decoder to a count of seven. Other distributed sources of interference, such as rain or noise, produce an echo with a random phase pattern that does not match the phase pattern of the transmitted pulse.

Distributed clutter produces an rms level equal to $\sqrt{N}$, in this case an rms level of $\sqrt{7}$. When the echo from a point target is only partially in the decoder, the desirable codes provide outputs even less than noise alone. Only point targets create detectable outputs and only when centered in the decoder.

A digital radar receiver combining the functions of MTI, limiting, pulse compression, and video integration is shown in Fig. 9. Each function following the MTI canceller will be described.

Digital Limiter—All amplitude information is destroyed (limiting) before pulse decoding so that only phase information remains. This eliminates the amplitude effects of different intensities of noise or interference. One form of digital limiter operates to convert all possible input numbers into just three output numbers (+1, 0, −1).

Since the DMTI produces an output signal that fluctuates about zero, limiter output is symmetrical. Unlike analog limiters, this digital limiting procedure has no effect on phase, the output characteristics are entirely predictable and reproducible, and, in multichannel MTI systems, such limiters are identical.

Digital Decoder—The output of the limiter, as described above, consists of two bits: a sign bit and a magnitude bit. The decoder stores N adjacent range cells of this data in a shift register (the digital equivalent of an analog tapped delay line). It then processes these N data samples in the following manner:

1) The sign bits in those range cells

8—Timing relationships are shown for a seven-bit Barker code transmission.

9—A typical digital subsystem consists of digital MTI, limiter, decoder, integrator, and threshold.

10—Typical digital feedback video integrator, shown in block diagram form (*a*), provides the impulse response (for each range cell) shown in (*b*).

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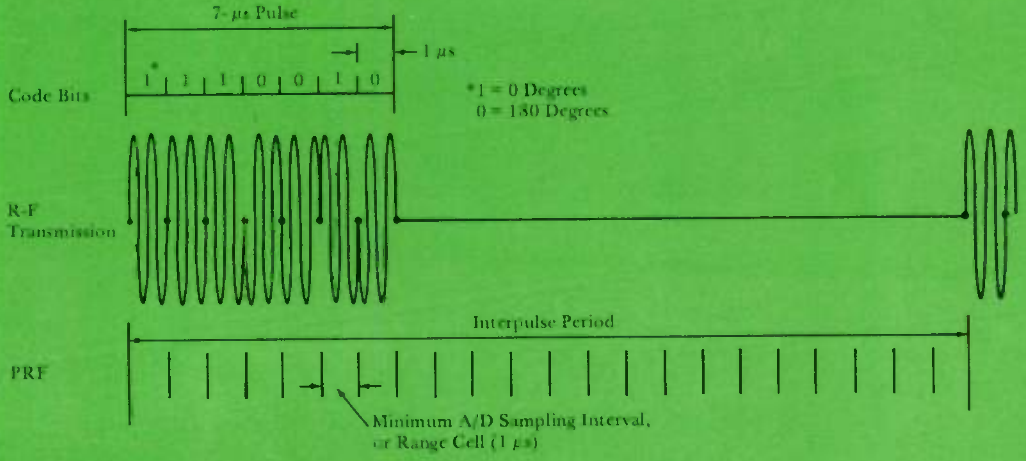
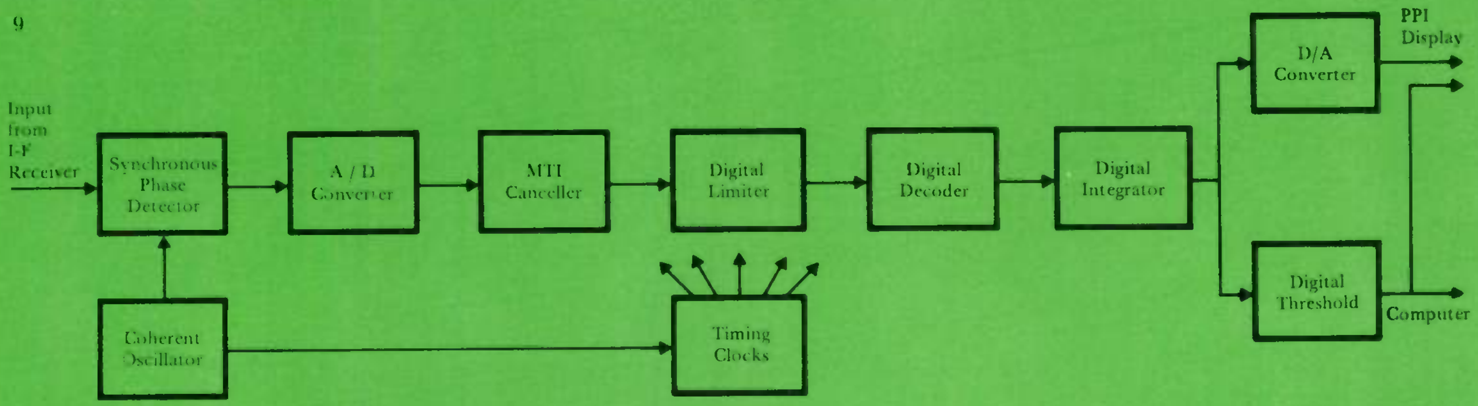
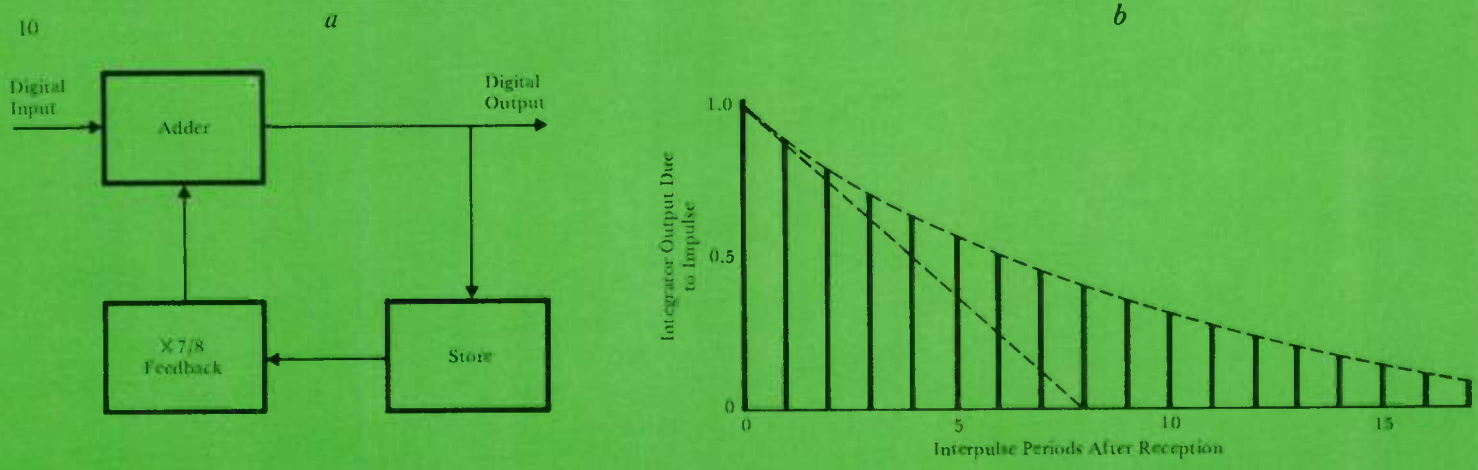

7-μs Pulse
1 μs
Code Bits
1 1 1 0 0 1 0
*1 = 0 Degrees
0 = 180 Degrees
R-F Transmission
Interpulse Period
PRF
Minimum A/D Sampling Interval, or Range Cell (1 μs)

9


Input from I-F Receiver
Synchronous Phase Detector
A / D Converter
MTI Canceller
Digital Limiter
Digital Decoder
Digital Integrator
D/A Converter
PPI Display
Digital Threshold
Computer
Coherent Oscillator
Timing Clocks

10


a
b
Digital Input
Adder
Digital Output
X 7/8 Feedback
Store
1.0
0.5
0
Integrator Output Due to Impulse
0
5
10
15
Interpulse Periods After Reception

where the transmitted pulse was coded 180 degrees are reversed so that an echo from a point target, when centered in the shift register and after this polarity reversal, produces N outputs of the same polarity.

2) The N outputs of the above process are added.

3) If the result is negative, the result is complemented.

The final output of the decoder is magnitude only (no polarity sign) with a maximum value of N (7 for the seven-segment Barker code). When the echo is not centered in the shift register, the maximum output is 1. Since noise signals add randomly, the rms value of noise coming out of the decoding process is $\sqrt{N}$, or $\sqrt{7}$ in this case.

Digital Integrator

Better detectability is achieved if the individual data samples from the decoder are integrated before thresholding for a data processor, or before D/A conversion for display. The integrator may have a variety of forms, but the digital feedback variety is most common (Fig. 10). As the antenna scans a target, it provides many successive echoes on the same target due to the width of the radar beam. The integrator stores each echo plus a fraction ($1-K$, slightly less than one) of the stored data for the previous hits. The action is equivalent to summing all prior echoes from the same range, after multiplying each by the indicated weighting factor, which decreases with age of the echo.

Before integration, the maximum contrast between target echoes and noise is $\sqrt{N}$; integration magnifies this contrast by approximately $\sqrt{1/K}$. This permits a threshold at the output of the integrator to be a more efficient decision device for a digital processor and assures better contrast and a lower false alarm rate on the PPI display.

Typical Digital Subsystems

Westinghouse has pioneered the use of digital techniques for signal processing in tactical radars. During the past five years, a wide variety of DMTI cancellers and associated functions have been implemented with these digital techniques. These range in complexity from a simple two-pulse canceller to a four-pole elliptic feedback canceller with variable constants. Each digital system was tailored to meet the requirements of a particular program. Table III contains the general characteristics of several different digital subsystems developed by Westinghouse.

In general, the lower performance two-pulse and three-pulse cancellers were designed to meet the requirements of long-range (100 to 200 nmi) search radars, which have a low PRF and few hits per beamwidth. The four-pulse and feedback cancellers were designed for short-range (<100 nmi) high-PRF radars, with good MTI performance the primary requirement. Some of these are used in new production radars and others in the modification of older radars.

All of the digital subsystems in Table III have been field tested with excellent results. Many are in quantity production.

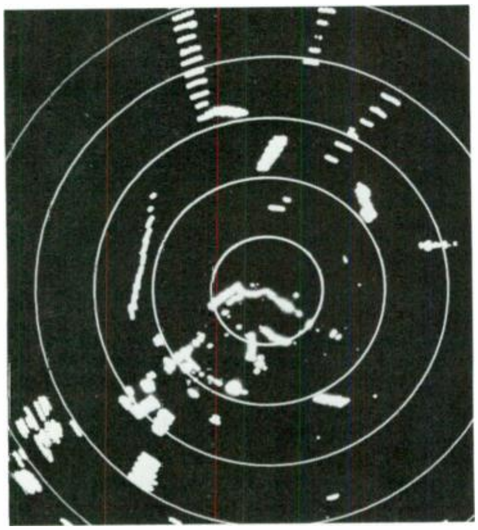
Table III—Westinghouse Digital Signal Processors (typical)

Digital MTI							*Digital Limiter Output (LSB)*	*Digital Pulse Compression (Barker code segments)*	*Digital Video Integrator (feedback factor)*
Type of Canceller	*Number of Bits/Word*	*Sample Rate (μs)*	*Memory*		*Maximum Possible Improvement Factor (dB) (LSB=RMS noise)*	*Staggered PRF (steps)*			
			Type	*Size (bits)*					
Two-pulse	6	1.0	Core	6,144	30	3			Sliding window
Two-pulse	7	1.3	Core	7,189	36				
Two- to three-pulse selectable	7	1.0	Core	28,672	36	3			
Three-pulse	6	0.5	Core	24,576	30	6			7/8
Three-pulse	6	0.5	MOS-SR	20,448	36	3			
Three-pulse	8	0.25	MOS-SR	13,632	42	5			7/8
Three-pulse	8	0.5	MOS-SR	68,160	42	6	−1 to +1	13	7/8
Four-pulse	8	2.0	Core	24,576	42	64	−7 to +7	13	15/16
Four-pulse var. wgt.	8	1.0	MOS-SR	10,224	42	8 or 10	−1 to +1	13	7/8 to 31/32
Four-pulse	10	2.0	MOS-SR	12,780	54	16	−7 to +7	13	15/16
Four-pole elliptic	12	4.8	MOS-SR	3,072	66	(scan) 2			63/64
Five-pulse	8	2.0	MOS-SR	27,264	42	5			7/8

11

12a

12b



11—The AN/TPS-61 tactical radar uses digital signal processing techniques described in this article and has demonstrated excellent performance, mobility, and availability.

12—Display provided by a single scan of raw video without digital processing (*a*); display of same area provided by 11 scans of video with digital processing (*b*). (Five-mile range rings.)

Although the systems shown are only typical of those produced, the range of parameters given represents the state of the art in digital signal processing for tactical radars.

AN/TPS-61

A new ground radar that was made feasible because of the digital signal processing techniques described in this article has clearly demonstrated the advantages of these techniques. Designated AN/TPS-61, this 100-mile-range radar system weighs just 3700 pounds and can be transported by a 2½-ton military cargo truck or by helicopter (Fig. 11). It can operate from the truck bed if necessary and be put into operation within an hour. The system includes a 16-inch PPI display and integral interrogation and identification capability.

In recent tests by the U.S. Marine Corps, the system was integrated with the Marine Tactical Data System. It demonstrated the ability of the radar to supply information to tactical data systems in gap-filling and contingency roles. In addition to those demonstrations at Camp LeJeune where its assigned role was a simulated air defense mission, the radar was tested earlier by the Marine Corps in an extremely high-clutter environment at Camp Pendleton.

In June 1970, the AN/TPS-61 was used by the Air Force as a tactical airfield surveillance radar at a site with extremely severe ground clutter. In all of these demonstrations, the clutter suppression characteristics of the radar system have been excellent. Typical PPI results that demonstrate the excellent performance of this radar are shown in Fig. 12.

As demonstrated by the AN/TPS-61, digital signal processing has made practical a moving-target indicator with a multiple-pulse canceller and a coded-pulse anticlutter system. Both of these techniques feature no adjustment, a minimum of maintenance, and outstanding performance. This compact digital circuitry has permitted the system to be relatively light in weight, so that it can be easily transported. In addition to these advantages, digital signal processing is compatible with various tactical data systems that may be employed. These digital techniques have truly advanced the performance, mobility, and availability of present-day tactical radars.

Oxygen Analyzer Makes Possible Continuous Analysis of Stack Gases

Efficient use of fuel in combustion processes requires burning it with the right amount of air. Too much air puts heat up the stack and too little puts smoke into the outside air, either of which is costly in terms of money and pollution.

One way to tell whether or not the proportion of air is right is to know the content of unused oxygen in the stack gases. To provide that knowledge, a new type of oxygen analyzer has been developed. It provides a continuous real-time analysis of combustion gases that can be used to reduce pollution from gas or oil furnaces. Known as the Hagan Probe-Type Oxygen Analyzing System, it is applied directly in the stack-gas stream, eliminating the costly and difficult-to-maintain sampling systems required for conventional reagent-type analyzers.

Because the analyzer is in direct contact with the stack gases and responds in milliseconds, time delay in reading the oxygen content is negligible. That is extremely important when the analyzer is used as part of a closed-loop system to monitor stack gases and automatically control airflow to the combustion chamber. The analyzer makes possible, for the first time, reliable control of the combustion process from continuous analysis of the oxygen content of stack gases.

Unlike conventional analyzers, which operate on a dry-sample basis and disregard the water portion of the stack gas, the Hagan analyzer considers the whole gas in providing its continuous reading of percent oxygen. The distortions common in conventional systems due to water vapor content, as well as sampling system errors, are thereby eliminated.

Accuracy of the analyzer is ±0.1 percent at 2 percent oxygen by volume. The accuracy is particularly high in the critical area of low oxygen concentration because of the inverse log relationship of the sensor-cell output to oxygen concentration. The scale of the chart readings is 0.1 to 10 percent log scale. System response time is less than 200 milliseconds, an extremely high speed with respect to the rate of change of oxygen concentration and, therefore, essentially instantaneous for the purposes of closed-loop control.

The analyzer operates on the fuel-cell principle. At its heart is an yttria-stabilized zirconia disc, which is positioned on the end of a shielded probe inserted directly into the gas stream. When held at a constant temperature of 1550 degrees F (maintained by a heater), and using air as a reference, the cell generates a voltage proportional to the difference in oxygen partial pressures. The voltage is caused by the migration of oxygen ions from the area of high concentration to the area of low concentration.

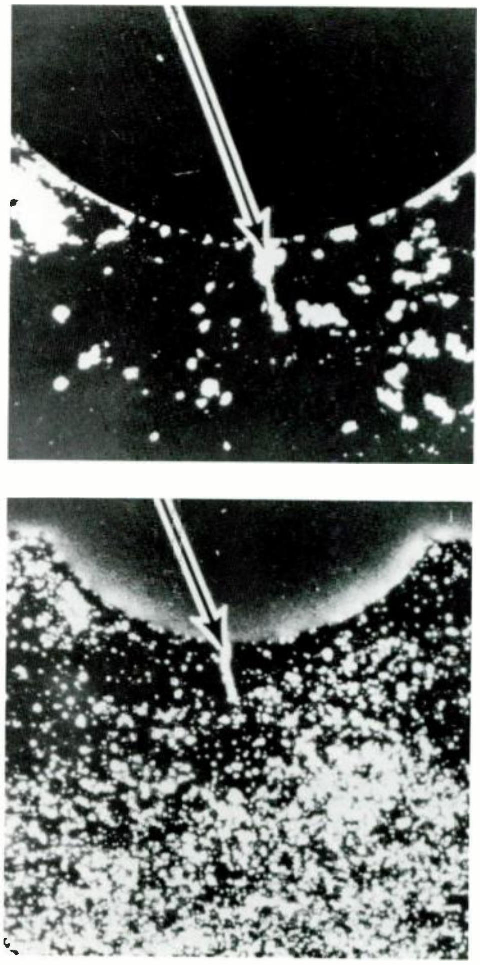
The oxygen analyzer is easy to maintain because it has no sampling system, no moving parts, and completely solid-state circuitry. If the cell gets dirty, it can be withdrawn for cleaning without disconnecting any wires. The system is made by the Westinghouse Computer and Instrumentation Division.

Sensitive TV Camera Detects Cracks in Metal Objects

One way to test turbine blades and other artifacts nondestructively for invisible defects (such as small cracks) is to let radioactive krypton-85 gas adsorb onto the surface of the defects and then detect the radiation from the gas. An improved version of that process, using a low-light-level television camera to detect the radiation, has been demonstrated by the Industrial Nucleonics Corporation, Columbus, Ohio.

The previous detection means was autoradiography, in which radiation from the gas in the defects exposed photographic film placed near the part being examined. That method provides good spatial resolution, but it is slow because the small amount of radioactivity in the defects necessitates long exposure times.

The low-light-level camera makes more efficient use of the incoming radiation, so it is much faster than film. The camera used is a Westinghouse intensified SEC (secondary electron conduction) system.* Its input end includes a phosphor layer for converting the radioactive emission to light and a fiber-optic bundle for



Crack detection with the camera system (*top*) is comparable in accuracy to detection by autoradiography (*bottom*) and is much faster. It required only a 20-second exposure in this comparison test, while autoradiography required a three-hour exposure. The test piece was an aluminum plate that had been cracked by stress fatigue.

good spatial resolution.

Test results, such as those illustrated, show a close correspondence between the effectiveness of the two detection methods, even though the camera method is much faster. In one comparison, for example, defects in the leading edge of a turbine blade were revealed about 10^5 times as fast with the camera system. The method is not limited to inspection of turbine blades, of course, but can be used with other metals and products as well.

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*A. P. Laponsky and V. J. Santilli, "Recent Developments in Low-Light-Level Camera Tubes," *Westinghouse ENGINEER*, May 1971, pp. 81-92.

Kansai and Westinghouse in Plutonium Recycle Demonstration Program

A joint plutonium-recycle demonstration program has been undertaken by Kansai Electric Power Company (of Japan) and Westinghouse. The program consists of fabricating four mixed plutonium-uranium-oxide fuel assemblies and irradiating them as part of reload region No. 5 in the Mihama No. 1 reactor. The Shikoku Electric Power Company, Kyushu Electric Power Company, and the Mitsubishi Group are also participating in the program.

Westinghouse is designing the assemblies and fabricating them at its Plutonium Fuels Development Laboratory in Cheswick, Pennsylvania. Kansai is leasing the plutonium required for the program from Japan Atomic Power Company; it was shipped to the United States from the reprocessing facility of British Nuclear Fuels Ltd. in England.

The assemblies will be inserted in the reactor during the scheduled refueling in early 1974. They will supply about 10 percent of the energy generated by the region during its three cycles of operation in the reactor.

As the program develops, provision might be made for removal and examination of selected fuel rods from the assemblies during subsequent scheduled refuelings. Destructive examinations might also be performed on selected fuel rods after the region is removed for reprocessing.

The recycle demonstration program will add substantially to the experience gained by Westinghouse in a number of other plutonium development and demonstration programs. Kansai and Westinghouse see it as a major step toward achieving commercial plutonium recycle capability during the middle 1970's, when many electric utilities will have large amounts of plutonium on hand from their operating power reactors.

Waste Paper and Waste Plastic Make Serviceable Hardboard

Almost 2000 years ago, the Chinese learned how to turn wood into paper. Now so much waste paper is produced that Americans would like to learn how to turn it back to wood.

Engineers at the Westinghouse Research Laboratories are working on the problem and have produced a hardboard material. The simulated wood is made from shredded newspaper and an equal weight of an industrial waste material, urea-formaldehyde flash. (Flash is scrap resulting from the manufacture of such "plastic" items as wall plates, switches, and receptacles.) The mixture is heated to about 300 degrees F and squeezed with a pressure of about a ton per square inch.

The project is part of a broad program in the Ecological Systems Department of the Laboratories to find uses for solid waste materials.

Special Blue Lamp Helps Treat Jaundice in Newborn Infants

Newborn infants, especially the premature ones, often develop jaundice because of an excessive amount of a yellowish substance called bilirubin in their blood. Although the jaundice usually clears up in a few days, the condition (known as hyperbilirubinemia) is serious because it can cause lasting brain damage.

Bilirubin is a product of the decomposition of red blood cells, which is a normal and continuous process in the human body as old cells are replaced by new. Bilirubin is normally broken down by the liver; the abnormally high concentration often seen in the newborn results largely because the liver is not yet fully developed. A contributing factor may be some abnormality such as incompatible blood factors between mother and infant.

Observant medical research workers noticed years ago that the color of blood samples containing bilirubin faded in light, due to decomposition of the bilirubin. Moreover, nurses noticed that babies with hyperbilirubinemia improved fastest if they were near a window.

Then, in 1958, English clinical research workers found that the condition can be treated successfully by irradiating the baby with light from fluorescent lamps, especially blue lamps. The light breaks down bilirubin in the blood, thus helping the liver restrict the concentration to a safe level. Such phototherapy has been broadly adopted by hospitals.

Continuing research in the past few years at Temple University School of Medicine in Philadelphia has produced further insights into the condition and its treatment. The program is directed toward establishing the range or combination of light wavelengths that decomposes bilirubin most effectively into products that are not injurious and are readily excreted, and then applying that information to improve the treatment of hyperbilirubinemia. The Westinghouse Fluorescent and Vapor Lamp Division has supplied fluorescent lamps in various colors for the program, including a special blue lamp developed for phototherapy.

Typical laboratory studies have involved irradiation of solutions of bilirubin in blood albumin with a variety of lamps, and then measuring the optical density of the solutions to see how much they had faded. The decreasing order of effectiveness of the lamps used was found to be: special blue, blue, daylight and green equal, pink, gold, and red. Other experiments using blood serum from jaundiced infants showed essentially the same order of effectiveness, with the special blue lamp markedly more effective than any other color.

Analysis revealed that the order of

effectiveness of the lamps coincided with the order of their output of blue light (in the wavelength range of 425 to 475 nanometers). The ineffectual gold and red lamps emit little radiation of less than 525 nm, but the special blue lamp has nearly all of its output in the 425- to 475-nm range. (See figure.) It has since been demonstrated that the action spectrum for bilirubin decomposition, as measured in the laboratory, contains three peaks: the major peak is near 450 nm and two lesser ones are near 410 and 490 nm.

Clinical studies at the school also have demonstrated the effectiveness of blue lamps. In a recent one, 55 infants with excessive bilirubin levels were treated under a bank of ten lamps of daylight, standard blue, or special blue color. Bilirubin level was measured before the phototherapy and at 8- to 10-hour intervals until therapy was completed. The most rapid decrease in bilirubin level was achieved with the special blue lamps, with standard blue and daylight lamps following in that order.

Approximately 80 percent of the infants treated with standard or special blue lamps required only two days for completion of the phototherapy, but only 22 percent of those treated with daylight lamps completed it in that time. None of the infants treated with blue lamps required more than three days of phototherapy, while 16 percent of those treated with daylight lamps required five days.

The special blue lamp contains a new phosphor, europium-activated strontium chloroapatite. Its maintenance of light output is comparable to that of standard cool white lamps and far superior to that of standard blue lamps; the original set of ten experimental 20-watt lamps supplied to Temple University in April 1969 was retired in April this year after more than 3700 hours of use. Factory-produced 20-watt lamps are being provided to the Temple research team and to several other institutions for continuing laboratory and clinical studies.

Short-Range Search Radar Developed for Navy

A new radar system, designated AN/SPS-58, is designed for short-range air search to detect targets in sea clutter. When used with the basic point-defense surface missile system, it is intended to counter low-flying aircraft.

The AN/SPS-58 is the first Navy shipboard radar to use a digital doppler moving-target indicator (MTI), which cancels out radar signals from the surface of the sea. (See article on page 147.) Previous MTIs have been analog rather than digital, and their clutter rejection has not been sufficient to detect small targets through severe clutter.

Four production prototypes were built by the Westinghouse Aerospace and Electronic Systems Division. One of them is installed aboard the U. S. Navy's *USS Norton Sound* for shipboard tests, two others are undergoing environmental tests, and the fourth was borrowed by the U. S. Army for feasibility tests in a tactical acquisition radar situation at Fort Bliss, Texas.

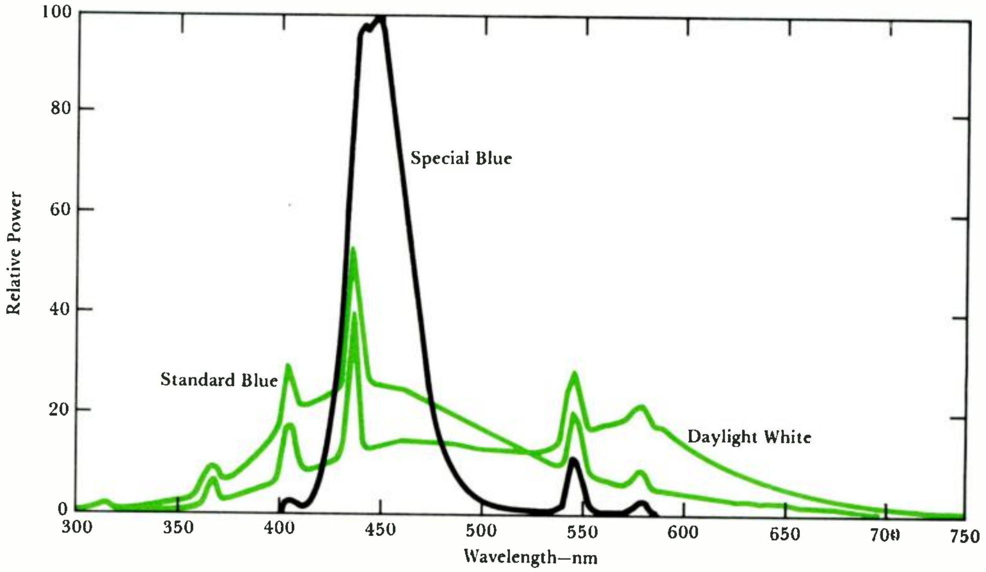
In addition to the new radar's clutter rejection, it also has a high data rate, a low false-alarm rate, and improved radar signal processing. The high data rate enables rapid detection of fast low-flying aircraft. The combination of high data rate and low false-alarm rate provides the fast reaction time essential in a point-defense radar system.

At 4000 pounds, the radar is comparatively light in weight. Its below-deck equipment consists of only two equipment racks, a bulkhead cabinet, and a display console.

Solid-state electronic components are used throughout, except for the klystron tubes in the last two stages of amplification in the transmitter and a power tube in the transmitter power-supply regulator. Built-in test equipment isolates failures to replaceable plug-in assemblies.

Electrostatic Induction Effects of EHV Lines Calculated

When a conductive object insulated from ground is placed in the vicinity of an energized power line, a potential may be induced on the object; if the object is connected to ground, a capacitive (or "charging") current flows in the connection. With increased use of extra-high-voltage (EHV) transmission, electric-utility designers must consider electrostatic



Light outputs of three of the fluorescent lamp types evaluated in the laboratory and clinical studies are compared here in terms of power distributions along their wavelength spectra. The special blue lamp has nearly all of its output concentrated in the 425- to 475-nanometer range, which accounts for its effectiveness in breaking down bilirubin.

induction effects on conductive objects in the vicinity of their lines. (The electrostatic induction effects of EHV systems are considered more of a problem than they are for lower-voltage lines because ground clearances for overhead conductors do not increase in direct proportion to voltage.)

The levels of voltage and current induced in a particular object depend on the voltage of the power line, physical dimensions of both the power line and the object, position of the object relative to the power line, and the quality of the insulation between the object and earth. The amount of charging current that flows through a person touching the object depends also on his body resistance and the insulation between him and the ground.

Before an EHV line is built, it is advantageous to the utility to determine the maximum induced voltages and charging currents that could be encountered along the proposed right-of-way for typical objects such as wires, vehicles, and buildings. Problem areas can then be determined and eliminated before the line is energized.

Computer programs for making the determinations have been devised by the Advanced Systems Technology group in Westinghouse Power Systems. They are based on analytical methods that have been checked out by electrostatic induction measurements made at the Apple Grove 750-kV Test Project. Required inputs for lines include conductor diameter, phase spacing, and heights of conductors. For objects, such parameters as length, width, and height of vehicles or buildings must be known, or the height and diameter of fence wires.

New Literature

Water Coolant Technology of Power Reactors is a 439-page book authored by Paul Cohen of the Westinghouse Advanced Reactors Division. It was prepared under the sponsorship of the American Nuclear Society for the Division of Technical Information, United States Atomic Energy Commission. Written primarily for the operational scientist or engineer, the book presents elements of the supporting scientific and engineering disciplines and gives an interpretive summary of the specialized literature in the field. It starts with an introduction to reactor coolant technology and reactor types, followed by chapters on fluid flow, heat and mass transfer, the physical chemistry of water and aqueous solutions, radiation chemistry, and the behavior of gases in reactor systems. Other chapters cover radioactive and nuclear chemistry of water reactor systems, chemical shim control and pH effect on reactivity, coolant purification and waste disposal, corrosion, and plant contamination. Price of the book is $13.75. It was published by Gordon and Breach Science Publishers, 440 Park Avenue South, New York, New York 10016.

Services for Industry

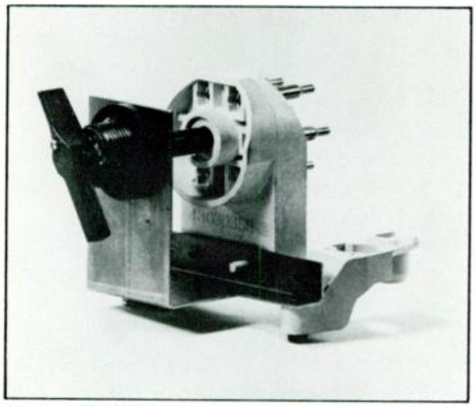
Lighting demonstration room provides a comfortable place where designers, architects, and lamp users can visualize the effects of various kinds and combinations of lighting. To demonstrate room lighting, for example, several systems of fluorescent, incandescent, and high-intensity discharge lamps are installed above a louvered ceiling; switches and dimmers then make it possible for viewers to appraise the chromaticity and color-rendering ability of various types, combinations, and intensities of lighting. The walls also are lined with display and demonstration facilities for the various kinds of lamps. *Westinghouse Lamp Divisions, One Westinghouse Plaza, Bloomfield, New Jersey 07003.*

Training programs for turbine-generator operation and maintenance are designed to train both new and experienced personnel. Courses include instruction and equipment orientation on all Westinghouse fossil and nuclear turbine-generators and their associated auxiliaries. The courses are supplemented by simulation of actual power-plant conditions; a "hands-on" approach is emphasized through use of actual operating equipment, models, and video tapes. Tuition includes the cost of textbooks, workbooks, study aids, and course materials. The programs are conducted either at utility-plant sites or at Westinghouse training centers at Lester and Cheswick, Pennsylvania. *Power Generation Service Division, Westinghouse Electric Corporation, Lester, Pennsylvania 19113.*

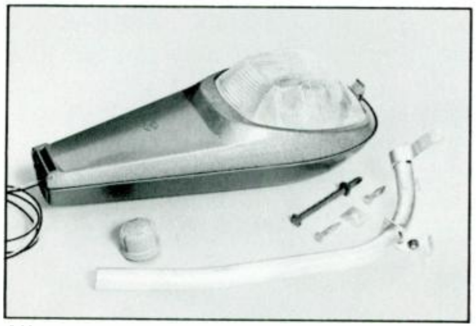
Products for Industry

Security system for protecting properties against intruders employs an electro-optical transmitter to direct a narrow invisible infrared beam to a receiver placed up to 500 feet away. An intruder who interrupts the beam sets off a warning system. The receiver is adjusted to respond to any beam interruption longer than 0.050 second, so it can detect even a fast-running intruder; briefer interruptions by smaller objects, however, such as a bird or a falling leaf, are ignored. The system operates throughout adverse weather conditions, when human visibility may be only 20 to 30 feet, and it withstands temperature variations from −30 degrees to +140 degrees F. A single transmitter can be connected to two or more receivers by means of a beam splitter, and mirrors can be used to turn the beam around corners. Optical amplifiers can be used to extend the range of the system by some 40 percent. The equipment cannot be opened, dismounted, or electrically disconnected without generating an alarm, and provisions are built in to notify a guard if power is interrupted or a component fails. *Westinghouse Specialty Electronics Division, 7800 Susquehanna Street, Pittsburgh, Pennsylvania 15221.*

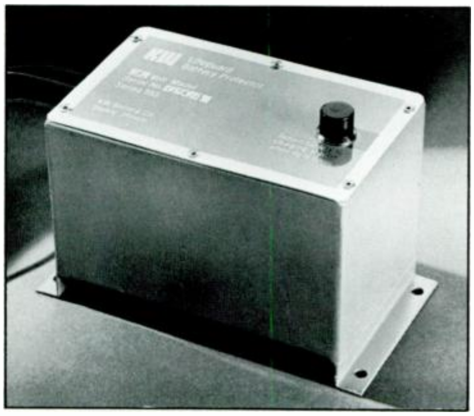
No-load tap changer now available on overhead distribution transformers is externally mounted to save time for the lineman, who only needs to de-energize the transformer, change the switch, and energize again. Previously, much more time was required in removing the transformer cover to change tap position. Voltage rating is 18 kV, with BIL level of 125 kV and maximum continuous current of 90 amperes. The tap-changer handle, located externally just below the oil level



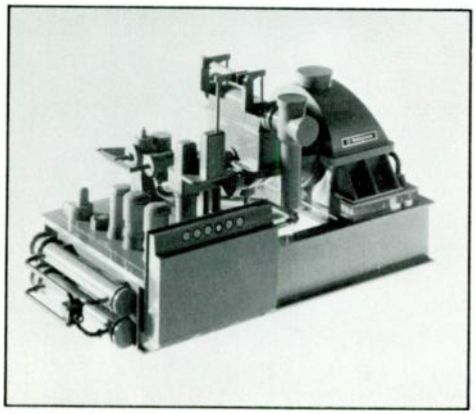
No-Load Tap Changer



OV-400 Mercury Luminaire



Battery Protector



Auxiliary Steam Turbine

of the transformer, is connected directly to a low-friction roller-type contact immersed in oil inside the tank. All seals are made of high-temperature fluorosilicon rubber. *Westinghouse Distribution Transformer Division, Newton Bridge Road, Athens, Georgia 30601.*

OV-400 mercury luminaire combines modern appearance, economy, and good optical performance in a completely packaged unit to simplify installation. Its built-in 400-watt ballast is prewired and has two 7-foot line leads attached. The optical system is completely sealed to minimize entry of moisture and other contaminants. The OV-400 package includes aluminum mounting bracket and accessories, a photocell, and either a clear or color-improved 400-watt lamp. *Westinghouse Outdoor Lighting Department, 1216 W. 58th Street, Box 5817, Cleveland, Ohio 44101.*

Battery protector protects the batteries of electric lift trucks and prolongs their useful lifetimes by preventing overdischarging, detecting weak or damaged cells before damage spreads, and assuring that a regular schedule of battery charging and maintenance is kept. In addition, the KW Lifeguard battery protector prevents the lift truck's electrical system from operating at excessively low voltages that may damage the motor by arcing, high temperature, and high current draw. It monitors battery voltage, and, when the voltage drops to a preset level, warns the lift-truck operator with a red light. After the light goes on, the operator has 3 minutes in which to complete any immediate tasks. After that time, the battery protector disconnects the truck's lift controls; all the driver can do then is lower the lift and drive to a recharging station. Consistent use of the battery protector provides an automatic system of regular battery maintenance and recharging based on battery use: batteries are recharged only when they need it, they are no longer overdischarged, and the chargers aren't tied up for excessive periods with rundown batteries. If the warning light goes on soon after a recharged battery is placed in the truck, the operator knows it has a weak or damaged cell. The protector is available in models to match industrial batteries rated from 12 to 72 volts with from 6 to 36 cells. *KW Battery Company, Division of Westinghouse Electric Corporation, 3555 Howard Street, Skokie, Illinois 60076.*

Auxiliary steam turbine is made as a packaged unit for rapid installation as a drive for boiler feed pumps or fans in electric-utility power plants. The new packaging concept, called START (Steam Turbine Available in Rapid Time), has the turbine and all component parts including piping factory-mounted on a bedplate. Installation time is thereby substantially reduced over conventional methods, which require field assembly of components, and delay and expense from misplacing or damaging loose parts is eliminated. The bedplate serves as an oil reservoir besides supporting the instrument console, oil coolers, and other peripheral equipment. Since there are no protrusions below the bedplate, the unit can be installed on a concrete slab. After alignment and final connection of steam, water, and electrical lines, the turbine is ready for service; START units are factory-tested before shipment, eliminating lengthy field verification. The turbines are available up to about 22,000 hp for both fossil and nuclear cycles. The unit is approximately 20 feet long, 12½ feet wide, and 12½ feet high. *Westinghouse Small Steam and Gas Turbine Division, Lester Branch, Box 9175, Philadelphia, Pennsylvania 19113.*

About the Authors

Henry J. von Hollen graduated from Stevens Institute of Technology with a BSME in 1951, and he also attended the Oak Ridge School of Reactor Technology in 1957. He joined the Westinghouse PWR Systems division in 1957 and has since held a variety of positions.

Von Hollen participated in the initial design of the Saxton reactor and worked on the Selni reactor (Italy). In 1962 he was appointed Manager of Systems Development, and a year later he was made Project Manager for the San Onofre Project (described in his coauthored article on these pages in September 1965). During the final stages of that project, he also assumed project management responsibility for the initial design phases of the Turkey Point Project.

Von Hollen presently is Manager of Systems Engineering. He has overall responsibility for implementation and design of the nuclear steam supply fluid systems for all PWR reactors that Westinghouse presently has under contract.

W. A. Webb is Manager of Application Engineering in the PWR Systems division, where he has overall responsibility for technical support of the division's marketing activities. He graduated from the University of Virginia with a BSME in 1948. After working for a consulting firm on aircraft test facilities, he joined the Westinghouse commercial atomic power activity in 1955.

Webb spent two years in California as Westinghouse technical representative during the early phases of the Southern California Edison San Onofre Station. He also spent two years in Switzerland as Nuclear Plant Director for the design and construction of the NOK Beznau plant. Prior to assuming his present position, he was the Westinghouse Project Manager for the VEPCO Surry and North Anna Units and for the Duquesne Light Company Beaver Valley Station.

Donal E. Baker graduated with a BS degree in Electrical Engineering from the University of Denver in 1966. He joined Westinghouse on the Graduate Student Training Program and went to the Aerospace Electrical Division. In the Utilization Systems Department there he contributed to design and development of control and power circuitry, including electronic temperature controllers, ac power modulators, and regulated ac-to-dc converters.

Baker transferred to the Power Electronics Department in 1970 as a design engineer in solid-state controls. His main responsibility there has been design and development of remote power controllers, and he has produced several patents and technical papers in that area. Earlier this year, he received an MSEE degree from the University of Pittsburgh.

David A. Fox joined the Aerospace Electrical Division in 1967 after graduating from Case Institute of Technology with a BS degree in physics. He worked first on design of generator voltage regulators and control units for aircraft and ground power applications. Among his designs was the voltage-regulator portion of the generator control unit for the DC-10 aircraft.

Fox then worked on the remote power controllers described in this issue, contributing improved trip circuits to the overall designs. He also aided in design and production of 300-horsepower test stands for aircraft power systems. He left Westinghouse earlier this year to work as a design engineer at North Electric Company, Galion, Ohio.

Kenneth C. Shuey graduated from the University of Missouri at Rolla in 1968 with a BSEE degree, and he has received his MSEE degree from the University of Pittsburgh. He joined Westinghouse on the graduate student training program and went to the Aerospace Electrical Division.

Shuey worked first on development of the electrical load control unit for the Boeing 747 aircraft. He has also contributed to the development of aircraft window temperature controls and an automatic digital programmer for a 300-horsepower test stand for aircraft power systems. Since 1969, he has worked in design and development of remote power controllers. He is project engineer for the ac controllers.

S. Edward Franklin brings a variety of industrial experience to his discussion of the coordination of protective-device settings in electrical distribution systems. He graduated from West Virginia University in 1941 with a BSEE degree and joined Westinghouse on the graduate student training program. His first permanent assignment was to Electric Service Division headquarters as a field trouble liaison engineer, working mainly with power rectifiers, electric locomotives, and industrial electronics. In 1944, he went to the Congo (Belgian Congo at that time) to install five 70-ton electric locomotives and three 1000-kW ignitron rectifier substations in copper mines.

Franklin moved in 1948 to the Syracuse, New York, sales office to initiate electric service activities and district application engineering. He returned to Pittsburgh in 1953 to serve in the district sales office as District Consulting Engineer, Electric Utility. Franklin left Westinghouse in 1958 and returned in 1967 as staff consulting engineer and marketing representative for the Electric Service Division, Eastern Area. In 1969, he assumed his present position as Manager, Newark District, Electric Service Division.

Along the way, Franklin earned MSEE and MBA degrees from the University of Pittsburgh (1958 and 1960). He also devised and taught the first graduate courses in electrical distribution for industrial plants at New York and Brooklyn Universities.

Richard A. Linder is Manager of the Signal Processing Section of the Systems Development Division. He is responsible for the development of radar signal processing hardware and techniques, including frequency generation, synchronization, filter network synthesis, analog receiver processing, digital data processing, and hybrid microelectronics.

Linder joined Westinghouse after obtaining his BSEE from Mississippi State University in 1957. He added an MSEE from the University of Pittsburgh in 1958.

John W. Taylor, Jr., has more than 20 years experience in radar design at the Westinghouse Defense and Space Center. He received his B.S. degree from the Massachusetts Institute of Technology and did graduate work at the University of Pittsburgh. His broad experience encompasses design of antennas, microwave components, display equipment, receivers, and signal processing devices. For several years, all receivers used by Westinghouse surface and shipboard radars were designed under his direction, with special emphasis on reducing their vulnerability to jamming.

As Advisory Engineer since 1962, Taylor has been involved in radar system design, concentrating on techniques to provide search radars with high clutter cancellation and constant false alarm rates, employing both analog and digital processes. He has also developed digital techniques for tracking radars which improve range resolution and tracking capability. He holds 20 U.S. patents on these radar techniques.

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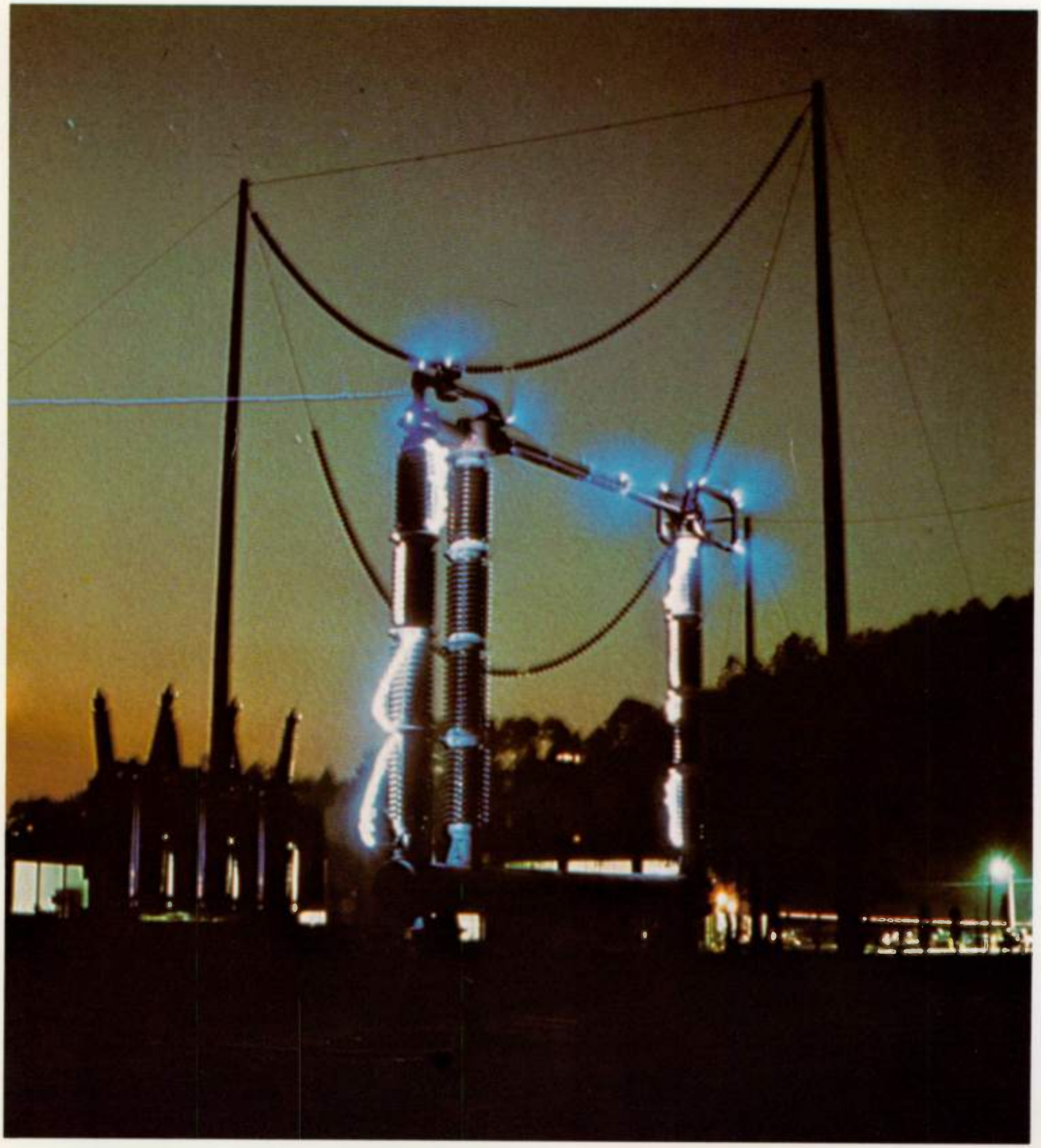

Engineering design of a 500-kV EHV disconnect switch is verified by testing at a million volts to induce flashover. (More information on contents page.)