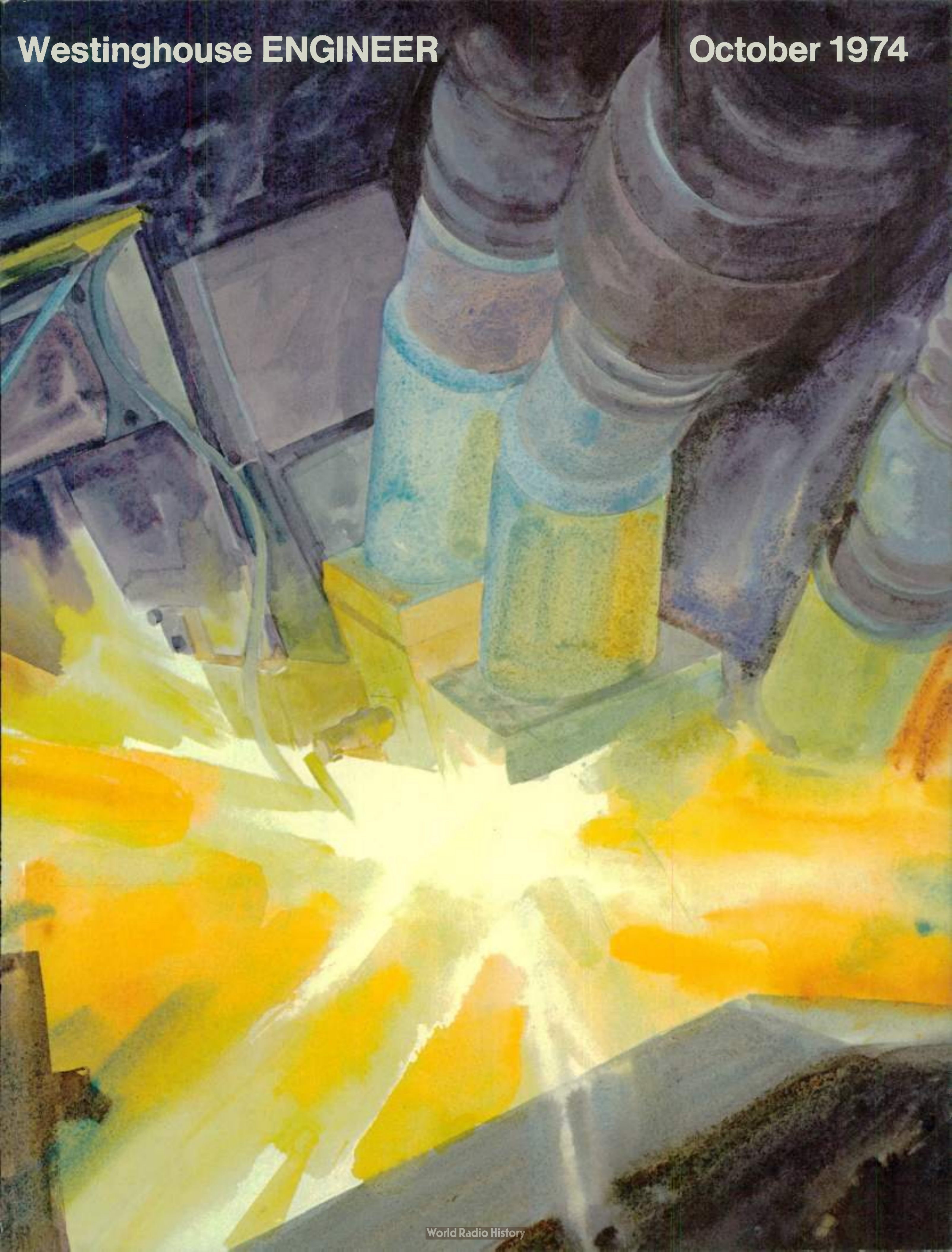
Westinghouse ENGINEER October 1974

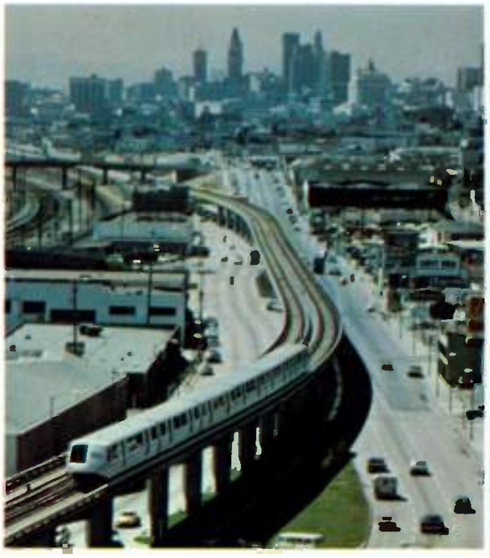


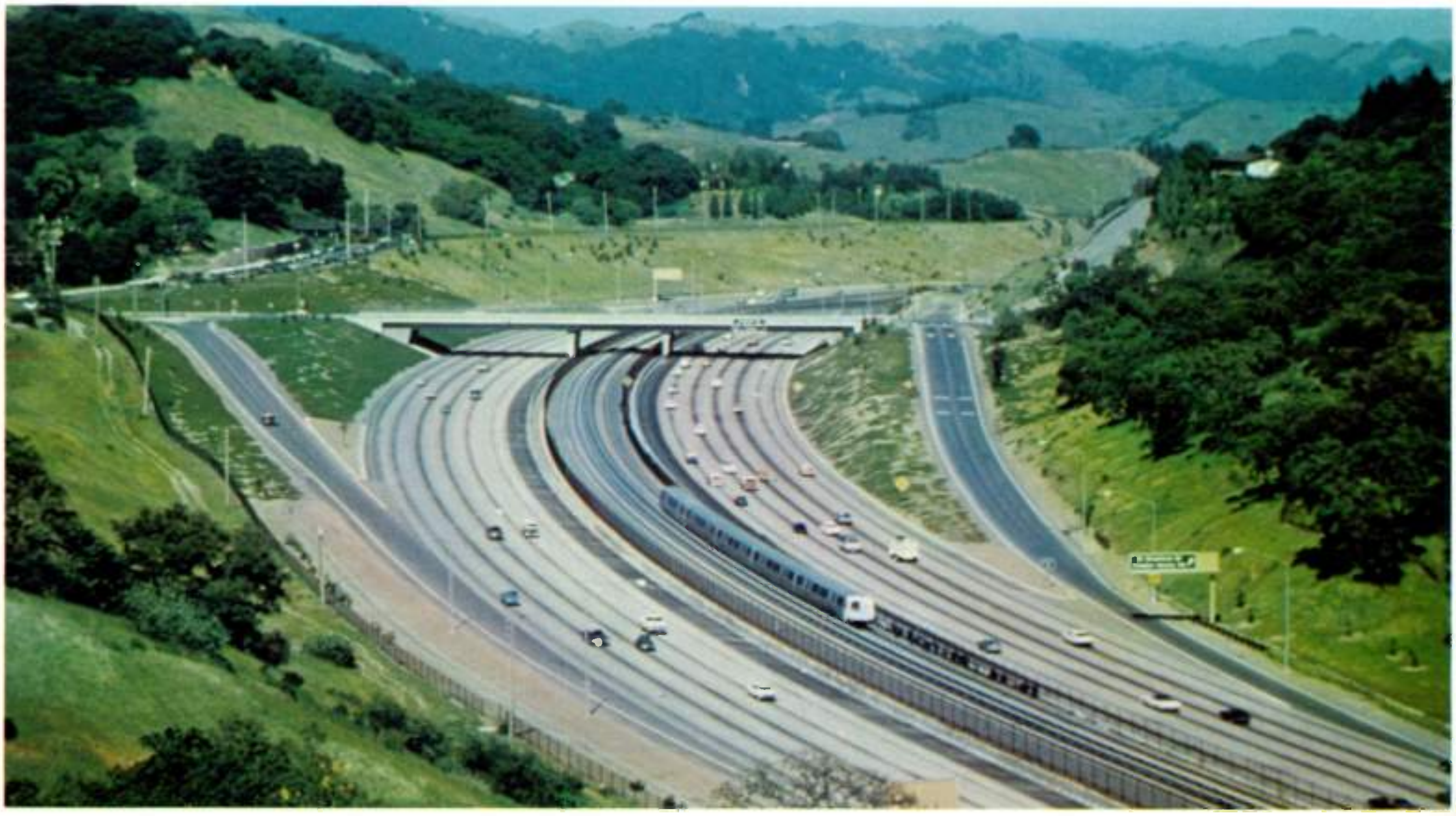
BART Serves Commuters in San Francisco Bay Area

Rapid transit and freeways coexist in the San Francisco Bay area to their mutual benefit. The rail lines for BART (Bay Area Rapid Transit) and some of the new freeways were planned together so that they could be located on common rights of way with a consequent saving in space and money. They were also planned to accommodate foreseeable growth patterns in the area.

The innovative transit system is fully automated, and its modern cars feature large windows, wide aisles, air conditioning, cushioned seats, and a smooth quiet ride. It has 71 miles of double track connecting San Francisco with communities to the south and east. The photograph at right shows the Oakland-Downtown Line passing through Oakland; the one at bottom shows the Central Contra Costa Line east of Orinda, where it shares the right of way with State Highway 24.

Westinghouse supplied the central and local train control and communication systems, car-carried control and propulsion equipment, and car air conditioning equipment. The cars were built by Rohr Corporation.





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Front Cover: The bright light comes from metal heated to incandescence by the intense energy in the beam from a nonvacuum electron-beam welder. An article on such welders, which are freed from the need for a workpiece vacuum chamber, begins on the following page. The cover design is by Tom Ruddy.

Nonvacuum Electron-Beam Welding—An Advanced Metals Joining Technique

R. J. Lanyi
B. W. Schumacher
J. M. Wells

Unlike other electron-beam welding methods, nonvacuum electron-beam welding does not require a vacuum enclosure around the workpiece. Consequently, it provides the many advantages of electron-beam welding without the limitations of vacuum-chamber size and pumpdown delay times. Its speed and adaptability to automation make it especially useful where high productivity is important.

Electron-beam (EB) welding is a fusion welding technique with distinct advantages over the more conventional arc techniques for fusion welding. The high power and power density available in the electron beam produce a fusion penetration mechanism that is not dominated by thermal conduction (see *Electron-Beam Welding*, below). Consequently, EB welding can provide higher ratios of weld depth to width than the other fusion welding processes and also greater single-pass penetration and faster welding speeds.

A further advantage of EB welding is that its concentrated beam transfers a lower total heat input to the workpiece, so it causes less distortion of the workpiece and a smaller heat-affected zone with altered metallurgical structures. Moreover, power and power density can be controlled more closely than in arc welding because the electrical circuits are totally independent of the workpiece. These advantages result in capability for deep, fast, high-quality, reproducible welding.

A major impediment to broader industrial use of the older vacuum EB welding processes has been the generally unacceptable delay time necessary to fully or partially evacuate the vacuum chamber in which the workpiece has had to be placed. Some EB welding applications, mainly in the aerospace industry, can tolerate the evacuation delay; in fact, the more reactive metals require the noncontaminating vacuum environment to achieve high-quality welds. However, many industrial welding applications could not be economically justified with the slower production rates of a vacuum-type EB welding process.

Therefore, nonvacuum electron-beam (NVEB) welding was developed to eliminate the need for a vacuum chamber.[1] It has brought EB welding into the broad area of industrial high-productivity welding applications. NVEB welding can produce quality welds at speeds many times faster than conventional fusion welding techniques at competitive costs. In addition, its high throughput capability justifies adaptation to fully automatic operation, further improving the cost effectiveness of the process. It has been successfully applied to a number of high-volume applications including welding of automobile frame members, emission control devices, collapsible steering columns, ball joints, compressor housings, and transmission assemblies.

Westinghouse NVEB Welding System

Welding Head—The welding head, from which the electron beam emerges, can be operated with the beam directed downward, horizontally, or at any angle between those extremes. Moreover, the welding head can be readily moved at high speeds and can withstand high accelerations. Thus, it provides the operating flexibility required for automation (Fig. 1).

The vacuum stages in the lower section of the welding head are connected by flexible hoses to mechanical vacuum pumps (Fig. 2). The pumps for the gun chamber and for the next lower vacuum stage are rigidly attached to the welding head; they are oil diffusion pumps of 2-inch diameter.

The end of the beam transfer column is pressurized to slightly above atmospheric pressure by air or other effluent gas to prevent entry of weld vapors. After the electron beam passes through the exit

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R. J. Lanyi is Manager, Specialized Welding and Cleaning Products and Processes, Process Equipment Department, Industrial Equipment Division, Westinghouse Electric Corporation, Sykesville, Maryland. B. W. Schumacher is Manager, High-Power Electron Beams, Systems Physics Development, Research Laboratories, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. J. M. Wells is a Senior Research Engineer, Metals Joining Research, Research Laboratories.

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Electron-Beam Welding

All electron-beam welding employs a well-defined beam of high-speed electrons, which transfer their kinetic energy to the workpiece on impact. Because the total kinetic energy of the electrons can be concentrated onto a small area on the workpiece, power densities as high as 10^6 watts per square centimeter can be achieved. That is higher than is possible with any other known continuous beam, including laser beams. The high power density plus the extremely small intrinsic penetration of electrons in a solid workpiece result in almost instantaneous local melting and vaporization of the workpiece material.[8] That characteristic distinguishes electron-beam welding from other welding methods, in which the rate of melting is limited by thermal conduction.

When the electron beam strikes the workpiece, it almost instantly produces a vapor-filled cavity with a sloped melt front. As the beam is moved relative to the workpiece, molten metal flows into the cavity and solidifies behind the beam. If the path of the beam is along an interface between two parts, solidification of the molten zone fuses the two together.

The electron beam is produced in an electron gun, which consists essentially of an electron emitter called the cathode, an anode opposite the cathode, and a beam-shaping electrode (the "grid") surrounding the cathode. (See Figs. 2 and 3.) Electrons are generated by heating the metal cathode to thermionic emission temperature, at which electrons boil off.

During operation, the cathode assembly is maintained at high negative voltage relative to the anode's ground potential. The electrons are accelerated and shaped into a beam by the resulting electric field and pass through a hole in the anode. Once the beam passes the anode, its energy is simply carried as kinetic energy of the electrons. The beam diverges due to the angular aperture of the gun, so it is refocused by a magnetic lens.

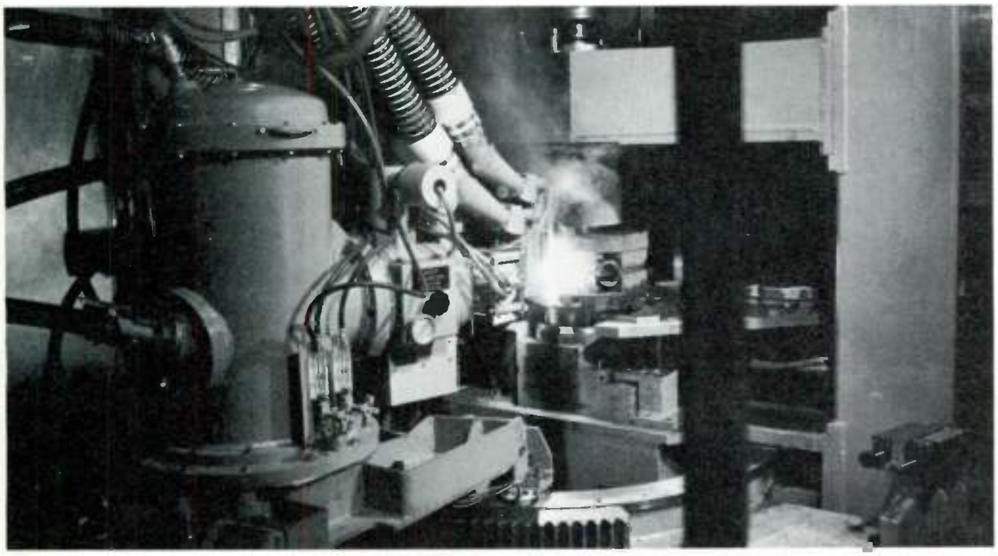
All elements of the electron gun are operated in high vacuum (10^{-4} Torr) to prevent high-voltage discharges and scattering of the electrons due to collisions with gas molecules. In nonvacuum electron-beam welders, a semivacuum is needed along the beam transmission path to limit beam spreading caused by scattering. It is provided by a series of small chambers progressively evacuated by vacuum pumps. The chambers are separated by orifices of small diameter through which the beam passes until it reaches atmospheric pressure at the exit nozzle.

nozzle, its diameter increases because of scattering of the electrons. The increase in diameter can be minimized by using helium as the effluent; because of its much lower atomic number, helium reduces electron scattering to about 5 percent of what it is in air and thereby enables the beam to retain greater power density at a given distance.[2]

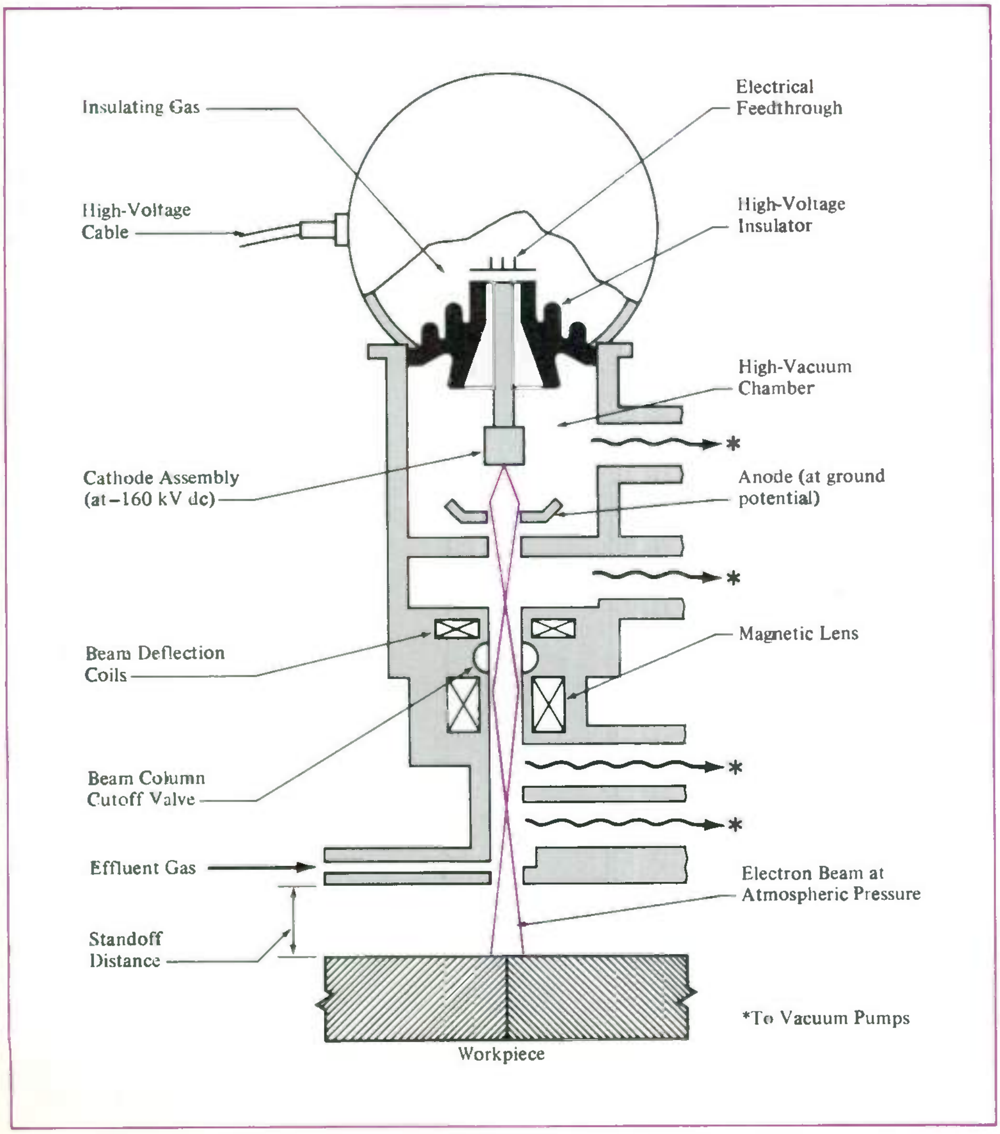
High-voltage power is supplied to the 36-kW welding head by a flexible cable from a remote high-voltage power supply. Welding heads of 12- and 24-kW rating have their high-voltage power supplies directly attached, eliminating the need for the cable. Auxiliary power supplies for the cathode are built into the welding head.

The welding head can be used as a vacuum welder by attaching it, minus the first two vacuum stages, to a workpiece vacuum chamber.

Electron Optics, Beam Formation, and Beam Control—The power density in an electron beam is subject to imperfections of the electron optics, as well as to thermodynamic limits.[3,4,5] A type of cathode that has nearly ideal electron optical properties has been adapted for the welder described here.[6] Electrons are drawn from the flat cylindrical end face of a tungsten bolt, 0.11 inch in diameter and 1.5 inches long, which is heated by electron bombardment from two auxiliary filaments (Fig. 3). This cathode has neither the geometric-optical aberration problems nor the strong magnetic



1—(Top) *The welding head of the 36-kW nonvacuum electron-beam (NVEB) welder is shown here in an application employing a horizontal beam. Both the welding head and the workpiece move under computer control to maintain constant welding speed. The workpiece is an exhaust emission control device for automobiles.*



2—(Bottom) *Main elements of the welding head are shown in this simplified diagram. Electrons are emitted from the cathode and are accelerated to high speed by the high voltage between cathode and anode. The resulting beam is focused and directed into the atmosphere. A series of vacuum chambers is evacuated to progressively lower pressures so that the cathode chamber can be kept at high vacuum. Air or other effluent gas is injected near the beam exit nozzle to prevent ingestion of welding vapors.*

fields of the conventional resistively heated cathodes. In addition, beam current and gun focus are electrostatically controlled over the full current range. Since emission is grid controlled, the stability of the heater circuits is not critical. This cathode can provide as much as 0.4 ampere, and its emission is completely stable and reproducible even after exposure to air. Useful life at 36 kW can exceed 50 hours of beam time, a 10-to-1 improvement over resistively heated cathodes at the same power level.

The high-voltage field between cathode and anode determines the initial direction of the beam. Fine adjustment is made possible by suspending the anode in gimbals so it can be tilted slightly in any direction, thereby shifting the electric field. This directional adjustment is needed mainly after cathode replacement to direct the beam through the uppermost nozzles without grazing them. A thermocouple attached to each nozzle monitors its temperature continuously; overtemperature shuts off the beam.

The gun focus, or first crossover of the beam, falls between the two uppermost nozzles. Then the beam spreads until it reaches a magnetic lens, which refocuses it at or near the exit nozzle. Fine adjustment of the beam alignment in this section of the machine is provided by two pairs of magnetic deflection coils above the lens. The small angular aperture and small diameter of the high-voltage beam generated in this system make the system insensitive to lens aberrations. (See *Beam Physics*, p. 101.)

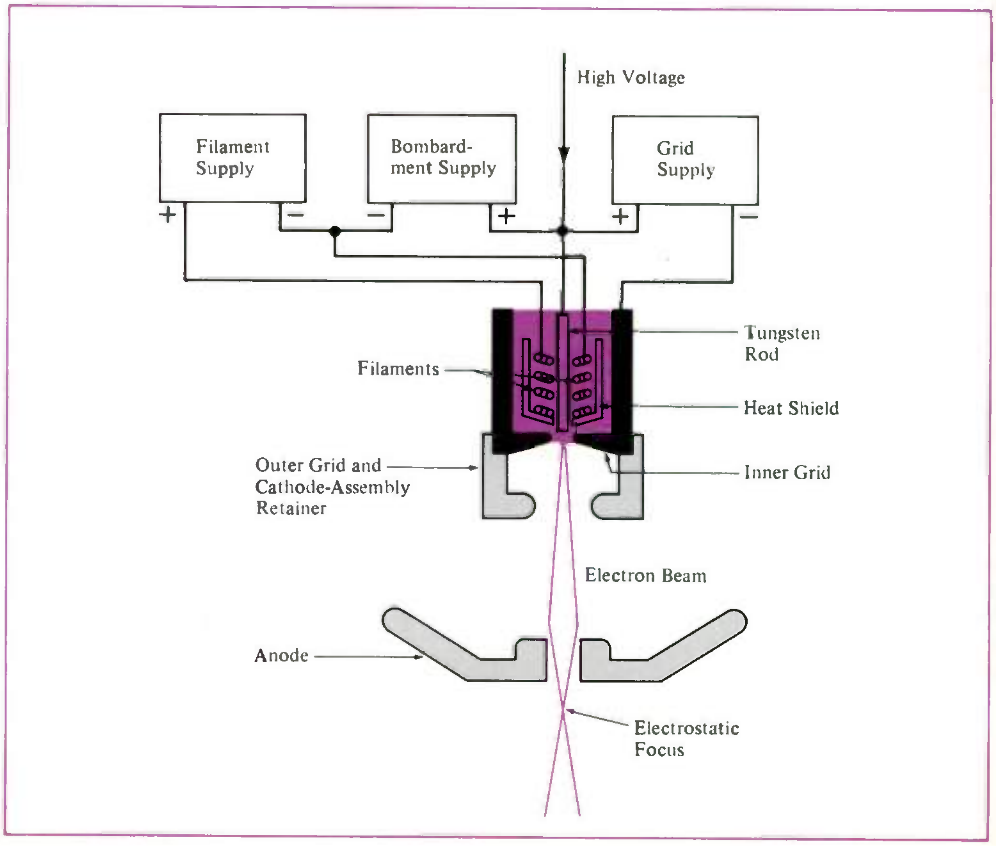
When the beam passes through the residual gas in the intermediate vacuum chambers, it forms positive ions that counteract space-charge spreading of the beam. Another beneficial effect with beams of high power and high power density is that the beam heats the gas in its path, thereby decreasing the gas density, which in turn drastically reduces scattering.[2] That effect results in larger useful beam projection than one might expect for NVEB welding.[7]

Power Supplies and Controls—Nominal operating voltage for the dc high-voltage power is 150 to 160 kV. The power is supplied by standard 12-kW modules that require 220-volt 400-Hz single-phase primary input. One, two, and three modules are used, respectively, in the 12-, 24-, and 36-kW welders.

The size of the module is kept small by energizing it with 400-Hz power and by use of pressurized sulfur hexafluoride gas as insulation. The module measures 16 inches in diameter by 24 inches long and weighs 160 pounds. Its 400-Hz input comes from a motor-generator set with field control by which the dc output voltage can be set and automatically controlled within ± 1.5 percent.

All operator controls for the gun are combined in one control cabinet along with all instruments needed to monitor such operational conditions as cathode power, nozzle temperatures, vacuum levels, beam voltage and current, and load sharing of the high-voltage modules. However, after the initial setup, a beam of preset power is simply turned on and off by pressing a

3—The cathode is a tungsten rod contained in a plug-in assembly that is readily replaceable (above). *The assembly also contains the auxiliary filaments that heat the cathode by electron bombardment* (right). *The cathode's operating characteristics are much more constant than those of resistively heated types, and it has much longer life.*



button. When required, a welding program can be provided to change beam power as a function of such variables as position of the welding head.

Process Considerations

Standoff distance (the separation between the beam exit nozzle and the workpiece) is limited in NVEB welding because the power density of the electron beam is gradually diminished by scattering. It is about 1.2 inches maximum with 36-kW beam power and air effluent, and about 2 inches with helium effluent. Weld penetration depth, for a given welding speed, decreases as standoff distance increases (Fig. 4).

Beam power (the product of beam accelerating voltage and beam current) also affects penetration depth and welding speed. In general, the depth of penetration achievable at a particular standoff distance, voltage, and welding speed increases approximately linearly with increasing beam power (Fig. 5). This increased penetration capability is a result of the increased power density (watts/cm²) at the higher power levels, since the beam diameter in NVEB welding stays about the same regardless of power level. Power levels to 36 kW are presently available; higher power levels have been achieved at the Research Laboratories in a continuing product development program. At 50 kW, for example, capability of penetrating 2 inches of steel has been demonstrated at a speed of 10 inches per minute.

Beam Physics

The quality of an electron beam is characterized by its radiance (W^*), which is the power per unit area and per unit solid angle. The thermodynamic limit of radiance is given by the cathode properties and relates to the focus properties as follows:

$$W^* = \frac{I_0 U_0}{\frac{\pi}{4}(\alpha_0 d_0)^2} = \frac{j_K U_0^2}{\pi U_{th}} \quad Wcm^{-2}sr^{-1}$$

where I_0 is beam current, U_0 is beam voltage, α_0 is beam angle at the focus, d_0 is Gaussian width at the focus, j_K is cathode emission current density, and U_{th} is mean electron temperature expressed in volts (typically 0.2 volt). For a tungsten cathode and a beam voltage of 150 kV, the theoretical numerical value is: $W^* = 2 \times 10^{11}$ $Wcm^{-2}sr^{-1}$. For a beam of 36 kW, i.e., $I_0 = 0.24$ ampere, and a focusing half angle of $\alpha = 2$ degrees (solid angle $\pi\alpha^2 = 3.8 \times 10^{-3} sr$), the equation yields a spot diameter (d_0) of 0.14 mm. In practice, because of lens aberrations and imperfections of the cathode surface, the actual focal spot has a diameter of the order of 0.6 mm, requiring an exit nozzle diameter of 1.8 mm.

Increasing welding speed at a particular standoff distance, beam voltage, and beam power level decreases weld penetration depth (Fig. 6). A further example of penetration depth versus welding speed is shown in Fig. 7.

Inert-gas shielding is not generally needed when welding steel. It is needed with the more reactive metals such as aluminum, titanium, and zirconium to minimize or prevent oxidation and porosity; helium should be used as the effluent gas and either helium or argon as the shielding gas. Simple but effective gas shielding devices have been designed for use as needed.

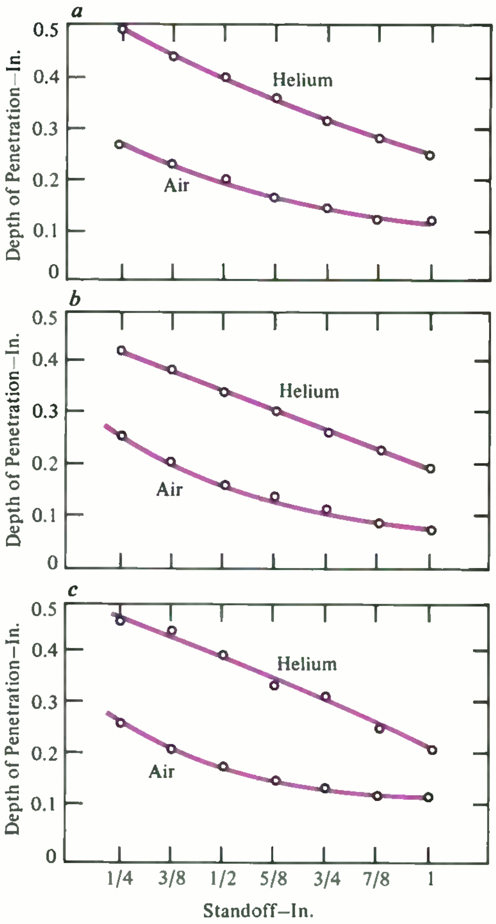
Joints are usually made without filler metal. However, filler metal can be added where weld appearance, joint fit-up, or metallurgical constraints require increased metal volume or alteration of the chemical composition of the weld metal.

Economic Considerations

Fully automated NVEB welding has greater throughput capability and flexibility than the more conventional welding methods have, so it is economically justifiable in high-volume applications. For relatively low-volume applications, however, the more conventional methods prove to be more economical.

The primary operating costs for NVEB welding, excluding special application considerations that might require wire feed or shielding gas, are electrical power, cathode assemblies, beam exit nozzles, and effluent gas. NVEB welders are efficient devices, with 90 to 95 percent of the generated beam energy delivered to the workpiece. If ancillary equipment such as vacuum pumps is considered, the overall

4—The depth of weld penetration with an electron beam in air diminishes with standoff distance. It is considerably greater when helium is used as the effluent than when air is used. The values shown are for a 24-kW 150-kV machine welding (a) *5083 aluminum at 240 inches per minute,* (b) *1010 carbon steel at 120 inches per minute, and* (c) *304 stainless steel at 120 inches per minute.*



efficiency of a basic 36-kW welder is 55 to 60 percent. At $0.02 per kilowatthour, this results in a cost of $1.40 per hour for electrical power. Approximate operating costs are summarized in Table 1.

The 12-, 24-, and 36-kW cathode assemblies are guaranteed for 60, 50, and 40 hours respectively and can be rebuilt. Total machine down-time for replacing a cathode assembly is typically 30 minutes, and beam exit nozzles can be replaced in less than 10 minutes.

Table 1—Approximate Hourly Operating Costs for NVEB Welders

	Power Rating		
Cost Items	*12 kW*	*24 kW*	*36 kW*
Electrical power*	$0.80	$1.10	$1.40
Cathode assemblies†	2.00	3.50	4.50
Beam exit nozzles and miscellaneous	1.00	1.25	1.50
Effluent gas—air	—	—	—
Effluent gas—helium with recovery‡	3.00	3.16	3.33
Effluent gas—helium without recovery‡	9.00	9.50	10.00
Total—air effluent	3.80	5.85	7.40
Total—helium effluent with recovery	6.80	9.01	10.73
Total—helium effluent without recovery	12.80	15.35	17.40

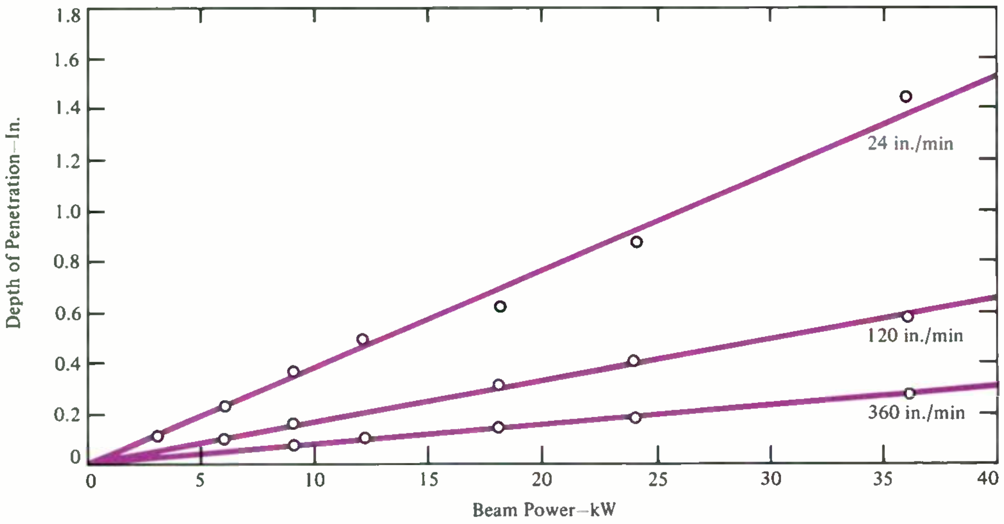
***At $0.02 per kWh.**
†Based on guaranteed life and rebuilding cost.
‡At $0.06 per cubic foot.

Production Adaptability

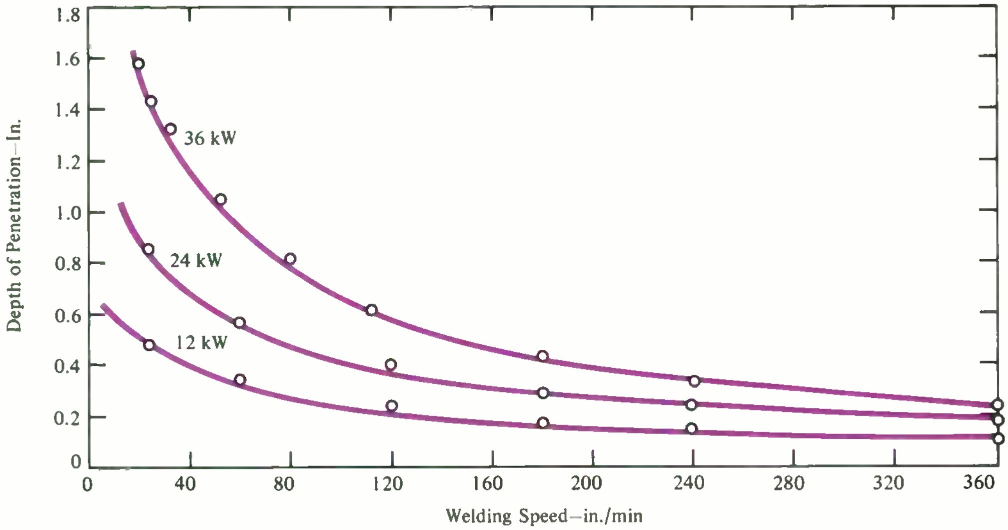
The welder's capability for high welding speed and consequent low operating cost per unit of output justifies use of fully automated handling equipment for many applications. Since welding is done without the need for vacuum pumpdown, the parts to be welded can be moved freely to and from the welder at speeds that fit modern high-production technology. Controllability of the process and equipment results in consistent welds of high quality. Operating simplicity and reliability are attained by fully automated machine sequencing.

The handling equipment selected for a specific application must serve two major functions—nonprecision transfer of the material to and from the welding location, and precision motion control of the material relative to the electron beam during welding. In some instances, such as the longitudinal seam welding of continuous tubing, the same transfer equipment serves both functions. At the other extreme, it may be necessary to use a CNC (computer numerical control) positioner to move the welding head rapidly along a complex seam, and transfer parts by some other high-speed mechanism.

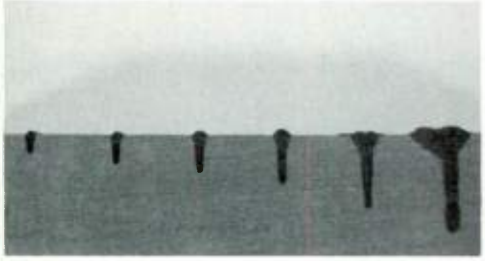
Two examples of fully automatic NVEB welding systems follow.



5—(Top) *Penetration depth at a given welding speed depends also on beam power. Here the material is 1010 carbon steel welded with helium effluent at ⅜-inch standoff and 150 kV.*



6—(Bottom) *Penetration depth is plotted versus welding speed here for three power levels. The material is 1010 carbon steel welded with helium effluent at ⅜-inch standoff and 150 kV.*



7—This photograph of bead-on-plate weld specimens also illustrates the effect of welding speed on penetration depth, as well as the characteristic shape of NVEB welds. Welding speeds were, from left to right, 360, 240, 180, 120, 60, and 24 inches per minute, and penetration increased from 0.160 to 0.830 inch. The material is 1-inch 304 stainless steel, welded with helium effluent at 24 kW and 150 kV.

8—This component of an automotive frame was welded in a prototype EB welding system that can make the butt welds at 280 inches per minute. The component is 36 inches long. It is held stationary while two welding heads, one on each side, follow the seams and make the welds.

Example 1—A prototype system for welding automotive frame components has two 36-kW welders mounted with beam axes horizontal on two independent four-axis CNC positioners. The welders face each other and simultaneously contour-weld the two butt seams of a complex steel box section (Fig. 8). Welding speeds range up to 280 inches per minute. Dual synchronous shuttles, each holding two parts, transfer parts to and from the welding position through radiation gates at each end of a shielding booth enclosing the positioners and welders. When one shuttle is in the welding position, the second shuttle is outside the booth for automatic unloading and manual reloading. Total machine cycle time for welding two parts, each 72 inches of weld length, is 22 seconds, yielding a gross production rate of about 325 parts per hour.

Assuming the use of two operators for manually loading parts, a utilization factor of 80 percent, no use of filler wire, and the welder operating costs listed in Table 1 for air effluent, the welding cost per part is approximately $0.11, which compares favorably with the approximate cost of $0.26 for the presently used gas metal-arc manual welding with filler wire.

Example 2—A three-axis CNC system has been supplied for edge seam welding of stainless-steel automotive emission control devices (Fig. 9). The shape of the part made it impossible to contour-weld by moving only the welding head. Use of a fixed-position head and contouring by moving only the part was ruled out because of the high-speed reversals that would be required on the servo-driven axes. Such reversals would require extremely large servo systems, sufficiently uniform contouring speed would be difficult to maintain even under the best conditions, and weld quality might be degraded by high acceleration forces on the weld puddle.

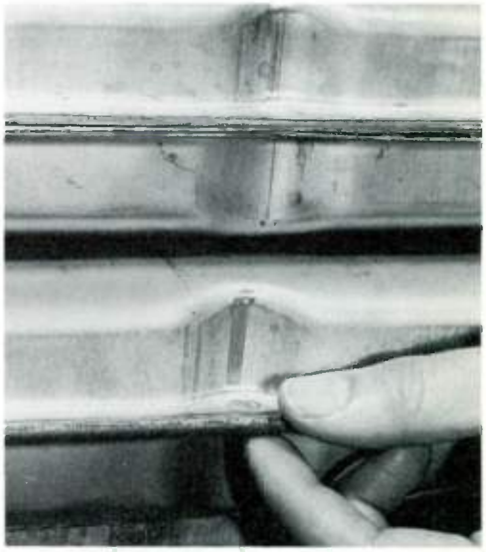
Consequently, a combination of welder motion and part motion is used (Fig. 10). A three-axis CNC system provides rotational motion of the part around its centerline (*A* axis), in/out motion of the horizontally mounted welding head (*Z* axis), and rotary motion of the welding head around the beam impingement point (*B* axis) to keep the beam perpendicular to the weld seam. Since the welding head rotates around the beam impingement point, only the relatively slow-moving *A* and *Z* axes influence the welding speed and need to be precisely controlled. While the welding head moves rapidly to maintain beam perpendicularity, the part experiences only low accelerations, which helps produce a high-quality consistent weld. Time sharing enables one CNC unit to control several welding machines simultaneously.

Use of infeed and outfeed tunnels for part transfer eliminated the need for radiation gates, which would have imposed high speed requirements on the transfers and would have added cycle time. This approach resulted in use of three low-speed indexing transfers having a U-shaped floor arrangement (Fig. 10). The transfers deliver parts to and remove them from a dial index table that rapidly moves the parts to and from the welding station. The nonwelding portions of the machine cycle consist of a 90-degree index motion of the dial table and short vertical motions to raise the part off the dial table at the welding station and lower it back onto the dial table after welding. A programmable controller is used for machine sequencing, allowing the CNC unit to be dedicated to control of the three servo axes.

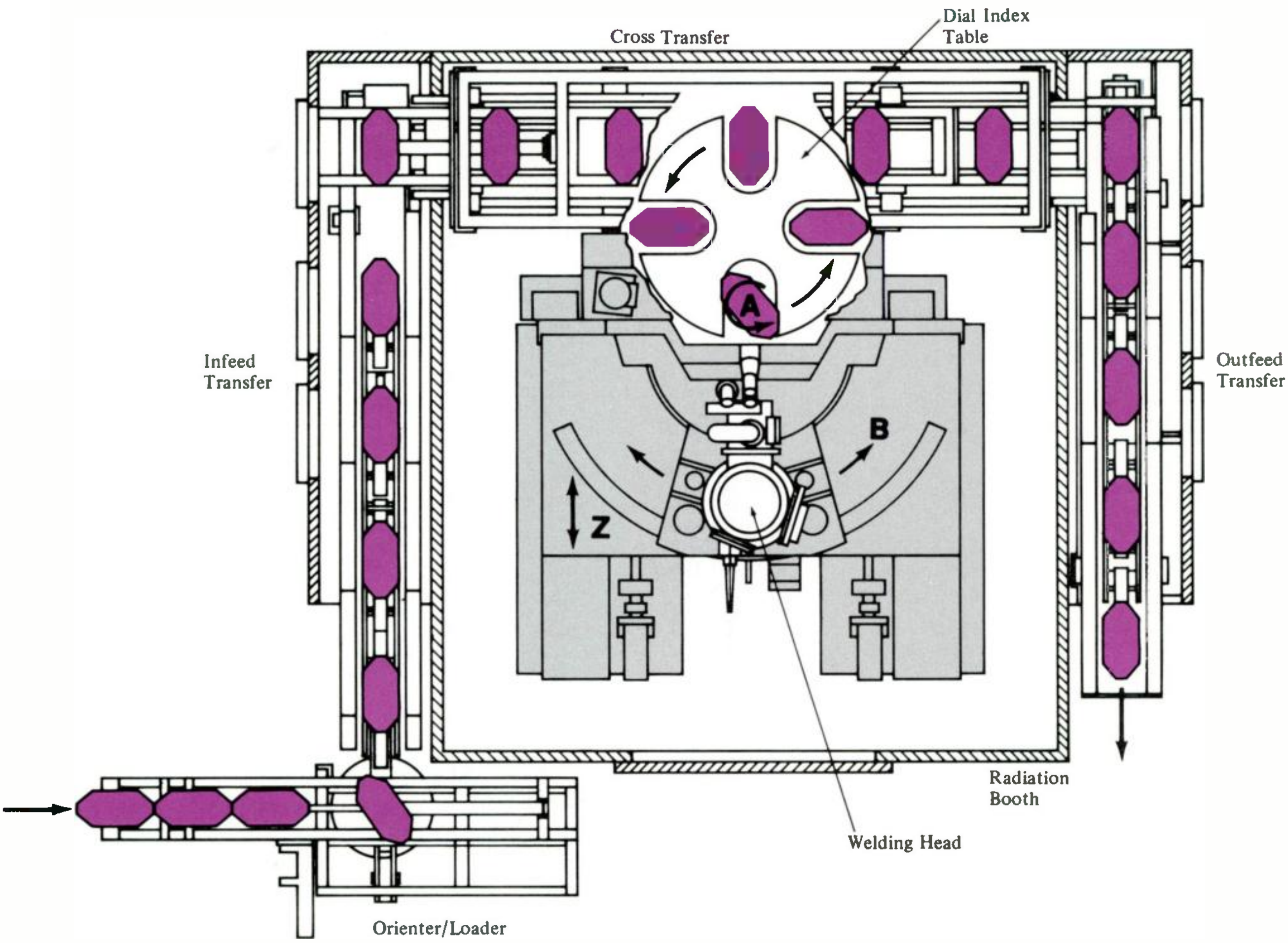
Welding at 36 kW and at 300 inches per minute, 48 inches of weld is made on each part in 10 seconds. Three seconds are used for changing the workpiece.

Conclusion

NVEB welding provides industry with a high-speed high-quality metals joining process. No vacuum chamber is required for the workpiece, simplifying adaptation of



9—The automobile emission control device being welded in Fig. 1 is shown here, at top, before welding and, bottom, after welding. The 48-inch weld is made in one pass that takes 10 seconds.



10—In this simplified diagram of the system for welding the emission control device, workpieces enter at lower left, are oriented, and are conveyed into the lead-lined booth that traps X rays emitted by electron-beam welding. They are placed on the dial index table, which brings each piece in turn to the welding head. The part being welded is lifted off the table, clamped, and rotated around its centerline (the A *axis) while the weld is made. At the same time, the welding head moves in and out* (Z *axis) to keep standoff distance small, and the head also rotates around the beam impingement point* (B *axis) to keep the beam perpendicular to the weld seam. The speeds of all motions are controlled to keep the relative speed between beam and workpiece constant. When a piece has been welded, the dial index table returns it to the cross transfer for delivery out of the booth.*

the process to high-volume applications and to large parts. Recent developments have extended the power capabilities of available equipment and have simplified equipment operation. By combining the process advantages of NVEB welding with the proper system concept, quality welds can be made with economy at high speeds on many metals and on a wide variety of shapes and sizes.

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Designing and Implementing Integrated Material-Handling Systems

Darrell B. Searls

Material handling and material management are integrated with each other and with other distribution and production functions in a new problem-solving approach. Such integration of functions can reduce capital costs and operating costs by making continuity of movement and automation much more feasible than they once were. To be successful, the approach requires a careful study of the problem, an imaginative but practical system design to solve the problem, and professional project management to implement the design.

Good material handling provides for the delivery of material to the point of use at the required time and in the required condition for the least expenditure of capital and labor. Therefore, it cannot exist without good material management and vice versa—the two are mutually dependent. For brevity, the combination of material handling and material management is just called material handling in this article. It encompasses purchasing, inventory policy, receiving, inspection, transporting, material control, storing, retrieving, picking, packing, shipping, traffic control, electronic data processing, planning, and indeed every aspect of a distribution or production system.

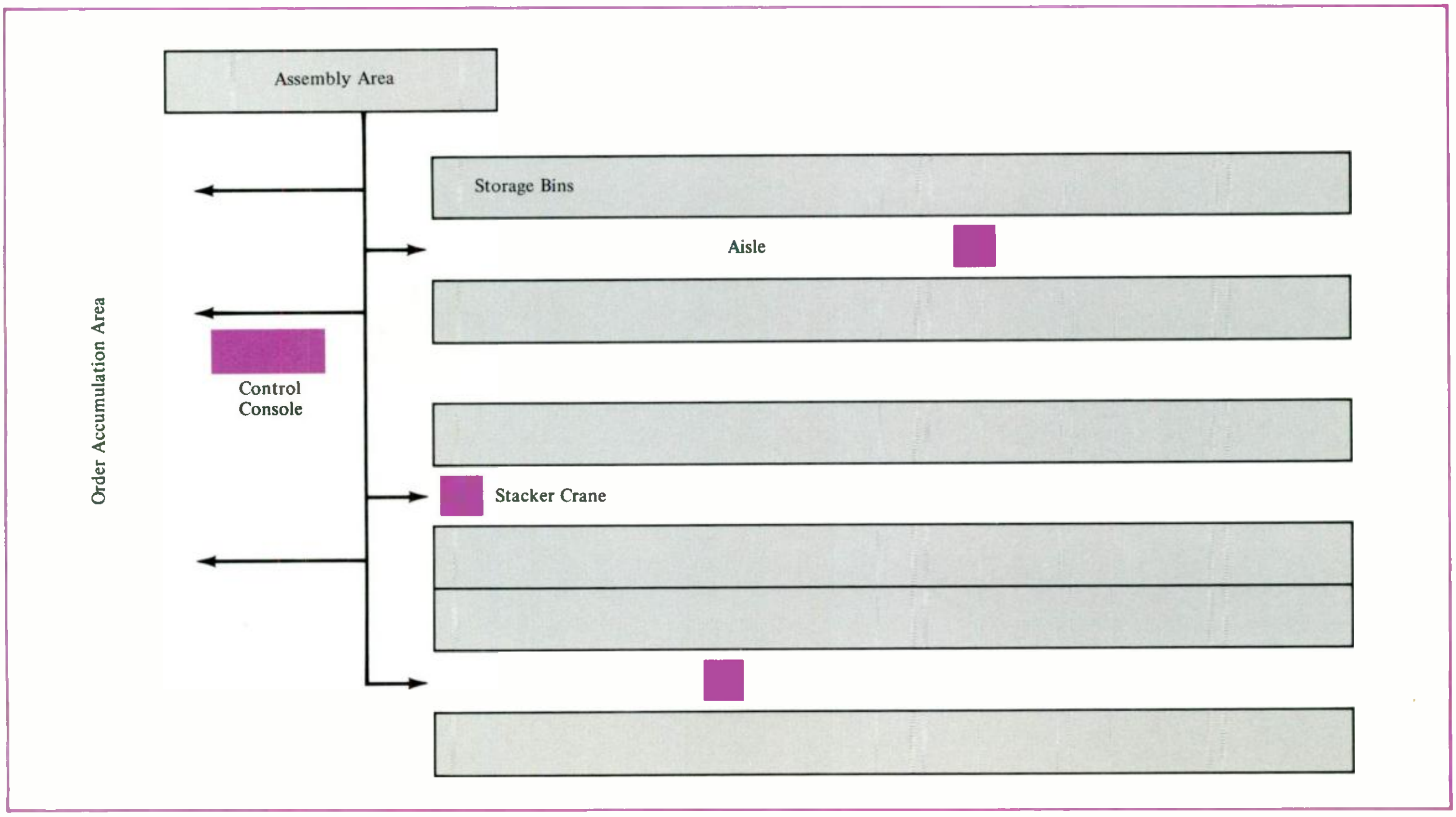
Acceptance by management of this philosophy of integrating material handling with other plant functions has resulted in integrated systems that have reduced operating, capital, and product-distribution costs substantially. It has also established material handling as a line management responsibility.

Integrated Material-Handling Systems

For this article, a "system" is defined as a combination of elements that satisfies the requirements of a complete function. Integrated systems, then, are still broader combinations satisfying the requirements of many related functions.

The new philosophy of material handling has three main facets: integration of functions, continuity of movement, and automation. The most important of those is integration of material handling with other plant functions.

Integration means that the distinction between functions becomes blurred in good material handling. For example, receiving, order verification, inspection, storing, rec-



1—An early example of the integrated approach to a warehouse system is this one at the Westinghouse Interior Lighting Division in Vicksburg, Mississippi, where three semiautomatic stacker cranes store some 250 different items on 4- by 4-foot pallets in 3000 storage openings. The storing and retrieving of the plant's products are integrated with the flow of information about products and orders. Input to (and output from) the storage system is accomplished by loading and unloading static buffers with forklift trucks. Information on inventory and available storage locations is filed on cards. Material and information movement is batched, but within a time frame that at least suggests continuous movement. Automation consists of hard-wired programmed control of the stacker cranes that integrate lifting, traveling, and depositing functions in a continuous sequence in response to input or output commands from punched cards or digit switches.

Darrell B. Searls is Manager, Automatic Material Handling Systems Group, Industry Systems Division, Westinghouse Electric Corporation, Buffalo, New York.

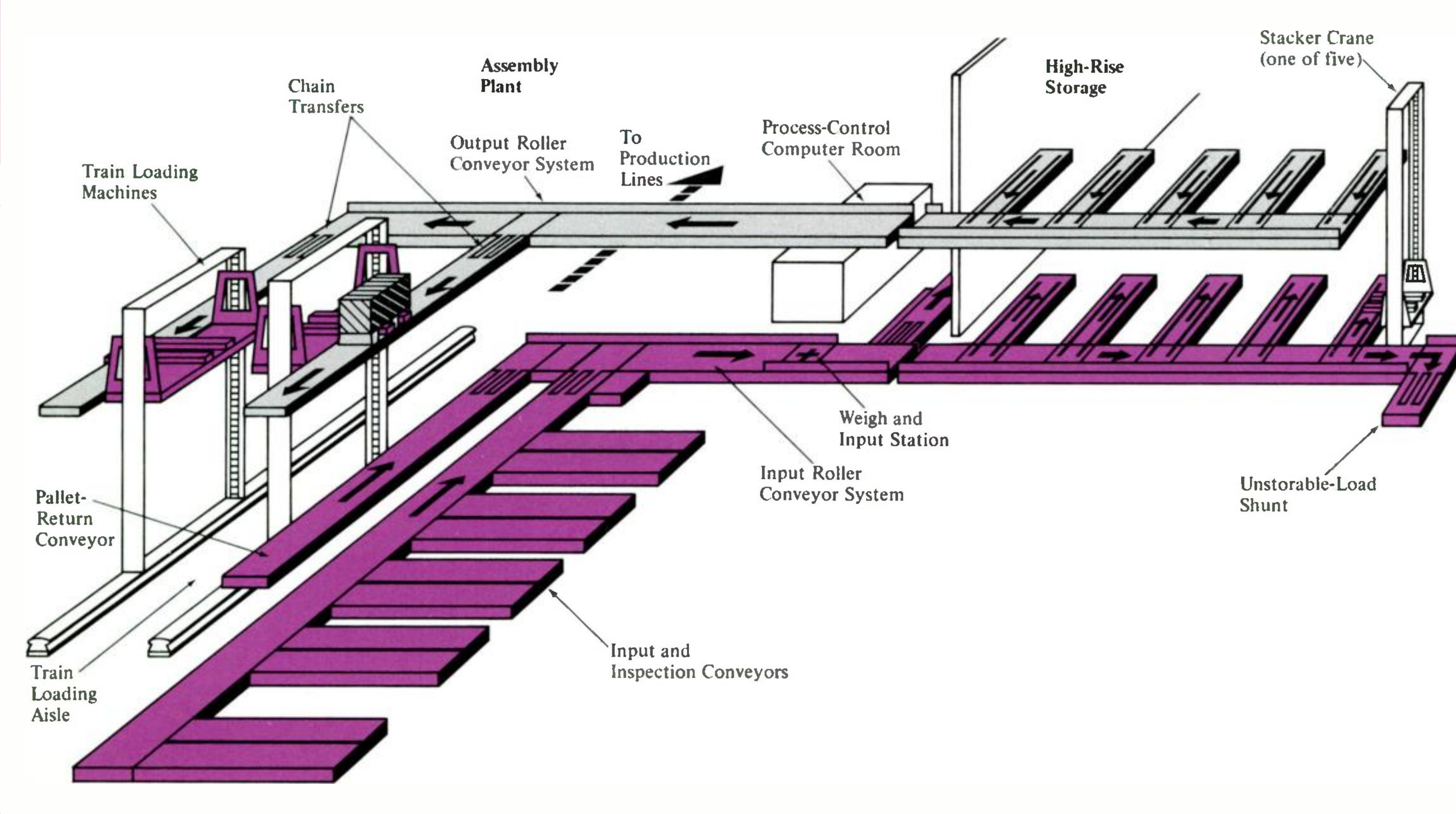
ord keeping, production scheduling, retrieving, and moving functions are melded into handling and transport, with computer-based control coordinating all actions. With breakdown of the artificial barriers between functions and a coordinated approach to the total process, continuity of movement throughout a manufacturing cycle (or other process) becomes possible, and it becomes easier to justify automation of the integrated functions.

Evolution of Warehousing—The integrated systems approach to material handling evolved from mechanized warehouses, where receiving, transporting, storing, retrieving, and inventory-control functions were first served by one integrated system. An example of such a warehouse is the one at the Westinghouse Interior Lighting Division plant, which was completed in 1966. There, fluorescent lighting fixtures are moved from production lines into storage and held until required to fill customer orders (Fig. 1).

Continuity in movement of material and information was developed further with automation of input to and output from high-rise storage via conveyors, lifts, and transfer cars. One such warehouse was built to receive and dispense all purchased material at the East Peoria plant of Caterpillar Tractor Co., where three production lines turn out large crawler tractors and other lines produce engines and transmissions. Material, and information identifying the material, are introduced into the storage system at a point remote from the storage area. The material travels via conveyor or transfer car, and the information flows via electronic telecommunications to central data processors and controllers that then track the flow of the material into storage. Movement is continuous and automatic. For retrieval, the accurate inventory file enables the system to locate the material and move it to an output or order-picking location. Thus, this warehouse has achieved integration of material storage, transportation, and accounting functions.

Further development has involved larger systems and more integration of functions. For example, another warehouse being designed for Caterpillar is larger and more extensive than the one just discussed. It will serve a new engine plant in Mossville, Illinois, and it is scheduled to be in full production in 1976.

Warehouses have evolved into "distribution centers," which have essentially complete computer control of material movement and information flow with data processing done by hierarchies of computers communicating with each other. The central warehouse for Hankkija, a cooperative in Finland, is an example of the current state of the art. Material arrives by rail or truck, having been ordered in response to business projections and stocking rules developed by Hankkija's management. The material is received, assigned a load number, and dispatched to a storage area. It is stored, retrieved for order picking, and the remainder stored again under the control of a Westinghouse P-2500 process-control computer, which also records each transaction. At the end of the day, a summary of the transactions is passed to a data-processing computer,



which extracts data, prepares management reports, and keeps a backup inventory file as insurance against possible malfunction of the process-control computer. The data-processing computer processes customer's orders and prepares retrieval schedules for order filling. The schedules are passed to the process-control computer in the form of magnetic tape identifying the loads to be retrieved and the material to be picked to satisfy each order.

Application to Manufacturing—The benefits of integration of function, continuity of movement, and automation are greatest in a factory environment because they include manufacturing benefits as well as warehousing benefits. The benefits are a reduction of inventories of raw, in-process, and finished goods because of real-time on-line inventory control, reduction of manufacturing time because of continuous flow of material and information, and reduction of direct labor costs because of automation. Those benefits reduce direct product cost, and the reduction of manufacturing time increases throughput per unit building volume and thereby reduces indirect product cost.

2—Greater continuity in movement of material and information is achieved by further automation of input and output, as in the plant illustrated by this simplified diagram. It is Rockwell International's Marysville assembly plant for truck axles, where material handling is integrated advantageously into manufacturing operations. Parts are received in containers, which are unloaded by forklift trucks and placed on an input and inspection conveyor. The containers are moved by transfer car and conveyor under the control of a computer to the weigh and input station and then are stored in random order in high-rise storage consisting of 7000 openings and served by five stacker cranes. Computer control also directs a continual flow of parts from storage to the assembly lines via conveyors and driverless tractor trains.

An example is Rockwell International's Rockwell-Standard axle assembly plant at Marysville, Ohio (Fig. 2). Finished axle parts, received in containers from supporting plants, are placed on combination input and inspection conveyors. From that point, movement of the parts is controlled by a Westinghouse P-2000 process-control computer until the parts appear at the point of use on the production lines.

The process-control computer stores the material in high-rise storage and then reports to a central data-processing computer that the material is in storage and ready for use. That computer contains detailed information relating to the manufacturing process, bills of material, substitution schedules, standard times for assembly operations, and availability and condition of work stations—in general, the data base for the manufacturing operation.

Production scheduling, which is dependent on the many factory variables, is accomplished in a batch mode on the data-processing machine, which formulates schedules from the data base stored in its large memory. Once the optimum schedule is established, retrieval information is prepared for the process-control computer telling it to withdraw and dispatch material to production-line work stations to arrive two hours before actual use.

Designing an Integrated System

The degree of success of a plant depends on how well the material-handling system is designed and how well it is integrated with all other plant functions. Logical steps must be followed in the design of the system, its associated production area, and the envelope that will enclose the total facility. The designing of the material-handling system must proceed concurrently with plant design, and flexibility must be designed into the total system to accommodate a reasonable amount of product change.

The design effort requires interaction of many technological disciplines. Because the delineation between plant functions is reduced, the system designer must have a broad knowledge of the technology supporting all the interacting functions and the managerial ability to control the team of experts required to develop the facility. The design approach taken by the Westinghouse Automatic Material Handling Systems Group is outlined in Fig. 3.

Data Collection—Success in planning a material-handling system depends on the planner's ability to generate an accurate data base extensive enough to allow systems analysts to define the material-handling problem. All too often, planners jump ahead to problem solution before the problem is adequately defined, with the predictable result that the system finally implemented does not solve the real problem.

The data base that must be acquired before integrated material-handling concepts can be developed consists of production-line requirements and data on such details as size and shape of parts, identification of parts, and inspection policies.

Actually, the design doesn't start with the plant or the material-handling system but with the product itself. Armed with a bill of material of all parts required to make the product, designers place themselves at the end of the production line and work backward along the line, identifying the places where parts must appear and at what rate to meet planned production rates. They trace all parts back to their points of origin and define what material-handling and control techniques are required to place the parts where they are needed at the right time. Everything is planned to operate in real time under continuous control, with feedback routes from the point of use back to the source of parts so the system can respond to emergencies such as the discovery that parts are defective; in that event, the system must be able to route replacement parts quickly so that the production line is not shut down.

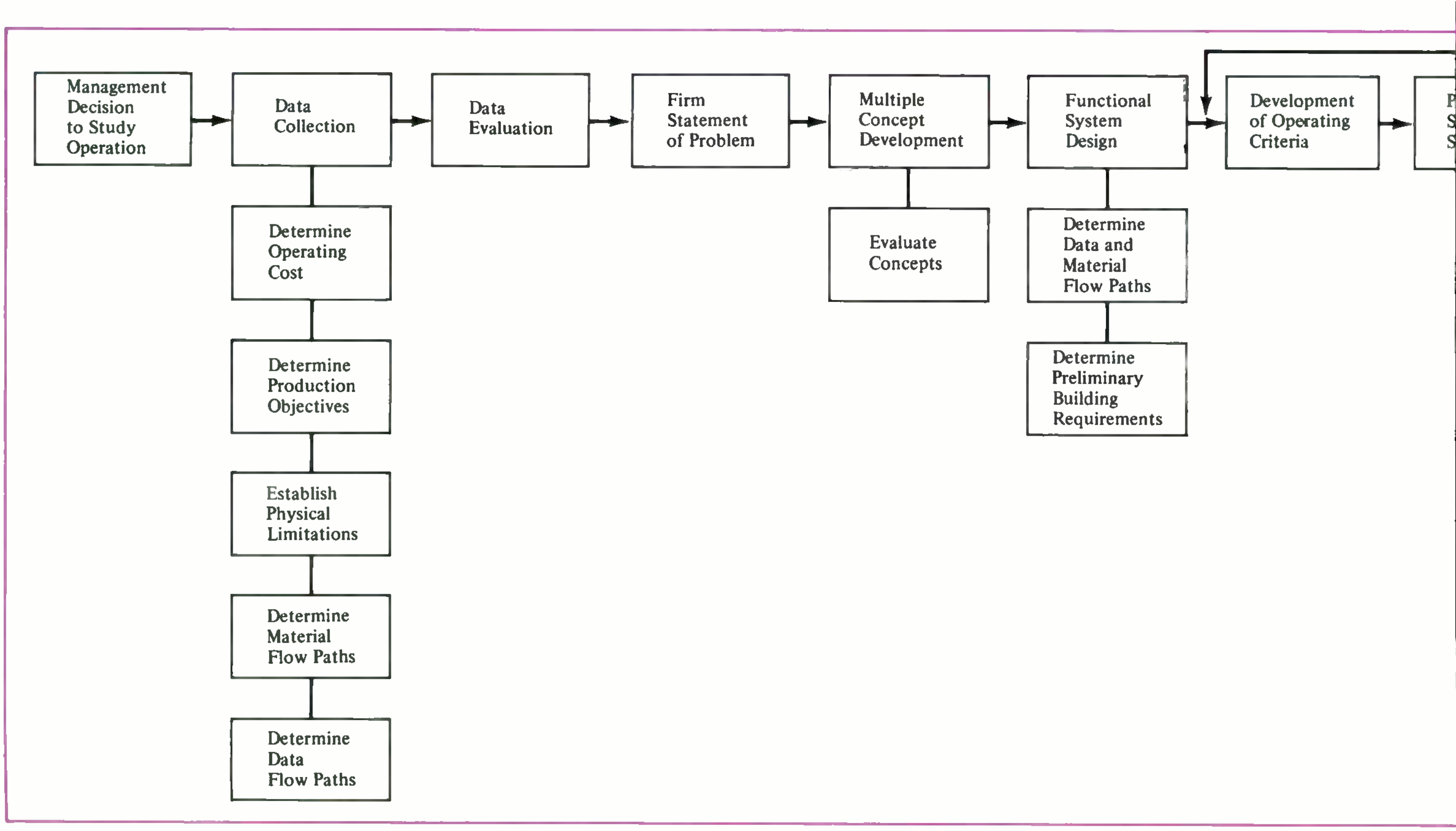
The warehouse inventory is the source of information for production planning, and production control establishes hourly and daily schedules that automatically program the material-handling system responses. Some producers are trying to look still further back into the supply chain, recording vendor stock and vendor lead times for purchased material and incorporating that information into production planning to determine the required size of raw-material and purchased-part stocks.

Generally, the task of acquiring the data base for planning is simplified if historical data are available. For the warehouse at the East Peoria plant complex of Caterpillar Tractor Co., for example, detailed historical data were available on such things as the material to be stored, activity of individual parts, inspection procedures required on each part, cyclical inventory procedures, and engineering change procedures. The data collection task was still formidable, because the functions to be combined into one facility and operation were scattered over several warehouses and storerooms that kept data in different formats. That, together with the fact that physical dimensions and information on nesting qualities of some parts were not available, made it necessary to develop some of its data from a physical sampling of the material to be stored.

To establish a basis of comparison for justifying the concepts that will be developed, the data base must include not only sizes, shapes, and activity figures on material to be stored but also details of current operations. Also needed is information on physical limitations that will affect flow lines, building cost, and transportation cost; existing material flow paths and data flow paths with which the new facility must integrate; and, most important, the justification guidelines that will be used in comparing the project with others that will be competing for available capital funds.

Statement of Problem—The raw data are evaluated and manipulated to find families of parts, patterns of movement, container sizes, and operating requirements until an accurate and complete statement of the problem is developed. Old policies and rules are challenged and discarded if they cannot be defended as necessary for successful operation. At Caterpillar, for example, a policy dictated that direct parts (those that would become part of a tractor) and indirect parts (those that would be consumed in the plant) must be separated in the warehouse by a physical barrier. It was an outgrowth of the fact that two separate accounting groups had been accountable for the two classes of parts. Also, indirect parts had more general utility and, therefore, required a higher degree of security than direct parts. That justification for the policy was not valid in a central high-rise warehouse, so the policy was discarded.

Concept Development—This is the problem-solving function, and it is dependent on the experience and creativity of the designers. Since there are generally a number of solutions for each problem, the designers must find the solution that best solves the problem. For example, the movement of unit loads from one point to another can be accomplished by lift trucks, roller conveyors, chain conveyors, carts towed by in-floor or overhead chains, tractor trains, transfer cars, cranes, and other means. Each solution must be analyzed for cost, throughput, flexibility, controlability, maintainability, and adaptability to the rest of the system. Analysis must be thor-



ough, and personal biases should not influence the evaluation. Final selection then should be relatively simple.

Integration of functions reduces the number of interfaces and, more important, requires that planners look beyond each interface to the function in the adjoining operation. The Caterpillar plant, for example, is designed for continuity of material and information flow (Fig. 4).

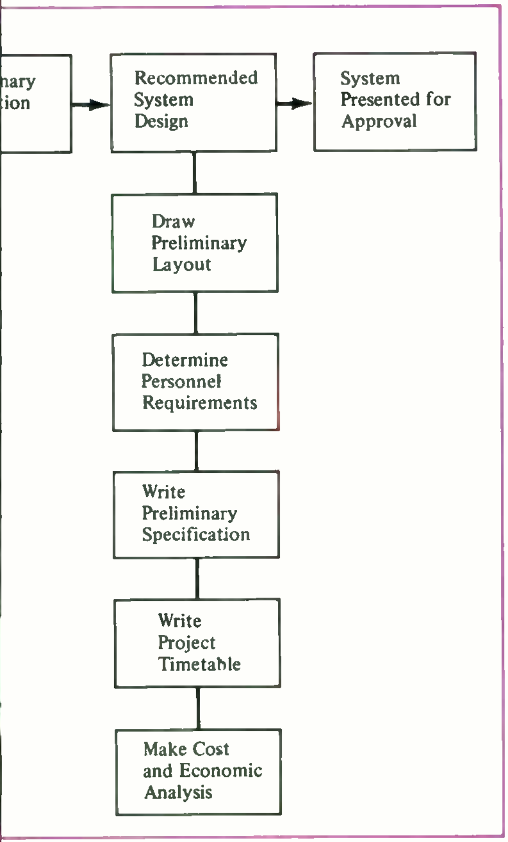
The integration concept also had a significant impact on building design and plant layout at the Rockwell-Standard plant. Production lines were developed on the premise that enough production material to support two hours of running time would be stored at the line and no intermediate marshalling of material would be allowed (Fig. 5). The response time of the primary storage system is such that material flows directly and continually to production lines. Elimination of intermediate marshalling reduced the physical size required for the plant, with the result that the warehouse physically dominates the facility.

Opportunities for cost savings arise in the design of the structure as well as in the design of the material-handling systems. For example, one of the features of the Hankkija warehouse mentioned earlier is utilization of the rack structure, which supports the pallet loads, as the building support structure. That approach reduces construction time, because installation of the material-handling equipment doesn't have to wait for completion of the building.

The concept-development stage is not the place for a "do-it-yourself" philosophy; instead, it is essential to obtain the best help available. That kind of help comes from systems engineers who have developed and implemented problem-solving concepts in related areas. Most plant management groups build only one new plant in their corporate lives, while a team in a systems engineering and project management group conceives and builds a new system every two years on the average.

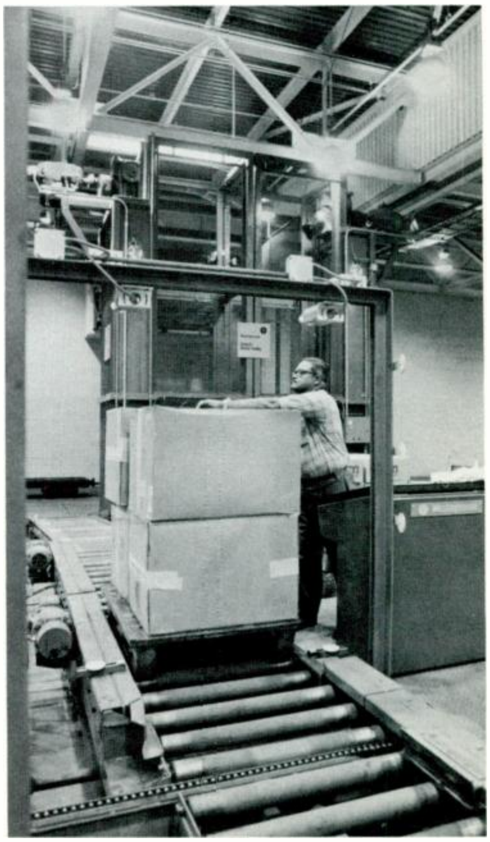
The creativity of the systems engineer in developing concepts is tempered by his experience in implementing systems, which limits his "blue sky" thinking to something that can be handled in the real world. Also, his thinking will be evaluated by other systems engineers in his organization, and his concepts will be scrutinized by the customer's project team (which should include people who will be responsible for operating the system). Moreover, even if there is consensus among all concerned on a system concept, it will still be subjected to the harsh mathematical scrutiny of a simulation study before it is accepted.

Design Recommendation—The recommended design must be well documented so that decisionmakers get a complete and comprehensive picture of the benefits to be realized by going forward with the project, as well as of the cost and time that must be expended. Documentation should include a summary of the data used to define the problem, a statement of the problem in terms of capacity and throughput, an explanation of concept development, a description of the recommended system, a description of operation, an estimate of system cost and benefits, and supporting documents such as simulation results.



3—Designing an integrated system requires a disciplined approach as diagrammed here. This approach insures that all variables are considered in defining the problems to be solved and that problem-solving concepts are tested against operating requirements before a system recommendation is made.

4—Material and identifying information are introduced into the storage system together at the East Peoria plant of Caterpillar Tractor Co. The system is described on the back cover.



Documentation may include a three-dimensional model of the total system.

Final Design and Implementation

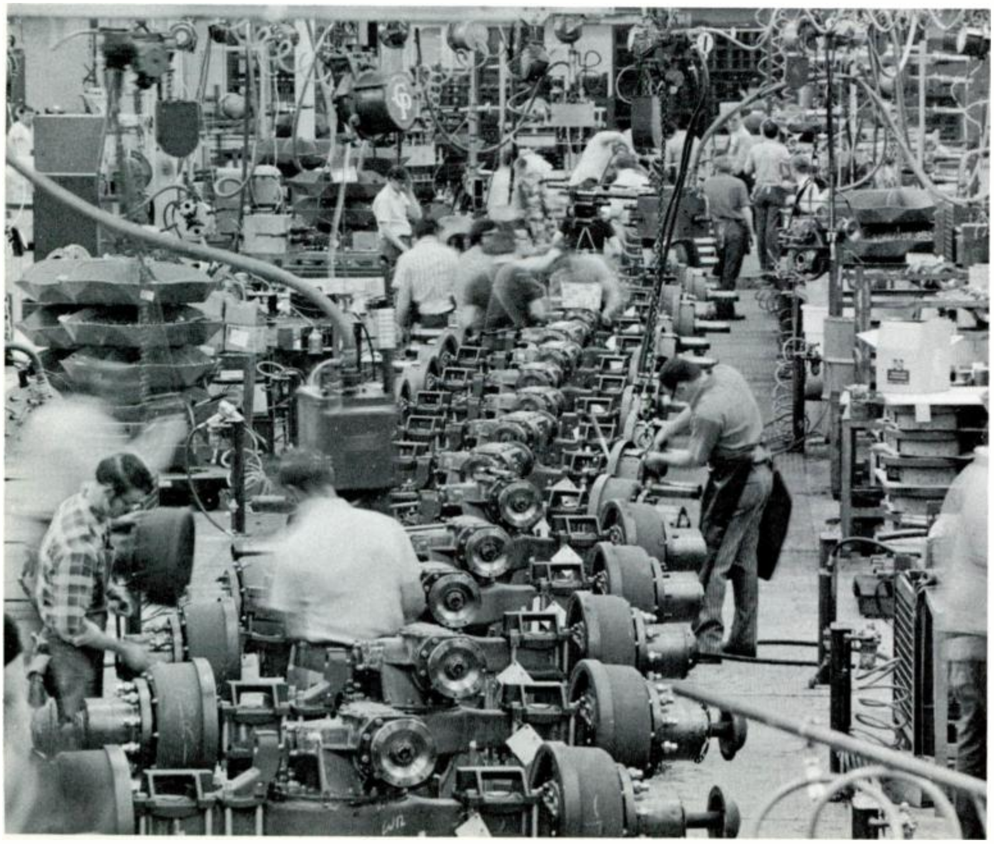
While a poorly executed concept-development study results in project failure, a well executed study does not guarantee a successful project. A concept can be lost in the final design, which is the first phase of implementation (Fig. 6).

Final System Design—This is a critical stage of the project because designers find that changes and improvements in the original concept are necessary in some cases and desirable in others; the danger lies in the concept being so altered as to lose the very features that made it the best solution to the problem. For example, a warehouse designed to feed production lines controlled by a centralized production control scheme would operate effectively if the same control scheme were used to schedule material out of the warehouse to meet the established production rate; however, it would be totally inadequate if the production lines were operated individually on a demand basis, with an undisciplined demand for parts from the warehouse.

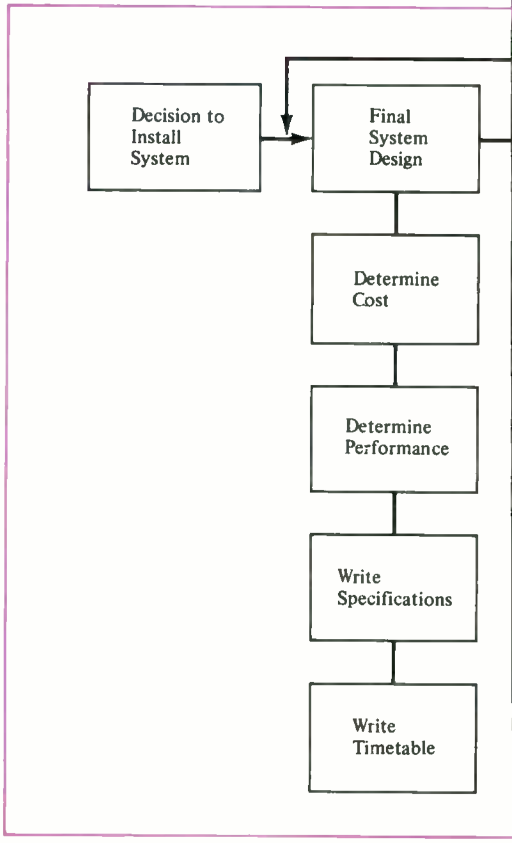
The designer must not lose contact with the data and the development process that led to the problem definition. Experience indicates that the best assurance this will not happen is to have the same team that did the concept-development study perform or supervise detailed system design, and to require the team to check the final design with a complete system simulation before construction begins.

Manufacture—Selection of equipment should be based primarily on reliability as proved by operating experience. Fortunately, there are generally two or more qualified suppliers of most equipment normally incorporated into a material-handling system. If an untried piece of equipment is to be utilized to gain an innovative advantage, it should be built and exhaustively tested as a component before installation in the system.

Control design and equipment selection are best left to the system supplier. He should have extensive experience with control systems because control is a key function in a complex system. The control design must be flexible—even more flexible than hardware design. Flexibility is needed to cope with changes that will occur during the life of the system, such as changes in throughput needs, number of locations served, and number of parts in the system.



5—At the Rockwell-Standard axle plant, integration of warehousing and manufacturing made it practical to deliver parts continuously from storage to the assembly lines, and that capability eliminated the need for large storage areas in the assembly plant. To allow for minor material-handling interruptions, enough material is stored right at the assembly lines to support two hours of work.



6—When a recommended material-handling design has been accepted by the user, the project enters the final design and implementation phase. The work is structured so that the original problem-solving concept will not be altered and the benefits of the concept lost. A computer simulation of the system, following final design, assures the integrity of the concept, and project management holds the project to the established time and cost schedules.

Project Management—Project management consists of planning, organizing, and controlling the work to implement the system. It is important for the user that these functions be carried out successfully so that the project is completed on schedule and return on the investment starts when planned. It is essential to the systems supplier that schedules be met, if he is working to a fixed-price contract, as any schedule extension is costly to him.

Personnel training is necessary to instill operator confidence in the system. Good design practice for automated systems assumes a reasonable amount of operator intervention to keep the system running smoothly. Redundancy and elaborate backup schemes designed to provide automatic recovery from simple malfunctions in lieu of operator intervention can increase system cost beyond the point of justification.

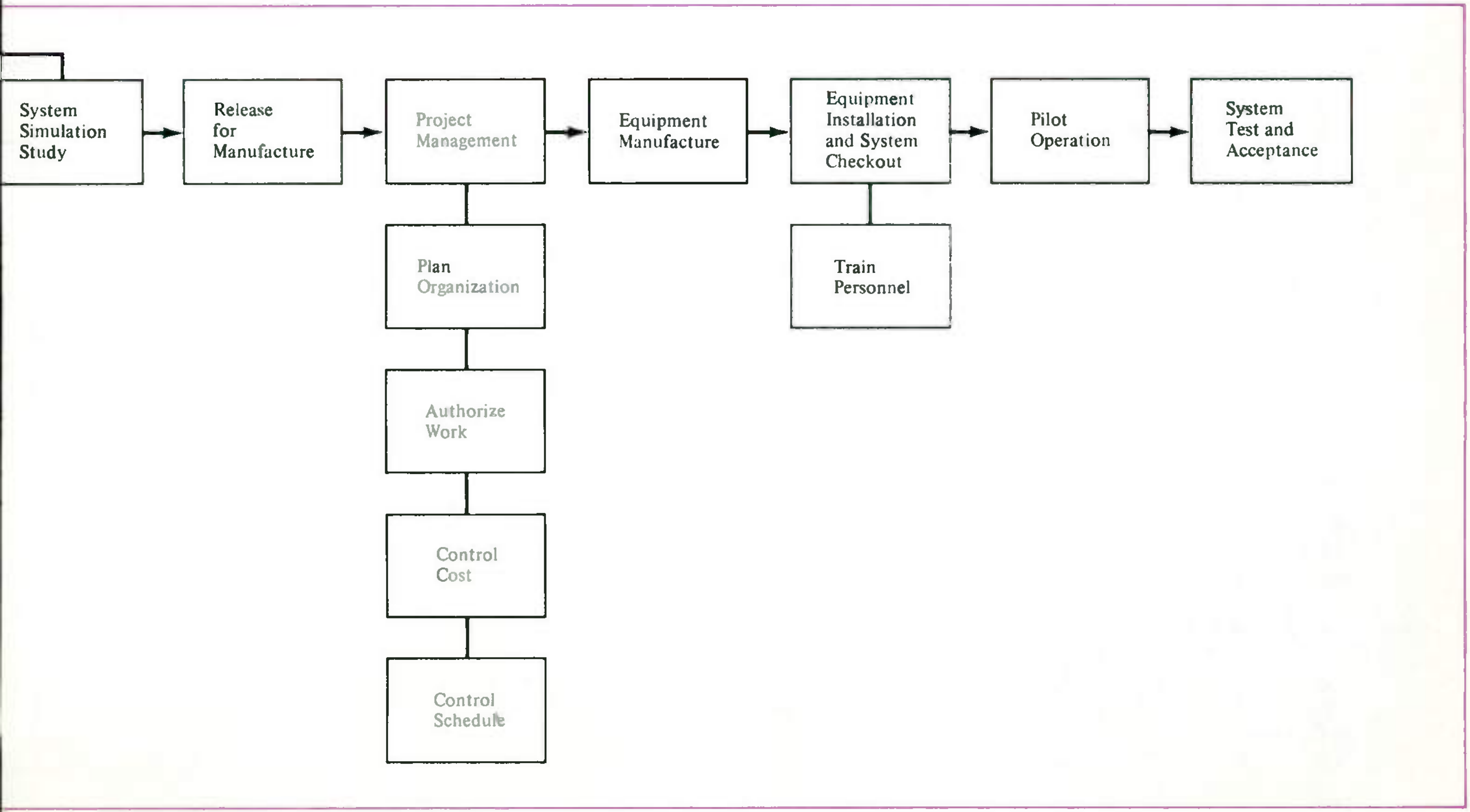
Pilot Operation and Testing—Pilot operation gives the user the opportunity to become familiar with his system and to identify any problems. It is essential that the system get a good workout before being committed to production.

Testing under conditions simulating actual operation is useful only to the extent that the simulation approximates real life. Moreover, there is little justification in developing elaborate simulation testing when the real problem—pilot operation—is at hand to test the system. Everyone must understand, however, that pilot operation is not production and that downtime to fix system problems must be tolerated.

Acceptance of the system's *equipment* by the user is a prerequisite to pilot operation; the user assumes maintenance of the system, and the equipment warranty period starts at that time. Acceptance of the *system* occurs when pilot operating results indicate that production requirements can be handled. The system warranty period begins at that time.

Conclusion

The approach to solving material-handling problems outlined here applies equally well to large-scale manufacturing problems, such as the feeding of assembly lines at Caterpillar Tractor Co., and to such problems as the distribution of foods, linens, and supplies in a hospital. The former system is designed for 3000-pound loads; the latter handles loads averaging 200 pounds or less. In both, material-handling costs are significantly reduced by the focusing of management attention on material handling and by the concepts of continuity of movement, automation, and integration of functions.



What's the Weather Down There?

M. J. Spangler

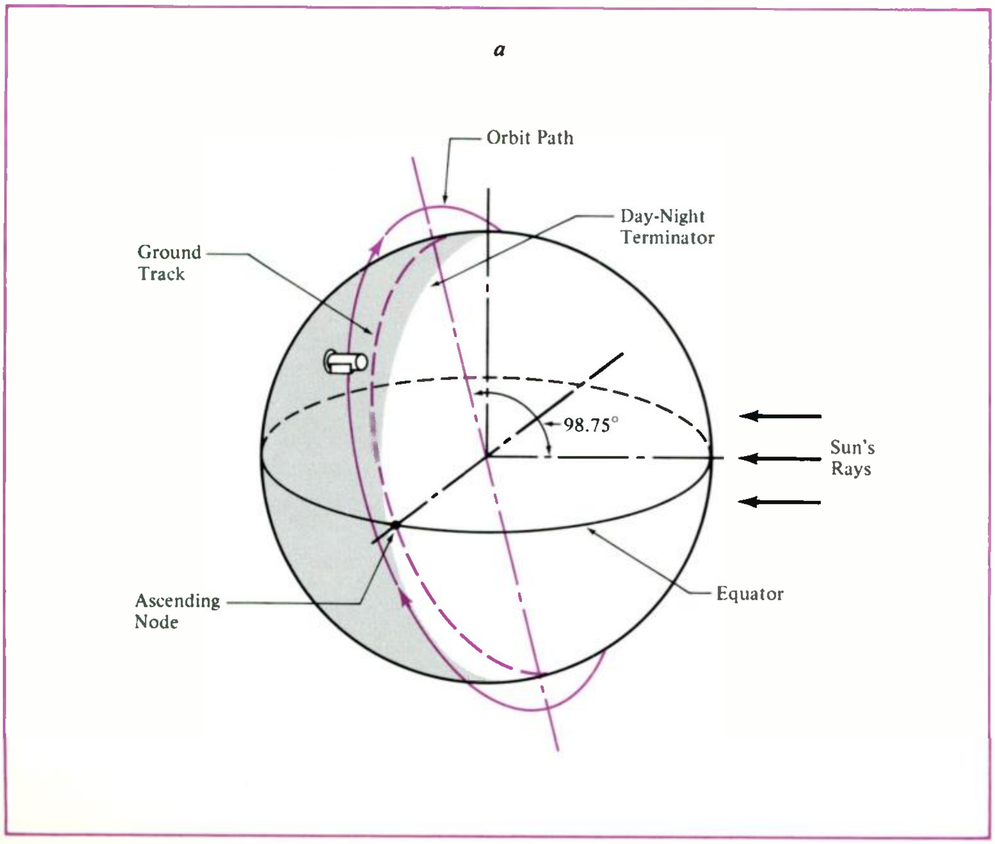
The dynamic characteristics of the earth's atmospheric environment demand frequent, if not continuous, observations on a global basis if the weather is to be fully understood and predicted well in advance. The Defense Meteorological Satellite Program (DMSP), utilizing a pair of sun-synchronous satellites, is now obtaining global observations four times a day for weather forecasting purposes.

Prior to 1960, as much as 80 percent of the earth's weather went unobserved because only about 20 percent of the earth's surface is inhabited. Today, this situation no longer exists. A single low-altitude (450 miles) meteorological satellite can circle the earth every 100 minutes and, by sequential passes, can deliver detailed observations of the entire earth and its cloud cover twice daily for analyses.

During the mid to late 1950's, cameras were first carried aloft by sounding rockets and missiles. The photographs recovered from these cameras demonstrated the value of high-altitude photography to meteorology. Although these first pictures were infrequent, crude, and highly distorted, they contained the basic information from which weather conditions within a limited area could be inferred. Their usefulness prompted the suggestion of placing television cameras on satellites for global weather observation purposes. This was successfully accomplished in the early 1960's by the Tiros series of meteorological satellites. Photographs of the earth's cloud cover during the daylight hours were transmitted by the thousands to ground reception stations where the individual frames were assembled into mosaics and studied by meteorologists the world over. Those mosaics confirmed that the earth's cloud cover was highly organized on a global basis with coherent cloud systems extending over thousands of miles. Also, it was readily apparent that these cloud patterns were a signature of the global weather system. In fact, if one superimposes a cloud cover photograph obtained from a satellite on a weather map, it is remarkable how closely the cloud systems match the weather systems. It is almost as if nature were drawing a weather map directly onto the earth.

In 1973 the U.S. Air Force disclosed the existence of the Defense Meteorological Satellite Program (DMSP) and announced that DMSP data would be given on an unclassified basis to the National Oceanic and Atmospheric Administration (NOAA) and its National Weather Service meteorologists for their use in the day-to-day forecasting as well as to any other interested user in the scientific community. (See *Development of DMSP Sensors*, page 114.)

In addition to the weather-watching mission, the pictorial imagery obtained from DMSP sensors has made possible the



1—(a) *The satellite carrying the Westinghouse Meteorological Sensor is a three-axis stabilized vehicle launched from the Space and Missile Test Center (Vandenburg AFB, California) into a nominally circular orbit 450 nautical miles above the earth and with an orbital inclination of approximately 98.75 degrees to the equator. This combination yields a sun-synchronous orbit plane precession, whereby the orbit plane drifts easterly in inertial space at the same mean rate that the earth moves about the sun (approximately 1 degree per day). This drift rate causes the spacecraft to pass over a given geographic location at approximately the same local sun time each day. The circular orbit also keeps the satellite at a constant distance from the earth, which permits uniform acquisition of data. The earth's rotation (15 degrees per hour) beneath the orbit causes the satellite to observe a different portion of the earth's surface each pass. The combination of orbit altitude and field of view of the sensor provides global coverage from a single satellite every 12 hours.*

(b) *Rotating mirrors in the sensor provide the cross-track scan of approximately 1600 nautical miles. Along-track scanning is provided by the forward motion of the spacecraft. Since the scanning mirrors rotate at a constant angular velocity, geometric resolution on the ground decreases as the distance from the satellite subpoint increases in the cross-track direction. Also a picture produced from the video signals would appear foreshortened at the edges unless rectified by the ground equipment. One of the unique features of the Westinghouse ground display equipment is its ability to rectify the data and correct it for errors in spacecraft altitude and attitude, thus producing high-quality film copy with a constant scale factor.*

M. J. Spangler is Program Manager for the Block 5 OLS System, Systems Development Division, Westinghouse Defense and Electronic Systems Center, Baltimore, Maryland.

observation of other terrestrial conditions. Nonmeteorological observations have generated data for ice flow charting, snowpack river runoff studies, dust storm studies, visible pollution sources and tracking, light source studies from nighttime light from cities, oil and forest fires, and many other phenomena.

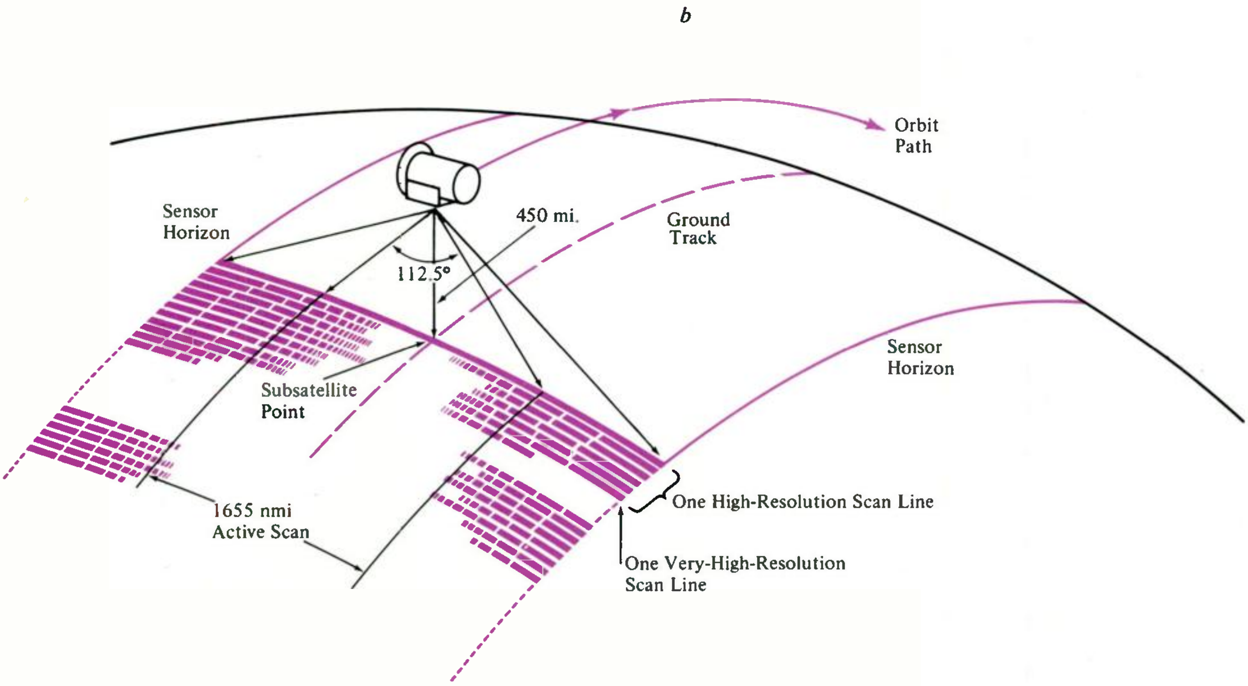
Scanning Radiometer

The primary sensor for the DMSP satellites is a scanning radiometer designed to simultaneously collect both visual and infrared imagery of terrestrial scenes from a nominal altitude of 450 nautical miles (Fig. 1a). It replaces the television cameras formerly carried by meteorological satellites and senses radiation continuously both day and night in two spectral intervals by two pairs of detectors. Both of the infrared and one of the visible-spectrum detectors are designed to operate with both day and nighttime illumination conditions. The second visible-spectrum detector, which senses very-high-resolution data, is designed to operate only on or near the daylight side of the day-night terminator.

A scanning radiometer does not take a picture in the same sense as a television camera. In fact, it is not a camera at all but a telescope with a detector behind a pinhole aperture. Energy from the scene is focused onto the detector, where it is converted into an electrical signal proportional to the intensity of the incident illumination. This electrical signal, commonly called video, is transmitted to the ground where it is converted into an image on photographic film. Scanning is accomplished by viewing the scene via a flat rotating mirror; the transverse scan across the satellite ground track results from rotating the mirror at a constant angular rate in a plane perpendicular to the spacecraft velocity vector (Fig. 1b). The forward motion of the spacecraft relative to the ground provides along-track scanning so that a continuous line-by-line picture results when the video is reproduced as shades of gray on photographic film by the ground display equipment.

The radiometer has two apertures for collecting scene energy. Each aperture has associated with it a pair of detectors—one for visible-spectrum data and one for infrared-spectrum data. The visible-spectrum detectors are sensitive to radiation reflected from the earth in the 0.4- to 1.1-micrometer band, an extension of the visible light range of 0.4 to 0.7 micrometer. The wider spectral band is needed to help distinguish tropical vegetation from water (Fig. 2a). The output of these detectors is used to produce cloud-cover pictures.

The infrared detectors sense radiation emitted from land, water, and cloud surfaces in the 8- to 13-micrometer spectral region. This spectral band was selected to maximize energy input (Fig. 2b) and thereby to insure detection of high thin cirrus clouds, which sometimes do not appear in visual imagery. The channels cover the 100-degree range between 210 and 310 degrees K. Electronic circuitry in the sensor converts the sensed infrared energy directly into equivalent blackbody temperature, thus making temperature (as opposed to radiance) the amplitude parameter for the



output signal. Therefore, shades of gray of a picture produced from these signals are proportional to the temperature of the radiating source: the whitest areas in the picture are the coldest and represent clouds; the black areas are the warmest and represent land or water masses.

The two detectors for each spectral band are not redundant channels because they provide data with two different resolution capabilities. The detectors associated with the larger aperture (Fig. 3a) collect *high-resolution* visual and infrared imagery (day and night) on a global basis for wide-area synoptic use. The detectors associated with the smaller aperture collect *very-high-resolution* visual (daytime only) and infrared imagery (day and night). Very-high-resolution imagery is collected on a selective basis and is used for analysis of cloud types and distribution. It is also useful for accurately locating cloud features with respect to major landmarks on the ground and for determining the fine structural details in cloud patterns.

High-Resolution Channels—A simplified optical schematic of the radiometer is shown in Fig. 3b. Both the high-resolution visible and the high-resolution infrared data channels share one set of collecting and focusing optics. The scanning mirror for these channels (*M1*) is a flat mirror driven at a constant angular velocity of 1.78 revolutions per second. The infrared and visible scene energy is separated by a dichroic beam splitter (*BMS*), placed in the converging beam off the parabolic surface of mirror *M2*. Spectral separation is accomplished by reflecting the infrared energy and transmitting the visible spectrum energy onto separate detectors located at the focal points. The fields of view of these two channels are essentially equal and controlled so that the lines of sight are coincident.

Both the visible and the infrared high-resolution channels are designed to operate with both day and night illumination conditions. The detector in the visible-spectrum channel is a silicon PN photodiode with stringent requirements on the noise and sensitivity characteristics. It is cooled to about −20 degrees C and provides a linear current output as a function of irradiance over a range of more than six decades of input power levels. The angular field of view is 4.5 milliradians, which provides a resolution element size at the subsatellite point of approximately 2.0 nautical miles.

The detector in the infrared-spectrum channel is an immersed thermistor bolometer operated at a controlled temperature near −15 degrees C. Electronic circuitry converts the bolometer output directly into equivalent blackbody temperature. Thermal calibrations are provided so that the absolute accuracy of the channel is five degrees K over the temperature range of interest. The field of view is 5.4 milliradians, which provides a subsatellite resolution element size of approximately 2.5 nautical miles.

Very-High-Resolution Channels—The very-high-resolution visible and infrared channels have collecting and focusing optics separate from those of the high-resolution channels (Fig. 3b). Scanning is accomplished with a two-faceted mirror (*M*3) driven at 5.34 revolutions per second, three times the speed of the high-resolution mirror. Thus, the two-faceted mirror driven at triple speed results in six lines of very-high-resolution data for each line of high-resolution data.

The scan direction of the very-high-resolution data is opposite that of the high-

Development of DMSP Sensors

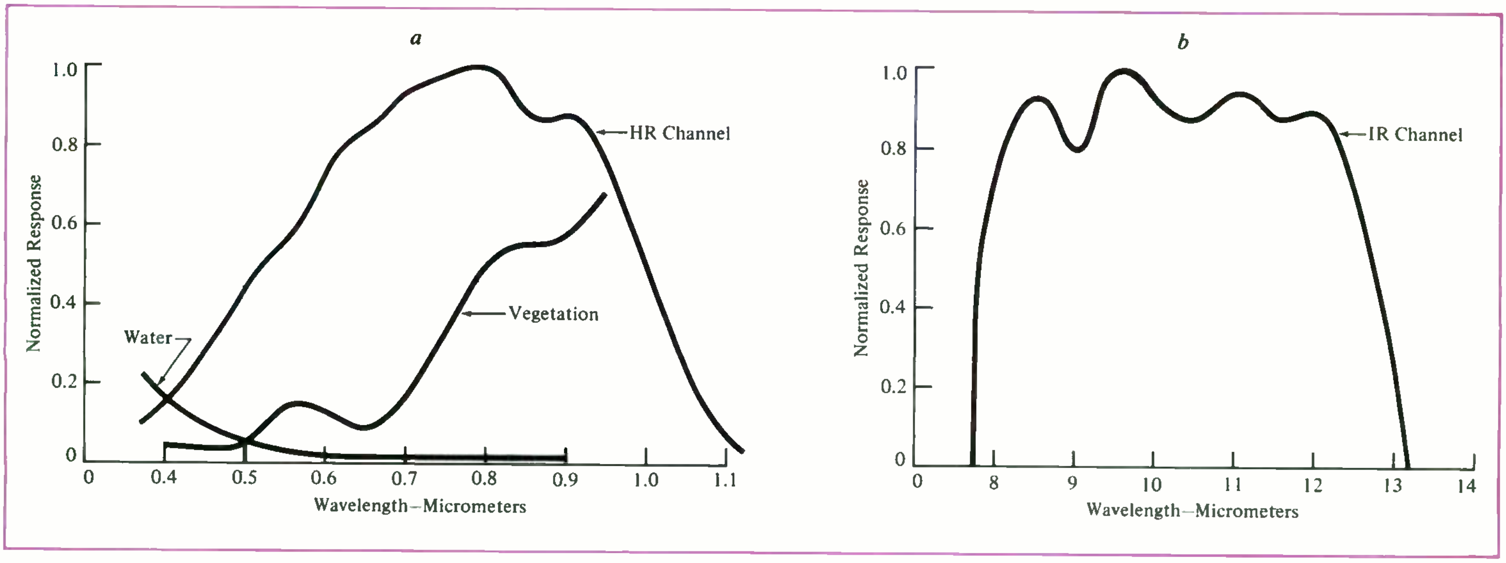
In 1966 Westinghouse was awarded two study contracts, one for the sensor and the other for the ground data-processing and display system. (This project was designated *Block 5* at Westinghouse.)

Using the results of the studies performed by Westinghouse and by other potential vendors, the Air Force's System Program Office (SPO) formulated the system concept that went out to three vendors for bids. The request for proposal and price was divided into a sensor segment and a display segment. Westinghouse was the successful bidder on both segments and was awarded two contracts. One contract called for the delivery of two engineering test models and four flight-qualified sensor models plus numerous pieces of support and test equipment. The display contract was for six qualified display equipments of four configurations plus an option, which was later exercised for three additional equipments.

Immediately after launch, the first sensor began sending back cloud-cover imagery. The first imagery, transmitted on the second orbit (*left*), was nearly perfect, marred only by some data dropouts due to ground-tracking problems.

Engineering and design verification tests were conducted on the new spacecraft and sensor system for about one month. At the conclusion of these tests, the system was declared operational and the data immediately put to use. The system has been in continuous operation since and has produced hundreds of miles of high-quality 9½-inch film (*right*).

Westinghouse is currently engaged in further refinement of equipment to provide even more advanced capability.



2—(a) *The spectral bandwidth of the visual channel is 0.4 to 1.1 micrometers, a range that optimizes the distinction between clouds, ground, and water.* (b) *The spectral bandwidth of the infrared channel is 8 to 13 micrometers. This band insures the detection of high thin cirrus clouds, which sometimes do not appear in the visual imagery.*

resolution data. The opposing rotations of the two mirrors along with a flywheel weight on the very-high-resolution scanning mirror assembly provide momentum compensation, which simplifies the spacecraft attitude control system.

The detector in the very-high-resolution visible spectrum channel is a silicon PN junction photodiode operated in the photoconductive mode. This detector is used for daytime and twilight coverage only. It has a 0.75-milliradian field of view, which gives a 0.33-nautical-mile nominal resolution element size at the subsatellite point on the ground track.

The detector in the very-high-resolution infrared-spectrum channel is a photoconductive trimetal (Hg Cd Te) detector with an 8- to 13-micrometer bandpass filter multilayer coating on the window. This detector is maintained at a 110 ±0.1 degree K operating temperature by a passive radiative cryogenic cooler and oven arrangement. The cold elements are protected from contaminant condensation by a special window labyrinth assembly operated at the main structure temperature of approximately 10 degrees C. The channel has a 0.8-milliradian field of view, which provides infrared temperature data of about the same resolution as the very-high-resolution visible data.

Visible-Channel Gain Control

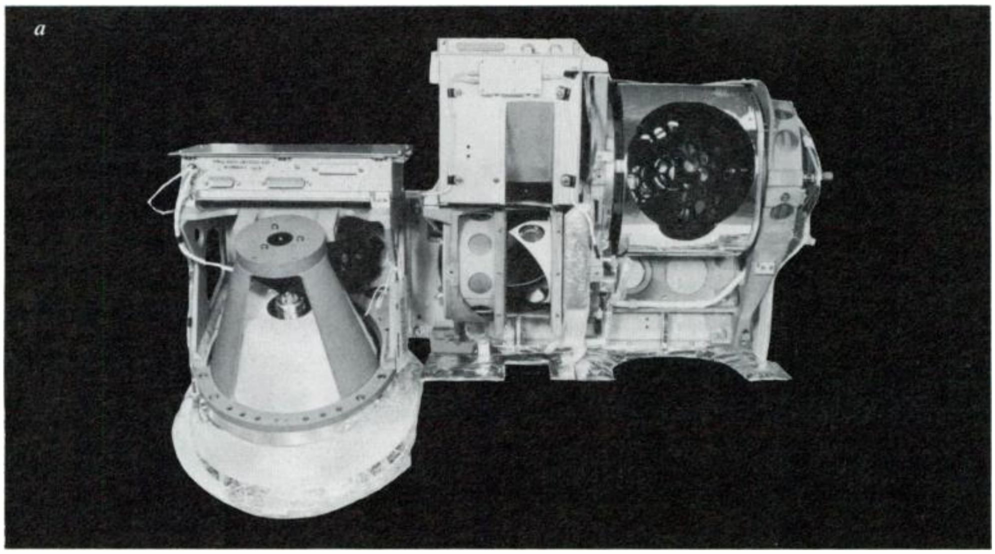
Because the signal outputs from the visible-channel detectors vary linearly with solar illumination of the scene, the channel electronics must provide a wide dynamic range for signal amplitude. This is accomplished by changing channel gain as the ground track of the scan passes from day to night illumination. For a near noon-midnight orbit plane, changing gain only in the along-track direction suffices (Fig. 4a). However, for an early-morning ascending orbit where the ground track includes much of the terminator region (Fig. 4b), gain must be changed in both the track and the scan directions. Signals to control channel gains in both track and scan directions are derived from two sensors not shown in Fig. 3b.

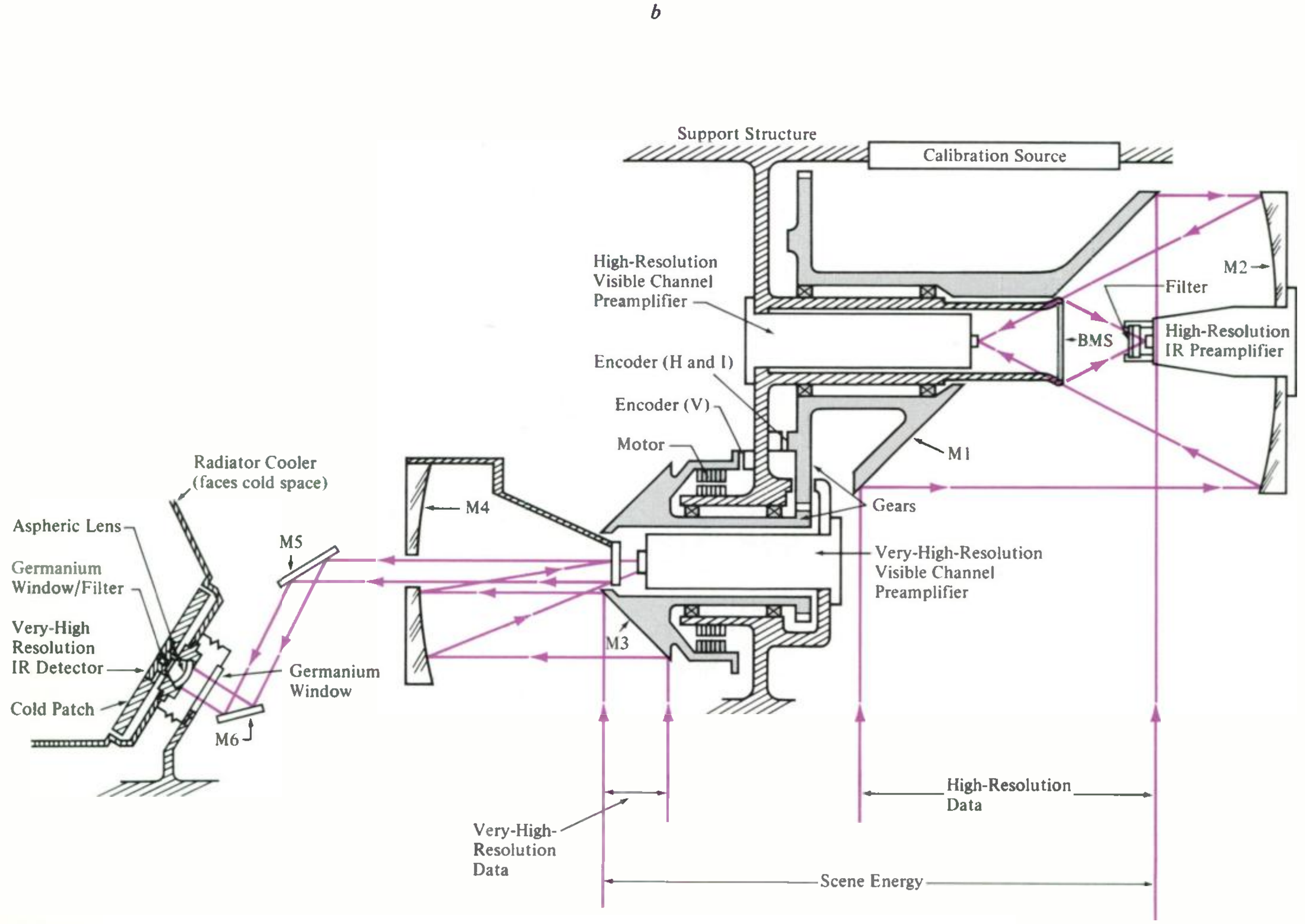
One of the sensors is a *zero-resolution detector* (silicon PN photodiode), mounted within a hemispherical window on top of the spacecraft diametrically opposite the subsatellite point so that it performs as an incident light meter. This sensor views space and provides an output of $I = I_0 \mathrm{Cos}\ \omega$, where ω is the angle between this sensor optical axis and the sun line, and I_0 is the sensor output when angle ω is equal to 0 degrees (sun overhead). This sensor can effectively control the gain of either of the visible-spectrum channels in the track direction for near noon-midnight orbits when the spacecraft is within 84 geocentric degrees of subsolar (Fig. 4a). Beyond 84 degrees the zero-resolution sensor is no longer effective and the channels revert to commandable fixed-gain values stored in the spacecraft memory.

This memory is periodically loaded from the ground with a gain program that is exercised as a function of the time from the ascending node. This method of gain control is especially useful for a noon-midnight orbit plane. It supplements the zero-resolution sensor and provides gain commands whenever the satellite is on the night side or within 6 geocentric degrees on the day side of the terminator. If desired, the gain-memory commands can override the zero-resolution sensor and provide channel gain control throughout the orbit.

The second sensor for controlling channel gain (in the high-resolution channel only) is a digital *solar-aspect* sensor. It measures the solar azimuth and elevation at a point on the ground corresponding to the beginning of a scan line (Fig. 4b). From this information, electronics in the instrument can continuously and automatically set the high-resolution visible-channel gain throughout the scan to the desired value, with a range of more than six orders of magnitude. This capability

3—The scanning radiometer instrument (a) *has two apertures for collecting scene energy. This simplified optical schematic* (b) *illustrates the collecting and focusing optics. All of the reflective optics are of lightweight design having a beryllium substrate coated with vacuum-deposited aluminum and a silicon-monoxide protective overcoating. The high-resolution optics have a 5.25-inch f/1 parabolic mirror with a 1.625-inch hole diameter; the very-high-resolution optics have a 3.875-inch f/1 parabolic mirror with a 0.62-inch hole diameter.*





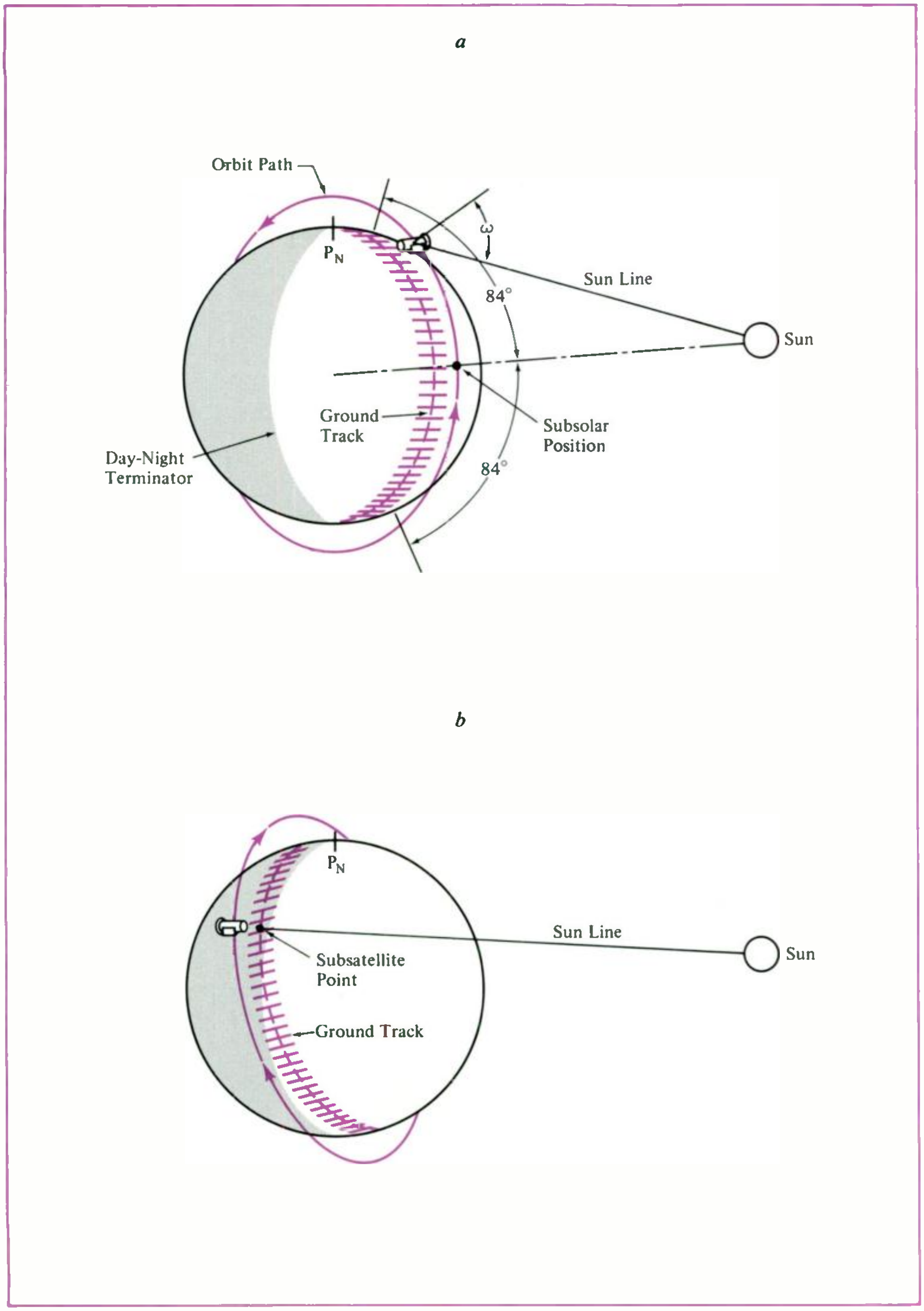
provides a means for obtaining visible-spectrum data over a full scan line in a near-terminator (early morning) orbit. A system that does not have this feature would have only a narrow band of useful data since one edge of the ground track would have too much illumination while the other would have far too little.

Radiometer Electronics Subsystem

The radiometer views terrestrial scenes only for a portion of the full revolution of each scanning mirror. During the remaining portion the mirror views space and/or the instrument housing. During this time, synchronization signals, time-code data, calibration signals, and telemetry data are inserted into the data stream. The radiometer electronics also provide synchronized wow-and-flutter clock signals for both the high-resolution and very-high-resolution scanning mirrors.

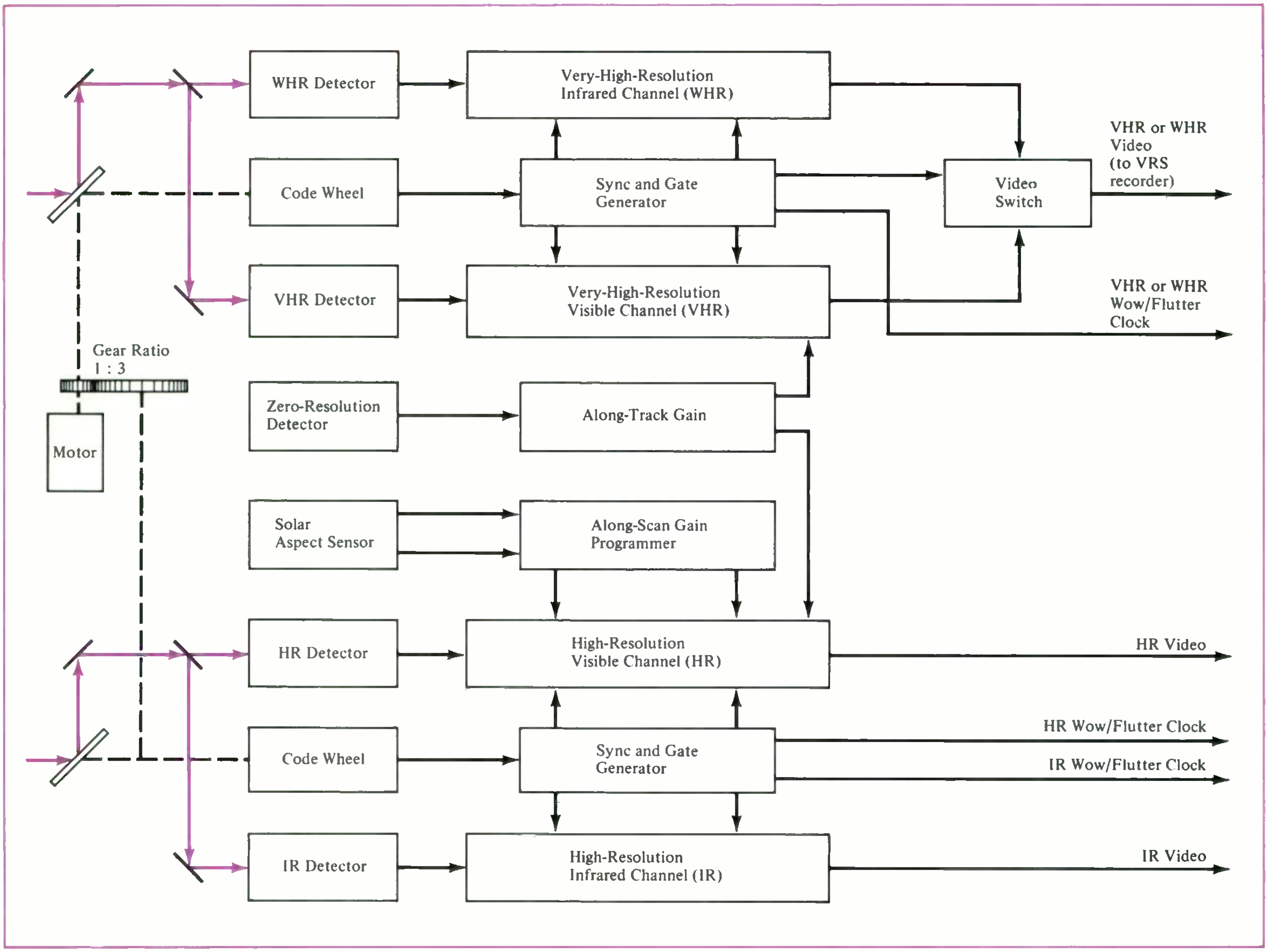
The radiometer electronics subsystem (Fig. 5) provides three sets of output signals to the spacecraft for transmission to ground. These signals contain the scene image data (video) and the calibration, synchronization, and clock signals for use by ground data-processing and display equipment. Equipment on board the spacecraft multiplexes these signals such that various operating options or modes are available to the ground. These modes are defined as follows:

Stored HR and IR—Tape recorders are provided on the spacecraft for storing data for readout. The HR/IR recorder is especially designed to multiplex and record both high-resolution visual (*HR*) and high-resolution infrared (*IR*) data since video information is generated for only about 46 percent of each scan line period. High-resolution visible and infrared spectrum imagery, calibration, and time-clock data are time multiplexed on a line-by-line basis. Multiplexing is accomplished by recording the two time-coincident bursts as frequency-modulated subcarrier ($f_{sc} = 4.65$ kHz and $\Delta f_{sc} = 2.5$ kHz) simultaneously on one length of tape by two record heads



4—Weather satellites are placed in near-polar orbits so that they can scan the entire earth's surface as the earth rotates beneath them. For a noon-midnight orbit (a), *the illumination of the ground track varies from a maximum when satellite position is at noon (sun overhead) to a minimum when it is at midnight. While illumination varies with track position, it is relatively constant for each scan line. The zero-resolution detector measures the incident illumination and provides a signal for controlling the gain of the visual channels when the spacecraft is within 84 geocentric degrees of subsolar.*

An early-morning ascending orbit (b) *places much of the ground track on or near the terminators so that the scene illumination varies not only in the along-track direction but also in the along-scan direction, which is perpendicular to the spacecraft direction of travel. The correct gain for the high-resolution channel for these variations in scene illumination levels is calculated from the sun's azimuth and elevation information provided by the solar-aspect sensor.*



5—The radiometer electronics generate the various video and synchronized wow-and-flutter clock signals, which are fed to the spacecraft tape recorders for storage and readout.

physically separated along the tape data track. The wow-and-flutter clock signal is similarly recorded on a separate track.

During playback, the tape is moved in the reverse direction. The playback-to-record speed ratio is 21 to 1, which gives a commutated *HR* and *IR* signal with a subcarrier of 97.65 kHz for transmitting to ground. Storage in analog form is sufficient for up to 210 minutes or approximately two complete orbits. Playback time is 10 minutes for two orbits of stored data.

Stored VHR or WHR—Very-high-resolution visible (*VHR*) or very-high-resolution infrared (*WHR*) imagery, calibration, and timeclock data can be stored as an analog signal on a very-high-resolution recording system (*VRS*) for up to 20 minutes (1/5 orbit). This is in addition to the high-resolution imagery storage since storage and acquisition of very-high-resolution data does not affect the acquisition and storage of high-resolution data.

The VRS recorder is similar to the HR/IR recorder except it does not commutate the visible and infrared data—only one or the other can be recorded. The subcarrier recorded is 53.5 kHz, and data is played back in the reverse direction at a playback-to-record speed ratio of 2 to 1. The output subcarrier thus becomes 107.0 kHz, which is multiplexed with the HR/IR subcarrier and the two wow-flutter subcarriers.

Direct Readout—For regional readouts

These three images of the west coast of the United States were made September 15, 1970. The very-high-resolution visual image (a) *was sensed in the 0.4-to-1.1-micron spectrum and has 1/3-nmi resolution. The high-resolution image* (b) *was sensed simultaneously and in the same spectral range but has 2-nmi resolution. The infrared image* (c) *was also sensed simultaneously in the 8-to-13-micron spectrum and at 2.5-nmi resolution. The cloud swirl that appears in the visible images* (a and b) *does not appear in the infrared image* (c), *indicating a low-altitude cloud structure.*

the direct mode of operation is used. This mode is digital, and the video data is converted into a 512-kilobit/second constant-rate digital bit stream and transmitted to ground as an NRZ-L PCM telemetry signal with the information contained in 144-bit data frames.

Direct readout time slots in an orbit are commandable. Commanding on or off this mode does not affect acquisition and storage of data on the tape recorders for later readout. A change of mode may be made during a direct readout sequence with no loss in recorded coverage. Stored ephemeris and spacecraft attitude data may also be transmitted at repetitive intervals during a direct readout sequence.

Ground Equipment

The ground station display equipment is dynamically matched to the sensor subsystem carried on board the spacecraft. The heart of the ground station display equipment is a high-resolution cathode-ray-tube film recorder containing a unique optical feedback exposure control loop, a highly accurate variable-speed film transport mechanism, and a self-threading three-step liquid chemical rapid film processor. It is relatively simple to operate, and it reproduces data from any one of the sensor channels (operator selectable) as a high-quality positive film transparency. The display equipment is housed in one cabinet and accepts either direct data transmissions from the spacecraft in real time or data stored on the spacecraft tape recorders and read out as the tape is rewound.

The display receives direct-mode data in the form of a 512-kilobit/second NRZ-L PCM telemetry signal or stored-mode data in the form of a nominal 100-kHz FM subcarrier. The equipment detects the baseband video signals from the digital bit stream and/or the FM subcarrier, removes and processes the calibration data contained in the signal, applies rectification corrections to remove geometrical distortions due to the earth's curvature, applies corrections to compensate for spacecraft altitude/attitude errors, and photographically reproduces this information as a pictorial image of suitable scale and projection for direct correlation to conventional world-wide map grids. The finished product, which may represent as much as two complete orbits on 21 feet of film, is available less than five minutes after the last data input has been recorded.

The photographs that accompany this article are examples of the imagery that has been collected by the DMSP sensors.

Weather Data

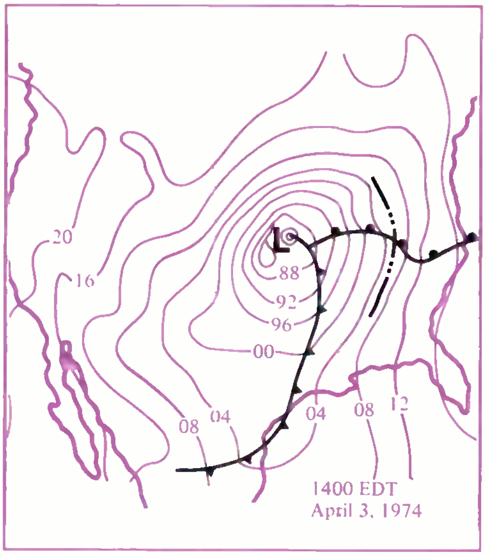
The amount of meteorological data available in any one day from a single spacecraft is staggering—approximately 250 feet of 9½-inch film (1:15,000,000 scale factor) of high-resolution imagery plus another 20 feet of very-high-resolution imagery. With these large quantities of very perishable weather data it is apparent that manual data reduction methods from film imagery alone are not adequate to provide the decision maker with the products he needs within minutes of the time the raw data was collected from space. The job of analyzing and selecting the information of specific value, processing and reducing it to its most usable form, and disseminating the products in a timely manner is now being performed by computers.

In the United States, recorded data are transmitted from the spacecraft to one of two high-latitude permanent command readout sites. These data are then relayed via a wideband data link to the Air Force Global Weather Central at Offutt AFB, Nebraska, where the video signals are digitized and computer processed. Computer processing allows for many other conventional observations as well as the satellite data inputs to be utilized to make hundreds of analyses and predictions routinely and nearly simultaneously. In many cases, this is done before an operator ever looks at the visual imagery.

Mobile terminals are also available. These terminals are used primarily outside the United States to provide satellite data to a local commander anywhere on the globe. The entire terminal, including the antenna, is contained in a mobile air-transportable van and provides direct regional readout on the spot. Several of these vans are currently deployed with the armed forces around the world, including two aboard Navy ships.

This high-resolution visible-spectrum image shows about one-third of the northern auroral oval. Since the broad spectral band includes the visible and near-infrared regions, the system integrates the auroral red and green lines to produce these remarkable photographs, heretofore unavailable. Evaluation of some of these data have revealed several auroral characteristics not readily detectable from terrestrial observations.

The weather system that generated fatal tornadoes in early April 1971 is seen in this Defense Meteorological Satellite imagery. A cold front stretches from Louisiana northeast to a low-pressure area over Iowa (see map). *As it moved to the northeast, it pulled warm moist air up from the Gulf of Mexico, adding to the weather's instability. Severe squall lines developed just ahead of the front and resulted in the numerous tornadoes that struck the Midwest.*



1400 EDT
April 3, 1974

Sunlight Will Help Air Condition and Heat a School Building

The George A. Towns Elementary School in Atlanta, Georgia, will be the first large building to be both air conditioned and heated with the help of sunlight. The National Science Foundation has awarded a contract to the Westinghouse Special Systems Department to design, install, and analyze a solar cooling and heating system for the 12-year-old building, which is not presently air conditioned. Sunlight will provide about 60 percent of the energy needed for the domestic hot water supply, absorption air conditioning system, and hot water heating system. The Towns school is used by 500 students throughout a four-semester school year and is used by the community during evenings and weekends.

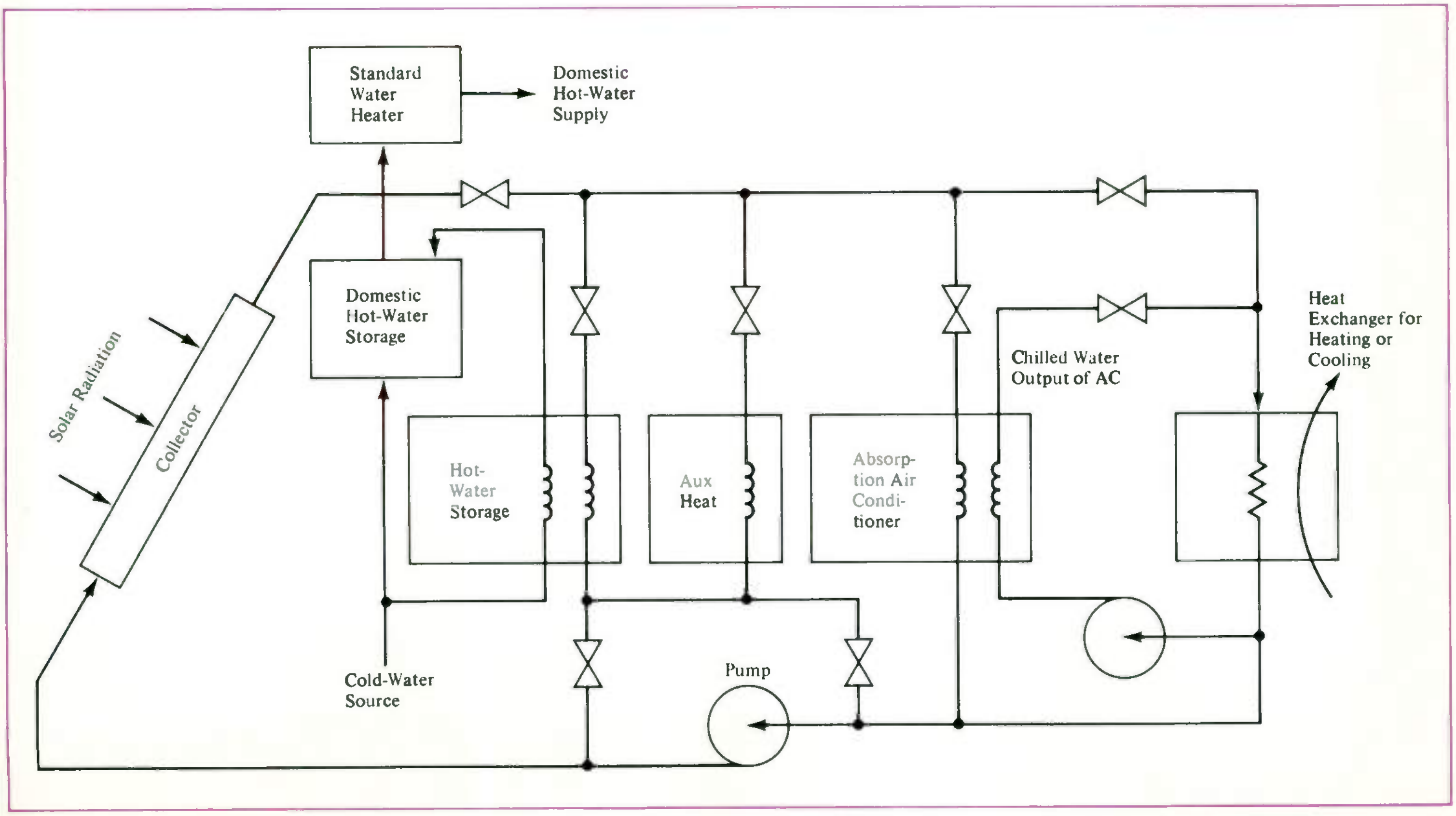
The experimental system will help demonstrate potential cost saving of solar heating and cooling systems. Equipment costs, operating costs, and fuel costs will be evaluated to project a break-even point for solar systems. Design and fabrication problems will be identified, and solutions will be suggested. Graduate students at Georgia Institute of Technology will be responsible for design and installation of the performance-monitoring equipment, and they will gather detailed operating data and weather data to analyze the system's performance for comparison of predicted and actual operation. About 30 different system parameters will be monitored in real time by a minicomputer.

Detailed design of the solar heating and cooling system will be performed by Burt, Hill and Associates of Pittsburgh, Pennsylvania, under a subcontract to Westinghouse, and detailed mechanical design will be performed by Dubin-Mindel-Bloome Associates of New York City.

The solar collector will consist of a number of standardized flat-plate collector modules, each module consisting of an absorbing plate and two layers of tempered glass mounted in a stainless-steel frame. The glass layers insulate the absorbing plate from the outside air temperature. Water circulating in the modules will be heated to a temperature between 160 and 215 degrees F. Each module will measure approximately 32 inches by 74 inches, providing 16 square feet of collector area. The number of modules used will provide about 10,000 square feet of collector area. The modules will be manufactured by PPG Industries, Inc.

The heated water from the rooftop collectors will heat the water needed for the school's domestic hot water supply and will supply energy for either the heating system or the air conditioning system (see diagram). Excess hot water will be kept in four 6000-gallon tanks for short-term energy storage. The building's existing heating equipment will provide the hot water needed for heating and cooling during long periods of cloudy weather.

During a period of three hours around noon on a clear day, the collector system will supply about 2 million Btu of heat



Sunlight heats water circulated through the collector at left in this simplified diagram. The hot water provides energy needed to heat and cool the building and to heat the domestic hot-water supply.

energy per hour. The collectors are expected to be about 50 percent efficient in converting solar radiation into heat energy.

A lithium-bromide absorption air conditioner that operates directly from hot water will be installed. It is rated at 100 tons of refrigeration capacity with a coefficient of performance of 0.71. Maximum heat input required by the air conditioner is 1.7 million Btu per hour, with a hot-water flow of 240 gallons per minute.

Variable-speed pumps and servo-controlled valves will be used to control the flow rates and to divide the hot-water flow from the solar collectors into several paths. If, for example, all the heated water from the solar collectors is not needed to power the air conditioner, some of it will be diverted into storage tanks. The tanks, with a total capacity of 24,000 gallons, can store enough heat energy to power the air conditioner for several hours or to heat the building for up to two days.

Metroliners Updated to Improve Reliability and Maintainability

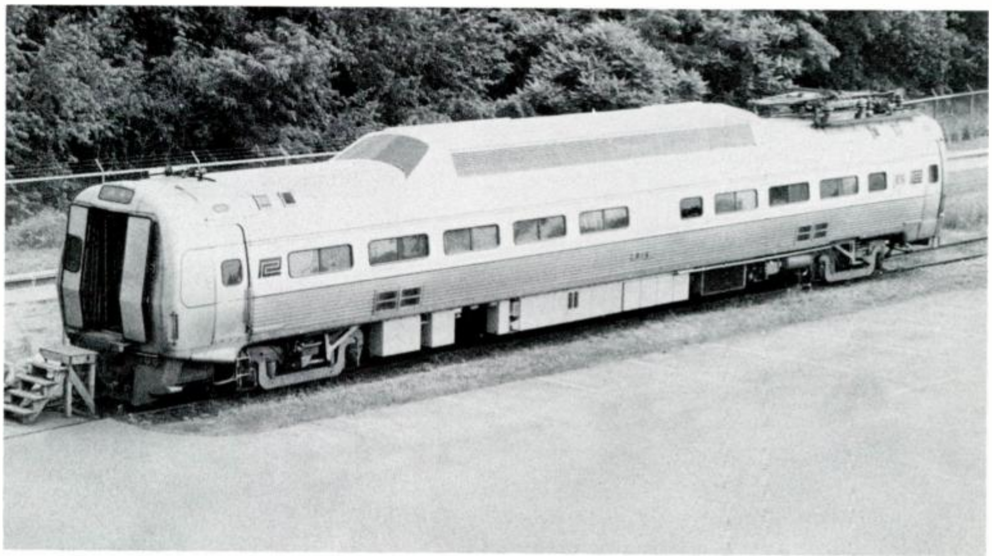
Metroliners, which are high-speed self-propelled electric passenger cars, have been operated in trains between New York and Washington, D.C., since 1969, and service was recently extended to New Haven, Connecticut. The trains have achieved a high degree of public acceptance and are a competitive mode of transportation in the Northeast Corridor. However, the Metroliners have been plagued by availability problems because the equipment sophistication required by the initial specifications resulted in a certain degree of unreliability and lack of maintainability. Consequently, the U.S. Department of Transportation has instituted a Metroliner Updating Program designed to improve the availability of the fleet.

Four of the cars have now been modified to a prototype configuration, two of them by the Westinghouse Transportation Division, and are undergoing verification testing in revenue service. The Westinghouse approach began with analysis of the causes of low reliability and poor maintainability, and that led to definition of the updating program. Briefly, the updating program consisted of simplifying performance requirements, making major modifications to several car systems to improve reliability, and designing the modifications for ease of maintenance.

The modifications aimed at improving reliability simplified functions, increased margins on components, and reduced the shock, vibration, heat, dirt, and electrical noise to which systems aboard the cars were subjected. Major modifications to the main power-conditioning system included development of a new main power circuit; use of semiconductor units with higher-rated devices, quick-disconnect capability, and built-in diagnostic plugs; substitution of unit-switch dynamic brake control for the previous chopper control; location of dynamic-braking resistors on the roof of the car; simplifying the low-level logic for car control and packaging it in a new electronic locker inside the car; and packaging all undercar main power-conditioning components into new boxes. The auxiliary power conditioning system was modified by use of a bridge rectifier of higher rating for controlling input to the motor-alternator set, improving the motor-alternator set, changing the air-conditioning control and monitoring equipment, adding a wayside plug to obtain three-phase 60-hertz power on the car with the pantograph down, and repackaging all auxiliary power-conditioning components in new boxes. The propulsion system was improved by a change in gear ratio from 2.36 to 2.81, use of traction motors with Class H instead of Class F insulation, thermal monitoring of motor fields, new gear-to-axle coupling units, and new Trac-pak suspension on the trucks.

An auxiliary roof was designed to house the dynamic-braking resistors and to provide a source of clean filtered cooling air to the undercar equipment (see photograph). Ductwork was installed through the interior of the car to carry roof-captured air to the underside of the car; subsequent modification of the car interior hid the ductwork.

These modifications are expected to improve the reliability of the updated Metro-



This Metroliner passenger car has been modified to a prototype configuration to improve its reliability and maintainability. The raised part of the roof is an addition that houses dynamic-braking resistors and captures clean air for cooling the equipment under the car.

liners over that of the present cars by a factor of four.

Maintainability was improved by installing monitoring equipment aboard the car, providing shop equipment for failure diagnosis, and designing components that have inherent low reliability in such a way that they can be replaced quickly. With these improvements, it is expected that 80 percent of all failures can be diagnosed and repaired in the turn-around time between a New York and Washington run (about one hour). That is a significant improvement over the present operation in which only about 20 percent of all failures can be handled in the turn-around time.

Thyristor Power Supply Engineered for Offshore Oil and Gas Industry

A thyristor power supply developed specifically for offshore drilling applications provides a single compact source of dc power that can be switched to energize various motors as needed. It is rated to handle all of the drilling drives on drilling platforms, semisubmersible rigs, and drill ships, including the propulsion and thruster drives on drill ships. The equipment is designed and built to withstand the tough offshore environment. It is supplied by the Westinghouse Industry Systems Division.

The power supply has unusually large (50-mm) thyristors to provide high power from relatively simple and compact circuitry. It is an ac-to-dc single converter employing the thyristors in a full-wave bridge. The bridge produces a dc output with six-pulse ripple current to minimize possible problems with motor heating and commutation.*

Input to the power supply is three-phase 600-volt 60-hertz ac power. The power-supply bridge has a maximum continuous rating of 1312 kW, 750 volts dc, 1750 amperes, which is enough power to supply motor loads totalling 1650 hp. Maximum short-time (10-second) current rating is 2200 amperes; at that output, the power supply can start large high-inertia loads requiring as much as 2000 hp, such as those associated with the drawworks (a hoist arrangement for raising and lowering drill pipe in the hole).

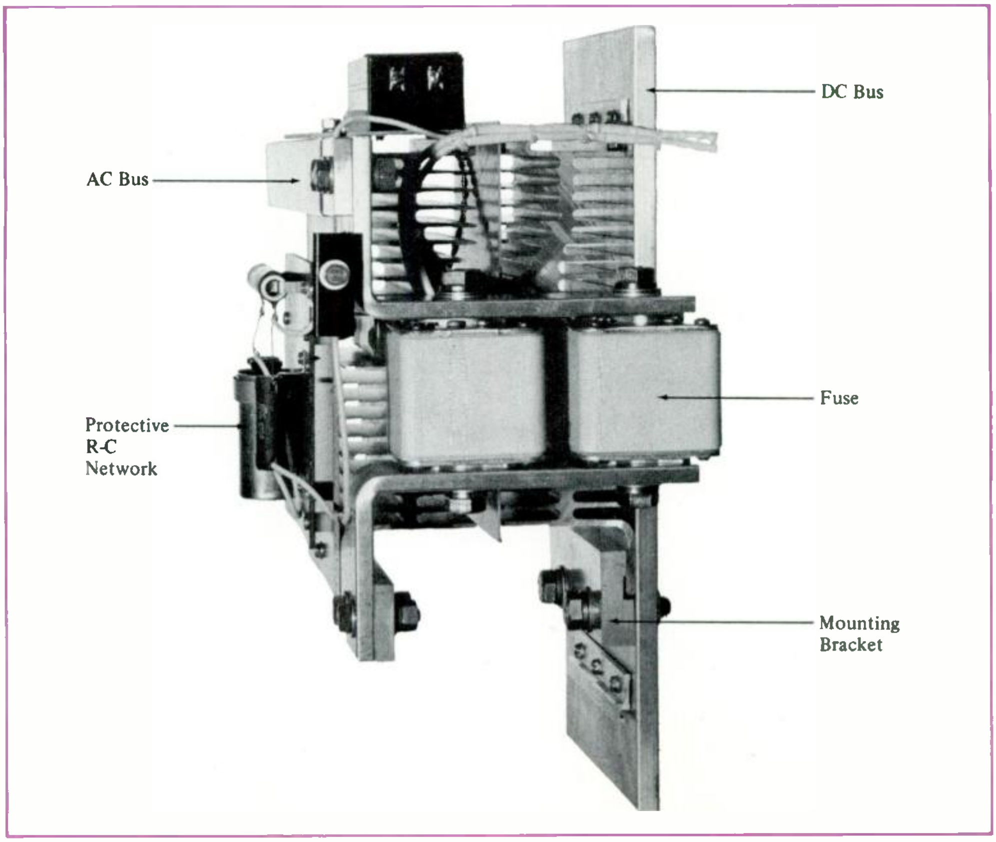
The equipment meets the requirements of the American Bureau of Ships, U. S. Coast Guard, and IEEE-45 ("Recommended Practice for Electrical Installations on Shipboard") for protection, safety, redundancy, and emergency provisions. Included in the design are special alloys for aluminum parts and nickel-plated electrical bus to combat corrosion.

The power supply's regulator includes a current loop for current-limiting control and drive torque control. It consists of integrated circuits on plug-in printed-circuit boards. A fault-detector card has indicating lights that show the location of certain faults that may occur.

A single current reference provides balanced currents between bridges in parallel operation.

Construction is modular. Each power module consists of a thyristor, two heat sinks, an R-C network, a gate pulse transformer, fuses, and a fuse-operation indicating light. (See photograph below.) The R-C network limits the rate of change of applied voltage and helps protect the thyristor from high voltage spikes.

The Industry Systems Division also supplies operator consoles. To withstand the environment, the driller's console and mud-pump console are built of stainless steel and are waterproof. The consoles are constructed with meters behind sealed glass and with door-mounted controls sealed to protect electrical parts from the elements. Air fittings are provided to pressurize the inside of the consoles with dry clean air, and gaskets at assembly openings prevent leakage of air.



Thyristor power supply for dc motors on off-shore oil-well drilling rigs consists essentially of modules such as this one. Each module includes a 50-mm thyristor sandwiched between two heat sinks. The module can be removed and replaced quickly, in the event of a failure, by loosening bolts and sliding the entire module out of its mounting bracket.

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*W. R. Harris and R. A. Morgan, "Solid-State Industrial Power and Control Come of Age," *Westinghouse ENGINEER*, July 1974, pp. 66-73.

New Sports Stadium in Caracas Is Fully Air Conditioned

Poliedro de Caracas, a sports stadium in Caracas, Venezuela, has become the first totally air conditioned stadium in South America. It is a circular structure with a dome that measures 400 feet in diameter and rises to a maximum height of 125 feet above the performers' level. The dome's structure is composed of prefabricated aluminum struts and cross members joined to provide both structural support and a dramatic appearance outside and inside. Two levels are enclosed: the upper level provides entrances and access to seating areas, the lower is a service and support area with facilities for performers and for expositions, banquets, and other private gatherings. Poliedro's maximum capacity is 13,500 seats. Of these, approximately 9500 are fixed while the remaining seats are added or removed depending on the nature of the event to be presented.

Cooling the stadium required three PE460 centrifugal water chillers, 17 central air handling units, and four split systems, all supplied by the Westinghouse Commercial-Industrial Air Conditioning Division. The air handling units and centrifugal chillers cool the main stadium. The split systems are complete air conditioning units much like central residential air conditioners; they are used to cool rooms within the stadium's service and support area.

Manufacturing of the air conditioning products was begun at the Division's plant in Staunton, Virginia, and then continued at Westinghouse facilities in Venezuela. The Venezuelan firm Sistemas de Aire Acondicionado T.P.T. specified and installed the equipment. The general contractor overseeing construction of Poliedro de Caracas was the firm of Aldrey & Simon.

Mobile System Monitors Air Quality and Weather

A comprehensive monitoring system has been developed to enable electric utilities, industrial companies, and government agencies to accurately monitor air quality and meteorological conditions on a real-time basis. The Adviser system, as it is called, includes all the software and hardware required. It was developed by the Westinghouse Meter Division's Environmental Systems Center.

Environmental monitoring system includes one or more mobile monitoring stations. The tower, which carries meteorological sensors, is lowered when the station is to be moved. Sensors and analyzers inside the station continuously monitor air pollutants and meteorological conditions. All instrumentation is located in a central island to provide accessibility to the front and back of each rack.

The system includes one or more complete mobile monitoring stations, each housed in an 18-foot trailer, and a central computer terminal that collects and records data virtually instantaneously and displays the collected data on a television screen or a teletype printout. Sensors and analyzers inside the station continuously monitor the six pollutants for which the U.S. Environmental Protection Agency has set national ambient-air quality standards (sulfur dioxide, oxides of nitrogen, particulates, photochemical oxidants, hydrocarbons, and carbon dioxide). A 10-meter tower mounted beside the trailer is equipped with sensors that measure meteorological conditions including wind speed, wind direction, and ambient temperature.

Historical and real-time data acquisition systems are provided; the availability of both types makes data available in the required format when needed. Automatic calibration eliminates the need for daily manual calibration.

The trailer has a temperature-controlled interior to help assure accurate functioning of sensors and data-acquisition equipment. Four cabinets and a workbench are provided for storage and work space. All instrumentation is located in a central island to provide accessibility to the front and back of each instrument rack. Fluorescent lights are flush mounted in the ceiling. Each station is completely assembled and tested as a system before it is delivered to the user.

The Environmental Systems Center offers the standard Adviser system on a turnkey basis. The turnkey package includes determination of monitoring requirements, selecting monitoring sites, supplying and installing the system, operating and maintaining it, and reducing and evaluating the data that the system collects.

PACE Combined-Cycle Power Plant Reaches Commercial Operation

A combined-cycle electric generating plant has reached commercial operation at the Comanche Station of Public Service Company of Oklahoma (PSCO). Located near Lawton, Oklahoma, the plant has been operating at continuous-duty power levels of 216 MW and higher. It was designed, manufactured, and erected by Westinghouse.

The PACE (Power at Combined Efficiencies) plant has two gas turbine generators and one steam turbine generator. Exhaust heat from the gas turbines helps produce steam for the steam turbine, making the plant more efficient than other fossil-fuel plants. Depending on site conditions, PACE plants are designed to have heat rates of about 8900 Btu/kWh when operated on natural gas. A central control system makes it possible to operate the three generating units in a flexible manner.*

The Comanche plant operates on natural gas, and it can also burn No. 2 distillate oil. With modifications, PACE plants can burn a wide variety of other liquid and gaseous fuels including residual oils.

Montreal Metro Will Get Central Control System

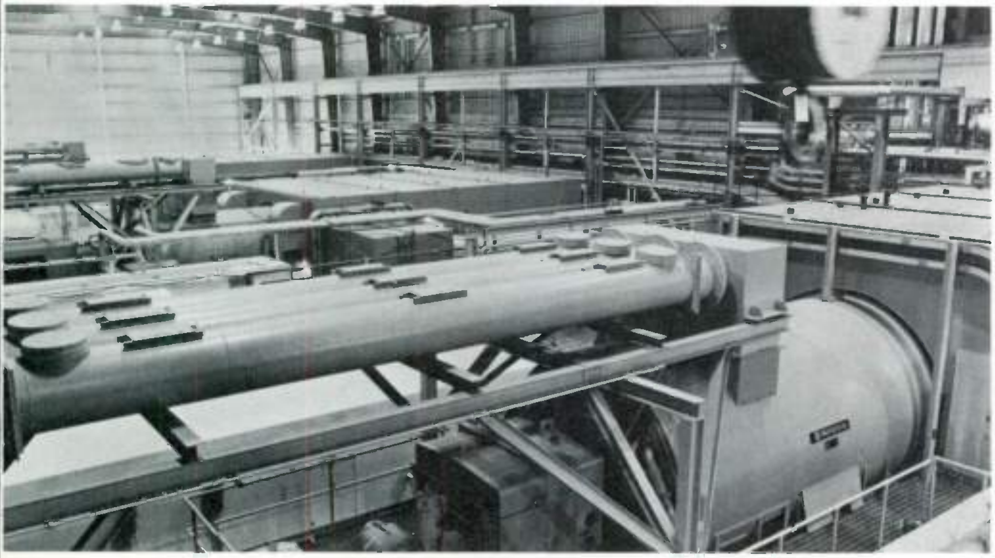
A contract to supply a central control system for the Montreal Metro subway system has been awarded to the Westinghouse Transportation Division. The equipment will control train traffic, electric power distribution, and auxiliary services throughout the entire subway system from one location. In addition, its central computer will supervise train scheduling and routing for maximum efficiency and energy conservation.

The Montreal Metro, which is under the jurisdiction of the Montreal Urban Community, has been operating the rubber-tired underground transit system since 1966. The system presently has 15 miles of track and 28 stations; it will be expanded during the next four years to 48.6 miles and 86 stations.

The central control system is scheduled to be operational for the 1976 Summer Olympics to be held in Montreal. It will schedule trains to run as close as 90 seconds apart to carry passengers to and from the locations of the Olympic events.

The equipment will come from locations in both Canada and the United States. Westinghouse Canada will supply operator consoles and displays for the central control, circuit breakers, station and tunnel signaling equipment, and cables, and it will supervise installation of the equipment.

Westinghouse has also supplied computerized central control systems for Bay Area Rapid Transit (BART) in the San Francisco-Oakland area and for the Saõ Paulo Metro in Brazil.



This 120-MW steam turbine generator and the two 60-MW gas turbine generators behind it are the heart of the PACE combined-cycle power plant. The plant is located at the Comanche Station of Public Service Company of Oklahoma.

The PACE plant covers less than an acre and has a low profile, appearing more like a small industrial building than a conventional power plant. Its two heat-recovery steam generators, at left, produce steam for the steam turbine from the exhaust heat of the two gas turbines.

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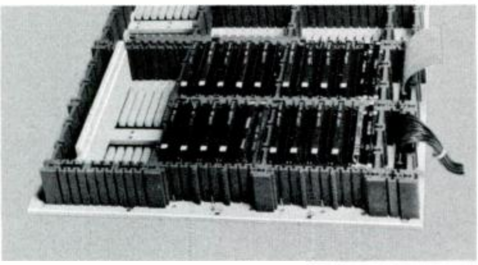
*T. C. Giras and P. A. Berman, "PACE Power-Plant Control System Provides Operating Flexibility and High Plant Availability," *Westinghouse ENGINEER*, April 1974, pp. 46-52.

Products and Services

Packaged computer, the 2530 Data Management System, is designed to help systems houses better serve the small business-system market. It incorporates the 2500 computer and includes a processor with 16K of core memory, automatic bootstrap, direct memory access, a 285-cpm card reader, a 200-lpm line printer, a moving-head disc, and a console. Standard system software includes a disc operating system, RPG compiler, disc management system with ISAM file capabilities, ISA FORTRAN IV, Basic, and a macro assembler. Hardware options include memory expansion to 64K and peripherals including teletypewriters, alphanumeric CRT displays, faster card readers, card punches, faster line printers, and cabinetry. Software options include communications emulators for several popular remote terminals including the IBM 2780, Multileaving HASP, and CDC 200 USER Terminal. *Westinghouse Computer and Instrumentation Division, 1200 W. Colonial Drive, Orlando, Florida 32804.*

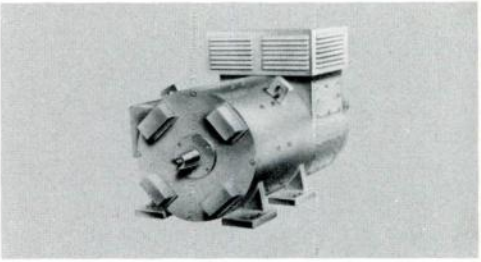
Three-phase potential transformers, outdoor Type APT, have been reduced in size and weight by using smaller and lighter core and coil assemblies and bushings of new design. They are available in 450-, 550- and 650-kV BIL insulation classes. Height of the 550-kV BIL unit, for example, is reduced from 97½ to 72¾ inches, and weight is reduced from 5450 to 2900 pounds. Key transformer features are retained, including solid insulation system that employs the uniform dielectric principle for service reliability. *Westinghouse Sharon Transformer Division, 469 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Packaging System



Packaging system for electronic circuit cards and relays, called LOC-4-SHOCK, is a virtually solid unit of high strength-to-weight ratio. It has high shock and vibration resistance, provides fast thermal dissipation, and offers excellent corrosion resistance. In addition to meeting the basic dimension standards of the Naval Avionics Standard Hardware Program (NAFI), the LOC-4-SHOCK packaging system can be modified and adapted for a wide variety of other military and industrial applications. Sections of aluminum fit together to form a receptacle for different sizes of wire-wrap plates, modules, and printed-circuit cards. The assembly is then secured to a support plate and/or wire-wrap plate and locked at the dovetail joints by locking pins. This modular approach to an electronic packaging system decreases repair time, and use of smaller plug-in devices of a throw-away type in place of a complete system of large printed-circuit boards allows discriminate replacement of small portions of a system. Card spacing can be varied, and cards, modules, and printed-circuit boards can vary in height and width to suit design requirements. *Westinghouse Marine Division, Hendy Avenue, Sunnyvale, California 94088.*

Drill-Rig DC Motor



Drill-rig dc motor meets the demanding requirements for rotating equipment for the offshore industry. The Type DR-81801 motor is a four-pole commutating-pole machine designed specifically for use with static power supplies of six or more pulses, and it can be operated at voltages up to 1000 volts. The armature utilizes a four-circuit winding, cross connections, and a commutator with a large number of bars to provide stable operation at high voltages. Precision balancing and a rigid shaft assure vibration-free performance. Field coils are individually made and insulated before being assembled to the poles. Both armature and field coils are insulated with Class H materials and then vacuum impregnated in Doryl, a Class H diphenyl oxide resin. The resulting insulation system has excellent resistance to moisture, oil, and other contaminants and is not damaged by chlorinated cleaning fluids. Mechanical stability of the coils is insured by the high bond strength of Doryl at elevated temperatures. *Westinghouse Large Motor Division, 4454 Genesee Street, P. O. Box 225, Buffalo, New York 14240.*

Data translation system, model WLT-30A, incorporates advances in software and hardware to allow recovery of data from tapes that cannot be translated on other systems. The programmable modular system can be expanded from a basic configuration to meet user specifications. The basic system includes a cartridge tape reader, special interfacing hardware and programmable clock, processor with 12K of core memory, teleprinter, and magnetic tape drive. It continually monitors time spacing between successive interval pulses, calculates an average spacing from beginning of translation, and predicts the occurrence of the next timing pulse. If an interval pulse has not been detected by the predicted time, the translator generates a simulated pulse that causes the data pulse accumulators to transfer their counts to latched buffers for temporary storage; the accumulators are then reset to zero and begin counting again. If a valid interval pulse is detected within ten percent of the interval spacing after the simulated pulse was generated, the data count in the accumulators is transferred and added to that in the latched buffers, thus restoring the actual interval. If an interval pulse is not detected, the counts in the latched buffers are used and an indication is made on the computer tape that this interval was simulated. *Westinghouse Meter Division, U. S. 1 North, P. O. Box 9533, Raleigh, North Carolina 27603.*

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Author Index

Author biographies appear on the inside back cover of each issue.

About the Authors

Ronald J. Lanyi earned his BS and MS degrees n mechanical engineering in 1958 and 1959 at Carnegie-Mellon University. He joined Westinghouse as a development engineer at the New Product Laboratories, where he worked in deelopment and application of ultrasonic processing quipment. He moved in 1961 to the former ndustrial Electronics Division (now part of the ndustrial Equipment Division), where he continued to work with ultrasonic processing equipment. In 1968, Lanyi switched over to electron-beam welding, serving first as project manager and then as engineering manager of that group. Last year he was made Product Line Manager for electron-beam and automated arc-welding equipment. In August of this year his responsibilities were broadened to include specialized ultrasonic cleaning products and processes.

Berthold W. Schumacher earned a degree in engineering physics at the University of Stuttgart, Germany, in 1950 and his doctorate in physics there in 1953 with a thesis that showed how to transfer a focused electron beam to the atmosphere most efficiently. Since then he has been working on all aspects of electron-beam physics and technology, including electron optics of beam formation, beam scattering and interaction with gaseous and solid targets, and high-voltage and vacuum systems engineering. He has also worked on the physics and technology of X-ray detectors and spectrometers. His inventions include, besides electron-beam welding and cutting in air, an electron-beam fluorescent probe for gas analysis at low pressure, a single-scatter gauge for gas or vapor density measurements, and a range-energy method for thickness gauging with electron probes. He has been awarded more than 20 patents.

Dr. Schumacher worked first in German industry as a design and development engineer in X-ray instrumentation and electronics. In 1954, he joined the Ontario Research Foundation in Canada to do industrial and military contract research; he became Director of its Department of Physics in 1958.

Dr. Schumacher's association with Westinghouse began in 1964 as a consultant in electron-beam technology. He joined the Company in 1966 as Manager, High Power Electron Beams. He has published more than 40 papers in scientific and engineering journals.

Joseph M. Wells graduated from Northeastern University in 1963 with a BS degree in Mechanical Engineering. He earned his MS degree in Mechanical Engineering at Northeastern in 1965 and his Sc.D. degree in Physical Metallurgy from Massachusetts Institute of Technology in 1970. While at MIT, he was a research engineer associated with the Instrumentation Laboratory. He then entered active duty with the U.S. Army, initially at the Materials and Mechanics Research Center and then in Vietnam as a captain in the Corps of Engineers.

Dr. Wells joined the Westinghouse Research Laboratories in 1972 as a Senior Research Engineer with the Metals Joining and Metals Processing Department. His current responsibilities include development of process applications technology for high-speed and thick-section non-vacuum electron-beam welding. He is also principal investigator in evaluation of structural materials for advanced cryogenic applications, and he is a consultant for the materials, processing, and fabrication technology associated with development of Westinghouse prototype 5-MVA superconducting generators.

Darrell B. Searls graduated from South Dakota State University with a BSME degree in 1948. He joined Westinghouse on the graduate student training program and served first in the Chicago and Fort Wayne district offices as a salesman and sales engineer for industrial and electric-utility products. He moved to Pittsburgh in 1959, where he progressed through a series of marketing positions in industrial equipment and systems.

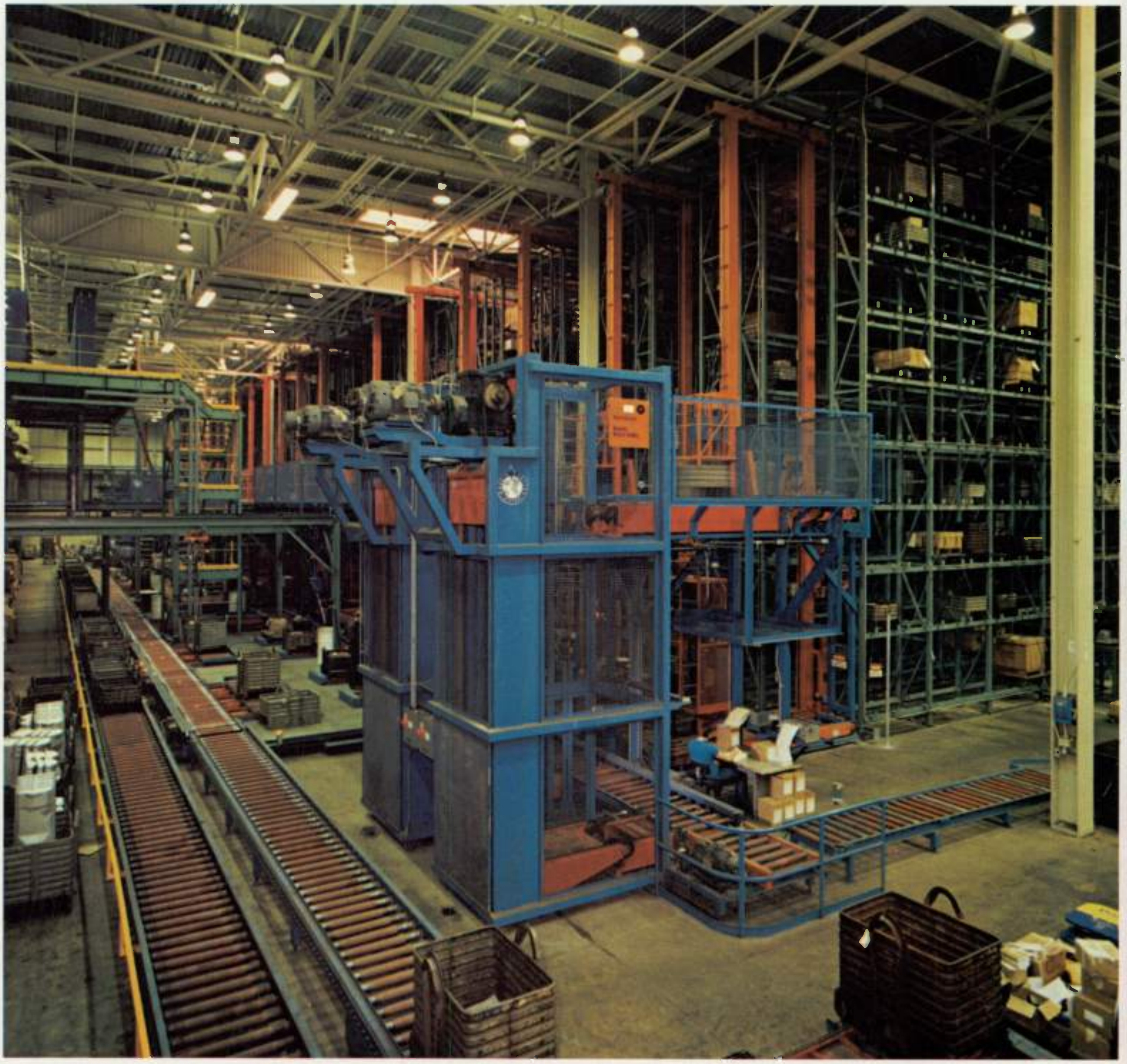
In 1965, Searls transferred to Buffalo as senior division salesman for automated material handling systems. He became project manager with marketing responsibility for material handling systems in 1967, and in 1971 he was made Manager, Automatic Material Handling Systems Group.

Searls' major interest has been application of the systems approach to problem solving in the material handling field. He has contributed to the application of computers to material handling systems, the concept of high-bay high-density storage of unit loads, and development of an automatic transport system for institutional, commercial, and industrial use.

M. J. Spangler graduated from Virginia Polytechnic Institute in 1953 with a BS in Industrial Physics. Upon graduation, he spent two years with the U.S. Army Signal Corps at White Sands Proving Grounds, working in the design, installation, and maintenance of radar and television equipment.

Spangler joined the Westinghouse Electronics Division in Baltimore in 1955. His first assignment was in circuit design for ground-based electronic equipment. He moved to the Westinghouse Surface Division in 1958, where he was made a Supervisory Engineer, with responsibility in system design and fabrication of data processing and display equipment. Spangler was promoted to Fellow Engineer in 1964 and assigned to the development of closed-circuit TV equipment. Since 1965, he has been engaged in system design studies and technical direction of programs involving spacecraft sensors, on-board data processing, and ground data collection processing and display equipment.

Westinghouse Electric Corporation
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222



The storage system at the East Peoria plant of Caterpillar Tractor Co. moves loads weighing up to 3000 pounds from receiving inspection to a storage area with 30,000 locations. Central data processors and controllers receive information about the material as it travels by conveyor or transfer car. They track the material by moving the information related to each load from one zone of the conveyor system to the next as the controllers receive signals from sensing devices along the route indicating passage of the load. When the load reaches a point where a stacker crane can pick it up, a controller selects a storage location, passes a storage command to the crane, and, when the crane cycle is complete, records load information and location on an inventory record file that enables the system to retrieve material when it is needed. A requested load comes out of storage into a retrieval area (shown here) with a computer-generated "pick ticket" attached to it. An operator picks what is needed, indicates on the pick ticket what he has taken, and returns the rest of the load to storage; the computer then adjusts the inventory record. For more information on integrated material-handling systems, see the article beginning on page 105.