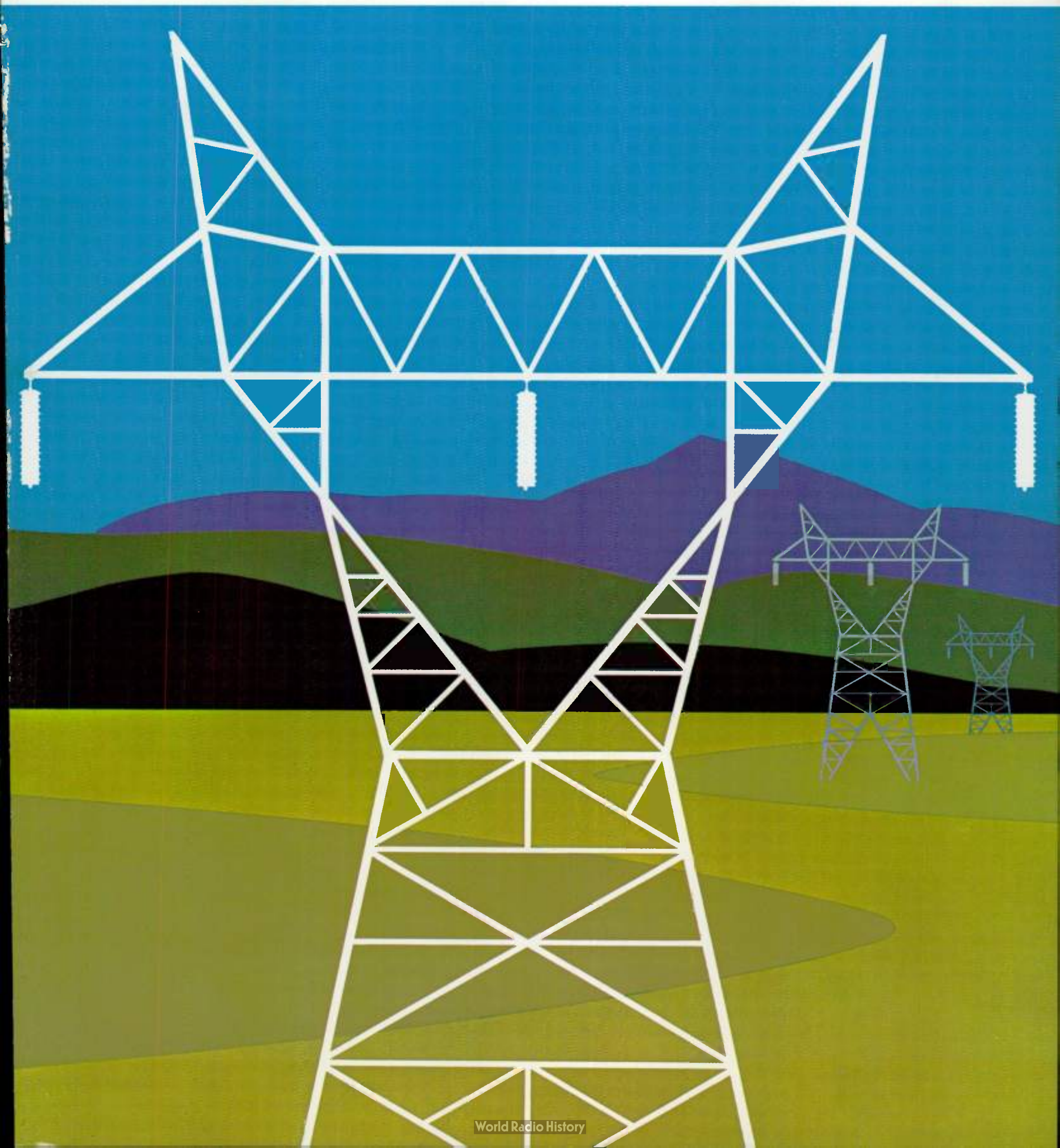
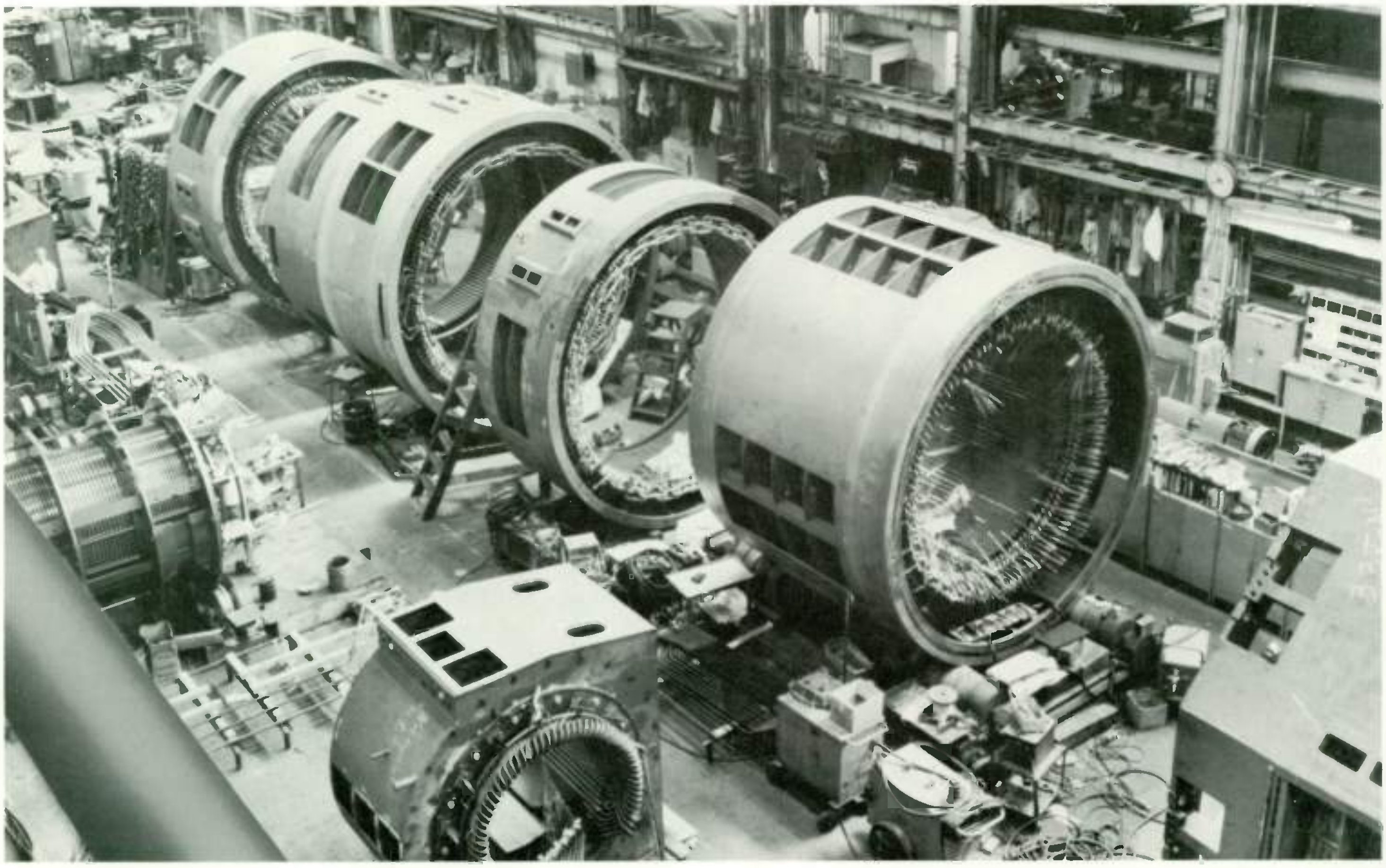
Westinghouse ENGINEER

March 1972





Large Pump Motors Will Serve California Water Project

The five large motor stators dwarfing the man in the photograph (extreme left) range in size from 17,000 to 80,000 hp. They were shipped recently to the California Department of Water Resources as part of a project to pump 5000 cubic feet of fresh water a minute to the people of Los Angeles County. The water will serve many uses including drinking, irrigation, and recreation.

The heart of the project is the California Aqueduct, which will move water from the moisture-rich northern half of the state to the water-poor southern reaches. Near Bakersfield the Techachapi Mountains present a 2900-foot obstacle that will be surmounted by pumps driven by the big motors, which are being supplied by the Westinghouse Large Rotating Apparatus Division.

Eleven 80,000-hp vertical synchronous motors will serve the A. D. Edmondston Pumping Plant, which will pump water 1938 feet in the last thrust over the hills and through 9 miles of tunnels to the far side.

Forty-two miles north, three 8500-hp and seven 17,000-hp motors at the Buena Vista pumping plant will lift the water 205 feet. Still farther north, the Wheeler Ridge pumping plant will have three 10,000-hp and six 20,000-hp motors, raising the flow 233 feet, and the Wind Gap pumping plant will lift it 518 feet with three 22,000-hp and six 44,000-hp motors.

The Large Rotating Apparatus Division is also supplying direct connected exciters and starting m-g sets for the four plants. Auxiliaries and excitation switchgear are being built by the Switchgear Division.

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Front Cover: Power transmission lines can be protected by many different types of solid-state pilot protection systems. Some guidelines for selecting a suitable system are discussed in the article beginning on page 50. This month's cover design is by artist Tom Ruddy.

Static Power Supplies with AC Machines

S. J. Campbell

More efficient use of power and improvements in process control result when static power supplies are applied with ac prime movers.

Various drive combinations of ac motor and static power supply are increasingly challenging both conventional ac industrial prime movers and dc drive systems, especially in the larger sizes (say 200 hp and larger). Moreover, they are providing novel problem-solving techniques for power transmission and generation systems.

The reason for both trends is the continuous development in static power supplies since their introduction, much of it directed toward adjustable-voltage dc drive systems but applicable also to ac systems. Power devices such as thyristors have been increased in voltage and current ratings, new regulator techniques have been perfected, reliability has been increased, low-cost modular systems have been developed, and the time required for engineering and manufacturing a system has been reduced by as much as 50 percent. All of those developments have made static ac systems increasingly attractive economically.

The conventional ac industrial drives being challenged by the new systems are mainly constant-speed motors with eddy-current clutches, wound-rotor motors with secondary resistors, and constant-speed synchronous motors with reduction gearing (Fig. 1). In power transmission and generation systems, applications of static ac power supplies include load compensators and accelerators for pumped-storage hydro plants.

The conventional static dc power supplies for drive systems are the "converter" and the "dual converter." They have become the standard supplies with dc motors in the complex adjustable-speed (and often reversible) drive systems used for mine hoists, metal rolling mills, papermaking equipment, and various process drives in rubber, textile, chemical, and other industries (Fig. 1d).

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A converter utilizes a six-thyristor circuit that provides forward dc power only. A dual converter has six more thyristors so power can flow in either direction. It applies or accepts constant frequency at constant ac voltage on one power side and applies or accepts adjustable dc voltage on the other side (Fig. 2).

Regulators, feedback control techniques, power hardware, and modular thyristor packaging for these dc systems have reached a level of sophistication limited only by the controllability of the process. Moreover, continuing increases in thyristor ratings are allowing more power in the same size package at only slight increases in cost. Even so, the system of dc motor with static dual converter is usually the most expensive type in overall first cost, mainly because dc motors generally cost more than ac machines and because there is more peripheral equipment such as regulators.

The main types of static ac power supply available today are the cycloconverter, rectifier-converter, and converter-inverter (Fig. 2). All use various arrangements of thyristors, diodes, firing circuits, and regulators. In this brief survey, they are discussed in terms of input and output characteristics because that is the best way for a potential user to evaluate them.

Cycloconverter

This static supply applies or accepts constant frequency at constant ac voltage on one power side and, on the other power side, applies or accepts adjustable frequency and adjustable ac voltage. Power conversion is performed by a single set of thyristors in each of the three ac lines. Controlled firing of the thyristors provides controlled modulation of the line-side input frequency. The line frequency can be modulated only to lower values, with the practical limits of load-side frequency being approximately 0 to 30 percent of line-side.

A cycloconverter requires 30 to 50 percent more thyristors than does a dual converter of the same capacity. However, the cost of peripheral equipment such as transformers, regulators, and power interrupters is about the same. In addition, ac motors are inherently less expensive than equivalent dc motors (especially in low speed ratings), they require less maintenance, and their air gap tolerances between rotor and stator are much less critical. Therefore, the combination of ac motor and cycloconverter is likely to be economically attractive, especially when the driven process includes a large low-speed revolving drum either direct coupled or geared and with requirements of speed adjustment, accurate dynamic control, and reversal. The first four examples following illustrate such applications; the last is an application in electrical power transmission.

Yankee Dryers—These components of papermaking machines are usually 12 to 16 feet in diameter, operate at speeds from 0 to 100 r/min, and require hollow drive shafts for passage of heating steam. A typical conventional drive consists of a hollow-shaft dc motor of 500 to 800 hp, with a static dc dual-converter power supply. The motor armature is mounted directly on the shaft of the Yankee dryer.

That conventional dc drive has now been superseded by a low-speed synchronous ac motor and a cycloconverter static supply with ac output of 0 to 15 hertz (Fig. 3). First costs are essentially the same because the somewhat more costly cycloconverter supply is offset by the simpler and more economical ac machine. The user has the advantages of less space requirement, less maintenance because of the ac machine, and availability of plant power-factor correction through use of additional static devices to control the machine's excitation.

Friction-Type Mine Hoists—These consist of a large drum (90 to 150 inches in diameter) that conventionally is direct-driven by a dc motor. Motors range from 500 to 7000 hp, and top speeds from 40 to 70 r/min. Dc static power supplies have seen only limited service to date because of their newness, seemingly greater complexity compared with m-g sets, and possible plant power factor problems in remote mine areas. When they are used, they are of the dual-converter type with full reversing.

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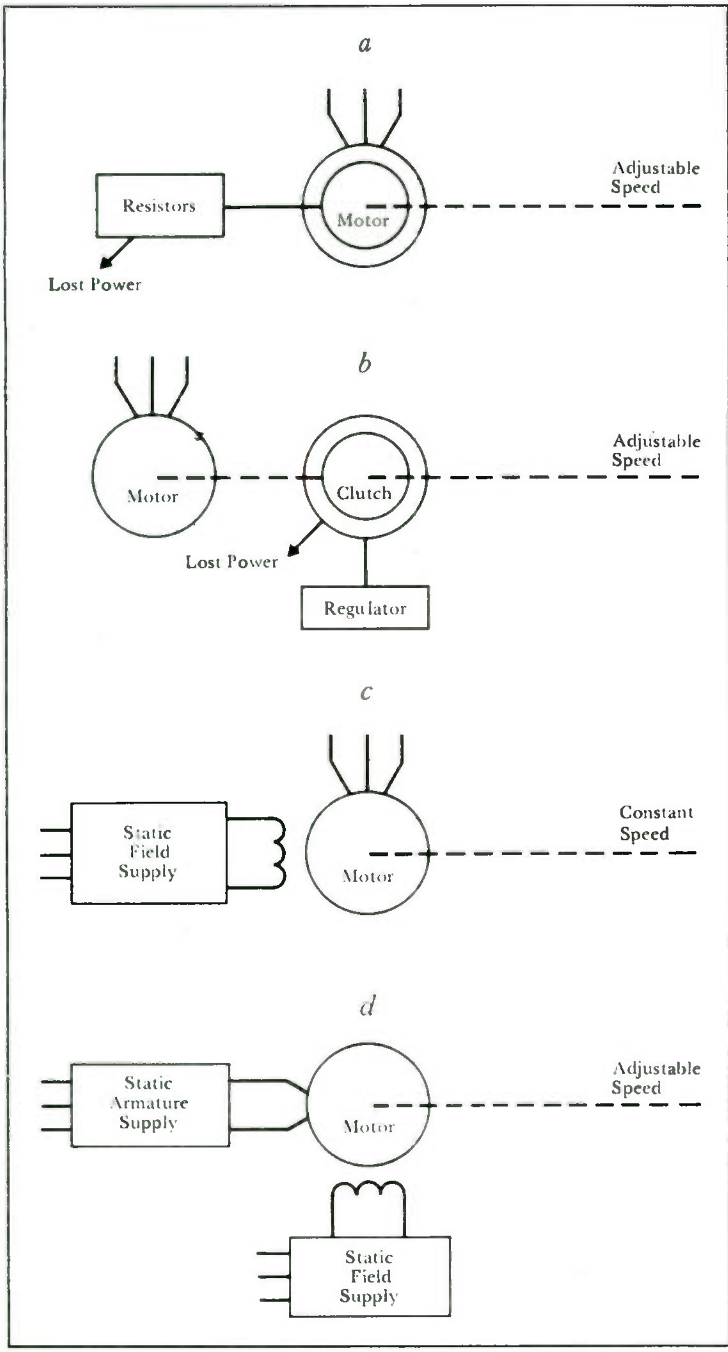

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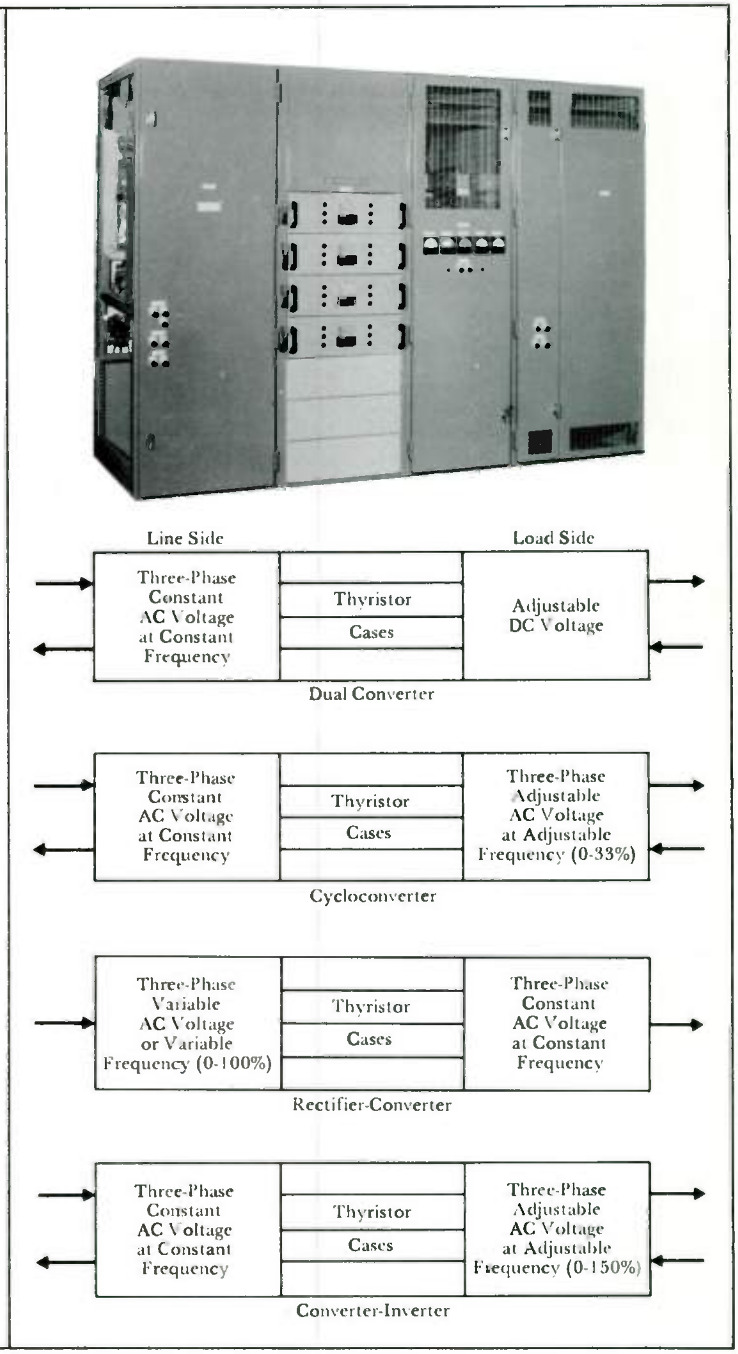

1—Conventional ac industrial prime movers are mainly (*a*) wound-rotor motor with speed adjustment by means of adjustable secondary resistance, (*b*) constant-speed squirrel-cage motor with eddy-current clutch for speed adjustment, and (*c*) synchronous motor supplying fixed speed at fixed frequency. Speed adjustment for the first two wastes power, which is dissipated as heat. Conventional static dc power supplies control the motor's speed by permitting adjustment of armature or field voltage (*d*). The choice between the various types of dc power supplies (mainly converter or dual converter) and the ac drive types depends on such considerations as the space available, accuracy and response requirements, cost, maintenance requirements, flexibility, and efficiency.

2—The power hardware of static power supplies, whether dc or ac, consists essentially of thyristor power cases connected in series or parallel as needed to provide the desired rating. Depending on the function generators, firing circuits, regulators, and thyristor connections used, the power supply may be the familiar dual converter or the newer ac static power supplies.

Direct ac drives with cycloconverters can be applied. The economics and benefits are similar to those with Yankee dryers.

Large Draglines—Used mainly in open-pit coal mining to remove overburden, these machines are equipped with two or more large cable drums to hoist and drag the excavating bucket. At present, each drum is driven at speeds on the order of 30 to 60 r/min by as many as six 500-hp high-speed dc motors through complex gear reductions. The heavy-duty mill motors are supplied with power from multiunit m-g sets. Complex dc controls, including load sharing regulators, are required. Gearing, dc motors, m-g sets, and ac and dc control may take as much as half of the deck space. The electrical machinery and gearing must be of extremely rugged design to withstand vibration, shock, tilting, high cyclic motoring and regenerating loads, and wide ranges of environmental conditions. Only recently have users and electrical suppliers felt that dual-converter dc static supplies could replace the m-g sets at a saving in first cost.

Now, however, the dual-converter stage of development can be leapfrogged, because closer evaluation of the actual process requirements—turning the drag-line drums—shows that a cycloconverter plus direct-drive shaft-mounted synchronous motor would have an advantage in first cost over the presently used m-g sets, mill motors, and reduction gearing. In addition, total deck space taken by electrical equipment would be reduced to 25 percent. Bearing maintenance would be reduced because there would be only two bearings per drum. Only half as much ventilating air would be required. The only mechanical alignments required for electrical equipment would be the noncritical air gaps in the ac synchronous motors. In the future, most draglines probably will be supplied with ac cycloconverter drives.

Large Attrition Mills—Ball, rod, pebble, and autogenous mills have been driven by various combinations of gearing and constant-speed ac motors. Inching provisions, high-inertia low-inrush starting requirements, and multiple motors have resulted in fairly complex drive and gear arrangements.

A completely gearless ac drive can now be supplied, using the same techniques as in the previous examples. It employs a single low-speed synchronous motor (for example, 8 to 15 r/min synchronous speed at 12 hertz or less) fed from a cycloconverter. First-cost economics still favor conventional ac drives up through 5000 hp. Above that level, individual circumstances may favor one type or the other.[1] However, at 7000 hp and up, it is certainly practical to consider the gearless type. Starting torque control, inching, power-factor control, and inrush

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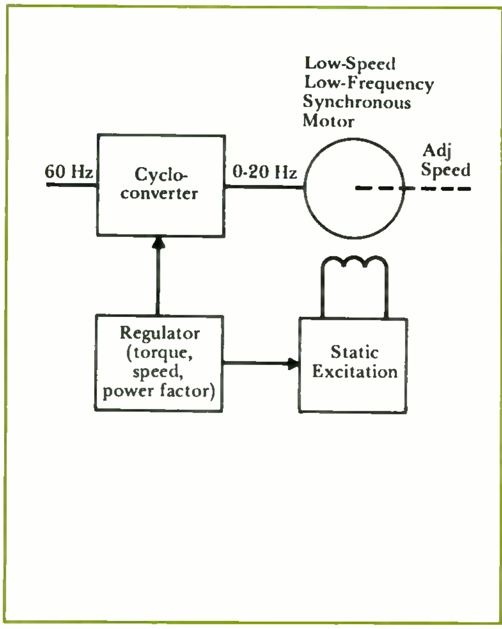

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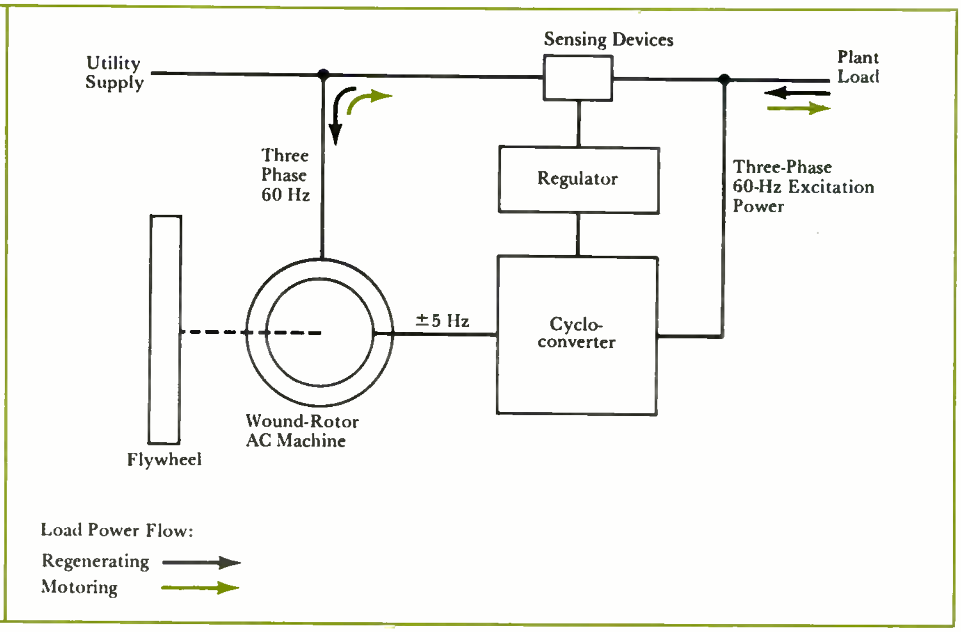

3—A low-frequency synchronous motor powered by a cycloconverter is likely to be a more economical drive arrangement than a dc type, especially when the load is a large low-speed drum. Such applications include papermaking machinery, mine hoists, dragline machinery, and grinding mills.

4—Cycloconverters are also used with asynchronous ac machines and flywheels to absorb and supply peak cyclic loads. Energy is stored in the flywheel (as a speed increase) during peak regenerating periods of the load motors; it is extracted as electrical power during peak motoring periods of the load motors.

limitation are all inherent features of this drive. Also, inherent ability for vernier speed adjustments could lead to use of speed control as a means of optimizing the grinding process.

Load Compensators — Cycloconverters can be used with wound-rotor ac machines and energy-storage flywheels as asynchronous power system load absorbers (Fig. 4). One application is with large excavators, which have such drastic swings in drawing and regenerating power that they can cause trouble on a small power system. The asynchronous load absorber has the effect of moving a new power source to the excavator site.[2]

Rectifier-Converter

This type accepts variable-voltage or variable-frequency ac power on the rectifier side, rectifies it to variable-voltage dc power, and then converts the dc power to constant-frequency constant-voltage ac power for connection to a conventional ac power system. At first glance that looks like a redundant operation. Consider, however, a wound-rotor ac motor with secondary slip rings. The frequency and voltage on the slip rings are functions of rotor speed. At zero speed, the rotor acts as a transformer: its frequency is equal to stator frequency and, theoretically at least, power is transformed from stator to rotor much as in a conventional transformer. At 100 percent speed, which is a theoretical condition, rotor frequency and voltage are zero.

Conversely, controlling rotor frequency or voltage provides an adjustable-speed ac drive. Such speed control is one of the purposes of secondary resistors on wound-rotor motors (the others being control of inrush, starting, and accelerating conditions). However, secondary resistance results in inefficient use of ac power and does not permit close speed regulation, vernier speed adjustment, torque limit, or other process-oriented feedback control features. Consequently, the wound-rotor motor has found only limited application compared with dc drive systems or with ac motors and eddy-current clutches.

Applying a rectifier-converter to the secondary removes all the objectionable features of secondary resistors and opens up new fields of application for wound-rotor machines. Adjusting the firing angle of the thyristors in the rectifier-converter controls the voltage that the rectifiers can accept. This in turn forces the secondary voltage of the ac machine so as to obtain the desired rotor speed. Secondary power normally dissipated in heating slip regulators or banks of resistors is, in effect, recycled back into the ac line through the rectifier-converter (Fig. 5). Consequently, this type of ac drive with static power supply is becoming known as a power reclaimer.

Compared with a dc drive, the system of wound-rotor motor with static second-

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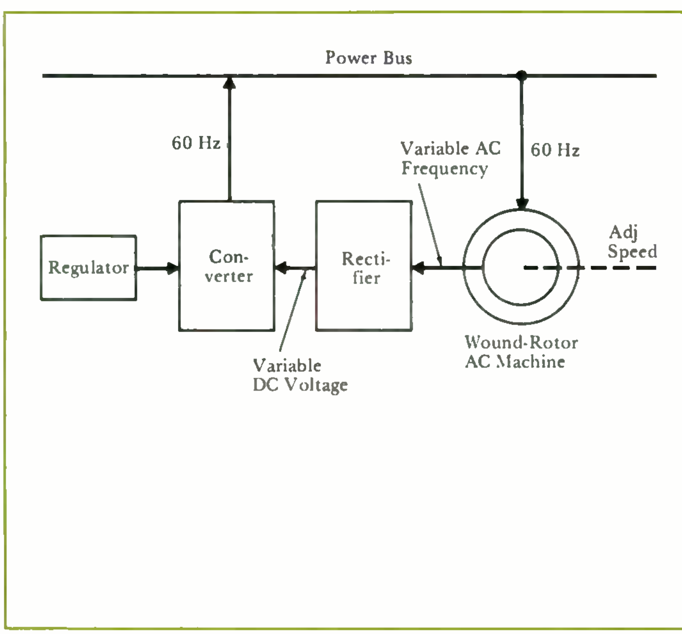

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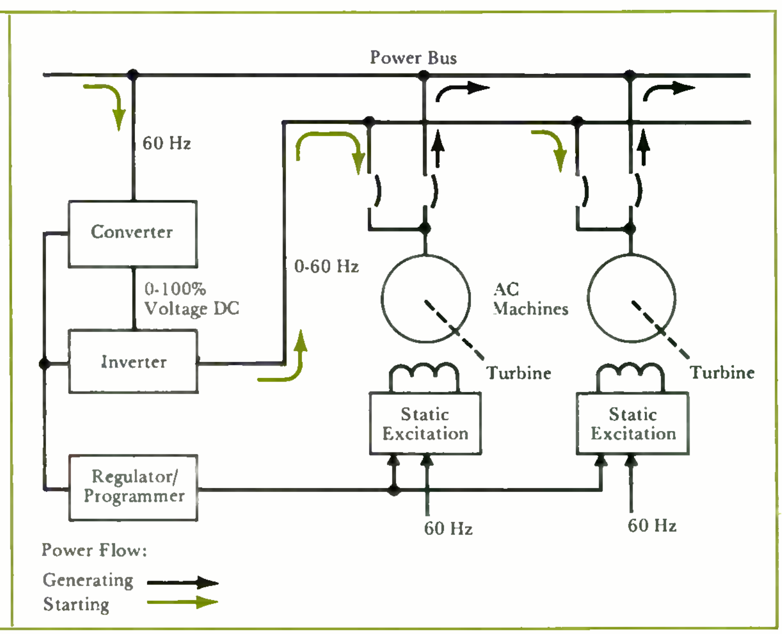

5—Rectifier-converter provides speed control for a wound-rotor ac machine by serving much as adjustable rotor resistance does in the conventional arrangement (Fig. 1a). In addition, it reclaims power that is wasted in the conventional arrangement.

6—Converter-inverter can be an economical starting system for the ac machines used by electric utilities in pumped-storage generating plants. When the machines are reversed and run as motors, their turbines serve as pumps. To start them in that mode, a single converter-inverter supplies adjustable-frequency power to accelerate each machine, in sequence, up to synchronous speed.

ary control has the advantages of lower first cost and provision of a simpler electrical machine driving the user's process. It cannot, however, provide reverse operation, and its cost tends to equal that of the dc drive when required production speed ranges exceed 4 to 1.

Compared with an induction motor and eddy-current clutch, the system has several advantages. Unused rotor power is returned to the line instead of being dissipated in water or air. For example, a constant-torque load that requires 1000 hp at 100 percent speed would require 500 hp at 50 percent speed; at the latter speed, an eddy current clutch has to dissipate 500 hp in heat but a wound-rotor motor with static secondary returns the 500 hp to the ac line. This power saving amounts to about $25,000 a year in a typical case—power cost of $0.01 per kilowatt hour and operation 24 hours a day for 280 days of the year. In addition, returning the power avoids the ecological problems that can arise when large amounts of heat are dissipated in water or air.

Moreover, space required for the drive is reduced by half. Maintenance and installation costs associated with clutch bearings and clutch cooling systems are eliminated, and control of the driven process is improved by the elimination of intermediate electrical and mechanical time delays.

The wound-rotor motor with static secondary supply should also find extensive use when process loads are of the fan type, the area where eddy-current-clutch drives predominate at present. A fan type load is one in which torque varies inversely as the square of operating speed. (For example, if 100 percent speed corresponds to 100 percent horsepower and 100 percent torque, at 50 percent speed load torque is 25 percent and load horsepower is 12.5 percent.) Centrifugal pumps, wind tunnels, and air-handling fans have that type of load characteristic. At 50 percent speed, an eddy-current clutch would have to dissipate 12.5 percent horsepower in heat, whereas the wound-rotor motor with static supply would return that horsepower to the ac line.

Power return capability will become of increasing importance in such systems as the large sewage and water treatment plants now being planned. Those plants will increasingly use adjustable-speed drives to provide closer process control. Savings in installed costs and building space, more efficient power use, tighter process control, and reduction in heating the surrounding air or water are all advantages of the wound-rotor ac static drive over presently used types.

Converter-Inverter

This power supply applies or accepts constant frequency at constant ac voltage on the converter side and applies or accepts adjustable frequency at adjustable ac voltage on the inverter side. There are two major differences between it and the cycloconverter: (1) Power is handled only once in a cycloconverter, being directly transformed to adjustable frequency through the single set of thyristors in each leg. The converter-inverter, in contrast, first converts the power to dc, and the inverter portion then changes the dc power into adjustable-frequency ac power. Therefore, the converter-inverter has more power hardware than the cycloconverter and has a correspondingly higher cost. (2) The converter-inverter is not restricted in output frequency as is the cycloconverter. It can be operated up to base frequency and as high as 50 percent above that frequency.

Applications of converter-inverters, such as the Westinghouse Accurcon, include the highly accurate power supplies required for synthetic fiber spinning lines. A number of small synchronous motors drive the spinning devices over a synchronous speed range.

Another important application is in conjunction with electric-utility pumped storage facilities. The power industry has long supplied peak loads by pumping water into storage during periods of low power demand and releasing that stored energy via hydroelectric turbines during peak demand periods. The trend is now to design both the electrical units and the hydraulic turbines for reversible service: the generators and turbines can become motors and pumps, respectively.

A means of starting the high-inertia motors is then required, as with any synchronous motors. The difference from other motor applications is the very high power rating — as high as 200,000 kW each. A single converter-inverter, serving several motors in sequence, is an excellent device for starting the motors and accelerating them to synchronous speed (Fig. 6). Compared with individual auxiliary starting motors, the converter-inverter has the advantages of substantially less maintenance, simpler hardware, improved efficiency because less power is lost in starting and braking, smoother starting, and considerable saving in floor space.

Application Considerations

Such considerations as power factor, line harmonics, ac noise, line voltage level and quality, alternative types of input-output equipment, and protective circuitry vary too much among applications of ac machines to be treated adequately in a brief review such as this. As with static power supplies for dc machines, the questions are resolved when the power supply is chosen and adapted for a particular set of conditions in a particular industrial application; any difficulties are usually inconsequential by comparison with the benefits provided by static power supplies. Later articles will include discussion of the application considerations as they apply to specific installations.

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[2] L. A. Kilgore and D. C. Washburn, Jr., "Energy Storage at Site Permits Use of Large Excavators on Small Power Systems," *Westinghouse ENGINEER*, Nov. 1970, pp 162-7.

Subminiature TV Camera

James H. Meacham

State-of-the-art hybrid packaging techniques, using digital circuitry wherever possible, make up the electronics for SUBMIN-TV, a camera contained in a 1.5- by 1.5- by 5-inch package that weighs only 9 ounces yet provides a full EIA composite video output format and 450 TV/RH resolution capability.

The significant advances in television systems for military and aerospace applications in recent years have been provided primarily by sensor improvements.[1] Although these systems have made use of solid-state circuitry, they have not fully utilized the expanding technology in integrated circuitry to achieve the significant size and reliability advantages that are inherent with the IC approach.

The effectiveness of miniaturized digital circuitry designed specifically for use in television systems was demonstrated by the sync generator hybrid package used in the Apollo color television cameras.[2] This sync generator uses 22 monolithic digital chips housed in a 1- by 1-inch ceramic flatpack. When provided with a digital clock input, the sync generator develops full EIA* mixed sync, mixed blank, and horizontal and vertical drive outputs.

The outstanding performance and reliability of the digital sync generator in the Apollo application provided the impetus for further development of subminiature camera circuitry using hybrid packaging techniques and digital processing wherever possible. The subminiature TV camera that has resulted from this effort is built around a 0.5-inch vidicon sensor tube with electrostatic focus and magnetic deflection. With the addition of a focus-coil current regulator, the SUBMIN-TV circuitry functions with any magnetic 0.5- or 1-inch vidicon.

Thus, the circuitry developed for the SUBMIN-TV camera is applicable to a variety of sensors (lead oxide, SEC, EBS) with 1-inch gun structures.

Subminiature Circuitry

Camera circuitry is divided, electrically and physically, into functional blocks that provide isolation and logical signal flow (Fig. 1). Each of the six major blocks is contained in a 1-inch square ceramic flatpack. These hybrid IC packages are applicable to any magnetic deflection sensor, and the sync, preamp, and postamp units will function in any TV camera with comparable format and bandwidth requirements.

*Electronic Industries Association (formerly Radio-Electronics, Television Manufacturers Association).

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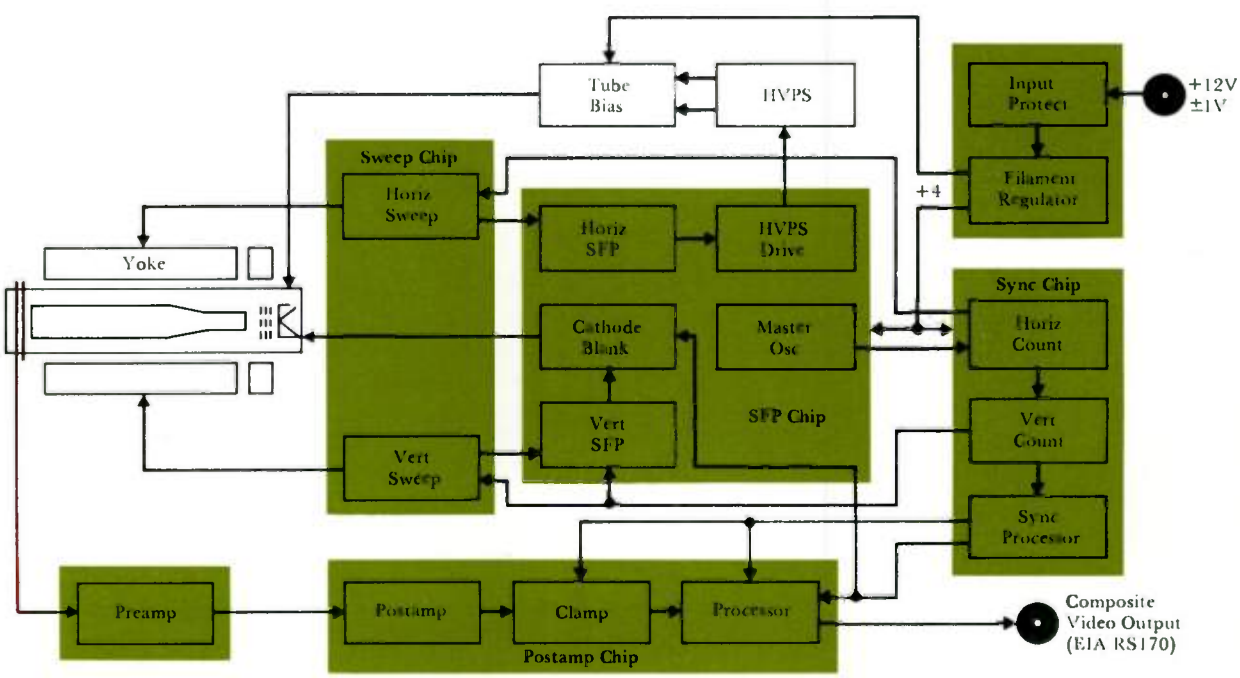


1—Most of the SUBMIN-TV camera circuitry is contained in six 1-inch square hybrid packages. The only input power requirement is 12 volts (±1 volt). The composite video output conforms to EIA RS170 broadcast specifications.

Composite Video Format for TV Broadcasting

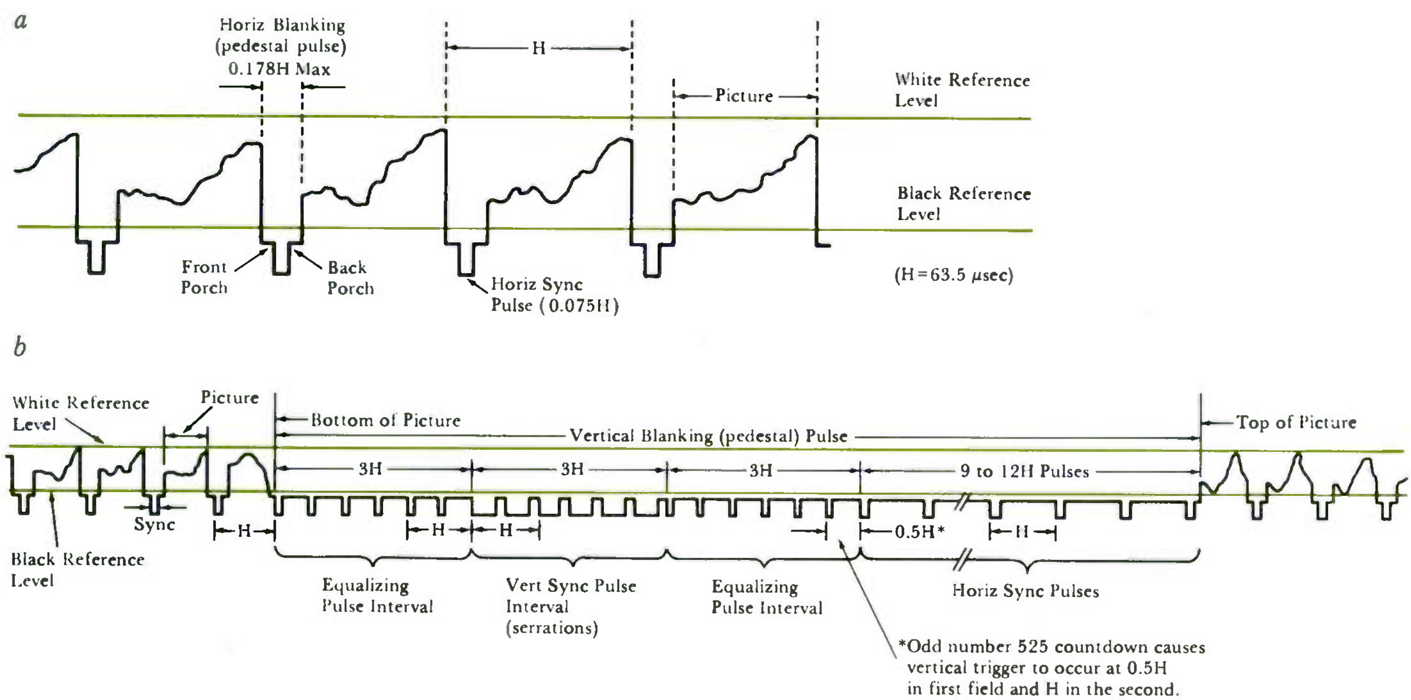
The broadcasting television frame (picture) in the United States is 525 lines, completed in 1/30 second. To reduce flicker, each frame actually consists of two interlaced fields, one field being the even numbered lines and the next field the odd lines. Thus, the standard TV vertical frequency is 60 fields per second (60 Hz). Since each field consists of 262.5 lines (average), line frequency is $60 \times 262.5 = 15{,}750$ Hz. The time (H) from the start of one horizontal scan to the next is 63.5 microseconds.

Each horizontal line scan for a monochrome TV broadcast signal (*a*) consists of a synchronizing pulse to lock the receiver's scanning beam to the broadcast scanning frequency, a blanking period to provide a "no write" interval for the scanning beam to return from the previous scan, and, of course, the video brightness signal that reproduces one line of the scene being scanned.

At the end of each field, a nine-line vertical synchronizing signal (*b*) is generated. It consists of three lines of equalizing pulses, three lines of serrations, and three more lines of equalizing pulses, all generated at twice line frequency. The vertical sync format conditions and triggers the monitor's vertical sync integrator to assure proper interlace.

The fields are interlaced due to the odd 525 countdown as referenced to the 31.5 kHz (2H) frequency that initiates the horizontal logic.

As suggested above, the timing and duration of the various synchronizing pulses that make up the composite video format are extremely critical.



The hybrid fabrication techniques used in the SUBMIN-TV camera lend themselves to an "off-the-shelf" building block approach for the design and manufacture of other specialized TV cameras in small lots. The small size of the hybrid IC package and its simple interconnection requirements permit adaptations to nearly any mechanical configuration.

Digital Synchronization

A unique feature of the SUBMIN-TV camera is its use of digital processing to generate all frequencies and sync signals required to operate the system. Typical TV camera circuits use one-shot multivibrators in RC configurations to generate the various logic forms of pulse durations and formats. By developing these functions digitally, the inherent tune-up and stability problems encountered with conventional circuit components can be avoided.

The pulse trains and logic required to develop the various synchronizing signals are generated digitally with pulse counters, NAND and NOR logic elements, and flip-flops (Fig. 2a). The 787.5-kHz clock frequency input to the half-line counter is divided by 25 to provide a twice-horizontal (31.5 kHz) frequency. The logic states available in the ÷25 counters are used to develop the equalizing pulses and serrations (Fig. 2b) needed for the vertical synchronizing signal. The horizontal blank, sync, and drive pulse trains shown both solid and dashed in Fig. 2b are generated at the horizontal line frequency (15.75 kHz), but switched in position with each successive field scan to provide line interlace. This half-line time shift (0.5H)

Digital Counting

Any number can be expressed in the form,
$$N = d_n R^n \ldots d_2 R^2 + d_1 R^1 + d_0 R^0$$
where N is the number, d is the digit, and R is the base or radix of the number system. The number is commonly written as:
$$d_n \ldots d_3 d_2 d_1 d_0$$
Hence, in the familiar decimal system,
$$25 = 0 \times 10^3 + 0 \times 10^2 + 2 \times 10^1 + 5 \times 10^0.$$
Similarly, in the binary world of the digital computer this same numerical value is expressed:
$$11001 = 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0.$$
The decimal equivalent of a binary number may be quickly determined by assigning a decimal value to each binary digit:

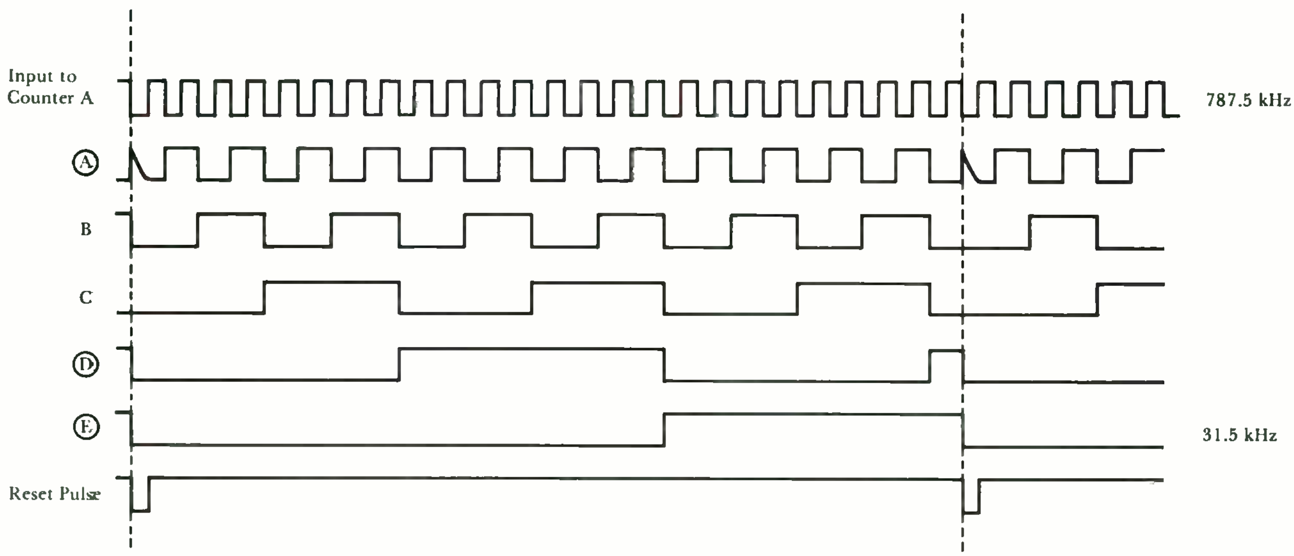
Decimal value	32	16	8	4	2	1
Binary 25	0	1	1	0	0	1

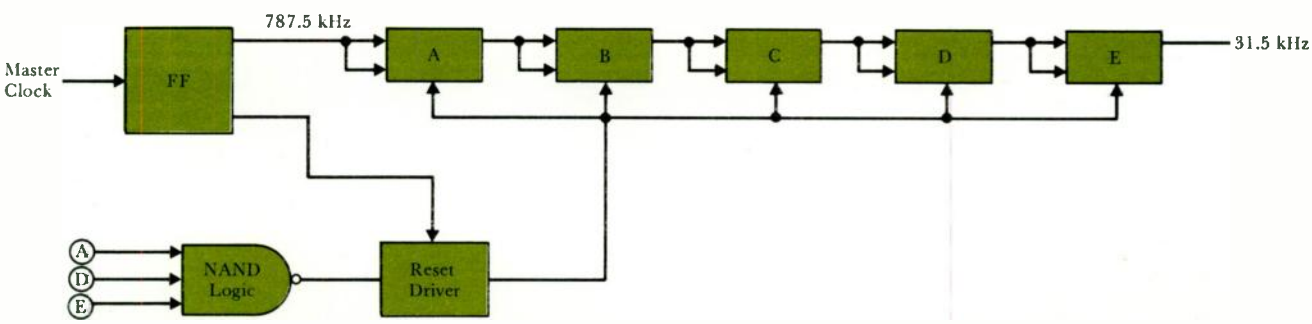
The binary counting chain shown (A, B, C, D, E) counts input pulses just as one would count in the binary number system, i.e., 00000, 00001, 00010, 00011, moving up one binary number with each input pulse to counter A, the d_0 position. (Note that the orientation of the counters in the diagram is in the reverse order of conventional binary number expression, or $d_0 d_1 d_2 d_3 d_4$.) The timing of the pulses in the five binary counters for this orientation is shown graphically.

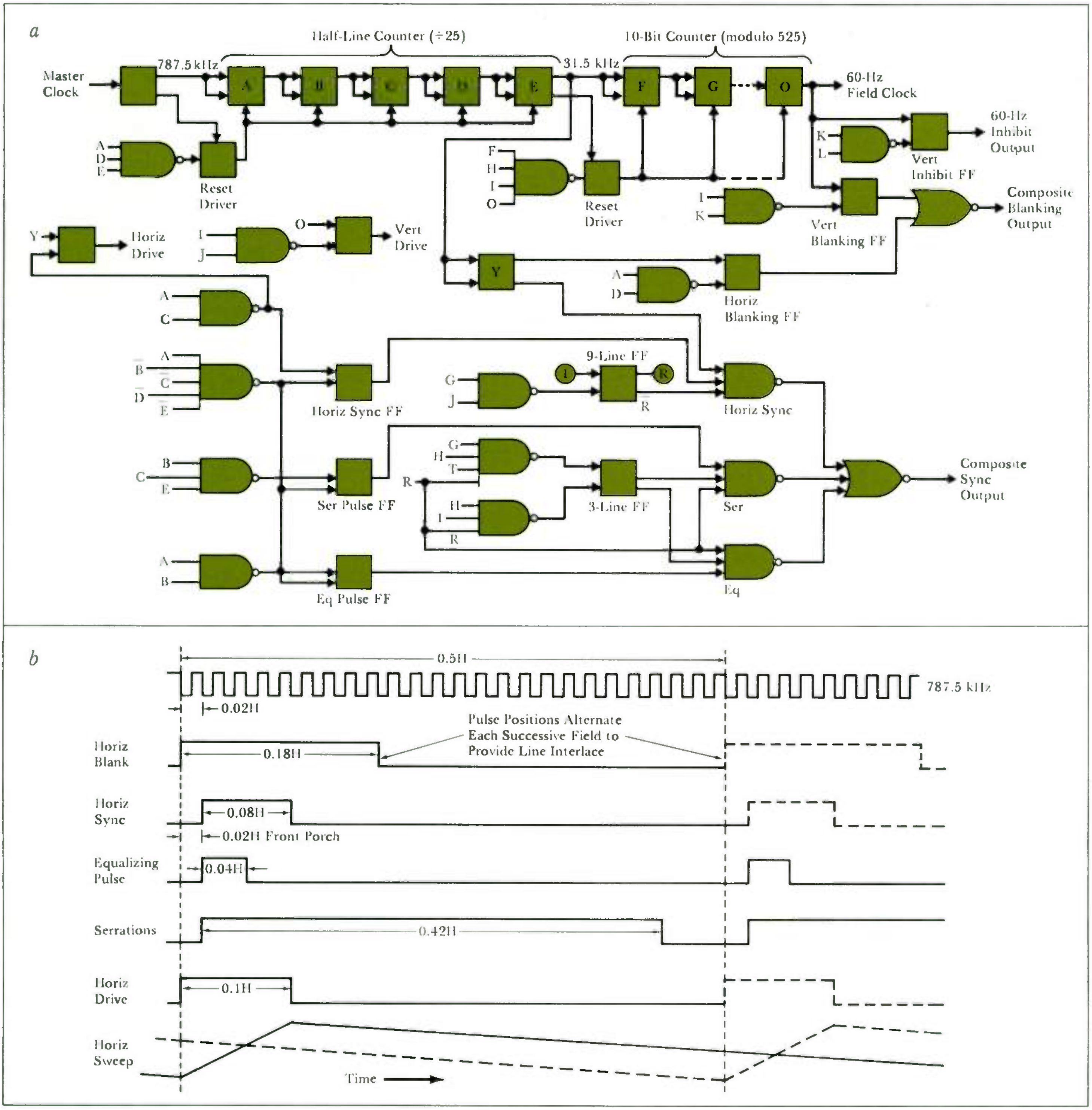
At the instant the counter reaches 11001 (binary 25), the counter resets to zero and begins counting again. Counter reset is controlled by the three NAND-circuit inputs from counters A, D, and E, the d_0, d_3, and d_4 positions respectively. Since A, D and E inputs first occur simultaneously the instant the counter reaches binary 25 (11001) this simultaneous input causes the NAND circuit output to switch from 1 to 0 and allow all counters to be reset by a pulse from the master clock.

Since each 25 pulses of input to counter A result in 1 output pulse from counter E, this is called a ÷ 25 counter, and the 787.5-kHz input frequency is reduced to a 31.5-kHz output. A 15.75-kHz TV horizontal frequency pulse train can be obtained by further division of the 31.5-kHz pulse train with another flip-flop element.

The logic for timing the initiation and duration of various horizontal pulse trains can be derived from the counter states as sensed by NAND and NOR elements in a fashion similiar to that used to detect binary 25.







2—The digital sync generator package develops all frequency and synchronizing signal requirements for the camera. All of this circuitry (*a*) is contained on 22 monolithic digital chips. Using logic available in the counters, pulse trains (*b*) are developed to conform to the rigid EIA specifications.

in horizontal pulse trains between successive fields is provided by correlating the logic of the horizontal and vertical scan sequences.

The vertical reference is generated by the 10-bit ÷525 counter that follows the half-line counter. The logic states available in the counters are used to generate the vertical drive, vertical blank, and the 3- and 9-line vertical sync intervals. The mixed-sync and mixed-blank outputs are formed by summation of their horizontal and vertical logic constituents. The sync generator can be operated either in the 525-line mode (60-Hz vertical) American standard, or with the change of one external jumper, in the 625-line (50-Hz vertical) European standard format. The final composite video output conforms to the EIA broadcast standards (RS-170) and contains full equalizing and serration pulses.

The horizontal and vertical drive pulse trains developed by the sync generator are fed to the sweep package (Fig. 1), where they trigger the generation of the sawtooth sweep currents that drive the magnetic deflection yoke.

The mixed-sync and mixed-blank outputs are fed to the postamp chip, where they are combined with the preamp signal from the sensor to form the composite video output.

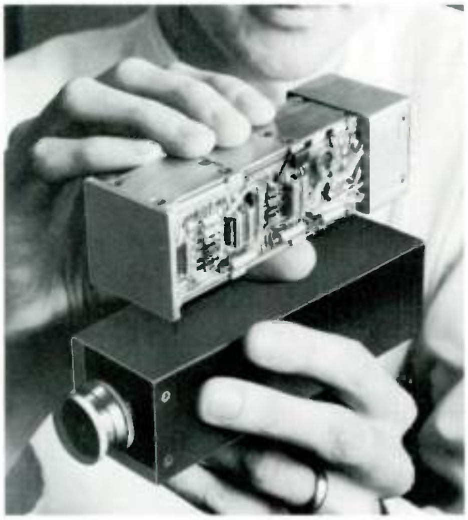
Sweep-Fail Protection (SFP)

To protect the sensor against beam sweep failure, which would cause a concentrated scan of one portion of the target and damage that area, sweep-fail detection circuitry is provided to blank the sensor cathode. Horizontal sweep failure is detected by integrating a sample of the horizontal sawtooth current; if the output level provided by this integration falls off, the high-voltage power supply (HVPS) is cut off.

An all-digital approach is used for vertical sweep-fail protection. A zero-crossover detector and two flip-flops verify the presence of the vertical retrace transition during the vertical drive interval. The detection of a vertical sweep failure initiates the cathode blank.

The reaction time of sweep-fail detection circuitry is not critical with a vidicon sensor, but it can be a major concern with the more sophisticated sensors such as the SEC camera tube. For example, loss of SEC vidicon sweep would cause a loss of video information, which would be interpreted by the automatic light control circuit as a command to increase photocathode voltage. This would cause SEC target damage from both scan loss and photoelectron thermal damage. The fast reaction times provided by the sweep-fail circuits in the SFP hybrid package—about 200 μsec for horizontal and 16 μsec for vertical—make this package suitable for use with any type of camera tube.

To prevent damage to the camera, an input protect hybrid package provides a 12 ±1 volt window; any input above or below this range is effectively ignored.



Top—The SUBMIN-TV circuitry surrounds the 0.5-inch vidicon camera tube. Two support structures and two PC boards form a frame around the sensor deflection yoke, the rear of which is supported by a collar that also draws heat from the filament and shields the socket from external pick-up.

Bottom—The SUBMIN-TV camera and a low-light-level camera (MINSIT) are built with the same basic electronic circuitry, but the larger camera uses a 16-mm *S*ilicon *I*ntensified *T*arget image tube. In addition, the MINSIT camera contains automatic gain, light level, aperture, iris, and dark current compensation.

Applications

The SUBMIN-TV camera is particularly suited to applications where size and power are major considerations. In combination with the Apollo Mini-Monitor, the SUBMIN-TV camera can provide a completely portable battery-operated television system.

Other possible applications for the subminiature system might include television guidance for missiles, security surveillance, drone reconnaissance, or space missions where the camera's high vibration tolerance makes it particularly suitable. Special cameras for low-light-level applications can also be developed with the same basic electronic circuitry built around more sensitive camera tubes.

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ACKNOWLEDGEMENTS:

The digital sync generator concept was originated by J. G. Gathright and was refined for TV broadcast use by J. M. Fawcett, C. M. Marie, and J. H. Meacham of the Westinghouse Systems Development Division.

Automatic Testing Will Simplify Maintenance of Rail Transit Vehicles

Frank S. Restivo
Frederick W. Jones
Kenneth H. Fraelich, Jr.

An automatic monitoring system can observe and record in-service performance of rapid-transit cars; if a malfunction is detected, a computer-controlled shop tester performs all operational tests and fault isolation sequences necessary for testing, calibration, and trouble diagnosis.

To attract and accommodate the riding public more effectively, transit authorities are placing more sophisticated demands on the performance of rapid-transit systems. Consequently, each new generation of rapid-transit cars provides a higher degree of comfort, safety, and economy.

These performance improvements have caused many technical advances in car subsystem design. Relatively new concepts such as automatic speed control (ASC), automatic train control (ATC), central traffic control (CTC), jerk rate, and integrated circuits have become the everyday language of the industry. Propulsion systems have grown from a basic package using four 55- to 100-hp motors per car to high-performance hybrids using four motors with ratings up to 300 hp each. Propulsion control has evolved from standard cam control systems to complex advanced cam or chopper designs with almost 100-percent solid-state logic. Auxiliary power supplies have grown from simple battery-charging m-g sets to complex systems supplying all of the car environmental and ancillary subsystems. All other car subsystems are going through similar processes of evolution.

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Higher complexity has generally resulted in better car reliability, realized primarily through the use of solid-state logic. However, this greater subsystem complexity has also complicated car maintenance in two basic ways:

First, higher circuit complexity increases the possibility of intermittent faults, random noise, and other similar conditions that can cause "on-the-road" failures, almost impossible to anticipate with routine maintenance techniques. In fact, field experience indicates that some of these system discrepancies often exist for a considerable time before they are detected.

Second, once a malfunctioning car is identified, considerable effort is required by highly skilled technicians to isolate the faulted component. In fact, the degree of skill and the test instruments required to perform fault isolation by conventional techniques are beyond the present capabilities of most car maintenance shops. Furthermore, time-consuming track testing is required to confirm that the proper fix has been made before the car can be returned to service.

To satisfy these maintenance needs, Westinghouse has developed a fully automatic test system for rapid-transit cars. The system consists of two complementary elements, designed to provide a fully comprehensive analysis of the operation and integrity of the various car subsystems: in-service monitoring of car subsystem performance achieved with an on-board monitoring system; and in-shop dynamic testing, calibration, and fault isolation performed by an in-shop car tester.

Developing a Test Philosophy

From the viewpoint of automatic testing, the propulsion and dynamic braking system is the most complex subsystem on a rapid-transit car. It produces the accelerating and retarding force required to make the car respond to wayside commands or the on-board operator. Proper performance of the propulsion and dynamic braking system is a function of its system integrity and coordinated interaction with these other car subsystems: cab signal system, ASC system, ATC system, operator's pilot devices, wheel slip-slide system, friction brake system, and the auxiliary power system.

Since the propulsion control is the interface upon which all these subsystems act, and since it is the heart of the propulsion and dynamic braking system, it demands the most comprehensive testing to assure proper car performance. This situation dictates that the test equip-

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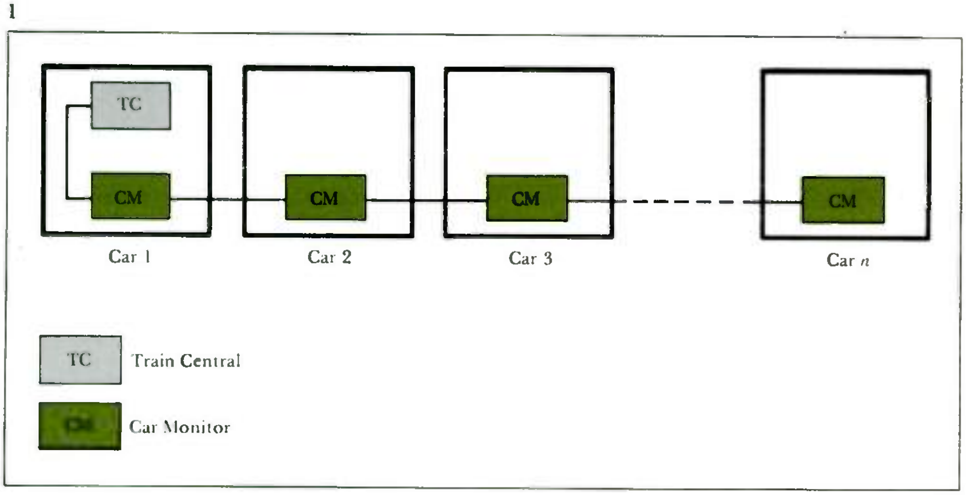

1—The on-board monitoring concept consists of a train central unit on the head car and a monitor unit on each car.

2—The car monitor consists of three basic subsystems: transducer, combinational logic, and transmission logic.

3—The train central is a portable unit consisting of transmission and central logic for communicating with the car monitors, and a manual display and magnetic tape recorder.

ment be designed primarily to provide a comprehensive test of the propulsion control. By the selection of proper test points and the use of suitable transducers, the test equipment will then inherently have the capability to test other car subsystems. Therefore, the propulsion control system and its design engineer were the logical starting point in the development of a test philosophy.

The propulsion control is designed to function and respond as a system to input signals. If the control responds properly as a system, it can be safely assumed that all of the components that make up the system are sound and that the control is suitable for revenue service. Measurement of the individual component characteristics need only be employed where necessary to locate a failed component. In fact, normal manufacturing tolerances on some control components make it very difficult to establish consistent *"go/no-go"* values. Thus, the most important criterion is that a device or component assembly functions properly, rather than that its various electrical parameters conform to an arbitrary list of *go/no-go* values. Therefore, propulsion control design engineers placed maximum emphasis on a simulated dynamic technique as the most comprehensive method for testing.

Minimizing of test points and test wiring is considered of almost equal importance because each test point and its associated wiring is a potential source of noise, faults, or grounds to the propulsion control. This is particularly true at the plug interface between the control and the tester. At this point, test leads to different circuits at different potentials are in close proximity, and proper contact through shorting bars is required to establish circuits for normal car operation.

With the above considerations in mind, Westinghouse design engineers specified that an automatic test system should have the following characteristics to yield a fully comprehensive analysis of the propulsion and dynamic braking system:

1) Continuous in-service monitoring of the operation and integrity of the propulsion control should be provided. A suitable display should give an arrival status report that will identify a car with a control discrepancy and indicate if the discrepancy requires taking the car out of service. Ideally, the monitor should provide a chronological record of circuit conditions immediately before and after a malfunction, in a format that provides preliminary fault diagnosis.

2) A fully automatic dynamic test of the propulsion control with the car at standstill in the shop should be provided. Both low-level logic circuits and power circuits should be tested under dynamic conditions that simulate the in-service environment as accurately as possible. If dynamic tests are properly designed and performed, no further propulsion control testing will be required when the test system indicates that the propulsion control is functioning properly.

3) A combination of automatic and semi-automatic fault isolation to the replaceable-component level should be provided. This permits identification of components that cause a *no-go* condition, detected by either the in-service monitor or the dynamic test.

4) A dynamic retest of the propulsion control should be provided to confirm that the proper fix has been made and that the transit car is ready to be placed in revenue service.

5) A means for readjustment of any control parameters indicated out of calibration during dynamic testing should be provided. This eliminates the need for track testing to set or confirm calibration settings.

6) All of the above requirements should be accomplished with a minimum of test points and test wiring in the propulsion control system. Each wire to a test point should present a high-impedance interface to the control so that the test equipment will not adversely affect the propulsion control during normal operation and during dynamic testing. Also, suitable protection must be provided in the test system to prevent damage to the propulsion control due to faulty test equipment operation.

Using these six criteria as the basic test philosophy, an automatic test system

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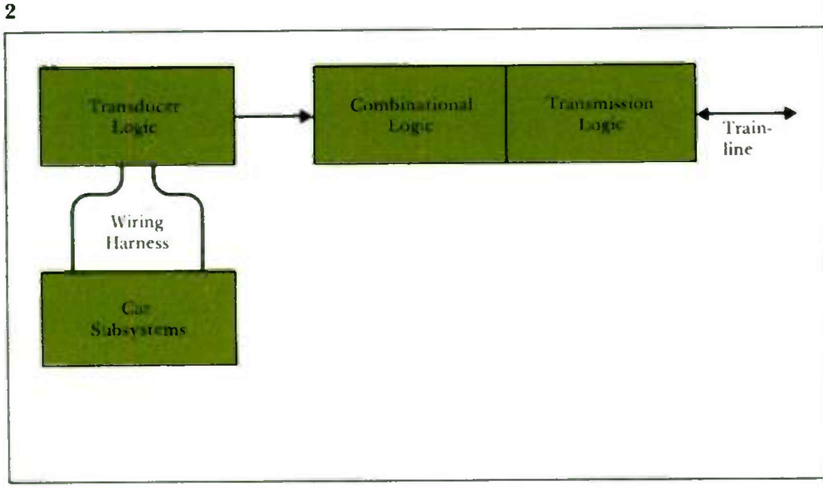

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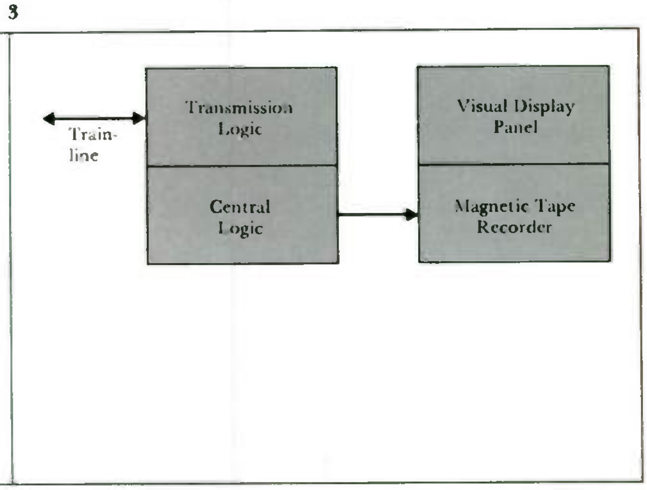

specifically designed to provide total subsystem testing of rapid-transit cars has been developed. The system consists of two basic elements: an *on-board monitor* and an *in-shop car tester.*

Automatic On-Board Monitoring System

An *A*utomatic *V*ehicle *M*onitoring *S*ystem (AVMS) has been designed, which can continuously monitor and record all car subsystems. In addition, AVMS would provide a chronological record of events immediately before and after each malfunction, and it would provide a preliminary diagnosis of the probable cause of the fault.

The on-board monitoring hardware is arranged into two separate packages. The *Car Monitor* package is a permanent part of each car (Fig. 1). It includes transducers that measure car subsystem parameters and the combinational and transmission logic required to communicate with the head-end car. The second package, the *Train Central* (Fig. 1), is a portable assembly that is plugged into the head-end car.

Car Monitor—The Car Monitor (Fig. 2) consists of three basic subsystems: transducer, combinational logic, and transmission logic.

The transducer subsystem continuously monitors test points in the various car subsystems and generates electrical signals indicating the status of the monitored points. Test points in each car subsystem are carefully selected to provide an optimum balance between the number of points monitored and the usefulness of the data derived from each point. The transducers are wired to solid-state circuit boards (mounted in the logic box under the car). This solid-state circuitry provides the primary interface between

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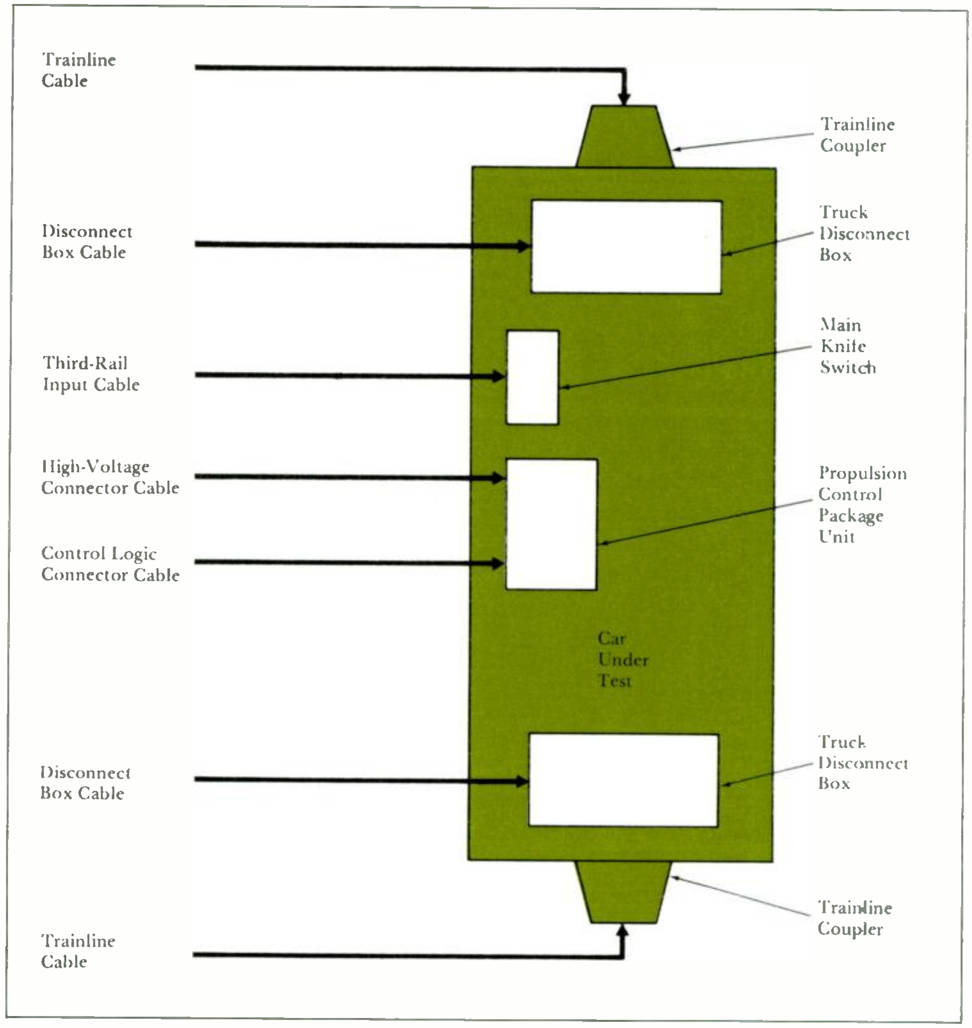

4—The MU car subsystem tester is connected to the car and performs fault isolation, dynamic tests, and calibration while the car is at standstill in the shop.

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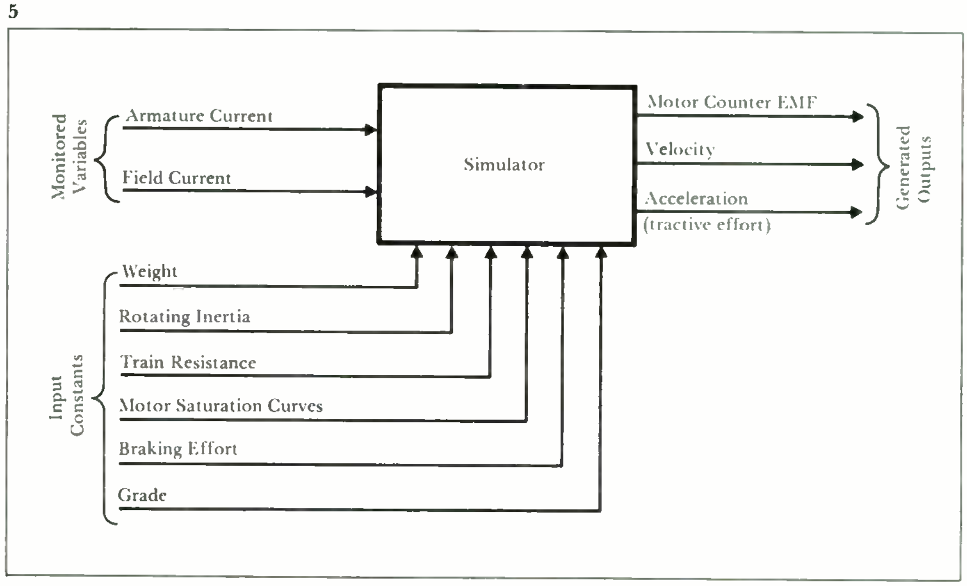

5—Analog simulator monitors field and armature currents, represents car and motor operating characteristics, and generates outputs that simulate car operation.

the transducers and the combinational logic subsystem.

The combinational logic subsystem receives the primary data and arranges it in a digital format.

The transmission logic subsystem provides the communication interface between the Car Monitor and the Train Central. Each time the Car Monitor receives an interrogation ("What is your present status?") from the head-end car, a complete car status report is transmitted to the AVMS trainline wire via the transmission logic subsystem.

Train Central—Interrogation of each car in the train and recording of the status report from each car is the responsibility of the Train Central system, shown in Fig. 3.

The Train Central hardware is arranged in two portable modules, both of which are plugged into the head-end car of the train at the start of a day's running. These two modules perform the following functions:

The *transmission logic and central logic module* processes the status reports received from each car into a format suitable for inputs to the record and display module. Each car in the train is interrogated in order and at regular intervals (2- to 10-second intervals depending upon train length).

The *record and display module* consists of a magnetic tape recorder and a visual display panel combined into one compact package. The tape recorder continuously records car-status reports in a format suitable for computer processing; the visual display panel contains six to eight fault lights for each car to identify major subsystem discrepancies. The visual display panel provides an arrival status report at a single location for every car in the train.

When a malfunction is indicated, the information stored on magnetic tape can be retrieved by computer processing. Computer printouts provide a record of each fault, a record of subsystem parameters before and after the fault, and a preliminary diagnosis of the cause of the failure. The computer printout provides background information for in-shop testing and maintenance.

Automatic In-Shop Car Tester

The second element of the Westinghouse total test system is a fully automatic MU car Subsystem Tester (MUST). The automatic tester provides an in-shop tool for performing dynamic tests, for fault isolation, and for calibration of propulsion subsystems. The tester uses safe low-voltage dynamic simulation for the functional tests and for calibration work; it utilizes a programmable diagnostic sequence for fault isolation.

A general-purpose digital computer is used for controlling the sequence, execution, evaluation, and display of all electrical checks. Functional and emergency controls on the console provide a means to control power, and they permit the operator to select the test function and mode, automatic or single-step operation. The test results are presented by visual display as *go* or *no-go* indications and by a printed output.

The computer has the following features: 16-bit word length, 16,000-word memory (expandable), integrated circuitry, real-time clock, power fail/restart, FORTRAN compiler, program debug package, diagnostic package, and voltage tolerance of $\pm$ 10 percent.

The dynamic portion of the test sequence verifies proper operation of the control, propulsion, and braking circuits and detects malfunctions. To accomplish these tests without car motion, an analog technique under direct control of the digital computer simulates the car dynamics and the reaction of the traction motors in response to the direction of the master controller. The dynamic response of the control to simulated input signals is monitored, and a visual display is provided when the responses are incorrect or when limiting performance parameters are exceeded.

A test sequence extends fault isolation down to the replaceable component level. Automatic fault isolation is performed to the extent possible through the use of test points readily available to the tester, such as the trainlines, the car monitoring test points, and the test harness. The programmed logical sequence provides resistance and leakage tests of desired circuits that are accessible through existing connectors including those for control cards.

Automatic fault isolation can be supplemented by the use of a manual probe and a remote control and display. The test operator utilizing the remote capability can locate faulty components not readily analyzed through existing test points. The display provides the necessary instructions and controls for the test sequence.

MUST Test Modes

The sequence of operations performed by the automatic tester can be illustrated by describing the check-out of a typical advanced cam-control propulsion system.

Although MU cars are scheduled to run in married pairs, for best diagnostic information these cars are tested in the shop as single units. A car is brought to the shop test station and the following plug-in connections are made (Fig. 4): to the electrical portion of the automatic couplers on each end of the car, to the propulsion control test points, to each truck disconnect box, and to the third-rail test input.

Automatic continuity and leakage tests are first performed on the general car wiring. Leakage tests on the main power and auxiliary circuits consist of applying the recommended high-potential voltage between the motor armatures and car-body ground, between motor fields and car-body ground, and between the connected main power circuits and car-body ground; leakage current is measured under each of these conditions. Leakage and continuity tests are made on the control circuits and on the train lines. Satisfactory completion of those tests verifies the integrity of the propulsion circuit wiring and initiates the following test modes:

In the *dynamic test mode*, the tester exercises the propulsion system by use of computer-simulated car *acceleration and braking*. The motors are disconnected from the control package unit and their dynamic function is simulated by inserting a voltage source controlled by an analog simulator (Fig. 5). A scaled-down third-rail voltage is applied (12 volts in place of 600 volts). As the control system

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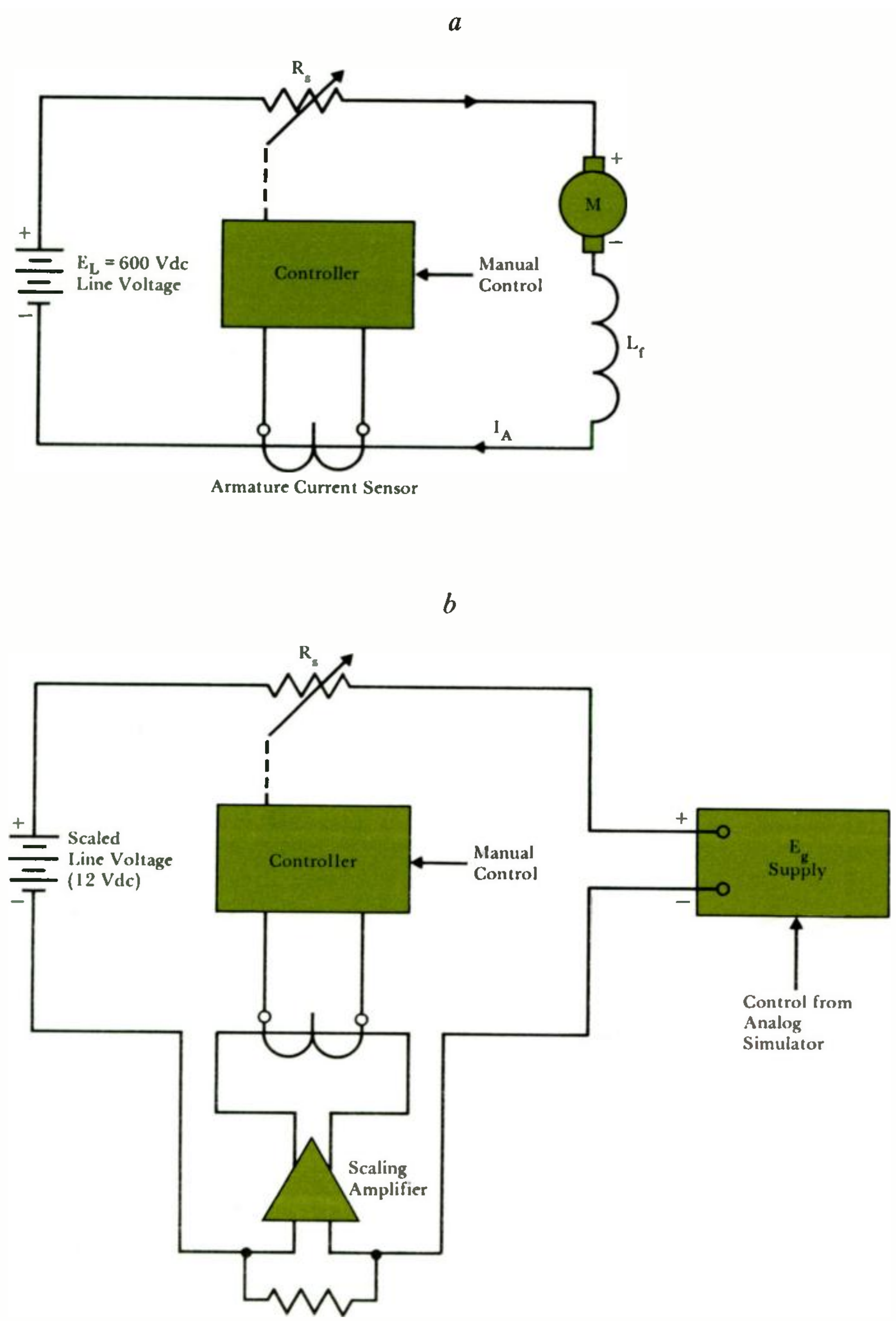

adjusts R_s, the change in armature current is sensed by the analog simulator; the scaled-down motor cemf (E_g) is controlled by the analog simulator. However, to properly simulate controller rate switching, currents through the armature current sensors must have the same values as during normal operation. This is accomplished by inserting an amplifier in series with these sensors so that the conditions that the sensing elements of the car propulsion system normally see during service are accurately reproduced (Fig. 6). The simulated armature current is monitored and is compared to the nominal values of current that should exist for the different conditions of acceleration, braking, and coasting. Armature current is also monitored for proper setting of the sensor trip levels.

The dynamic test mode is designed to provide a fully comprehensive and accurate analysis of propulsion system performance. Car testing can be terminated if a *go* indication is received for all dynamic test sequences because this provides verification of proper functional operation of the overall propulsion control system, i.e., acceleration rates, dynamic braking rates, speed control, armature currents, etc.

The *calibration mode* is interjected into the dynamic test mode when an out-of-tolerance indication is received. Control-circuit conditions are established to permit adjustment of circuit parameters of the acceleration limits system, the dynamic braking limit system, and the speed-control system. High or low indications are provided to simplify recalibration.

The *fault-isolation mode* locates faults with two procedures. If the faulty component can be isolated via the normal test connections, the nature of the fault or the identity of the faulty component is automatically displayed. However, if

6—In the dynamic test mode, the tester exercises the propulsion system (*a*) by use of computer-simulated acceleration and braking (*b*). Scaled-down line voltage and a scaling amplifier provide realistic current values to the controller.

7—Basic components of the computer-controlled MU car subsystem tester.

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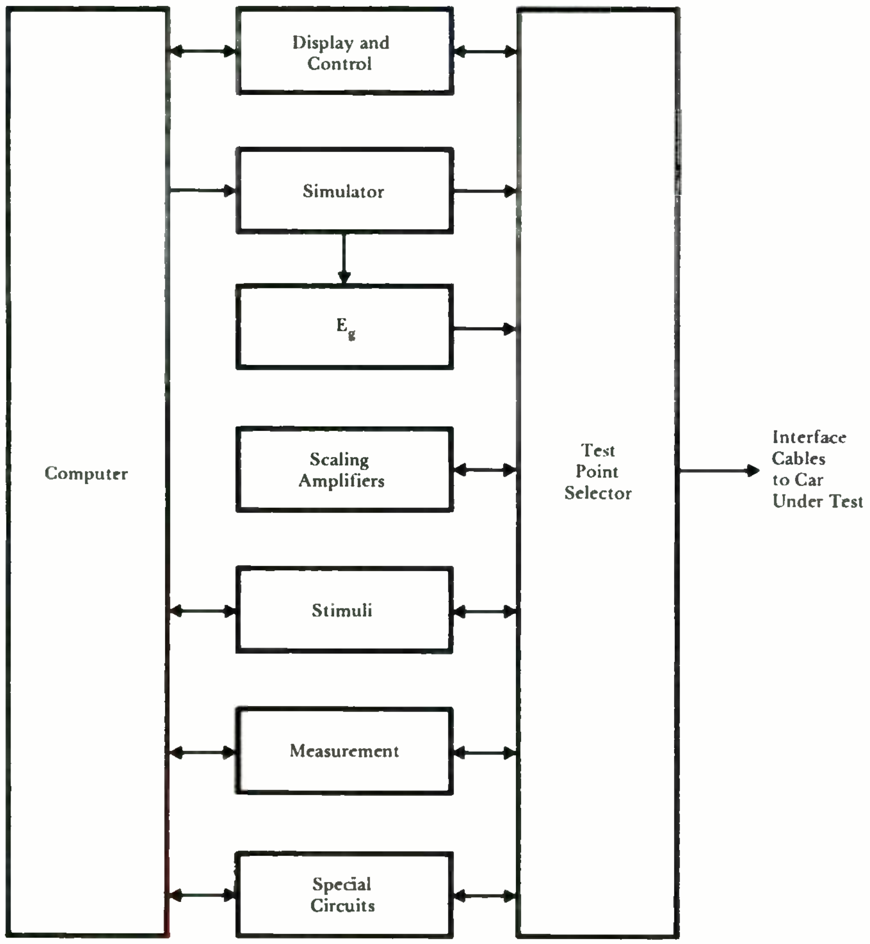

additional information is required to isolate the fault to a specific component, the test operator probes test points on the car as directed by the automatic tester. The test probe is part of a remote indicator and control box. (This approach to fault isolation is consistent with the basic philosophy of minimizing test wiring, because access necessary for 100-percent automatic fault isolation would require several hundred test wires in the propulsion control.)

A *retest mode* is employed after faulty components have been replaced to confirm that the proper fix has been made and that the control is ready for revenue service.

A self test and self calibration can be performed on the test system by a self-test program.

Conclusion

While designed basically as complementary elements, either the car monitoring system or the automatic tester can be applied separately. However, the following inherent limitations must be recognized:

1) The monitoring system would function only while the car is operating and can monitor operational parameters only under these conditions. With proper programming, it could provide fault analysis to the basic car subsystem functional level. However, it would not be practical for locating faulty components.

2) The automatic tester provides a dynamic in-shop test of the propulsion subsystems, but it does not monitor the car under actual on-the-road conditions. Thus, the tester may not be able to diagnose intermittent faults or others that cannot be duplicated during in-shop dynamic testing.

Therefore, both test systems are desirable to yield a full and accurate analysis of car performance under all conditions.

The new equipment is designed to test only the propulsion equipment at this time. However, similar systems may soon be able to supply quick answers to other electrical/mechanical problems, and they may be utilized for preventive maintenance.

Some Guidelines for Selecting a Solid-State Transmission Line Relaying System

W. A. Elmore

The proliferation of solid-state pilot protection systems and their auxiliary hardware has multiplied the choice available to the relay engineer. However, by applying suitable logic to the selection of the relaying channel and the pilot protection scheme, the engineer can select the least expensive system that will adequately fulfill the constraints of the application.

Today's solid-state transmission-line relaying systems differ from their electromechanical predecessors in no revolutionary way, nor in any unique principle. Rather, the differences are evolutionary in nature and, in some cases, rather subtle.

The operating principles of the basic types are familiar to system relay engineers (see *Pilot Protection Systems*, page 53). However, what is not so immediately evident is the significance of the various options that are now available with these solid-state systems: single and dual phase-comparison systems; current-only and distance phase-comparison systems; blocking and unblocking phase-comparison systems; blocking and unblocking directional-comparison systems; overreaching transfer-trip systems; and underreaching transfer-trip systems that can be either permissive or direct. Any of these schemes can be equipped with high-set overcurrent trips, zone-1 phase and ground support relaying, one-, two-, or three-shot reclosing, and so forth.

With such a myriad of options there is seldom a unique selection for any transmission-line relaying application. In general, the least expensive system that will fulfill the constraints of the application is the logical choice.

Selection of a suitable relaying system begins with channel selection and then proceeds to a determination of the most desirable relaying scheme for the selected channel. The selection process to be described will not necessarily choose the only usable relaying system for a given application, but it does consider the key factors necessary for making a logical choice. Tables I and II show the basic systems referred to in the selection process.

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Channel Selection

The typical process for choosing the pilot channel for a transmission-line relaying application uses the logic diagrammed in Fig. 1. As indicated, the pilot-wire relaying system (HCB-1), which is the most economic choice, can be applied to short lines if the available continuous pilot pair does not have excessive series resistance or shunt capacitance. On the other hand, if the transmission line is long and carrier spectrum is available, carrier is examined and one type is chosen if possible. And finally, if the line is short but pilot-wire relaying cannot be used, tones (and/or microwave) must be chosen.

The "continuous metallic pair" requirement in Fig. 1 assumes that dc channel monitoring will be used if the pilot-wire relaying system is selected and that the dc path cannot be broken by isolating transformers. Three-terminal pilot-wire applications are feasible only if the branch resistance and total capacitance limits are not exceeded. Circuits having more than three significant terminals (subtransmission line with more than one tap) represent a difficult pilot protection application, and pilot-wire relaying cannot be used.

If the economic pilot-wire relaying system is not applicable, the next best systems to consider are tones on metallic pairs for short lines, and carrier or microwave for longer lines. However, considerations other than relaying may dictate the choice of channel. For example, the presence of microwave with links to all other terminals of the transmission line would encourage its use for the relaying functions.

Carrier can be used only if a band can be found in the frequency spectrum in which interfering signals will not disrupt the normal relaying signal transmission. The magnitude of the interfering signal is as important as frequency separation. The 6-kHz criterion specified in Fig. 1 is based on the relaying receiver having 0-dBm sensitivity and the interfering signals being on either side of the relaying carrier frequency and at −28 dBm level each. However, the 6-kHz figure is intended only as an approximate guide. For example, where 40-dBm (10-watt) signals are coupled directly to the same coax and each full-level transmitter signal becomes to the adjacent receiver a very strong interfering signal, as much as 10-kHz separation may be required between the existing carrier frequency and the relaying carrier being added.

A reasonable limit of 25-dB total channel attenuation (excluding hybrids and LC units) is suggested for on-off (TC) carrier. This limit is based on a 15-dBm clear weather signal at the coax, a 15-dB signal deterioration allowance, and a −15-dBm white noise level.

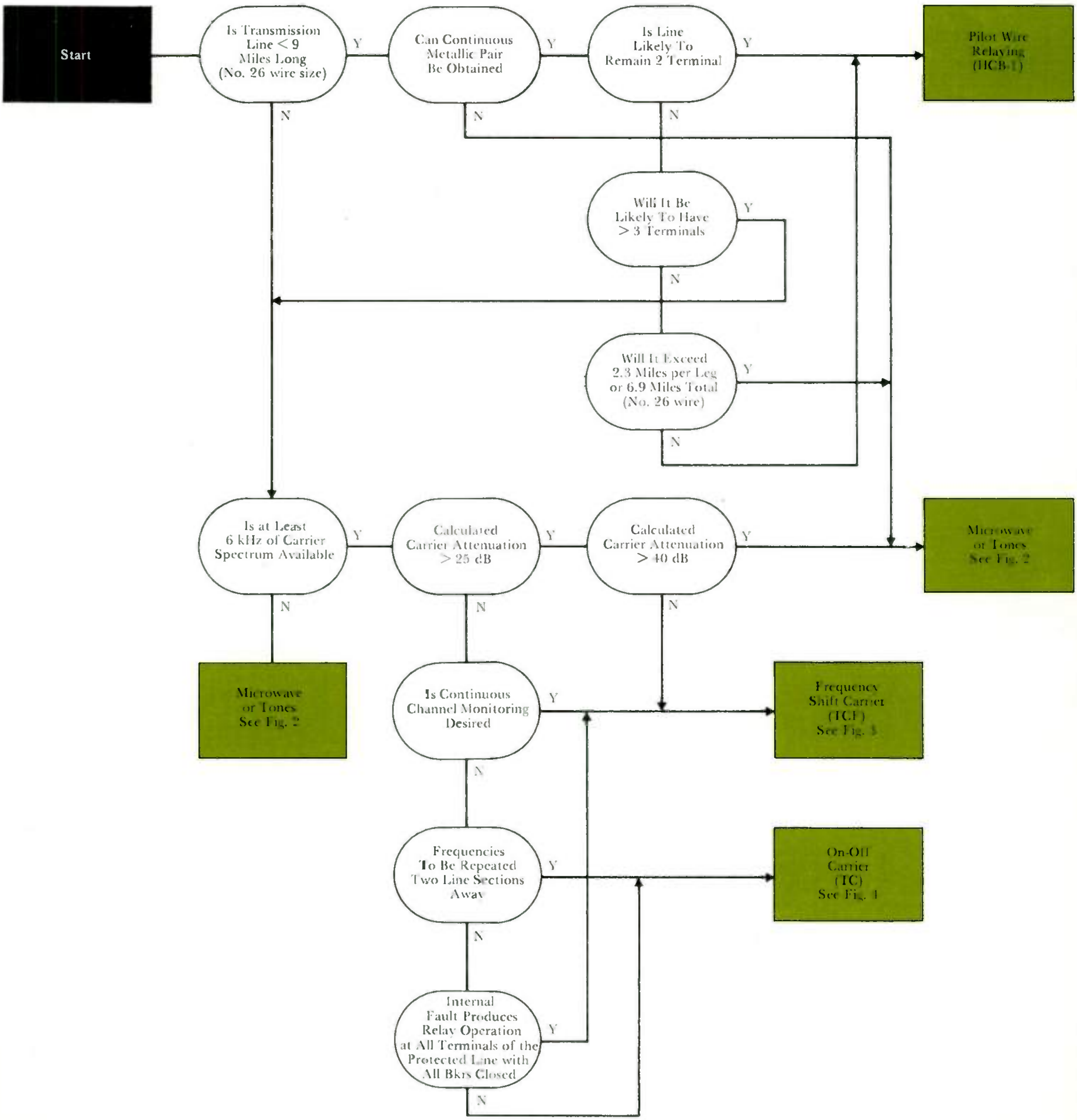
Channels with up to 40-dB attenuation are within the limits of frequency shift (TCF) carrier. Again, this assumes 0-dBm clear weather signal at the receiver coax, 15-dB signal deterioration allowance, and −15-dBm white noise level. Lower noise or less signal deterioration allowance (or both) permit operation of either type carrier system over a higher attenuation path.

The application criteria given in Fig. 1 are intended only to provide an approximate guide to carrier spacing and levels. In any specific application, closer spacing may be feasible depending on the type of carrier involved, margins to be permitted, and the use to which the carrier is put.

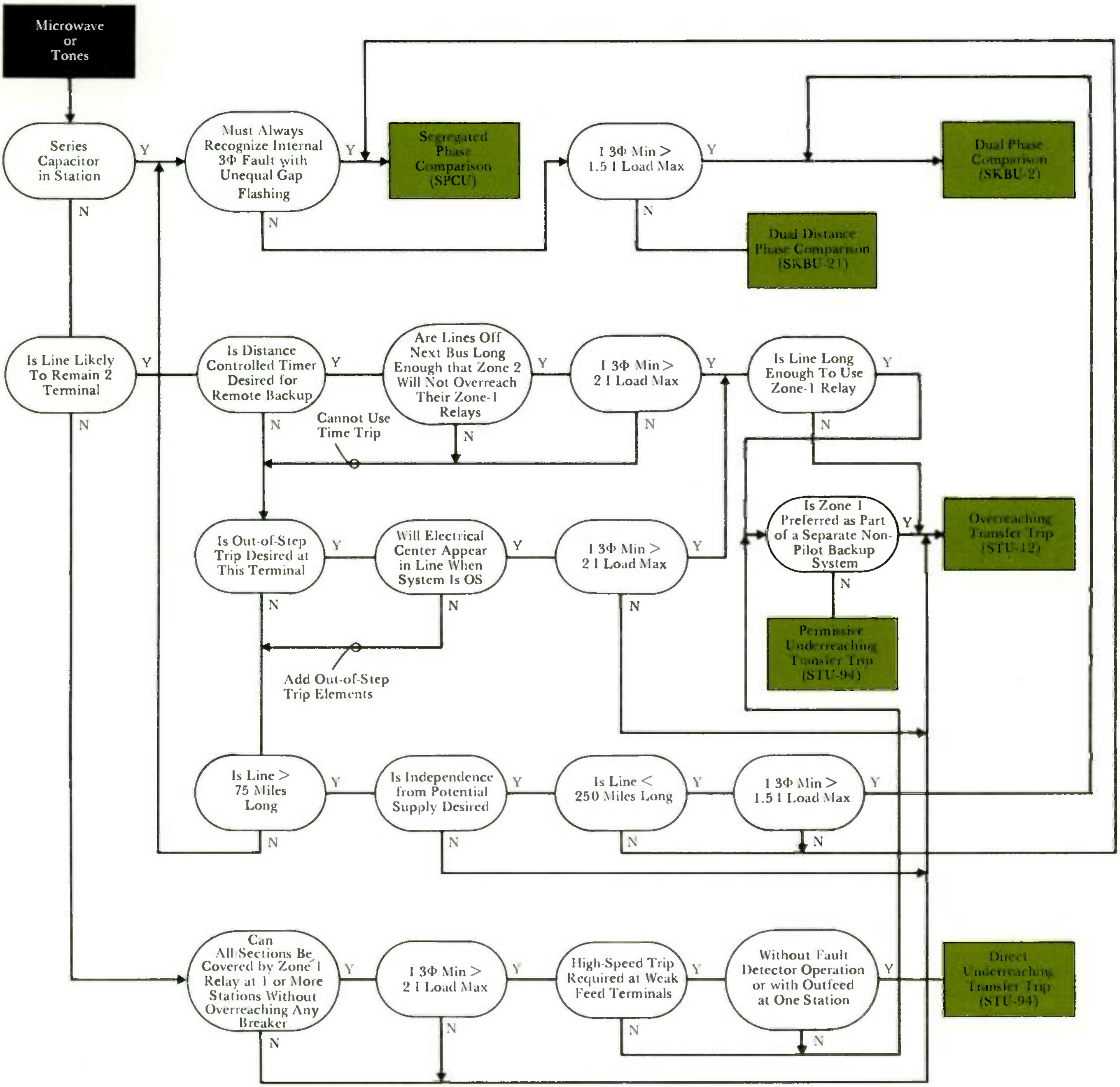
Continuous channel monitoring is usually permitted only if frequency-shift carrier is used; *periodic* sampling of the channel by checkback is widely used with on-off systems.

Service voice requirements at one time dictated the use of either an on-off carrier channel or microwave, but this is no longer a critical factor because a frequency shift system can now accommodate the voice option.

Where carrier frequencies are repeated at fairly close geographic intervals, care must be exercised that they do not interfere. For example, a continuous



1—Typical logic for selecting a transmission-line pilot relaying channel.



2—Typical logic for selecting a microwave or tone relaying system.

guard signal may interfere with proper tripping a few line sections away if identical frequencies are used for relaying systems on both sections. Similarly, voice communications or any continuous function using the carrier channel may block tripping on adjacent line sections unless different frequencies are used. Line traps do not eliminate this hazard.

A directional-comparison system is able to respond at "strong-feed" locations without any relaying action at "weak-feed" locations. A strong-feed location is a line terminal from which sufficient fault current is contributed to an internal fault to produce reliable operation of current-dependent tripping relays; if the line terminal contributes insufficient fault current to produce reliable operation of current-dependent relays, it is a weak-feed location. Tripping does not occur at weak-feed locations unless sequential action occurs as a result of fault current redistribution. Since an unblocking system is normally transmitting guard, relaying action is necessary to key the transmitter to trip. In a blocking system, carrier is normally off and not blocking tripping at other stations.

Pilot Protection Systems

The basic forms of pilot protection involve the transmission of relaying information from one terminal of a protected-line section to the other by means of a suitable channel—power-line carrier, microwave, tones, or a pair of wires. The systems can be categorized as directional-comparison, phase-comparison, or pilot-wire depending on the type of sensing relays used. The schemes can be further subclassified as blocking, unblocking, or transfer trip depending upon the use made of the transmitted signal.

Directional-Comparison—Directional relay elements at both line terminals sense the direction of the fault, either toward or away from the protected line section. A *blocking* scheme uses the transmitted signal (carrier or tone), initiated when a fault is sensed *away* from the protected line, to block tripping at the other terminal. When the fault is on the protected line, a blocking signal is not transmitted from either terminal. The absence of blocking signals allows directional elements at both terminals to operate in response to the fault and initiate circuit breaker tripping.

An *unblocking* scheme utilizes a frequency shift channel to provide a continuous blocking (guard) signal. Directional elements shift the transmitter to the trip frequency only if they sense a fault *toward* the protected section. For a short period of time following loss of guard (whether caused by a shift to trip or by the fault shorting the carrier signal), tripping is permitted at the receiving station. Thus, simultaneous loss of guard and directional relay operation initiates circuit breaker tripping. For faults outside the protected line section, guard is received at one terminal and the directional relay does not operate at the other, so tripping is prevented.

In contrast to blocking schemes which use the transmitted signal to prevent tripping, *transfer-trip* pilot protection requires the reception of the transmitted trip signal to permit tripping. Thus, when an internal fault occurs, directional relay operation in conjunction with the shift from the guard to the tripping signal from the other terminal sets up tripping.

In the preceding descriptions, only directional relays were mentioned as the element used in conjunction with the tripping signal received from the other terminal to initiate tripping. However, pilot systems always use distance relays for phase protection and often for ground protection for this function. Distance relays are directional but, further, have a distinct area of coverage irrespective of fault current variations. A transfer-trip scheme can be classified as either *overreaching* or *underreaching*. In the overreaching arrangement, the distance relays are set to reach beyond the next bus in the protected direction. These are called zone 2 distance relays.

In the underreaching scheme, the distance relays are set short of the next bus, but the distance relays at the two stations are set to overlap one another to assure that at least one operates for all faults on the protected line. These are called zone 1 distance relays. The scheme is "direct" if tripping is initiated for an internal fault by the distance relay at one terminal and by the received signal at the other. Actually, in this scheme, most faults are cleared by the distance relays operating at both terminals without the need of signal reception.

The other underreaching scheme is "permissive," and, in this arrangement, reception alone cannot produce tripping. Another local relay (usually an overreaching distance relay or a directional overcurrent relay) supervises tripping on signal reception.

Phase-Comparison—Sensing elements at each terminal derive a single-phase voltage from the phase and neutral currents at each terminal. That voltage is used to key the signal transmitting device on alternate half cycles and to operate one or more fault detectors that assure signal transmission and prepare the circuitry for tripping.

For a fault *external* to the protected line, the current-derived voltages at the two terminals are essentially 180 degrees out of phase. Thus, during the interval when either terminal attempts to trip, a signal is received from the other terminal to provide the necessary restraint.

When the fault is *internal*, the current-derived voltages in the "on-off" schemes are such that each terminal transmits its blocking signal on the same alternate half cycle and removes the blocking signal on the intervals between. During the half-cycle periods that the blocking signal is absent, tripping is permitted at both terminals.

In the "frequency-shift" schemes, *mark* and *space* frequencies are transmitted on the alternate half cycles. Keying of the transmitter to mark or space is controlled by the local current-derived voltage. The receiver converts the received frequency into a digital signal, which is compared with the current-derived voltage at that location. Comparison of the phase position of the local current-derived voltage and the mark or space signal received from the other terminal allows the fault to be identified as internal or external. Since *both* half cycles of the *local* quantity are compared to the mark and space signals derived from the *remote* quantity, tripping is possible on either half cycle.

As with directional-comparison systems, it is possible to operate a phase-comparison scheme in the blocking, unblocking, or transfer-trip mode.

Pilot Wire—Current-derived voltages at each terminal are compared directly over a pair of wires in this scheme. For an external fault, the relative polarities produce restraint from tripping. Supervisory relays are frequently applied to assure the integrity of the pilot wire circuit. Also, remote tripping can be accomplished as an adjunct to pilot-wire relaying. Pilot-wire relaying is economic, but it is only applicable to short line sections where pilot circuit resistance and shunt capacitance have low values.

Relaying Systems for Microwave or Tone Channels

When the logic for selection of the pilot relaying channel indicates that microwave or tone channels should be used, the choice can be made by the process shown in Fig. 2.

A series capacitor in the station is the first consideration because a capacitor introduces distinct problems in the protective relaying for transmission lines terminating in that station. Distance relays sense incorrectly the direction to a fault at the capacitor line junction. This problem is experienced by the relay on the lines with series capacitors and by those on adjacent lines with or without series capacitors. Phase-comparison systems are not afflicted with this difficulty.

An internal three-phase fault with unequal gap flashing will produce "through" negative-sequence and zero-sequence current flow so that a system using a filter with a heavy zero-sequence weighting factor will incorrectly sense an external fault. Where this type of fault is considered to be significant and other devices will not detect it, the *segregated* phase-comparison (SPCU) system must be used. In the segregated system, each individual phase and the residual circuit are treated as independent entities, and comparison between each of these quantities at the two line terminals by the relaying system is accomplished over the communication channel.

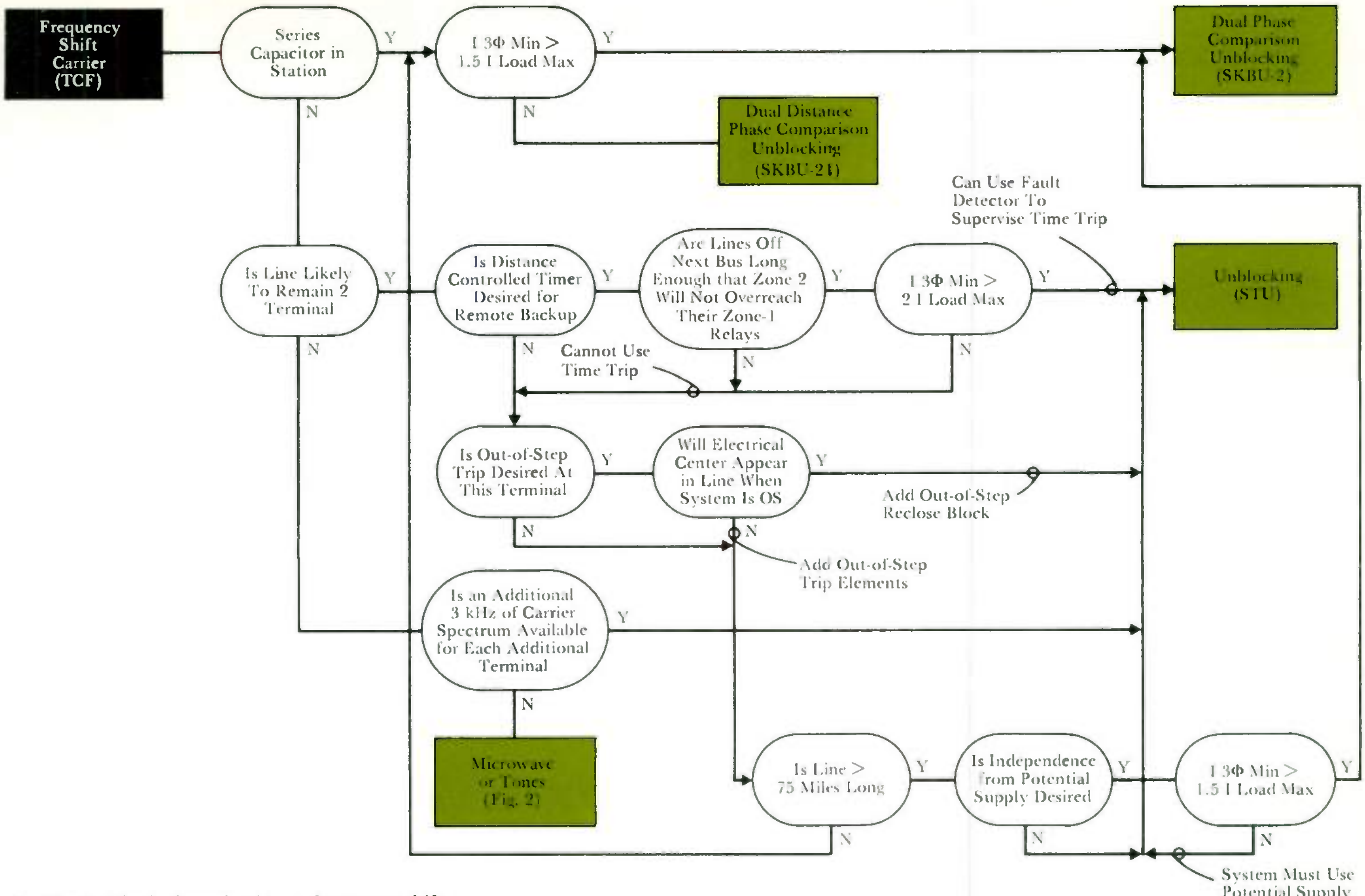
When conventional phase-comparison systems can be applied, the significant consideration is load current. The fault detector for three-phase faults should not operate on the maximum load flow. Although this would not produce tripping, it would represent an infringement on security because the system would be continuously armed. The dual distance phase-comparison (SKBU-21) system alleviates this load criticality by incorporating a distance relay that is insensitive to the high power factor conditions normally associated with load flow. The qualifying term "dual" means that a frequency-shift channel is used and tripping is possible on *either* half cycle. In the single comparer systems using on-off carrier, tripping can occur only during the "off" half cycle.

For two-terminal applications with no series capacitor problems, personal preference exercises a strong influence in the selection. The customary judgement process used in choosing between overreaching and underreaching transfer-trip systems is formalized in Fig. 2. The logic allows selection of the less expensive phase-comparison system only if system parameters permit.

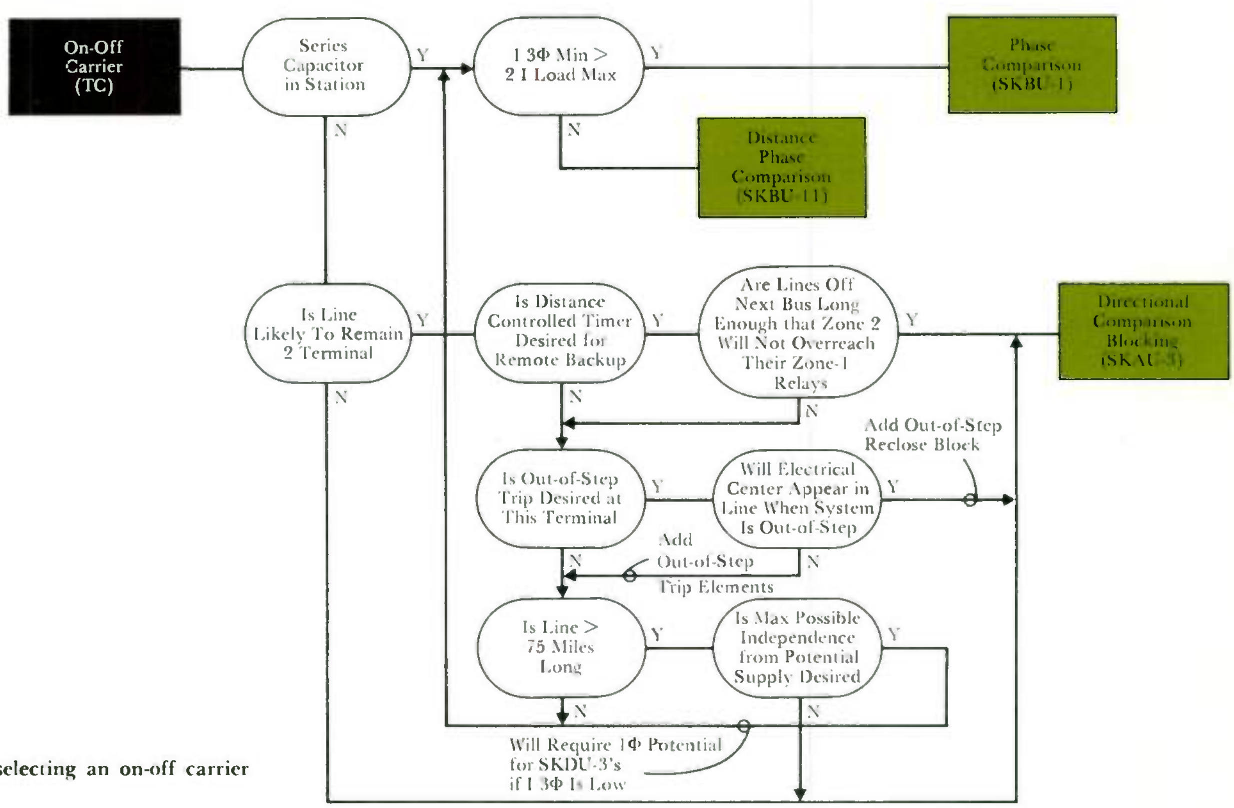
An underreaching transfer trip (STU-94) system is not allowed by the logic in Fig. 2 unless a fault detector overcurrent relay can be used. This avoids possible false trips due to potential circuit failure. The *direct* underreaching system is selected only for three-terminal applications where all faults can be

Table I—Transmission Line Solid State Phase Comparison Relay Systems

	Powerline Carrier Channels				*Wide Band Frequency Shift Audio Tone Channels*		
	Short and Medium Lines		*Long Lines*		*Short and Medium Lines*	*Long Lines*	
	Current Comparison		*Distance Comparison*		*Current Comparison*	*Distance Comparison*	*Current Comparison*
Relay Function	*Unblocking System On-Off*	*Unblocking Dual-Comparer Frequency Shift*	*Blocking On-Off Phase Distance*	*Unblocking Dual-Comparer Phase Distance Frequency Shift*	*Transfer Trip Dual-Comparer*	*Transfer Trip Dual-Comparer Phase Distance*	*Segregated Phase Comparison*
Phase Comparison Relay, FD-1 Carrier Start and FD-2 Arm Fault Detectors	SKBU-1						
Phase Comparison Relay, Dual Comparer, Single Fault Detector		SKBU-2			SKBU-2		
Phase Comparison Relay, FD-1 Carrier Start and FD-2 Arm Fault Detectors, High Sensitivity			SKBU-11				
Phase Comparison Relay, Single Fault Detector, Dual Comparer, High Sensitivity				SKBU-21		SKBU-21	
Phase Comparison Relay, Current Change Detector, Instantaneous Overcurrent Units							SPCU
Phase Distance Offset MHO Relay			SKDU-3	SKDU-3		SKDU-3	
Instantaneous Overcurrent Units, High Set for Direct Trip, Phase and Ground	Optional	Optional	SIU	SIU		SIU	
Output Package, Thyristor Trips, Target Lamps and Breaker Failure and Reclose Initiation	SRU	SRU	SRU	SRU	SRU	SRU	SRU



3—Typical logic for selecting a frequency-shift carrier relaying system.



4—Typical logic for selecting an on-off carrier relaying system.

recognized by zone 1 relays at one or more stations, where all terminals require high-speed tripping, and where fault detecting relays (including phase undervoltage and zero-sequence overvoltage) cannot recognize all internal faults.

Frequency-Shift Carrier

When the frequency-shift carrier (TCF) channel is indicated, the relaying scheme is selected as outlined in Fig. 3.

Again, a series capacitor in the station sharply divides the areas of application for phase-comparison and directional-comparison unblocking systems. Also, for the short and moderately long two-terminal lines for which the back-up and out-of-step trip functions are to be independent of the primary relaying system, a dual phase-comparison unblocking system (SKBU-2) is selected.

For three-terminal frequency-shift carrier applications, the unblocking system is preferred if sufficient carrier frequency spectrum is available. Three-terminal phase-comparison systems are possible but difficult, and they are not allowed by this selection process in the interest of restricting the choices to the flexible, easily realizable cases.

On-Off Carrier

The selection process for a directional-comparison or phase-comparison on-off carrier system is shown in Fig. 4. The presence of a series capacitor in the station, as in the other cases, forces the use of a phase-comparison system. The lack of desire to incorporate a distance-controlled back-up timing function in the primary relaying, or to use the primary phase-distance relays to clear out-of-step conditions, also encourages the choice of the less expensive phase-comparison system for all but extremely long-line two-terminal applications.

For three-terminal lines, the directional-comparison system has the distinction of requiring no relaying action at weak-feed locations for high-speed clearing to take place at the strong-feed locations for internal faults. This characteristic is based on the premise that there is no continuous use made of the carrier system at the weak-feed location. Otherwise, stopping of the weak-feed carrier becomes mandatory for the internal fault to clear.

As with frequency-shift systems, three-terminal applications of phase-comparison systems are not selected because of their inflexibility and restrictive nature. This does not mean that system characteristics never permit successful applications of three-terminal phase-

Table II—Directional Comparison Relaying Systems

	Blocking Carrier Systems (on-off carrier)					*Unblocking*	
	Phase and Ground Distance			*Phase Distance Directional Ground Overcurrent*		*Phase and Ground*	
Relay Function	*Pilot Only*	*Pilot and Zone 2 Timer*	*Pilot, Zone 1 (phase and ground) and Zone 2 Timer*	*Pilot Only*	*Pilot and Zone 1 (phase and ground)*	*Pilot Only*	*Pilot and Zone 2 Timer*
Zone 1 Phase Distance			SKDU		SKDU		
Forward Set Phase Distance, Carrier Trip and Carrier Stop	SKDU			SKDU	SKDU	SKDU	
Zone 2 Phase Distance Time, Carrier Trip and Carrier Stop		SKDU	SKDU				SKDU
Reverse Set Phase Distance Carrier Start	SDU-1	SDU-1	SDU-1	SDU-1	SDU-1		
Directional/Instantaneous Ground Overcurrent Carrier Trip and Carrier Stop, Dual Polarized				SRGU	SRGU		
Zone 1 Ground Distance			SDGU-7		SDGU-7		
Forward Set Ground Distance, Carrier Trip and Carrier Stop	SDGU-6					SDGU-6	
Zone 2 Ground Distance Time, Carrier Trip and Carrier Stop		SDGU-6	SDGU-6				SDGU-6
Instantaneous Overcurrent	SIU	SIU	SIU	SIU	SIU	SIU	SIU
Carrier or Tone Auxiliary Relay	SKAU-3	SKAU-3	SKAU-3	SKAU-3	SKAU-3	STU	STU
Output Package Thyristor Trips Reclose and Breaker Failure Initiation Reclose Blocking Indicating Lights	SRU	SRU	SRU	SRU	SRU	SRU	SRU
Channel	TC	TC	TC	TC	TC	TCF	TCF

comparison schemes. In fact, many such installations have performed excellently for many years.

Additional System Options

Any of the pilot protection systems selected can be equipped with a number of additional options to give the systems the desired degree of redundancy or to provide some additional feature required by a particular application.

High-Set Overcurrent Trips — This alternate is available in all of the standard systems and is highly recommended in applications where faults can be located on the basis of current magnitude alone. Air-gap units (overcurrent elements with gapped iron circuit) are available with no more than 17-percent overreach for maximum asymmetry due to dc component of fault current. They should be set 25 percent greater than the maximum current for an external fault in the forward or reverse direction. When high-set overcurrent trips can be used, they provide an excellent form of back-up that is fast, simple, inexpensive, and independent of all other sensing elements and the communications channel.

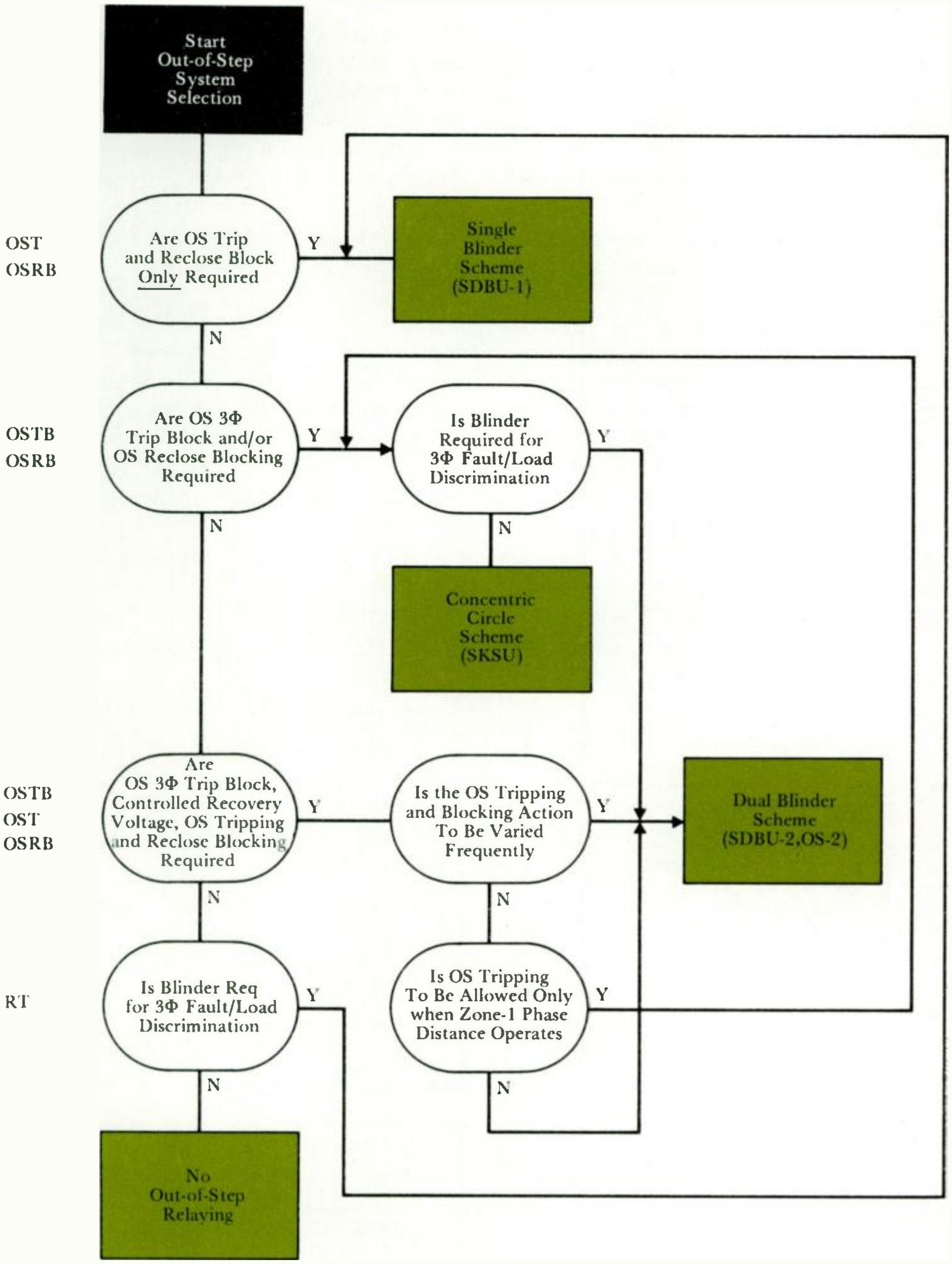
Zone 1 Phase and Ground Relaying — Phase and ground-distance relays are not as restricted in application as the high-set overcurrent relays, but the protected line must have sufficient length so a fault at the balance point will produce adequate operating energy for the relays to operate reliably. They are not responsive to external faults, they are fast, and they require no information from the remote terminal via the communication channel. They provide an excellent support function to most pilot relaying systems and are available as a part of all standard systems.

T2 Timer — Any system equipped with overreaching phase and ground-distance relays may drive a timer to provide remote back-up. In recent years there has been an increasing use of local back-up systems to cover the breaker failure contingency. However, there is still a place for distance-controlled timers. A single timer is adequate for the phase and ground functions with separate indication.

Out-of-Step Relaying — One approach for selecting an out-of-step relaying system is shown in Fig. 5. Although many other considerations enter into the selection, this logic does show some of the predominant influences in establishing the proper choice, once the desired philosophy is determined.

The philosophical input is not particularly easy to develop. It is dependent on whether instability can develop on

arrier Systems (frequency shift carrier)			*Transfer-Trip Systems (wide-band audio tone)*						
			Permissive Overreaching					*Underreaching*	
istance	*Phase Distance Directional Ground Overcurrent*		*Phase and Ground Distance*			*Phase Distance Directional Ground Overcurrent*		*Direct*	*Permissive*
Pilot, Zone 1 (phase and ground) and Zone 2 Timer	*Pilot Only*	*Pilot and Zone 1 (phase and ground)*	*Pilot Only*	*Pilot and Zone 2 Timer*	*Pilot, Zone 1 (phase and ground) and Zone 2 Timer*	*Pilot Only*	*Pilot and Zone 1 (phase and ground)*	*Pilot Only*	*Pilot Only*
SKDU		SKDU			SKDU		SKDU	SKDU	SKDU
	SKDU	SKDU	SKDU			SKDU	SKDU		
				SKDU	SKDU				SKDU
	SRGU	SRGU				SRGU	SRGU		
SDGU-7		SDGU-7			SDGU-7		SDGU-7	SDGU-7	SDGU-7
			SDGU-6						
SDGU-6				SDGU-6	SDGU-6				SDGU-6
SIU	SIU	SIU	SIU	SIU	SIU	SIU	SIU	SIU	SIU
STU	STU	STU	STU-12	STU-12	STU-12	STU-12	STU-12	STU-94	STU-94
SRU	SRU	SRU	SRU	SRU	SRU	SRU	SRU	SRU	SRU
TCF	TCF	TCF	TA-3	TA-3	TA-3	TA-3	TA-3	TA-3	TA-3



OST Out-of-Step Trip
OSRB Out-of-Step Reclose Block
OSTB Out-of-Step Trip Block
RT Restrictive Trip

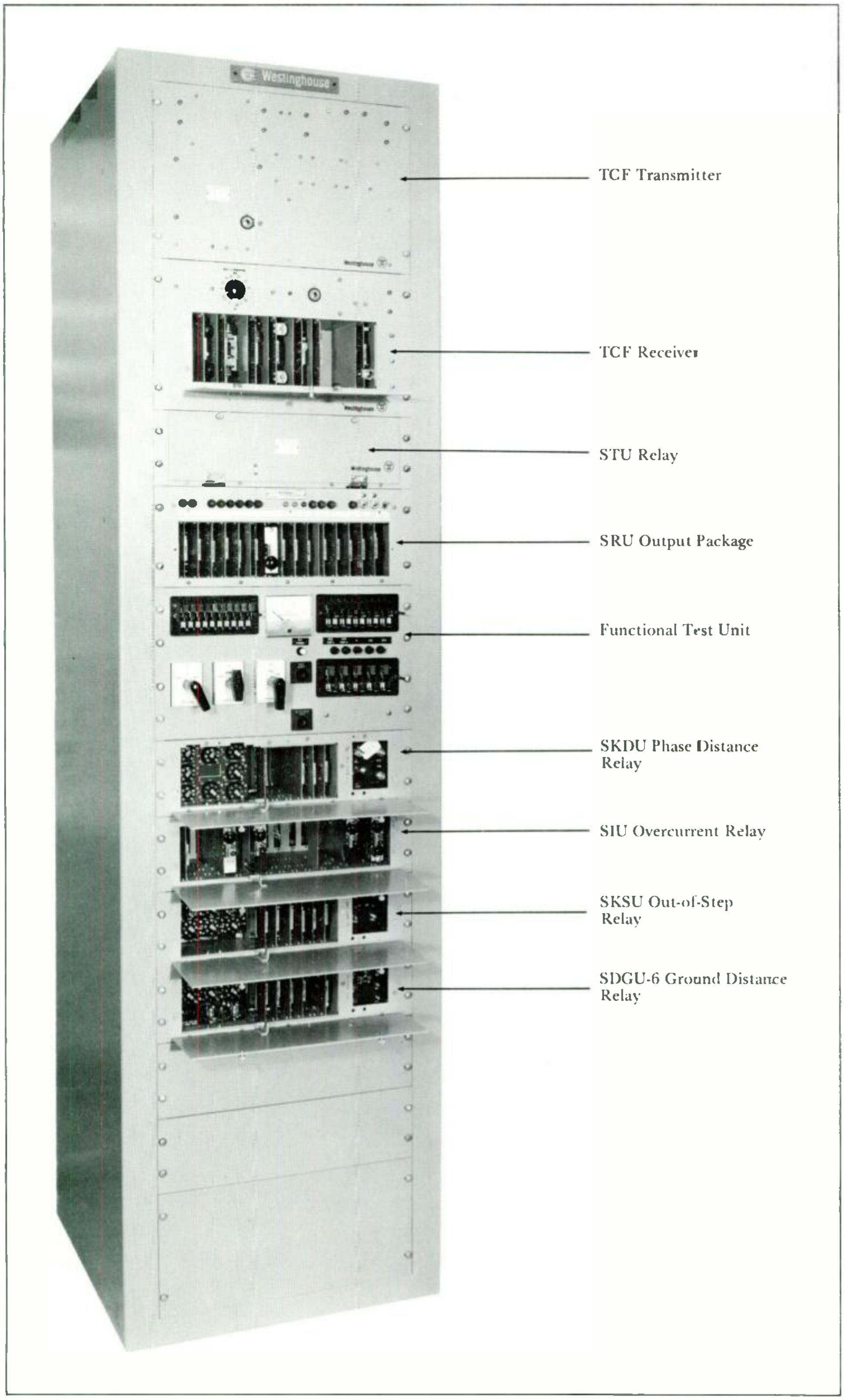
the system under consideration, where the electrical center appears to be when instability does develop, whether the out-of-step condition produces current high enough to cause an interruption problem with the very high recovery voltage that may accompany out-of-step tripping, what the minimum internal three-phase fault current will be, and what the maximum load current can be. All of this must be developed within reasonable contingency limits, and each factor may manifest its critical case with a completely different system arrangement from that for all of the other factors. The logic shown in Fig. 5 aids in the selection of the particular out-of-step system to be used through examination of the results expected from the system and from a consideration of the operating practices of the user. All out-of-step relaying variations indicated may be accommodated in the standard systems.

Choice of Reclosing System

Automatic reclosing is desirable in any application where it is expected that a fault may clear before the circuit is reenergized. For example, multishot reclosing relays are distinctly called for with overhead distribution applications because of their ability to improve service continuity. In transmission applications, reclosing relays are often used to provide a single high-speed reclosure when tripping is produced by pilot re-

5—Typical logic for selecting an out-of-step relaying system. The *single-blinder* scheme uses distance elements having a characteristic on a resistance-reactance plot consisting of two parallel lines centered about the origin and sloping at 15 degrees from the vertical. The *dual-blinder* scheme uses two such units, the second having a wider spacing than the first. The *concentric-circle* scheme, as the name implies, uses distance units having circular characteristics on a resistance-reactance plot. Usually the three-phase unit of the zone-2 relay in the transmission line relaying scheme is used for the inner circle and a separate relay equipped with the appropriate logic provides the outer-circle characteristic.

***Photo*—A typical directional comparison unblocking system is made up of various solid-state relays and components, selected to satisfy the requirements of the application.**



laying, and then to provide one or more time-delayed reclosures in response to synchronism check or hot-bus/dead-line control. Initiation of high-speed reclosing occurs in response to all high-speed tripping, with a further constraint customarily imposed by a control switch contact to prevent high-speed reclosing unless pilot tripping is in service.

Conclusion

There are many variations in the solid-state relaying systems that can be applied to transmission line pilot protection. The ones discussed briefly in this article are those that have been standardized by Westinghouse relay engineers in the interest of simplifying the application of pilot protection systems, both for the user and for the manufacturer.

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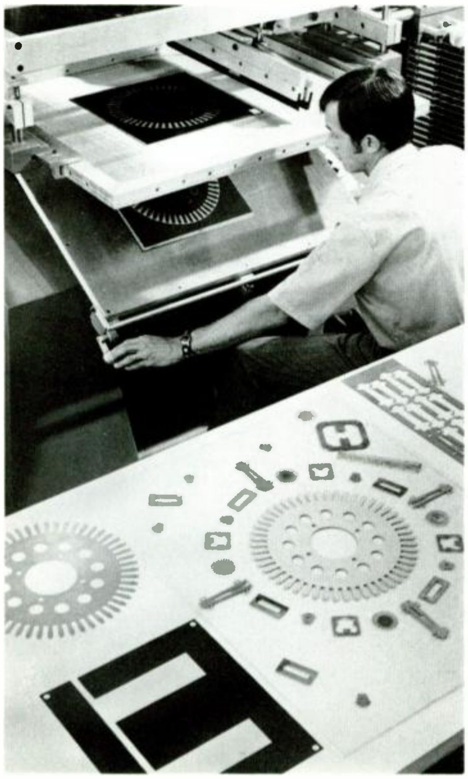
ACKNOWLEDGEMENTS:

The important contributions of R. G. Lakin, Relay-Instrument Division, Westinghouse Electric Corporation, to Tables I and II are gratefully acknowledged.

Etched Core Laminations Produced Experimentally

The conventional way of making laminations for magnetic cores of such electrical devices as motors, transformers, and circuit breakers is by stamping them out of thin sheets of electrical steel. It is a high-production method, but it has some disadvantages: the dies and punch presses are expensive, punching produces burrs on the laminations that have to be removed, and it produces stresses that degrade magnetic properties and consequently have to be annealed out.

Because of those disadvantages, the feasibility of cutting laminations by chemical etching has been investigated with encouraging results at the Westinghouse Research Laboratories. "Chemical blanking," as it is often called, has been highly developed for such purposes as etching the copper layer on printed-circuit boards, but it has been restricted to relatively thin material—up to about 0.006 inch. Electrical laminations are several times that thick, so new approaches are desirable to maximize processing speed and to minimize undercutting of the edges of the laminations.



One approach investigated was etching from both sides simultaneously, and experimental methods successfully produced laminations ranging in thickness from 0.014 to 0.035 inch thick. For production use, a fast automated method would have to be developed for applying the pattern of "resist" (a coating that masks the desired areas from the etching solution). The method also would have to be accurate to position the patterns in registry on both sides of the strip of steel going through the process.

The automated printing processes used for paper are rapid, so if such a process could be made sufficiently accurate it would provide a much faster and cheaper method than the photographic processes presently used to make resist patterns for chemical etching. Some experimental work has been done at the Laboratories to utilize screen printing, an adaptation of the ancient art of silk screening (see photograph). Since screen printing can be done on high-speed rotary presses, the required high-volume two-side printing process could be developed. Moreover, development of new kinds of resist might permit use of other high-speed printing methods such as rotogravure and offset.

Whatever the method used for printing the image on the steel strip, the strip would then be chemically etched on both sides simultaneously. The used etchant solution could be regenerated, preventing possible disposal problems.

Besides producing no burrs and no stresses in the laminations, chemical blanking would have other advantages. The printing screens or plates for making patterns would be much less expensive than the dies used in the present stamping process, so the process would be much more adaptable to product design changes. (Even the experimental methods have been of value in making special laminations for other development projects.) The process could produce shapes that are unsuitable for die punching. The resist remaining on blanked laminations would serve as the interlaminar insulation, eliminating the separate insulating step now required. And the process would be virtually silent, thus providing a better working environment than the present noisy punch-press shop.

At present, it is difficult for chemical blanking to compete economically where high volume and close tolerances are required. As better techniques and materials are developed, however, the process is expected to come into significant use for producing laminations.

Motors for High-Speed PATH Cars

The traction motors shown in the photograph were built for the Canadian Car Division of Hawker Siddeley Canada, Ltd., which is incorporating them into 46 high-speed transit cars for Port Authority Trans-Hudson Corporation, a subsidiary of the Port of New York Authority. The cars will carry passengers under the Hudson River on the PATH rail system connecting Manhattan and New Jersey.

Four of the high-performance dc motors will be mounted under each car, driving the four axles through parallel double-reduction gear units. The cars will weigh about 80,000 pounds loaded and will operate at speeds up to 70 miles an hour.

The motors were designed by the Westinghouse Transportation Division and manufactured by the Large AC/DC Motor Division. Other Westinghouse equipment in the cars includes the gear units, control systems, low-voltage auxiliary static power supplies, and high-frequency inverters for lighting.

Chesapeake-Bay Areas Get Environmental Study

A major environmental study is being performed along the eastern shore of Chesapeake Bay and in the Chester River, which empties into the bay. The study is focused on such basic problems as food chain relationships, the biochemistry of sediments, and the effects of circulation, sedimentation, and erosion. Some 50 stations along the river and 24 in the bay are collecting hydrological, geological, chemical, and biological information in an initial survey; 25 stations in the river and 12 in the bay will then be selected on the basis of the initial findings and will be monitored periodically for a year.

The program is being carried out cooperatively by Westinghouse and the Maryland Department of Natural Resources. Scientists and engineers from the company's Ocean Research Laboratory and its Oceanic Division (both of which are located on Chesapeake Bay near Annapolis) are doing most of the research. The cost of the project will be shared by the state of Maryland and the company.

The Chester River was selected for the study because its watershed is less developed than those of the other rivers that empty into Chesapeake Bay. Increased development is expected, so scientists will have a chance to evaluate its impact on the river and bay.

At the selected stations in the river and bay, the initial periodic measurements will be of current speed and direction, temperature, salinity, and water clarity. Differences in the readings from one survey to the next will show how circulation patterns change. As the study progresses, samples of water, bottom (including cores), and organisms will be collected. The amount of suspended sediment in the water samples will be determined. The sediments (suspended, bottom, and core) will be analyzed for mineralogical content and for the presence of chlorinated hydrocarbons (mainly pesticides). Organisms will be studied to determine their distribution and food chain and also for the presence of chlorinated hydrocarbons.

A permanent station on the bay's eastern shore will make long-term measurements of tides, salinity, conductivity, temperature, and wind speed and direction. The combined data will show how the bay water and river water mix and will also show the effects of runoff.

A photomosaic of the study area will be made to help evaluate shoreline conditions and land uses, to fix the locations of the stations, and to locate the sources of sediments and pollution. A side-looking sonar system will produce a kind of map of the bottom; further bottom and subsurface characteristics will be explored with another acoustic device called a subbottom profiler.

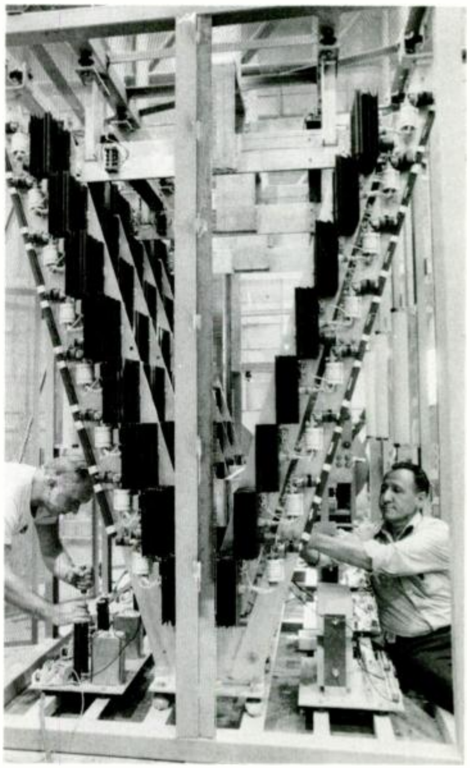
The results of the work will be used to produce an environmental atlas for the area studied. The atlas is expected to be useful for such purposes as showing how sediment and chlorinated hydrocarbons move through the system and helping predict how the levels of chlorinated hydrocarbons will change in the future.

Rectifier Cubicles for CTA

Three 2500-kW silicon-diode rectifiers were supplied recently for the Chicago Transit Authority. The units are built as indoor cubicles and will replace old ignitron equipment in the Authority's rapid transit system. Rated at 600 volts dc, they can withstand 450 percent of rated load current for 15 seconds.

The units are cooled by natural convection. Diode heat sinks with large fins heat adjacent air, causing it to expand and rise and thus maintain the air flow. A step arrangement of the heat sinks, shown in the photograph, enables each to be cooled by air at ambient temperature rather than by warmed air rising from lower sinks. The unit is designed for easy access to clean the heat sinks by brushing. Aluminum bus and heat-sink assemblies are welded together to eliminate the need for joint maintenance.

Similar units are designed and built by the Westinghouse Industrial Systems Division for electrochemical, other industrial, and transportation applications. Where required, they are designed to take overloads up to 500 percent of rated load current for 15 seconds and to withstand bolted short circuits without damage to diodes or fuses for as long as necessary for backup breakers to clear the fault (usually 10 to 15 cycles). Diodes have individual current-limiting fuses to isolate any that become shorted. Diode, fuse, and relay characteristics are co-



ordinated for maximum protection.

Equipment to protect the diodes against ac and dc voltage surges is located at the bottom of the cubicle. It consists of a resistor-capacitor network in each leg of the rectifier bridge and a Voltrap surge suppressor. Current between diodes within a leg is balanced by use of individual reactors with each diode and by sizing and spacing of the bus.

Automated System Monitors Water Temperature Profiles

An automated system now provides real-time monitoring of the temperature profiles of water bodies. Its buoy stations are located at fixed positions to continuously monitor temperatures in the area of interest, such as the thermal plume from a generating plant. Their instruments transmit continuous temperature signals to a shore station by underwater cable, and the station records and prints out useful data at selected time intervals.

Each buoy station contains up to 17 temperature sensors (thermistors) located at different water depths. The sensors are formed into watertight neoprene cable that connects to an electronics pack anchored to the bottom, and a float attached to the thermistor chain locates it vertically in the water. (See illustration, in which optional equipment is shown in color.)

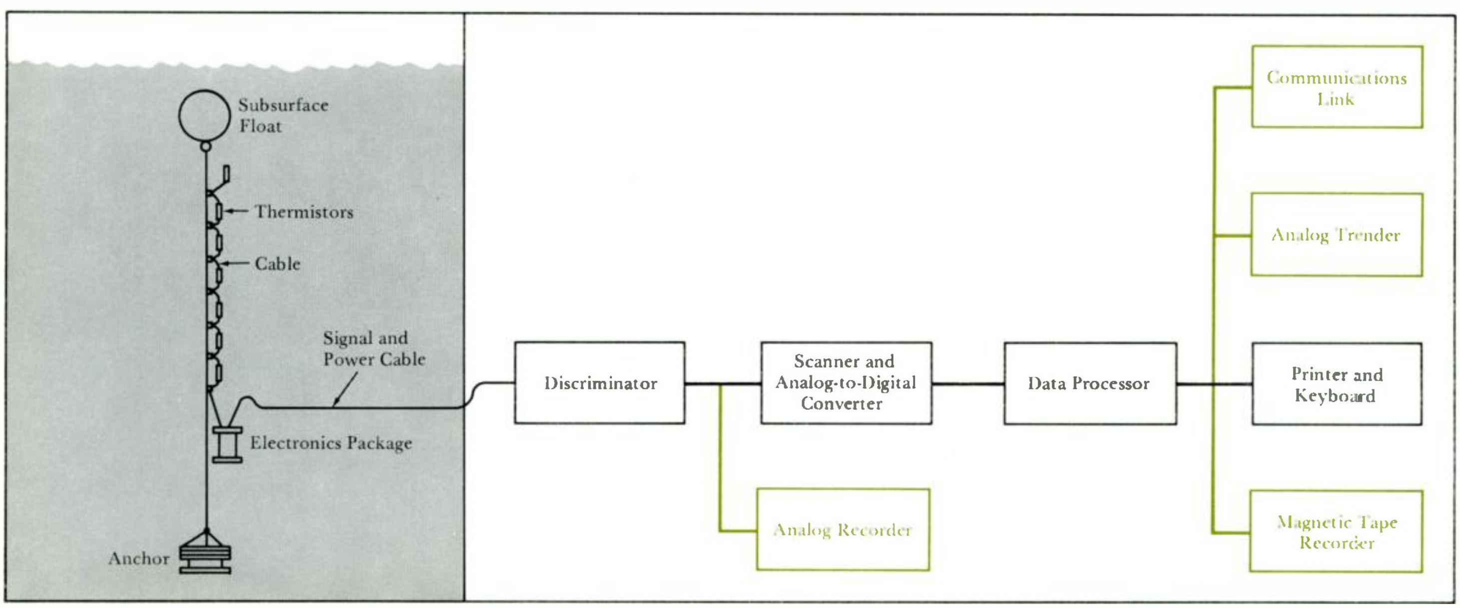
The electronics pack contains the components necessary to time-multiplex the signals from the sensors, convert the voltage signals to frequency signals, and transmit them to shore. It also generates three calibration signals (high, low, and midpoint) and synchronization signals. It automatically cycles through ten time-multiplexed channels—seven thermistor channels and three synchronization and calibration channels. The electronics pack can be expanded to 20 channels if desired.

Signals are carried to shore by three-conductor armored cables laid along the bottom. Each cable terminates at a discriminator board that converts the frequency signals from the temperature stations into analog voltage signals. Those signals are fed into the scanner, which samples all time-multiplexed channels at a preset rate and converts them into digital voltage levels for input to a miniature data processor.

The data processor provides control for the entire system. It is programmed to accept the series data from the analog-to-digital converter and distinguish between different sensors and different buoy locations. It converts the voltage signals to temperature, and it sorts and collects the data in easy-to-interpret format. In addition, the processor continuously monitors all temperatures and can be programmed to sound an alarm or print out data when it notes off-specification conditions on one or more sensors. The basic program provides for a complete printout of data at a selected time interval, which can be varied in the field. Additional software can be provided to calculate daily high, low, and average temperatures or other desirable manipulations of data. The data processor also can be programmed to handle mathematical modeling for future use in predictive mapping of the thermal plume.

The data processor controls a teletype printer that periodically prints a listing of the temperatures of all the sensors at each station and the date and time of the printout. The printer can also print daily, weekly, or monthly averages as desired. A paper-tape recorder connected to the printer records all printed data. The tape can be processed by the data processor or by an off-site computer.

The system is readily altered. For example, the number of buoy stations can be increased and the same data processor used. Buoy placement can be



changed to measure temperature in different areas. The core memory of the processor can be expanded to as much as 32,000 words, and the system can be incorporated into larger environmental-impact assessment and control systems.

A major advantage of the hardwired system is that it can be submerged completely, reducing vandalism and potential problems from power boats and floating debris. Since it doesn't propagate radio waves, it does not interfere with navigation. Power is supplied from the shore by the same cable that conducts the data signals; with no batteries to change, long periods of unattended operation are possible. However, a radio-transmission option is available.

The temperature monitoring system was developed by the Westinghouse Environmental Systems Department.

Fast Semiconductor Shipment Results from New Manufacturing Methods

Inventories of high-power semiconductor devices usually have been small because of the expense involved in storing fully assembled devices. Now, however, a manufacturing system initiated by the Westinghouse Semiconductor Division makes a large inventory economically feasible by fully testing semiconductor "elements" and then storing the elements in a comprehensive inventory system that the Division calls its semiconductor world bank.

The semiconductor element is the silicon wafer that actually performs all the electrical functions of the complete device. Since a fully assembled semiconductor device consists only of an element and a protective package containing wiring leads and a mounting surface, a future device's electrical performance can be determined accurately by testing only the element. The elements are not soldered in Westinghouse devices but instead are assembled with the other components by a mechanical arrangement known as compression bonded encapsulation, so assembly does not change the electrical characteristics.

The new manufacturing system begins with silicon wafers, which undergo a series of diffusions that give them the basic electrical functions of semiconductor devices. The resulting elements then receive a proprietary chemical coating to protect them. (Coated elements can be stored virtually indefinitely without deterioration.) Each element is tested and electrically characterized by equipment whose test probes duplicate mechanical conditions after final assembly. The fully tested and coated semiconductor elements are stored in the "world bank" and indexed by application and by customer. Thus, the bank maintains the user's inventory for him without the usual costs attached to inventory maintenance. The bank presently maintains an inventory of semiconductor elements for more than 1500 different thyristor and rectifier products rated between 35 and 2000 amperes and 50 and 3000 volts.

When an order is received, the correct elements are removed from the bank and assembled. Immediate availability of elements, assembly-line completion of the devices, and compression-bonded encapsulation assure that semiconductor devices are assembled and shipped within 54 hours of receipt of an order.

New Literature

Fast Reactor Safety is a 384-page book written for graduates and advanced undergraduates in nuclear engineering and for the practicing engineer who wants an overview of the safety field. It first presents the basic tools of safety engineering in a discussion of neutron kinetics, thermal analysis, feedback and closed-loop behavior, and fault tree analysis. Then possible system disturbances are analyzed and related to the reactor under consideration. The objective is to show how various parts of the system interact and affect each other and what tools are available to calculate those effects. Differences between fast and thermal systems are emphasized.

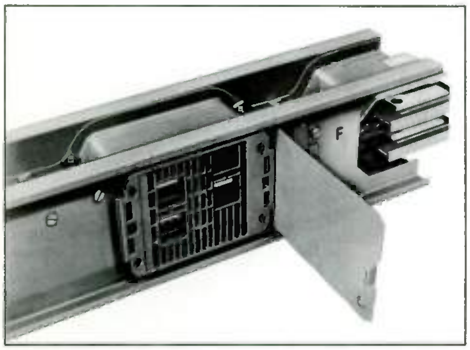
The book then traces a design chronology, from a discussion of criteria (including redundancy and common mode failure) to special fast reactor considerations, the concept of containment barriers, and the design basis accident. Licensing is treated and regulatory processes as they apply to safety are outlined. Other siting considerations, including air pollution and thermal effects, are discussed in relation to other power systems and the licensing process.

The book was written by John Graham of the Westinghouse Advanced Reactors Division. It is one of the Nuclear Science and Technology series of monographs and textbooks published by Academic Press, Inc., 111 Fifth Avenue, New York, N.Y. 10003, with editorial offices in London, England. Price is $18.

Display Storage Tubes, booklet SA-213, is a 52-page illustrated booklet that provides comprehensive information on display storage tubes. It describes principles of operation and includes application chapters on such topics as handling, controlling image brightness, and improving tube performance. Catalog sections list standard phosphors available and include a reference chart showing performance characteristics of all standard Westinghouse tube types. Supporting illustrations include spectral energy emission curves for standard DST phosphors and dimensioned outline drawings and pin configurations for standard tubes. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902.*

Products for Industry

One-design bus-duct system, called Westinghouse POW-R-WAY, eliminates the need for special adapter splice plates to make the transition from plug-in to feeder application or from indoor to outdoor. Lengths of duct of the same rating with or without plug-in openings are interchangeable. If a user installs a feeder system, for example, and later requires a plug-in takeoff, he merely installs a replacement plug-in section without disturbing adjacent sections. All joints are polarized to prevent incorrect phase arrangements; plug-in units and open-



One-Design Bus Duct

Safety-Designed Plug

Modular Office Components

ings also are polarized. An interlock prevents removal of a plug-in unit when its switch is in the "on" position. Bus bars are available in either aluminum or copper. Maximum voltage rating for three-wire systems is 600 volts; for four-wire systems, 277/488 volts. A complete line of accessories is available. The POW-R-WAY bus-duct line is UL listed and meets or exceeds NEMA standards. *Westinghouse Distribution Equipment Division, Beaver, Pennsylvania 15009.*

Safety-designed plug has a clear back for easy verification of proper connection between the power cord and the ground prong. In addition, it incorporates established safety features including dead-front construction, nonmetallic cord grip, and separate wiring pockets with clamp-type terminals. The new plug is available in configurations for 15- and 20-ampere 125- or 250-volt ac applications. Its body is constructed entirely of nylon and Lexan. *Westinghouse Bryant Division, Bridgeport, Connecticut 06602.*

Modular office components are designed to be rearranged easily and inexpensively. Called the Westinghouse ASD Group, the system is composed of free-standing partitions on which desks, files, cabinets, wardrobes, chalkboards, and other accessories are hung. Rearranging can be done by workers equipped with nothing more than an open-end wrench, a screwdriver, and a quarter. The partitions attach to a universal post, and they can be positioned anywhere around the post. All wall panels and work surfaces are of Micarta high-pressure laminate. *Westinghouse Architectural Systems Department, 4300 36th Street, S.E., Grand Rapids, Michigan 49508.*

Portable frequency meter, type PR-171, is a self-powered dual-range instrument. It incorporates two precision frequency transducers and a taut-band indicating instrument into a single unit. Accuracy is about twice that of corresponding switch-board-class meters that meet current industry standards. Temperature compensation permits use without correction factors over a wide temperature range. Broad or narrow measurement range is selected with a switch. *Westinghouse Relay-Instrument Division, 95 Orange Street, Newark, New Jersey 07101.*

Services for Industry

Cathode-ray-tube plots now make the output of the Westinghouse Protective Device Coordination Program more versatile by showing the characteristics of any device in the power system being analyzed. (The digital coordination program calculates and prints out a complete evaluation of the application, coordination, and operation of any power system's protective devices, including relays, fuses, and reclosers.) The new plotted output is of two types: (1) a replica of the manufacturer's characteristic curve for the selected device and (2) coordination curves showing the operating characteristics of both the overreaching and overreached devices plotted on the same axes. The former is useful for setting and maintaining each device; the latter provides quick evaluations of coordination margins throughout the system. *Westinghouse Power Systems Planning, East Pittsburgh, Pennsylvania 15112.*

Water flow measurement service employs a portable acoustic flowmeter to provide as much as a ten-fold improvement in precision. Applications include calculating efficiencies of hydroelectric turbines, large pumps, and cooling towers and measuring penstock bypass-valve flow.

Unlike other measuring methods, the acoustic system does not obstruct the passage of water, and it provides flow readings immediately. It employs acoustic transducers mounted in the sides of pipes or channels across from each other. Acoustic signals are sent back and forth between the transducers at a 45-degree angle to the direction of water flow. Signals traveling upstream are slowed by the flow; those traveling downstream are speeded up. From the time differential, the equipment calculates flow in volume per unit time. *Westinghouse Ocean Research and Engineering Center, P.O. Box 1488, Annapolis, Maryland 21404.*

About the Authors

S. J. Campbell is Manager of Engineered Systems and Drives, a part of the Industrial Process Systems Department of the Industrial Systems Division. He is responsible for application, marketing, design, and startup of process drive systems for the mining, pulp-and-paper, textile, rubber, lumber, and allied industries.

Campbell joined Westinghouse on the graduate student training program in 1950 after graduating from the University of Wisconsin with a BSEE degree. He went to the general mill section of the former Industry Engineering group to work on systems drives, and while doing so earned his MSEE at the University of Pittsburgh. In 1961, he was made Manager of Project Engineering in the metal industry section.

When the present Industrial Systems Division was formed in 1963, Campbell was made Manager of Pulp and Paper Systems. He became Manager of the division's General Industries Systems group in 1965 and assumed his present position in 1967.

James H. Meacham joined the Westinghouse Aerospace Division in 1967, after receiving his BSEE from the University of Delaware. His first assignment was in Electro-Optical Systems Development in the division's Advanced Development Engineering, where he worked primarily on the micro-miniaturization of TV camera functions utilizing hybrid integrated circuits. These circuits were developed for various SEC vidicon camera systems, such as the compact camera series used for surveillance and oceanographic applications.

From 1969 to 1970, he contributed to the design of the Apollo lunar color television camera, the ultraviolet compact camera for the Naval Research Laboratory's Solar Flare Aerobee launch, and investigated the use of solid-state mosaic techniques for a subminiature color TV camera.

In 1971, he was made program manager for the SUBMIN-TV and subminiature LLLTV cameras, which use the techniques described in this issue.

F. S. Restivo is a Fellow Engineer in the development engineering group of the Electronic Systems Support Division, a division of the Westinghouse Defense and Electronics Systems Center. He joined Westinghouse in 1958 upon graduation from the University of Maryland with a BSEE. His first assignment was at the former Surface Division, where he worked on the design of test systems for several large defense projects.

Most of Restivo's succeeding assignments have been in the design and development of automatic test equipment, both analog and digital. His most recent effort has been in the area of automatic test equipment for transportation systems; it includes the direction of technical proposals and support of marketing functions in related application problems.

F. W. Jones graduated from Northeastern University in 1967 with a BSEE degree. He joined the Westinghouse Defense and Electronics Systems Center to work in the Product Support Equipment Department.

Most of Jones' efforts at Westinghouse have been concerned with the design and application of automatic and diagnostic test equipment. In 1969, he became Project Engineer for transportation support in the Advanced Development group of the Electronic Systems Support Division, and he was responsible for starting the MU Car System Tester (MUST) development program. He moved to the computerized test products group in 1970 as Project Engineer for the first computer controlled MUST.

Jones has been Applications Engineer and Proposal Manager for MU Car System Testers and Transportation Support Equipment and is presently a Systems Engineer in the Product Line Engineering section. He is a member of the IEEE and has authored several papers on automatic testing applications.

K. H. Fraelich, Jr., joined Westinghouse in 1959 after graduation from the University of Pittsburgh (BSEE). Prior to graduation he had worked as a student engineer with the Bettis Atomic Power Laboratories. Upon completion of the graduate student training program, Fraelich was made a division salesman with the Rectifier and Traction Division in East Pittsburgh, with assignments on both product lines. When the Transportation Equipment Division became a separate entity in 1963, he was made a sales engineer handling equipment for mass transit vehicles. In 1970, Fraelich was made manager of car equipment sales.

W. A. Elmore graduated from the University of Tennessee with a BSEE in 1949. After two years of substation design work with a utility company, he joined Westinghouse and served 13 years as a District Engineer. In 1964, he moved to the systems engineering section of the Relay-Instrument division and is presently a Fellow Engineer there.

Elmore's most recent work has been in development and application of solid-state transmission line relaying systems, solid-state reclosing relays, and solid-state out-of-step systems. He is a registered professional engineer in the states of Washington and New Jersey and a member of the IEEE Power System Relaying Committee.

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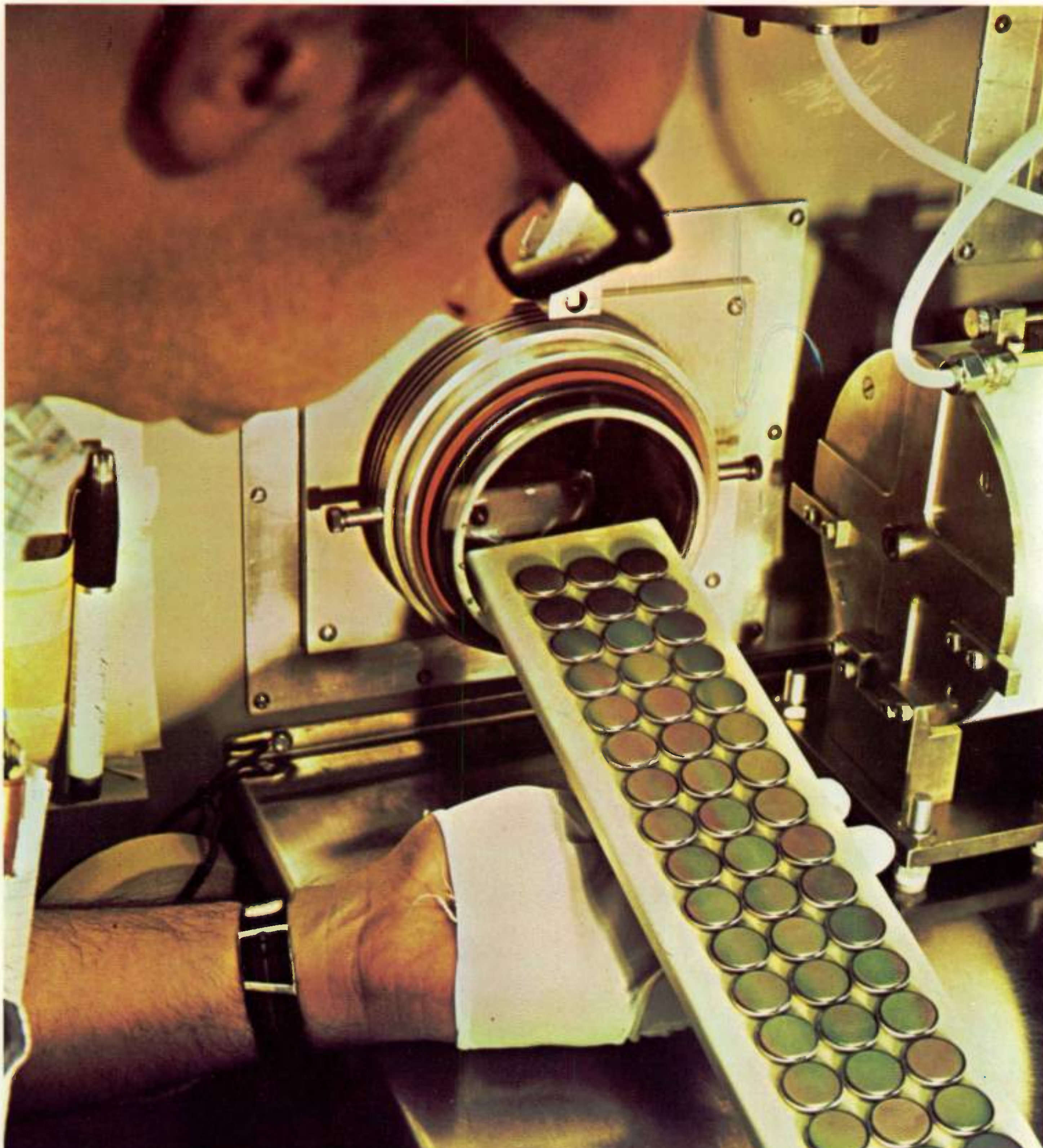

Semiconductor elements for power devices are given a coating that protects them in storage. (See page 63.)