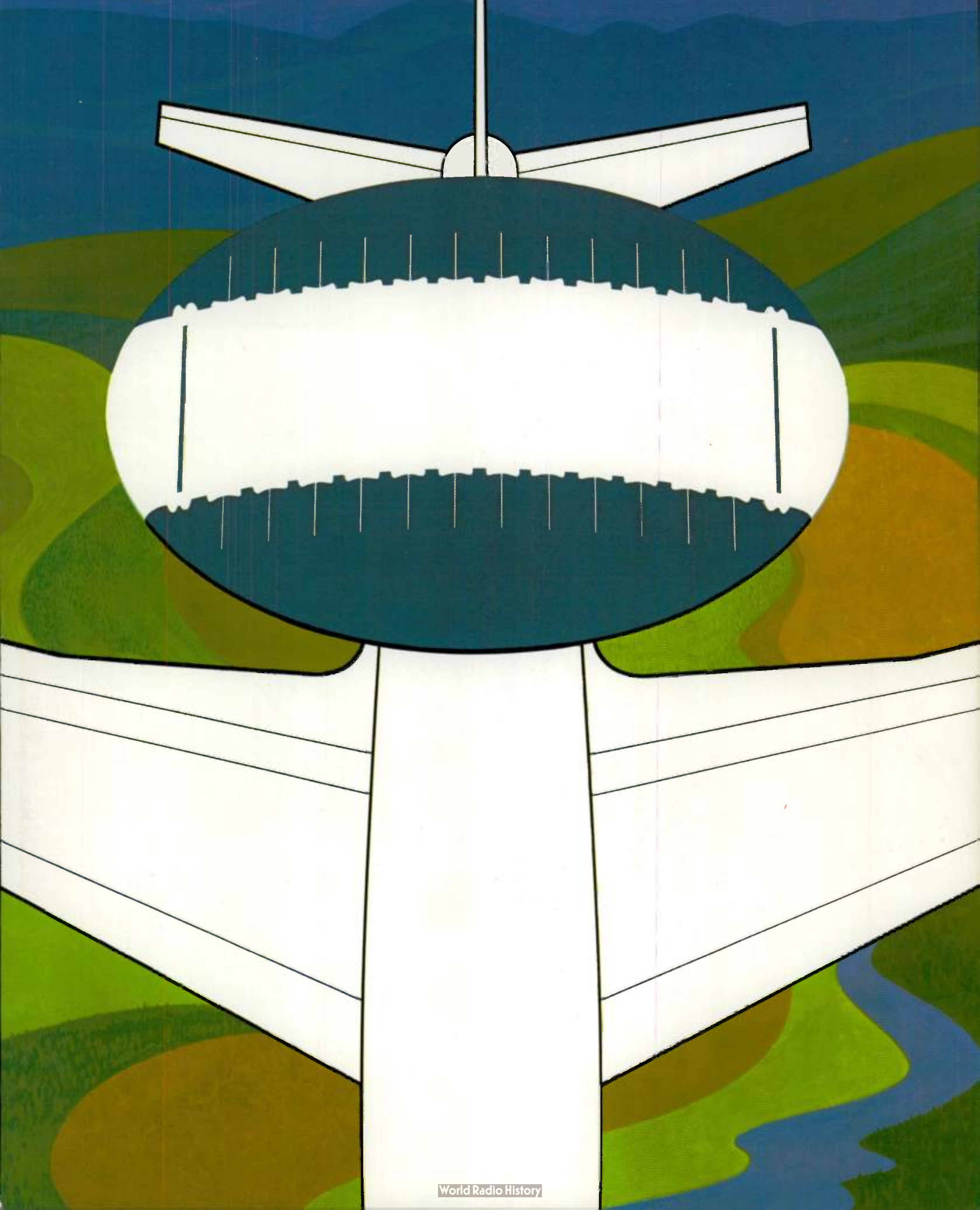
Westinghouse ENGINEER July 1973



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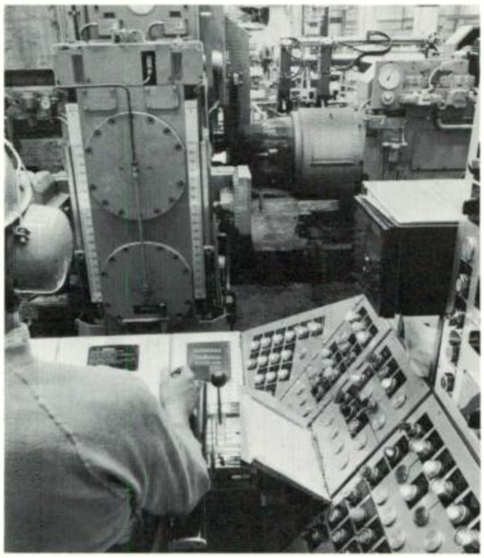

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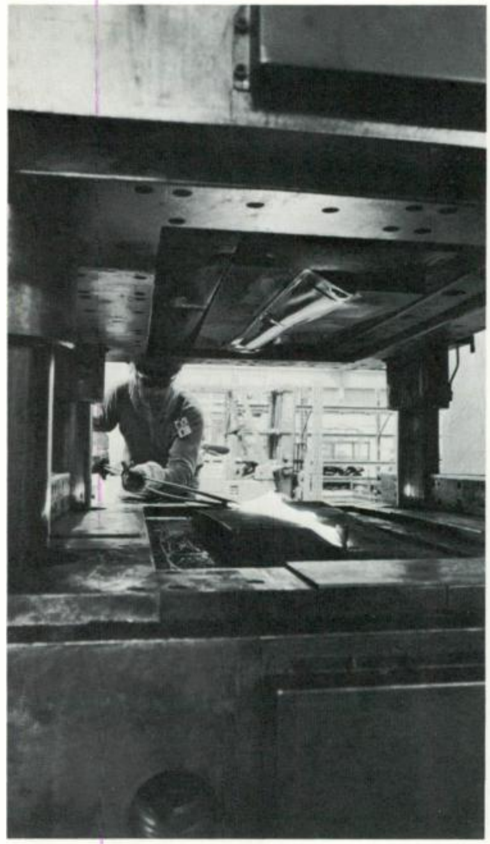

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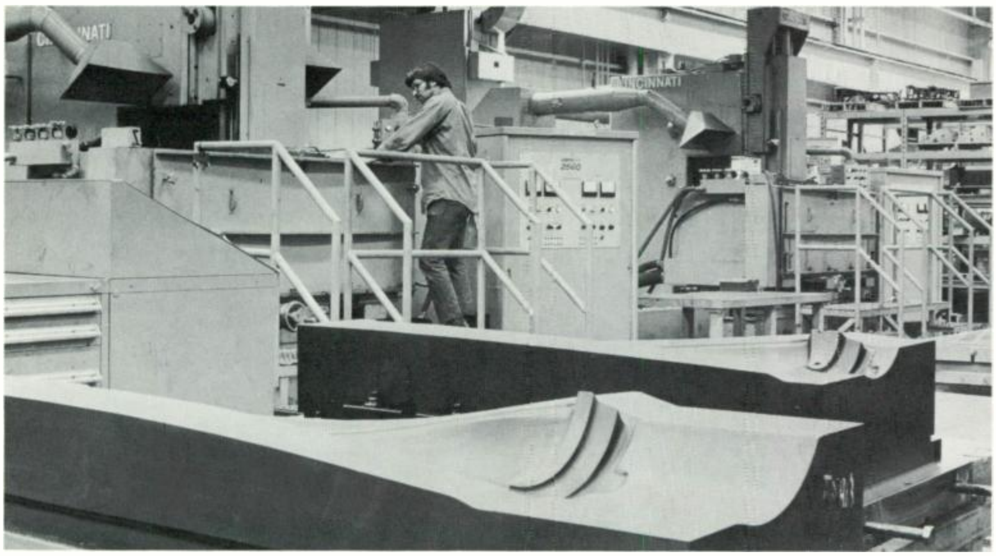

Precise Forging Techniques Produce High-Quality Turbine Blades

Precision forgings for tapered-twisted steam turbine blades up to 44 inches long are now in production in the new forge shop of the Westinghouse Turbine Components Plant near Winston-Salem, North Carolina. Precise forging processes minimize the amount of machining required, thereby helping achieve high quality in the finished blades. Airfoil portions of the blades require only grinding and polishing, and the lugs require machining of only a few thousandths of an inch.

Dies for the forging presses are designed to require the least amount of force for forging the blades. The design is aided by a computer program that simulates the forging process to help determine the best positioning of the cavities in the dies. The dies are made by electric discharge machining, using carbon electrodes milled under the direction of a numerical control program. (Electrodes are shown in the foreground in Fig. 1, and the electric discharge machines are in the background.) Electric discharge machining produces dies of uniform high quality and also speeds production of new blade forms. Finished dies are checked for accuracy with an optical comparator.

The computer program that simulates the forging process also helps determine the best preshape for billets. Billets are preshaped in a rotary forging machine operated by a numerical control program (Fig. 2).

Preshaped billets are forged to blade shape in one of two precision screw-type forging presses (Fig. 3). One press has a maximum impact force of 16,000 tons; the other, 8000 tons.

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Front Cover: The AWACS radar subsystem, described in the article that begins on the following page, is a key element in the high-flying long-range surveillance system for detecting and tracking aircraft. Artist Tom Ruddy used the rotodome, which houses the radar antenna, and the aircraft for this month's cover design.

Overland Downlook Radar Is Key Element of AWACS

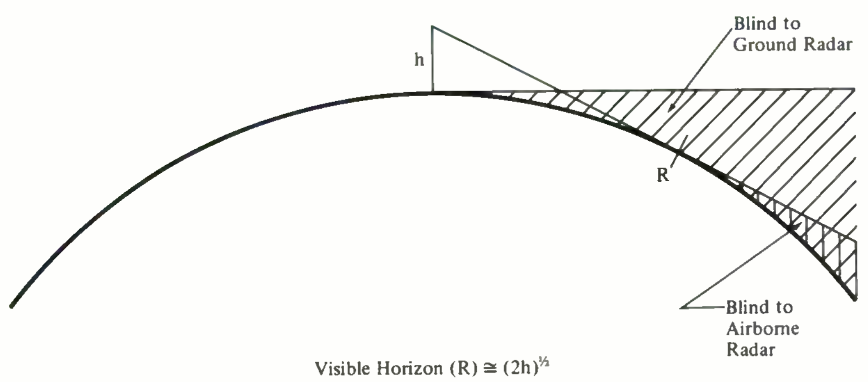
R. E. Hendrix

High-PRF pulse doppler radar with digital signal processing provides the capability and flexibility required for the U.S. Air Force's Airborne Warning and Control System. Westinghouse will continue the development of the radar subsystem under contract to Boeing, the prime contractor for AWACS.

The U.S. Air Force's Airborne Warning and Control System (AWACS) will substantially increase the effectiveness of United States air defense and tactical forces. The present defense system is composed of the fixed ground-based radars and control centers of the SAGE (Semi-Automatic Ground Environment) system, BUIC (Back-Up Interceptor Control), and a limited force of EC-121 radar picket planes. It has some vulnerability to low-altitude attack because of the line-of-sight limitations of ground-based radars, the fixed positions of the ground radar stations, and limitations of the EC-121 radar. Being airborne, AWACS will provide survivability in the event of attacks for the surveillance, command, and control portion of the air defense system, and it will substantially extend surveillance perimeters beyond present line-of-sight limits set by ground-based surveillance systems (Fig. 1).

R. E. Hendrix is a Senior Engineer in the Systems Development Division, Westinghouse Defense and Electronic Systems Center, Baltimore, Maryland.

1—The horizon for ultra-high-frequency airborne radar is approximately the visible horizon. Thus, for a radar altitude (h) *of 30,000 feet, the range* (R) *to the horizon is about 245 miles.*



The most critical component of the AWACS concept, the downlook radar that must pick out low-flying aircraft from ground clutter hundreds of miles away, was identified during the initial AWACS studies conducted by the Air Force in the 1960's. The technology required for providing sufficient rejection of the large clutter returns from land was not sufficiently developed, and the fundamental feasibility of the concept was in question. To resolve that question of fundamental feasibility, the Overland Radar Technology (ORT) program was established by the Air Force. (See *Development of AWACS.*) That program, completed in 1967, demonstrated the capability of pulse doppler radar for the AWACS application. (Pulse doppler radar is a general type of pulse radar that utilizes the doppler shift of the target returns for their detection.) Continued study and development following the ORT program led to a Brassboard program phase in which full-scale radars were demonstrated in a competitive fly-off. This resulted in selection of the high pulse repetition frequency (PRF) technique, the design proposed by Westinghouse.

As a result of the fly-off demonstration, the AWACS radar concept is now based on the use of high-PRF pulse doppler coverage to detect and track high- and low-altitude targets in the severe clutter environment at ranges up to and beyond the horizon.

The high-PRF pulse doppler coverage is supplemented by a conventional low-PRF pulse mode to enhance coverage of targets beyond the horizon.

High-PRF Pulse Doppler for AWACS

The high-PRF pulse doppler technique[1,3] was first developed by Westinghouse in the late 1950's, and it has been used in more than a thousand production radars for aircraft and missile system applications.

In many of these systems, the high relative speeds between radar and target provide enough doppler shift to completely separate target return from background clutter. (Doppler shift can be expressed as $f_d = 2V/\lambda$, where f_d is the frequency shift in hertz, V is the radial velocity of the target relative to the radar, and λ is the operating wavelength of the radar.) Therefore, in these applications there is no need to minimize background clutter with low-sidelobe antennas because target returns are well separated from the clutter spectrum. Large doppler separation of targets and clutter also permits relaxation of signal generation and processing requirements.

However, in the AWACS application, both high and low relative-speed target detection is required. Since low-speed target returns are not separated from the sidelobe ground clutter (as will be shown), techniques to minimize this clutter and maintain high sensitivity in the small residual clutter are necessary. It was the successful application of such techniques to the high-PRF pulse doppler concept that led to the successful AWACS radar. The technical breakthroughs for AWACS in this area include design of extremely low sidelobe antennas, development of ultrastable signal generation techniques, and advances in digital processing techniques.[2]

The transmitted radar signal is a train of coherent RF pulses at the high PRF (Fig. 2). As indicated, the frequency spectrum for that signal consists of a series of lines separated by the PRF and centered at the RF carrier frequency (f_0). The envelope of the lines of the spectrum is determined by the shape of the transmitted pulses. If the envelope of the pulses is rectangular as shown, the lines are weighted by the (sin x)/x function.

The frequency spectrum of the return signal from each target or ground scatterer also consists of a series of lines separated by the PRF, but the spectrum is centered at the RF carrier frequency plus a doppler shift. The composite signal return, illustrated in Fig. 3, consists of signals from both targets and ground.

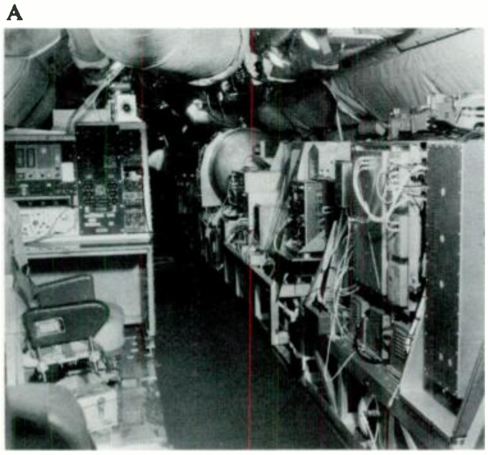
The ground returns, or clutter, appear at a variety of frequencies depending upon the radial velocity of the point on the ground relative to the radar platform. Thus, clutter frequency is proportional to the cosine of the angle between the line of sight to the point on the ground and the platform flight vector. The clutter return from ground at the horizon directly along the radar platform flight vector, with a relative velocity equal to plus the radar platform velocity, and the return from the horizon directly opposite the flight vector with a relative velocity equal to minus the radar platform velocity, define the maximum extent of the clutter spectrum.

Main-beam clutter, which results from the antenna's main-lobe ground illumination, is the largest clutter return. The frequency of main-beam clutter varies as the cosine of the antenna azimuth angle relative to the velocity vector of the aircraft; thus, main-beam clutter frequency moves through the entire clutter spectrum as a 360-degree scan is performed. The main-beam clutter return is rejected in the receiver by means of recursive delay line cancellation techniques. Briefly, this is done by passing the received RF signal return through a first mixer whose local oscillator frequency is varied to maintain a constant difference from the frequency of main-beam clutter. (See *Digital Signal Processing*.) The mixing action that results translates the main-beam clutter signal to a constant intermediate frequency (i-f), which is then translated to zero frequency by a second mixing operation. That signal is converted to digital form and processed by

Development of AWACS

The Airborne Warning and Control System (AWACS) began with the Overland Radar Technology (ORT) program, which was established by the Air Force in the mid 1960's to determine the fundamental feasibility of downlook radar for long-distance tracking of low-flying aircraft. The program tested three of the most promising downlook radar techniques proposed for AWACS in modified EC-121 radar picket aircraft. Two of the three techniques proved capable of detecting targets in the presence of large clutter return from land (as opposed to the lower amplitude return from sea). Both radar techniques were pulse doppler—the Westinghouse approach (*photo A*) used a high PRF and the other used a medium PRF. The radar antenna (mounted below the fuselage inside the aircraft's radome) was one of the first low-sidelobe antennas constructed and was the forerunner of the AWACS design.

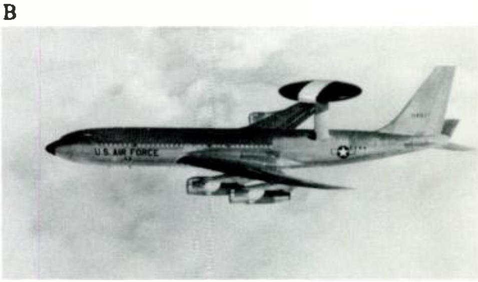
A



As a result of the ORT program, the Air Force prepared a Concept Formulation Package for the AWACS program, which was approved by the Department of Defense in late 1967 as a replacement for the SAGE/BUIC system. The contract definition phase was authorized by the Department of Defense in 1968 with the stipulation that a full-scale radar demonstration must be given before the full program would be authorized. The Air Force awarded The Boeing Company the prime contract for AWACS in July 1970. That contract was divided into three consecutive program phases—a Brassboard phase that included a competitive fly-off between the two pulse-doppler radars under consideration, Full Scale Development phase (formerly termed Design, Development Test and Evaluation, or DDT&E phase) and a production phase. Performance milestones were established within each phase, and successful completion of each milestone with approval of DSARC (Defense Systems Acquisition Review Council) was required before the program could proceed to the next phase.

The Brassboard phase was addressed to proving the capability of the radar system to detect and, in conjunction with the AWACS computer, precisely track low-flying aircraft in accordance with performance requirements established by the Air Force. Two commercial Boeing 707 aircraft were modified to flight test the competing radar systems. A 30-foot diameter rotodome was mounted atop the fuselage (*photo B*). This rotodome, which houses the radar antenna, the IFF (Identification, Friend or Foe) antenna, and the communications antenna, rotates continuously to provide 360-degree coverage. The electronic equipment inside the airplane fuselage included the radar transmitter (*photo C*) and receiver, a large-capacity digital data processor, displays, communications, and navigation equipment. The competitive fly-off from March through August 1972 resulted in the selection of the Westinghouse high-PRF radar. Following radar selection, airborne tracking was demonstrated by using the Westinghouse radar in conjunction with the AWACS central computer. The successful Brassboard demonstrations permitted the Air Force to proceed to the present Full Scale Development phase of the program.

B



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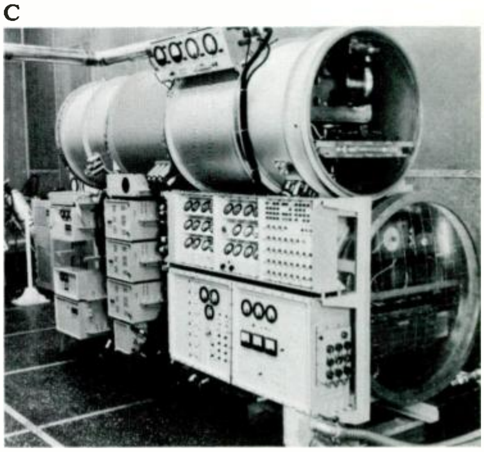

a cancellation network that severely attenuates signals at zero frequency (and multiples of the PRF) and passes all other signals.

The other much smaller clutter returns, termed sidelobe clutter, result from ground illumination by sidelobes of the antenna. The clutter return from ground directly below the radar (altitude line) has zero relative velocity with respect to the radar platform and therefore has no doppler shift and appears at carrier frequency (f_0).

Moving Target Detection—The doppler shift of a target reflection is determined by the radial speed of the target relative to the radar platform. Two examples are illustrated in Fig. 3. The approaching target (*1*) provides a positive doppler shift (f_1) equivalent to the vector sum of its velocity and the radar platform's velocity; the target being overtaken (*2*) has a positive doppler shift (f_2) proportional to the difference between target and platform velocity. The spectrum illustrated is typical of high-PRF pulse doppler radars. The PRF is selected to be high enough so that the separation between spectrum lines is greater than the extent of sidelobe clutter. Since the extent of sidelobe clutter is $\Delta f_c = 2(2V_{RADAR}/\lambda)$, the PRF for high-PRF pulse doppler is equal to or greater than Δf_c. The selection of a PRF based on this criterion produces unambiguous sidelobe clutter returns because the clutter associated with each PRF line never overlaps the returns from other lines. This has advantages in maintaining a low false alarm rate because clutter breakthroughs can produce false alarms only at the true velocity rather than at other ambiguous velocities.

Two basic requirements of the AWACS radar can be described in terms of the return signal spectrum shown in Fig. 3. First, extremely stable signal generation and processing are necessary to permit cancellation of the main-beam clutter in the receiver. Instabilities on this large return would spread the main-beam clutter signal in frequency and degrade target detection capability at other frequencies. The improvements in signal generation capability necessary for AWACS have been made through advances in circuit components including oscillator crystals and transmitter tubes. The signal processing advances were made possible by the application of digital signal processing and A/D converter development to the AWACS problem.

Second, low antenna sidelobes are necessary to minimize sidelobe clutter return and avoid reduction in detection performance for target returns that fall within the

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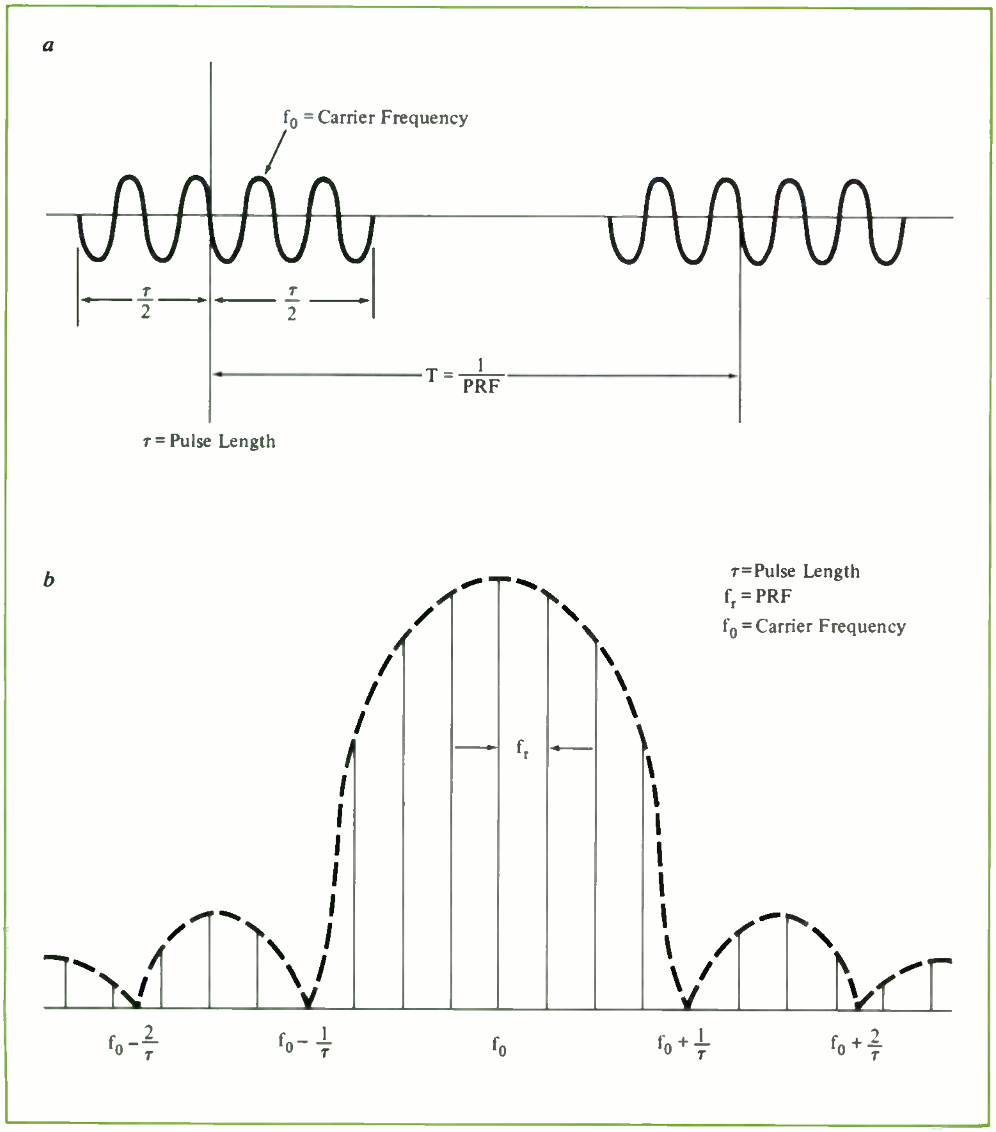

2—Pulse doppler transmission is a pulsed sine wave (a), *and the frequency spectrum that results* (b) *is a grouping of spectral lines above and below the carrier frequency* (f0), *encompassed by an envelope whose shape is determined by the shape of the transmitted pulse. For the rectangular pulse shown, the envelope approximates a* (sin x)/x *function. The spectral lines of the return signals will be shifted above or below the transmitted lines by doppler frequency, depending on whether the target has a closing or opening velocity.*

3—The composite pulse-doppler signal return consists of target returns that are doppler shifted from transmitted spectral lines proportional to the radial velocities of the targets relative to the radar platform; main-beam clutter frequency shift varies as the cosine of the antenna azimuth angle relative to the radar platform velocity vector; sidelobe clutter frequency shift for any point on the ground is proportional to the cosine of the angle between the line of sight to the point and the platform velocity vector.

4—The range ambiguity produced by a high pulse rate is resolved by using multiple pulse repetition frequencies. As shown for a two-PRF ranging system, target returns coincide only at true range (T_r).

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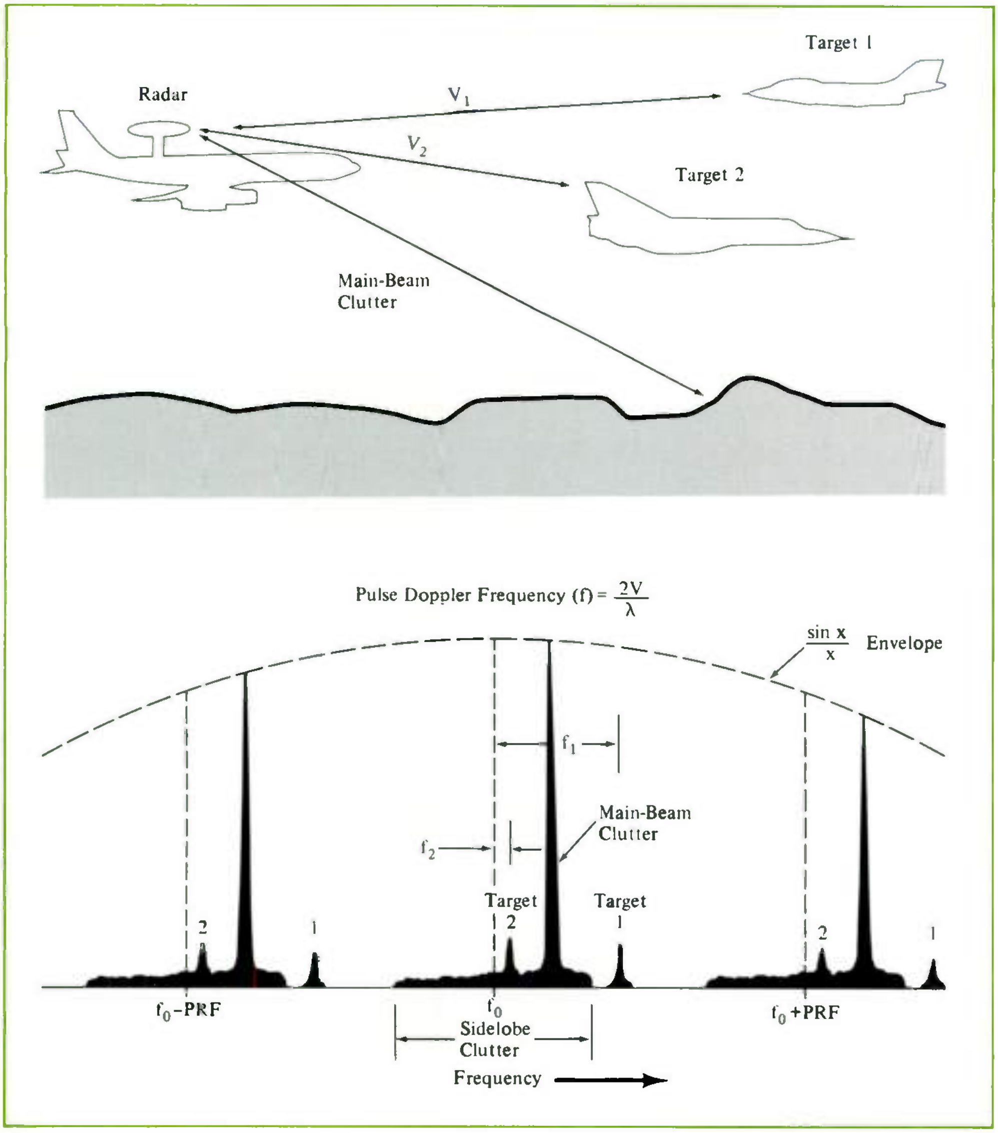

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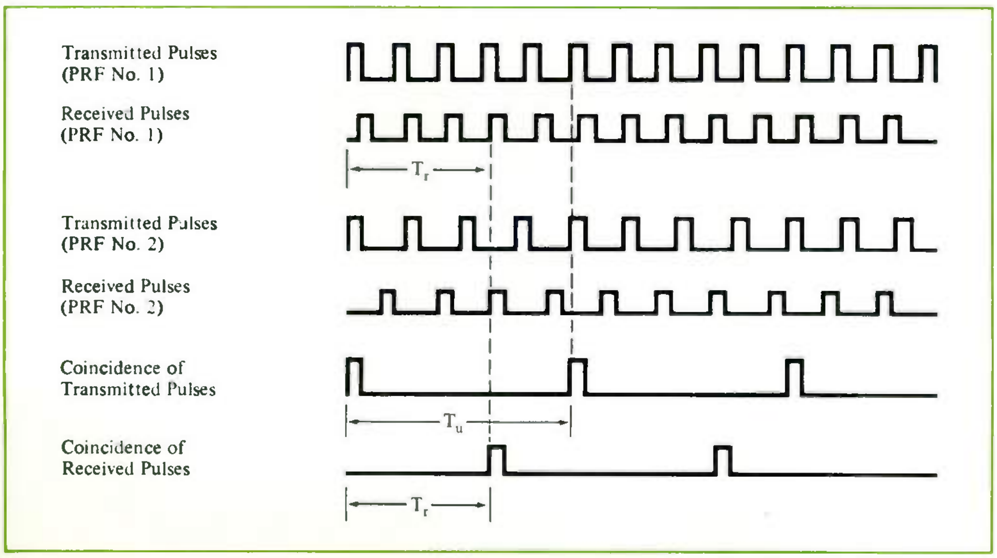


sidelobe clutter region. To prevent this masking of target returns, the antenna and radome are designed for extremely low sidelobe radiation. In fact, the low sidelobe patterns achieved in the AWACS represent a significant advance in the design of radar antennas and radomes. The advance was made possible by the application of the digital computer to the design of the antenna, the use of high-precision digital techniques in manufacturing the antenna, and improvements in radome design that enabled the low sidelobe characteristics of the antenna to be maintained when radiating through the radome. In addition to minimizing sidelobe clutter, the low sidelobes also help maintain radar performance in the presence of external electromagnetic interference.

Range Measurement—Because of the high PRF of the pulse doppler waveform, the time between successive pulses corresponds to only a few miles of range. Therefore, unambiguous range must be developed by the use of multiple PRF's. The principle of ranging with multiple PRF's is illustrated in Fig. 4. Two (or more) PRF's are transmitted sequentially in groups called bursts as the antenna beam is scanned over a target. The PRF's are chosen to have some common submultiple frequency ($1/T_u$) which is much lower than either PRF. (This occurs if the PRF's are obtained by dividing a common clock frequency by relatively prime numbers.) The transmitted pulse trains are compared in a coincidence detector to obtain the common submultiple frequency. Similarly, comparison of the return pulses in a coincidence detector produces the same submultiple frequency delayed in time by the target range delay, T_r. In the AWACS radar, range delay is calculated digitally from the ambiguous range measurements made in each of three PRF's.

Range Rate Measurement—Range rate, or velocity, is measured in the AWACS radar by measuring the doppler shift of a target return. The return signals, after being converted to digital form and passed through the main-beam clutter canceller, are analyzed by Fourier analysis. (See *Digital Signal Processing*.) This transform divides the signal into frequency components that relate directly to target velocity. Since the doppler shift for higher velocity targets is sufficient to produce an ambiguity (with signals from adjacent PRF lines), unambiguous velocity is developed by using the multiple PRF's in a manner analogous to that used for range.

Elevation Angle—The pulse doppler operation of the radar also permits the measurement of elevation angle, which is used in the AWACS central processor to determine target height. That measurement is made by rapid electronic scanning of the antenna beam in elevation as the antenna scans mechanically in azimuth by means of rotation of the entire rotodome. The amplitude modulation that results from electronic scanning is processed in the receiver to determine time of peak signal return, which is then used to calculate target elevation angle.

Low-PRF Radar

The low-PRF pulse operation of radar, which provides sufficient time interval between pulse transmissions to prevent ambiguities in range, is more conventional in nature than the high-PRF mode. The AWACS radar design permits simultaneous operation of low- and high-PRF modes. The transmit waveform for pulse operation consists of a long linear FM-modulated pulse at low PRF, which is tailored to efficiently use the average power capability of the transmitter and antenna. The long pulse transmission is at a different RF frequency than the pulse doppler transmission and is spaced between the high-PRF bursts. The long pulse is compressed on receive by a separate receiver, which uses a dispersive delay line to form a narrow pulse that is processed to provide range accuracy and resolution.

The Radar Equipment

A block diagram of the Brassboard radar, which is the basic configuration now being further developed in the Full Scale Development phase, is shown in Fig. 5. The transmitter, located in the airplane fuselage, includes a stable local oscillator that provides the high degree of phase stability required for main-beam clutter rejection. Two amplifier stages raise the stable local oscillator signal to a level sufficient to drive the power amplifier, which is a wide-band klystron.

The transmitter signal is fed up the rotodome strut to the antenna via a high-power rotary joint that provides signal continuity across the rotating-stationary interface.

The signal is passed through the transmit manifold, which divides it into 28 signals that have the proper amplitude weighting for low sidelobes. Those signals are passed through electronic phase shifters (which provide electronic scanning) and are radiated from the antenna. The antenna face (photo, turn page) is a planar array of slotted waveguides. The slot design provides the proper signal distribution across the array face for low sidelobes. A non-resonant antenna design is used to achieve low sidelobes simultaneously with broad operating bandwidth, an important feature for minimizing the effects of external interference. The antenna provides both the height-finding function and space stabilization, which is the positioning of the antenna beam to compensate for aircraft roll and pitch.

Target reflections received by the antenna pass through electronic phase shifters, are collected in the receive manifold, and are fed through the rotary joint to the pulse and pulse doppler receivers. Receiver processing includes analog-to-digital signal conversion, recursive clutter cancellation, and frequency analysis of the signal returns by a fast Fourier transform filter bank. A constant false alarm rate (CFAR) is obtained at the output of the filter bank by adaptive circuits that provide detection thresholds which adjust automatically to changing receiver noise levels or sidelobe clutter amplitudes.

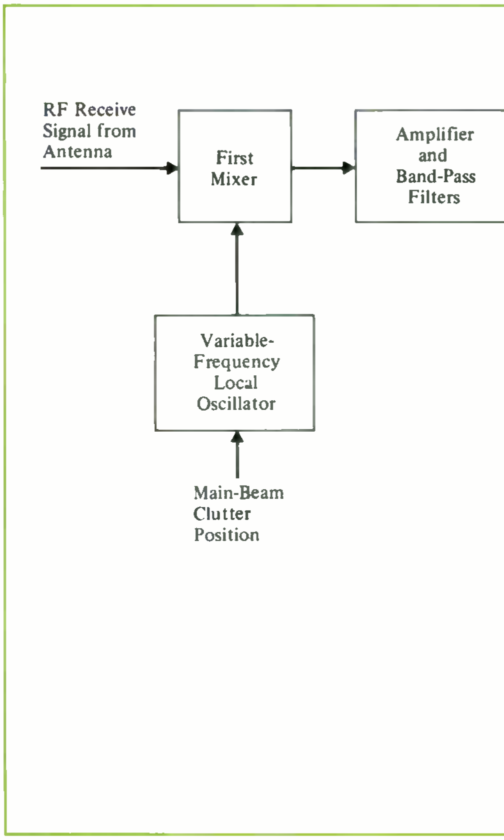
The radar data correlator is a high-speed programmable computer that performs overall radar management as well as processing detection data to form digitally formatted target reports. The reports, which include range, range rate, azimuth, elevation, and signal-to-noise ratio, are passed to radar displays and to the AWACS central processor. The central processor correlates the reports over successive scans to form target tracks. Radar control is accomplished by operating commands from the central computer or by commands from the radar operator console.

The radar design incorporates extensive ECCM (Electronic counter-countermea-

Digital Signal Processing

The basic block diagram for a typical high-PRF pulse doppler receiver using digital processing techniques is shown below. The *first mixer* translates the RF receive signal to an appropriate intermediate frequency (i-f), which is determined by the *local oscillator* frequency. The local oscillator frequency is varied to maintain a constant frequency difference from the main-beam clutter return so that the resulting first i-f signal stays constant as main-beam clutter frequency varies with antenna azimuth. The constant first i-f signal is amplified and passed through band-pass filters to reject unwanted mixer products.

A *second mixer* translates the spectrum to baseband where main-beam clutter and the doppler spectrum of interest are centered at zero frequency. To preserve both amplitude and phase information in the baseband signal, two



sures) to minimize the effects of enemy ECM. Also, an inherent feature of the radar design is its flexibility to accommodate future growth through software control. With software control, processing is accomplished with programmed instructions rather than with specific hardwired arrangements of circuitry. Thus, a function or process can be changed merely by altering the program of instructions rather than changing hardware. Characteristics under software control include target correlation algorithms, antenna beam positioning, system timing, CFAR processing, target report characteristics, and radar performance monitoring.

Changes to the Radar Design

The Brassboard radar design will be improved to the Full Scale Development phase with the objectives of reduced cost, improved reliability, and improved maintainability. To reduce system cost, the design is being simplified without compromising performance. For example, the

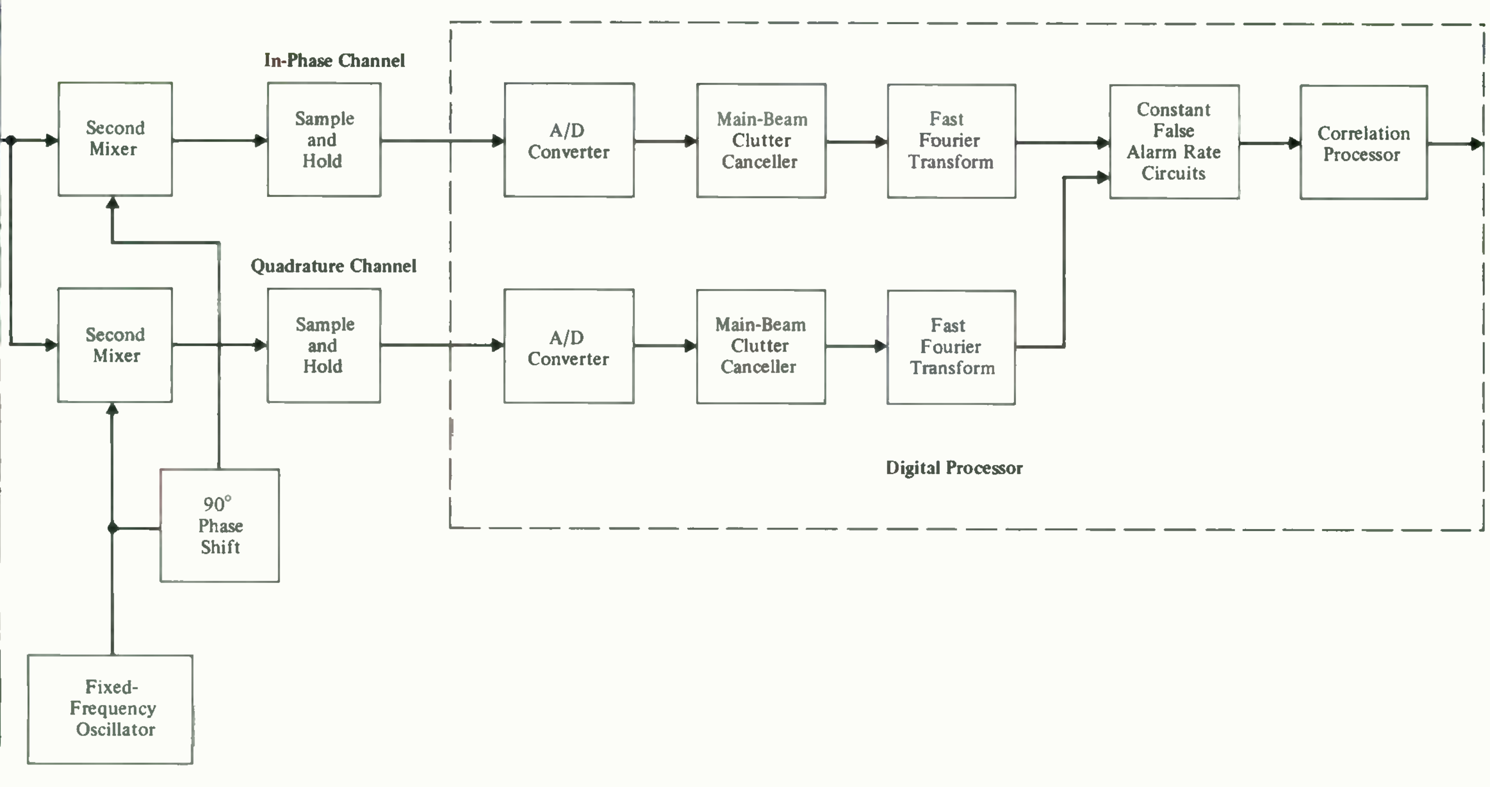
channels are used—an in-phase channel and a quadrature channel. The signal in each of these channels is divided into a number of range channels by means of a *sample and hold* circuit. The sampling process divides the interval between successive transmit pulses into a number of intervals, representing ambiguous range, each interval equal to the transmit pulse width. The samples are converted into digital form in the *analog-to-digital (A/D) converter*.

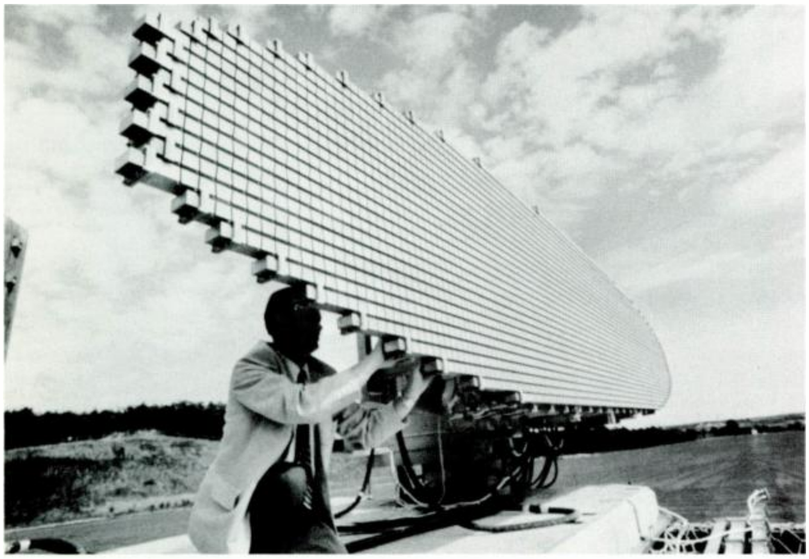
All processing in the receiver beyond the A/D converter is digital. The amplitude of the main-beam clutter return establishes the A/D converter dynamic range and stability requirements. The large dynamic range and stability for the A/D converter for AWACS required an applied development program, which produced a significant advance in A/D converter technology.

Since the main-beam clutter requires large dynamic range, the first digital processing function performed is cancellation of main-beam clutter. This is accomplished by addition and subtraction of successive pulses in a manner such that signals at zero frequency (and $n \times$ PRF where $n = 1, 2, 3, \ldots$) are cancelled. With main-beam clutter removed, the number of bits necessary to represent signal amplitude is greatly reduced. The remaining signals are then passed through a fast Fourier transform (FFT), which performs a Fourier waveform analysis of the signal to determine its frequency components. The FFT, a particular mechanization of the discrete Fourier transform given in mathematics textbooks, was developed to minimize the number of calculations required for frequency analysis. Generally, the FFT operates on a digital waveform of n words (where n is a binary number 2, 4, 8, 16, 32, etc.) to form n frequency components. The FFT is the digital form of the analog filter bank, a bank of contiguous analog filters used before the advent of digital processing techniques.

The signals from the FFT are processed by constant false alarm rate (CFAR) circuitry, which adaptively adjusts the detection threshold to the background noise or clutter conditions. Signals that exceed the threshold are passed to the *correlation processor* for correlation over successive PRF's to determine target report range, range rate, azimuth, elevation, and signal-to-noise ratio.

Digital signal processing provides significant advantages over analog processing in practically all areas including cost, weight, complexity, reliability, maintainability, and operability.





Photo—The Brassboard radar antenna, shown here on the test range, is a planar array of slotted waveguides that generates extremely low sidelobes.

5—Brassboard radar block diagram indicates major components of the high-PRF radar system being developed for AWACS.

6—The AWACS production configuration will be designed to permit growth to meet changing Air Force needs. The radar transmitter is located in the cargo bay, the antenna in the rotodome, and the receiver and signal-processing equipment in the main cabin area.

digital processing has been simplified by reducing the complexity of target elevation determination. To achieve the high reliability, built-in switchable redundancy is used throughout the system. To improve the maintainability of the radar, a highly sophisticated built-in test and fault isolation system is being designed to continuously monitor radar operation and, when failures occur, isolate the fault to the redundant grouping and automatically switch in that grouping. To help effect the ultimate repair, the system isolates the fault to the particular board so that replacement can be made manually. Commonality of boards is stressed to minimize spares costs and improve maintainability.

Present Status of AWACS

The Full Scale Development phase now under way involves a functional demonstration of the entire system in an operational environment. Among the major subsystems to be tied together and tested with the Brassboard radar in this phase are the central processor (the digital computer that ties the various subsystems together to perform the total AWACS mission), the display subsystem, the communication subsystem, the IFF subsystem, and the navigation subsystem.

Concurrent with the total system demonstration, production prototypes of the radar are being developed by Westinghouse. Subject to the successful completion of the Full Scale Development phase, the current configuration of AWACS is planned to enter into the production phase in late 1974. This system, illustrated in Fig. 6, is composed of the minimum equipment that is considered necessary for the Air Force's air defense and tactical missions. A key characteristic of this system is its capability for growth to meet the changing needs of the Air Force over the life of AWACS.

Missions for AWACS

The autonomous surveillance, command, and control functions of AWACS will enable it to perform both military and peaceful missions. The Air Force Tactical Air Command and Aerospace Defense Command will be the primary military users. AWACS will enable the Tactical Air Command to respond quickly to threat situations that develop in any part of the world. This capability will permit AWACS to be based in the United States and reduce the dependence on overseas complexes with their attendant costs and commitments. AWACS can also provide a unique enroute service to fighters and transport aircraft as those tactical forces are moved to a new area of deployment.

AWACS will provide the Aerospace Defense Command with an improved long range surveillance system. The airborne AWACS will provide for the survivability of the surveillance, command, and control portions of the United States defense system, and it will improve radar coverage of targets at all altitudes over both land and water.

The flexibility and capability of the AWACS system will permit it to be used to respond rapidly to disasters and other civil emergencies. As an emergency fill-in for ground-based control and communications systems, AWACS could establish an interim traffic control link that would minimize disruption of air movements in the affected geographical areas. In such emergency situations, AWACS can provide the communications interface for directing relief operations, providing navigational assistance, and maintaining air space surveillance.

REFERENCES:

[1] L. P. Goetz, "Fundamentals of Pulse Doppler Radar," *Westinghouse ENGINEER*, March 1969, pp 56-61.

[2] K. A. Linder and J. W. Taylor, Jr., "Digital Techniques Advance Tactical Radar," *Westinghouse ENGINEER*, September 1971, pp 147-55.

[3] M. I. Skolnik, *Radar Handbook* (Chapter 19, "Pulse-Doppler Radar," by D. H. Mooney and W. A. Skillman, Westinghouse Systems Development Division), McGraw-Hill Book Company, New York, 1970.

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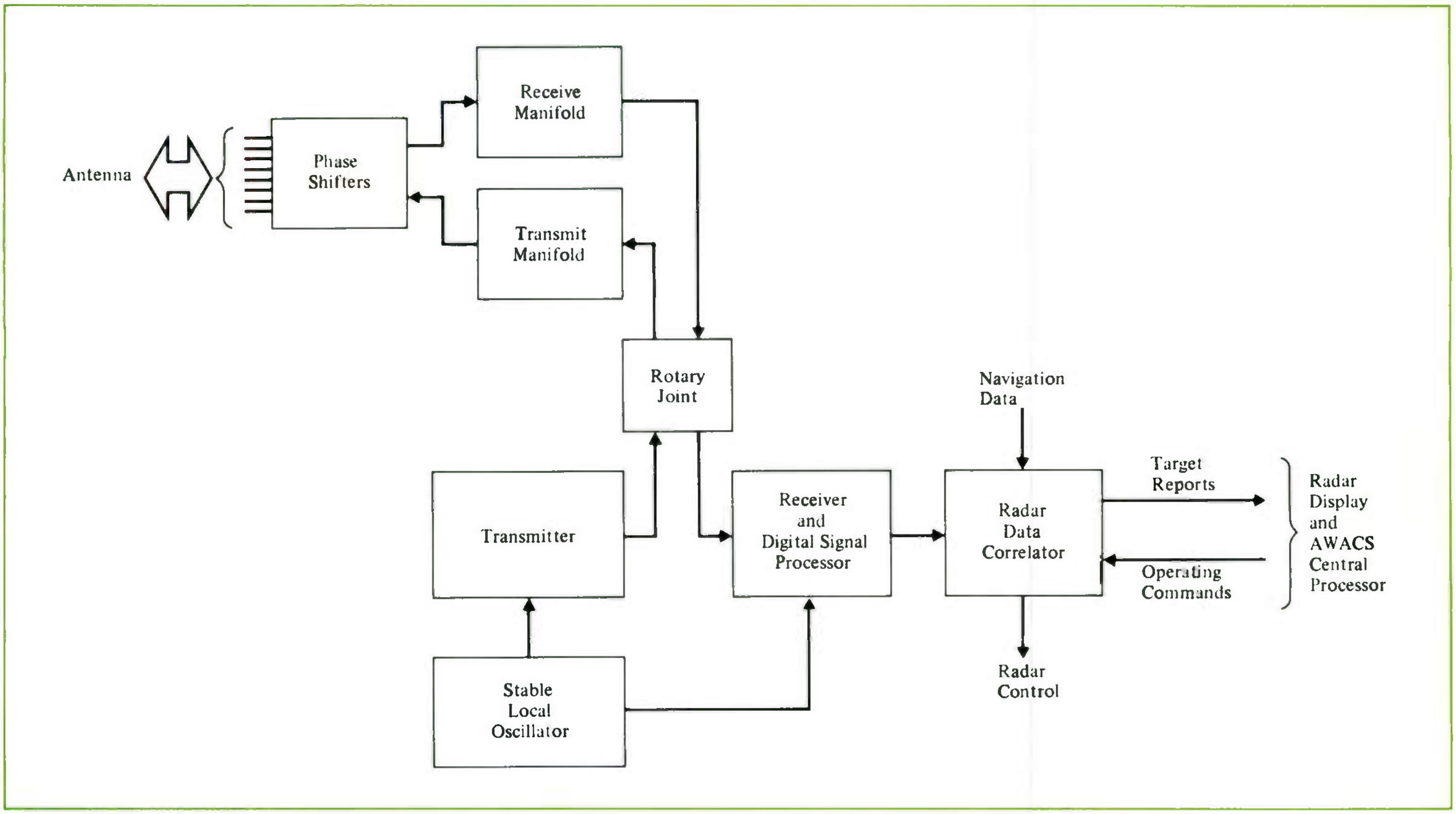
Antenna
Phase Shifters
Receive Manifold
Transmit Manifold
Rotary Joint
Transmitter
Stable Local Oscillator
Receiver and Digital Signal Processor
Navigation Data
Radar Data Correlator
Target Reports
Operating Commands
Radar Control
Radar Display and AWACS Central Processor

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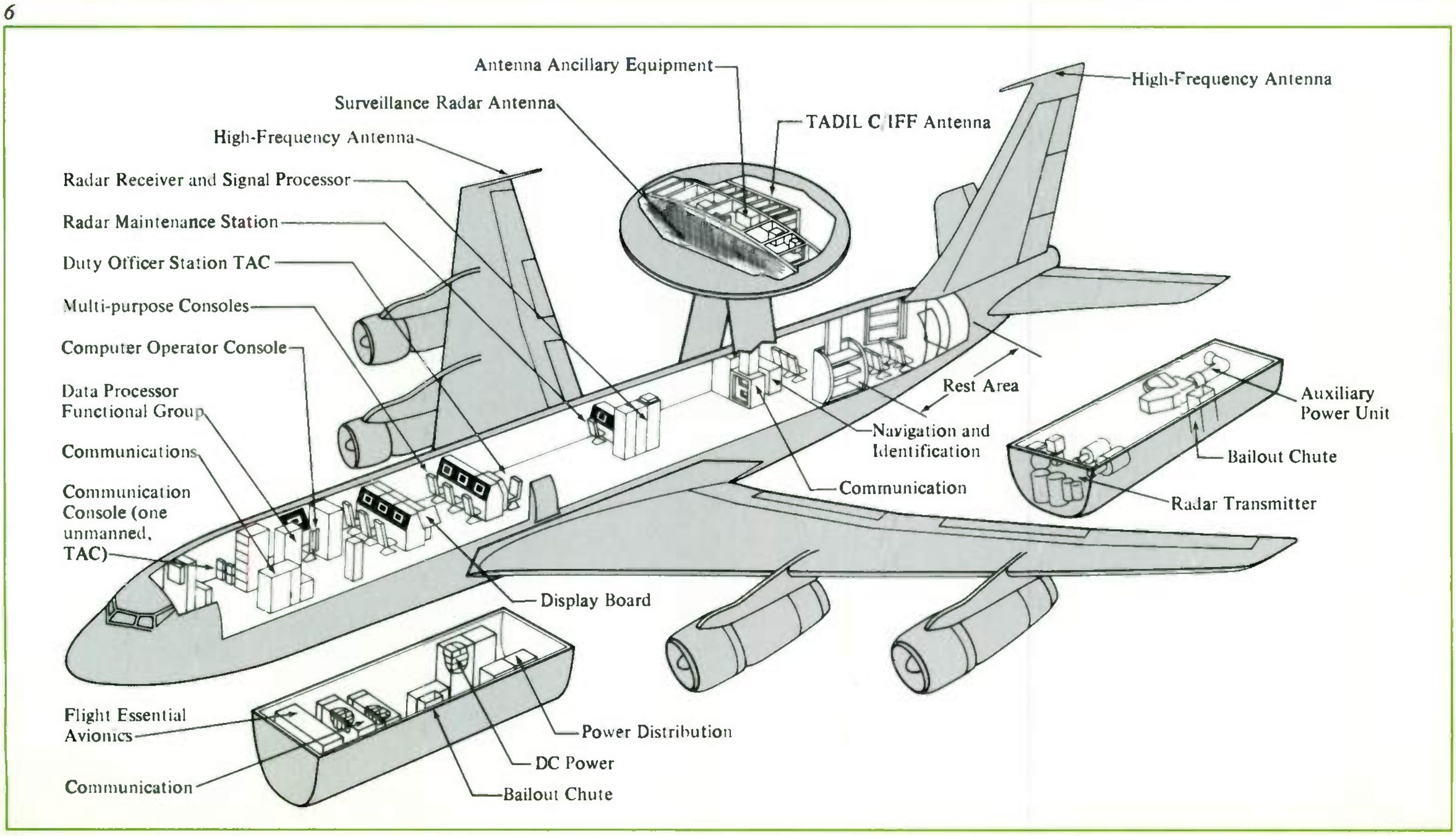
Antenna Ancillary Equipment
High-Frequency Antenna
Surveillance Radar Antenna
TADIL C/IFF Antenna
High-Frequency Antenna
Radar Receiver and Signal Processor
Radar Maintenance Station
Duty Officer Station TAC
Multi-purpose Consoles
Computer Operator Console
Data Processor Functional Group
Communications
Communication Console (one unmanned, TAC)
Rest Area
Navigation and Identification
Communication
Auxiliary Power Unit
Bailout Chute
Radar Transmitter
Display Board
Flight Essential Avionics
Communication
Power Distribution
DC Power
Bailout Chute

New Molded-Case Circuit Breakers Have Easy Selection of Continuous Current Rating

Alfred E. Maier
Alan B. Shimp

Use of a solid-state trip unit permits changing the breaker's rating without having to open the case and replace the trip unit. It also provides for selective tripping, and it permits operational testing of the breaker while in service. The trip unit and its current monitors are mounted inside the case of the new Seltronic circuit breaker.

Molded-case circuit breakers have been continually improved, since their introduction in the late 1920's, by such changes as increased ratings and addition of optional features. They all had thermal-magnetic trip units until, a few years ago, introduction of the Systems Circuit Breaker with a solid-state trip unit proved the basic concept, advantages, and reliability of applying solid-state components in a molded-case breaker.[1] That breaker has its current monitors and solid-state trip circuitry mounted external to the breaker case.

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Now the next step has been taken with the new Seltronic line of breakers, which incorporate a new type of solid-state trip circuitry mounted with the associated current monitors *inside* the breaker case. The Seltronic breakers are physically and electrically interchangeable with conventional molded-case circuit breakers of the same frame sizes.

The new breakers feature interchangeable rating plugs that enable the user to change their continuous current ratings easily. The three frame sizes span the range of 400 to 3000 amperes (Fig. 1). Other standard features provide for application in selective tripping schemes, for ground-fault protection, and for simple operational testing while in service.

Breaker Current Ratings

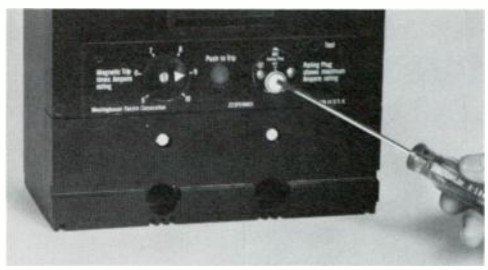
To change the continuous current rating of a conventional thermal-magnetic breaker, the breaker's entire trip unit must be removed and replaced. With the new Seltronic breakers, on the other hand, different continuous current ratings are easily obtained—within each frame size—just by changing the rating plug.

Two types of rating plugs are available: fixed and adjustable. The fixed rating plug is used when the initial load is constant and not expected to increase in the immediate future (Fig. 2). The adjustable plug is used when the initial load is expected to grow in the near future to the maximum plug rating; in the interim period, the plug can be adjusted downward to 70 percent to provide the ultimate in close protection of equipment against overloads (Fig. 3). The rating plugs are removed and inserted through an opening in the breaker cover, and they are retained by a single screw.

The ratings of Seltronic breakers, and the rating plugs available, are listed in Table 1. Interrupting ratings are the same as for thermal-magnetic circuit breakers of the corresponding frame sizes (MA, NB, and PB).

Seltronic breakers can be applied at up to 600 volts ac maximum. They cannot be used in dc circuits.

1—The new line of Seltronic molded-case circuit breakers includes three frame sizes. Frame designations are, left to right, NC, PC, and MC; the respective maximum continuous current ratings are 1200, 3000, and 800 amperes.



2—(Top) *Easily changed plugs determine the continuous current rating of each breaker. A fixed rating plug is being installed here.*

3—(Bottom) *Optional adjustable rating plugs can be used to adjust the breaker's continuous current rating between 70 and 100 percent of the plug's basic rating.*

Tripping Characteristics

Conventional thermal-magnetic breakers have two ranges of operation. The thermal trip range provides a nonadjustable inverse time/current trip characteristic with delays of seconds to minutes, depending on the magnitude of the overload. The magnetic trip range provides an essentially instantaneous trip at a preset current level; that level is adjustable, a typical range being 5 to 10 times the trip unit's continuous current rating.

Seltronic breakers, however, have *three* ranges of operation. They are the long-delay, magnetic (or short-delay), and instantaneous trip ranges.

All ratings of Seltronic breakers can be applied, up to their interrupting ratings as listed in Table 1, in fully rated selective and nonselective ac distribution systems where the conventional thermal-magnetic molded-case breakers and other protective devices have been used in the past. They can be selectively coordinated with other Seltronic breakers, Systems Circuit Breakers, or conventional thermal-magnetic breakers. The solid-state trip unit provides excellent repeatability over its entire operating range, and its time/current tripping characteristic is constant in normal operating temperatures. The three trip ranges allow the utmost in system selectivity at the current levels of most faults, yet the instantaneous trip operates the breaker rapidly to isolate high-level faults in the system.

The long-delay trip range is designed to prevent overheating of system components, including the conductors to the equipment being protected. That portion of the tripping characteristic approximates the thermal part of the curve of the conventional thermal-magnetic breaker. The long time delays range from a few seconds on large overloads to several minutes on slight overloads (Fig. 4).

Because of the flexibility of solid-state components, additional characteristic curves in the long-delay trip range can be provided on special order where closer overload protection with faster tripping time is desired. These optional tripping characteristics give a user a trip point as close as possible to the full-load rating of his load, minimizing insulation deterioration from overheating of conductors.

The term "magnetic trip range" is applied to the second operating range of the Seltronic breaker's trip characteristic because of its functional similarity to the actual magnetic range of conventional thermal-magnetic breakers. However, the "magnetic" trip range in the Seltronic breakers is derived by use of solid-state circuitry rather than conventional electromagnetic components.

The magnetic-trip current value, which is the minimum current at which the magnetic trip will operate, can be adjusted by means of a screwdriver adjustment on the front of the breaker cover (Fig. 5). This adjustment is calibrated in multiples of the breaker's continuous current rating. Since that rating is determined by the rating plug, changing the plug with a fixed setting of the magnetic trip adjustment changes the current level of magnetic trip proportionally.

The magnetic trip range provides a short delay, on the order of a few cycles. This

Glossary of Terms

Maximum continuous current rating is the maximum current that a breaker of a given frame size can carry continuously without exceeding allowable temperature limits.

Continuous current rating is the maximum continuous current a breaker will carry without tripping. It may be lower than maximum continuous current rating because each frame size can be furnished with several different trip units (for conventional breakers) or different rating plugs (for Seltronic breakers), each trip unit or plug providing a different continuous current rating for the breaker. As an example, an M-frame breaker has a maximum continuous current rating of 800 amperes but can be furnished with trip units (or rating plugs) providing continuous current ratings of 800, 700, 600, 500, or 400 amperes.

Interrupting rating specifies the current a breaker can interrupt without being damaged. It varies approximately inversely with voltage.

Table 1—Ratings of Seltronic Molded-Case Breakers

Frame Size Designation	*Maximum Continuous Current Rating (amperes)*	*Fixed Continuous-Current-Rating Plugs Available (ampere ratings)*	*Magnetic-Trip Range of Adjustment (times continuous current rating of plug)*	*Instantaneous-Trip Current (amperes)*	*Interrupting Rating at 480 Volts (rms symmetrical amperes)*
MC	800	400, 500, 600, 700, and 800	5 to 10	10,000	30,000
NC	1200	600, 700, 800, 900, 1000, 1100, and 1200	4 to 8	15,000	30,000
PC2000	2000	800, 900, 1000, 1200, 1400, 1600, 1800, and 2000	3 to 6	25,000	100,000
PC2500	2500	1000, 1200, 1400, 1600, 1800, 2000, and 2500	2½ to 5	25,000	100,000
PC3000	3000	1200, 1400, 1600, 1800, 2000, 2500, and 3000	2 to 4	25,000	100,000

short delay ensures service continuity for electrical systems by permitting coordination with downstream devices for selective tripping; that is, the breakers can be set so that the protective device nearest the fault clears the circuit, thus maximizing the up time for the system as a whole.

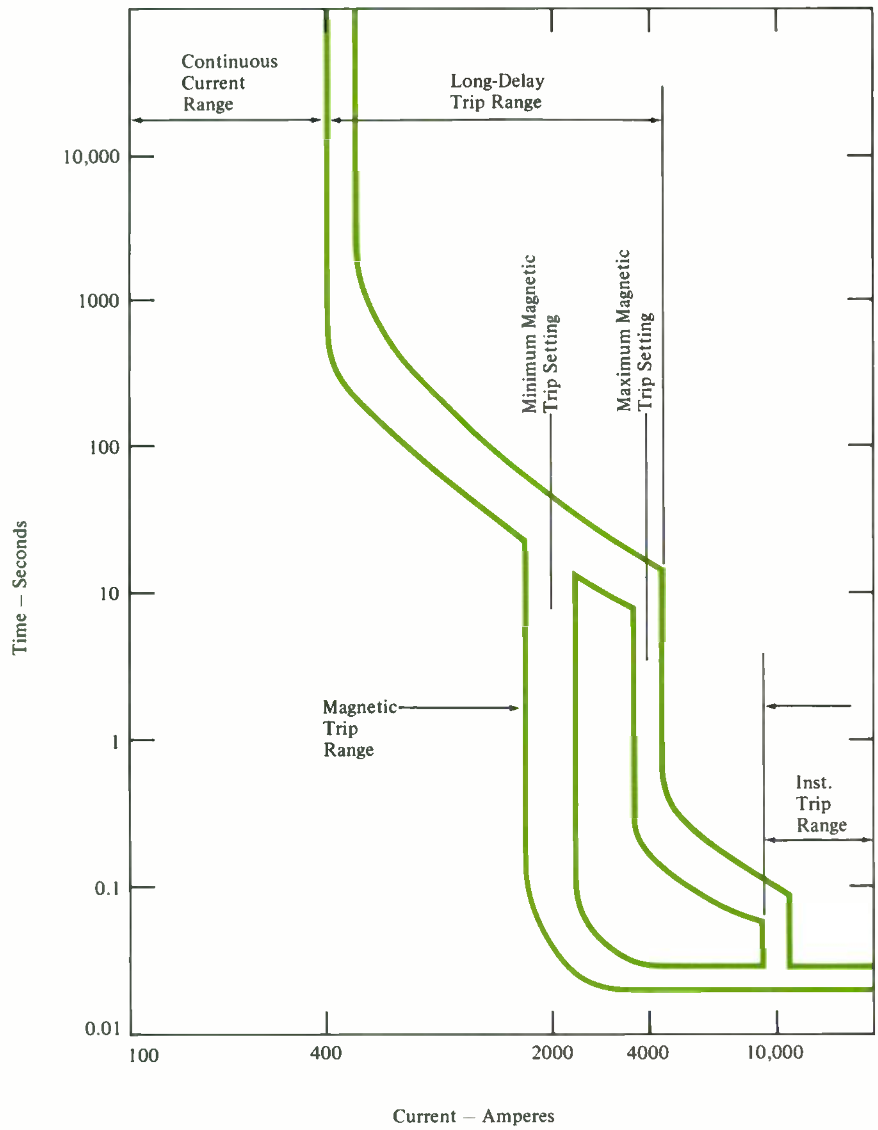
The screwdriver adjustment provides simultaneous variation of both the trip current value and the short-delay time. For example, the MC breaker has a magnetic trip range of five to ten times rated breaker current. At the minimum (5×) setting, a minimum short delay is provided. As the trip adjustment is turned toward the maximum (10×) setting, both the trip current value and the trip time delay increase simultaneously. The magnetic trip range for each size breaker is listed in Table 1.

The third trip range is instantaneous trip, which occurs at a fixed current level for each breaker frame size (Table 1). Its purpose is to override the short delay of the magnetic trip range so that the breaker trips as rapidly as possible on very high fault currents.

A typical curve of trip time vs current for an MC breaker is illustrated in Fig. 4. As an example, if the breaker has a 400-ampere rating plug, currents below 400 amperes do not trip the breaker. If the magnetic trip setting is five times rated, the breaker trips on currents up to 5×400, or 2000 amperes, with a time delay ranging from approximately 3 minutes at the lower currents to approximately 30 seconds at 2000 amperes. Between 2000 and 10,000 amperes (the magnetic trip range), the breaker trips with a short delay of approximately two cycles. Above 10,000 amperes, the breaker trips instantaneously as illustrated in the figure.

If the magnetic trip adjustment is changed to 10 times, the long-delay range increases to 4000 amperes. The magnetic trip range is now reduced to 4000 to 10,000 amperes, and the short-delay time increases to 12 cycles typically.

If the magnetic trip setting is left at five times but the rating plug is changed to a 600-ampere plug, the breaker does not



4—(Left) *Typical tripping characteristic (time versus current) is illustrated for a Seltronic MC breaker with a 400-ampere rating plug and a magnetic trip setting of five. The magnetic trip range depends on both the magnetic trip setting and the rating plug used. Regardless of the setting and rating plug used, the breaker trips instantaneously at currents of 10,000 amperes and higher.*

5—(Above) *Magnetic trip setting is adjustable. The adjustment is calibrated in multiples of the continuous current rating of the rating plug used.*

6—(Right) *Simplified diagram of a Seltronic breaker includes, at left, the two sets of current monitors that continually sense current level in the phase conductors. If their output rises high enough to cause a predetermined voltage drop across the rating plug, the appropriate trip circuit initiates a signal that causes the shunt trip to open the breaker.*

trip on currents below 600 amperes. The long-delay range is 600 amperes to 5×600, or 3000 amperes, and the magnetic range is 3000 to 10,000 amperes. The instantaneous trip value of 10,000 amperes is not changed by changing either the magnetic trip adjustment or the rating plug; it always remains 10,000 amperes for an MC breaker.

Construction and Operation

The Seltronic breaker consists of five basic components: frame, current monitors, solid-state sensor, rating plug, and flux-transfer shunt trip (Fig. 6). Years of engineering research, product design, and testing have gone into each component.

Frame—The frame includes the breaker contacts, contact carriers, de-ion arc-quenching grids, and operating mechanism. All of those elements are housed in a molded glass-polyester case, which also houses the other basic components of the breaker.

Current Monitors—Six current monitors (transformers) are used in each Seltronic

Solid-State Sensor Operation

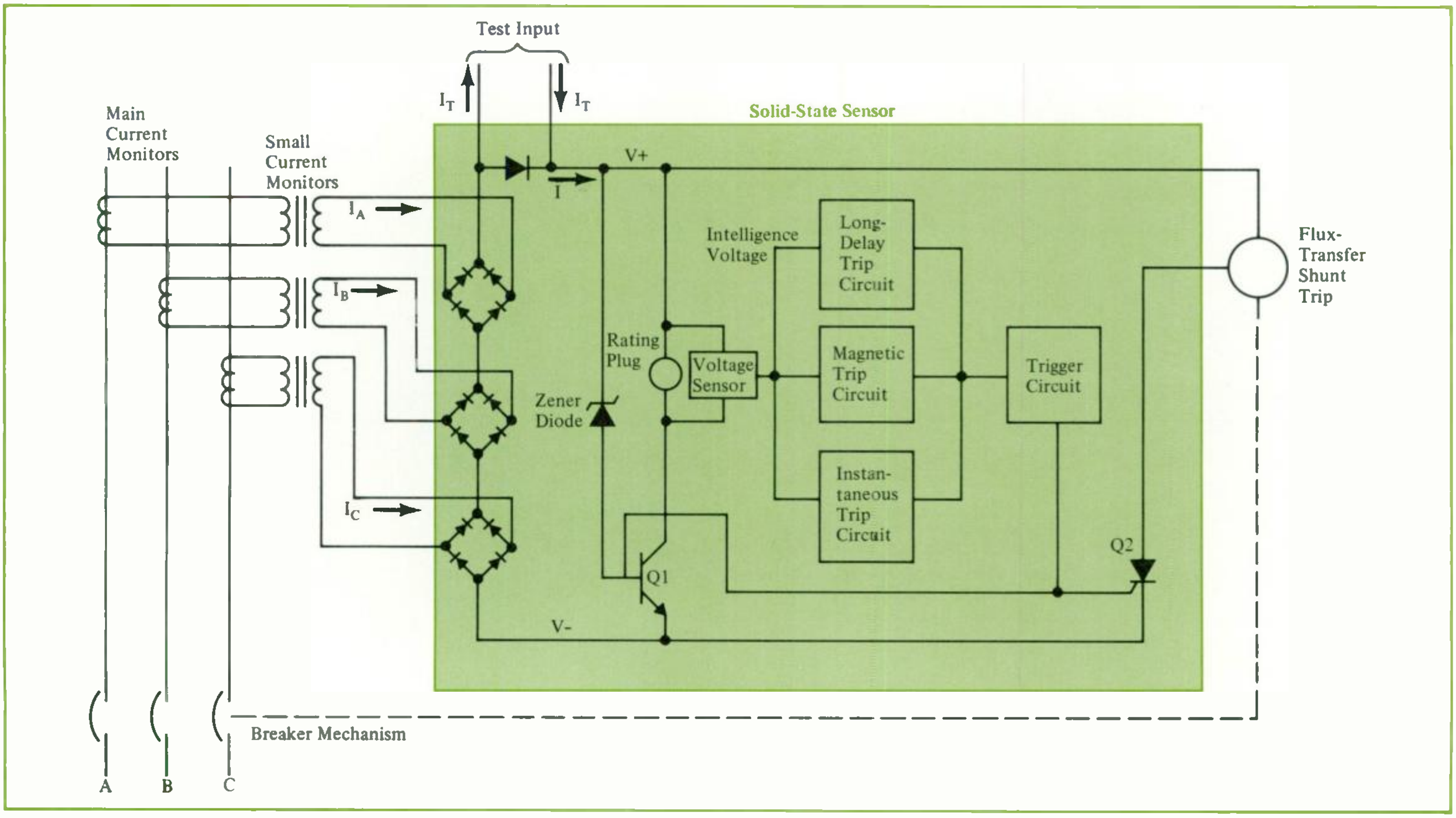
The current *I* flowing in the sensor is at all times proportional to the highest current in any breaker pole (Fig. 6). Transistor *Q1* and thyristor *Q2* act as switches. Before tripping, *Q1* is on and *Q2* off. Thus, all of current *I* flows through the rating plug to provide an intelligence voltage proportional to breaker current.

For moderate overloads, a relatively small voltage appears across the rating plug. It is insufficient to activate the magnetic or instantaneous trip circuits. It does, however, activate the long-delay trip circuit, which provides a suitable time delay before the trigger circuit is energized to turn on *Q2* and trip the breaker.

On higher overloads, the voltage across the rating plug energizes both the long-delay and the magnetic trip circuits. Since the magnetic trip circuit has a delay of only a few cycles, it energizes the trigger circuit and trips the breaker before the long-delay circuit has a chance to operate.

On very high fault currents, all three circuits are activated simultaneously. The instantaneous trip circuit activates the trigger circuit immediately to trip the breaker.

Operation of the trigger circuit turns on *Q2* and turns off *Q1*. On moderate faults, all of the current *I* is routed to the shunt trip coil to provide the maximum possible energy for tripping. On very high faults, *Q2* is turned on instantaneously and the zener diode conducts to clamp the voltage, *V*+ to *V*−, to a safe level. The zener diode also switches *Q1* back on, providing another path for current *I*. Also, saturation is designed into the current monitors so that at very high faults their output is somewhat less than proportional to the breaker current. These means prevent overvoltages and overcurrents that might otherwise damage the solid-state circuitry.



breaker. Each of the three main current monitors surrounds a phase conductor. Their ratio is the maximum rated current (for a particular frame size) to 5 amperes. For example, an MC breaker has main current monitors with a ratio of 800 to 5 amperes. The three small current monitors have a ratio of 5 amperes to 50 milliamperes; they are supplied from the main current monitors and in turn supply the solid-state sensor.

Solid-State Sensor—The solid-state sensor contains high-quality solid-state components arranged in reliable test-proven circuitry. It rectifies the secondary output from the three small current monitors. That output rises in proportion to any overload or short-circuit current in the phase conductors of the breaker. If it is sufficient to cause a predetermined voltage drop across the rating plug, the solid-state sensor initiates a signal that causes the flux-transfer shunt trip to operate and thus trip the breaker after a time delay or instantaneously, depending on the magnitude of the fault.

In other breakers with solid-state sensors, the sensors derive the necessary tripping energy from capacitors, which are charged through current monitors and then discharged through a shunt trip coil after sufficient tripping energy has accumulated. In the Seltronic breaker, however, the current monitors supply the tripping energy *directly* to the flux-transfer shunt trip without requiring energy-storage capacitors. That approach results in rapid tripping on high fault currents and also makes it possible to get all of the breaker's components inside a case of standard dimensions.

The current flowing in a breaker when it trips may vary from a few hundred amperes on a small overload to tens of thousands of amperes on a bolted fault. Therefore, the solid-state sensor has been designed so that it will have sufficient output to trip the breaker on small overloads yet not be damaged during a bolted fault.

The sensor's operation over that wide range of currents is described in *Solid-State Sensor Operation*, p. 109.

Rating Plugs—Each breaker frame size has its own group of rating plugs, designed so that it is mechanically impossible to insert a plug for one frame size into a breaker of a different frame size.

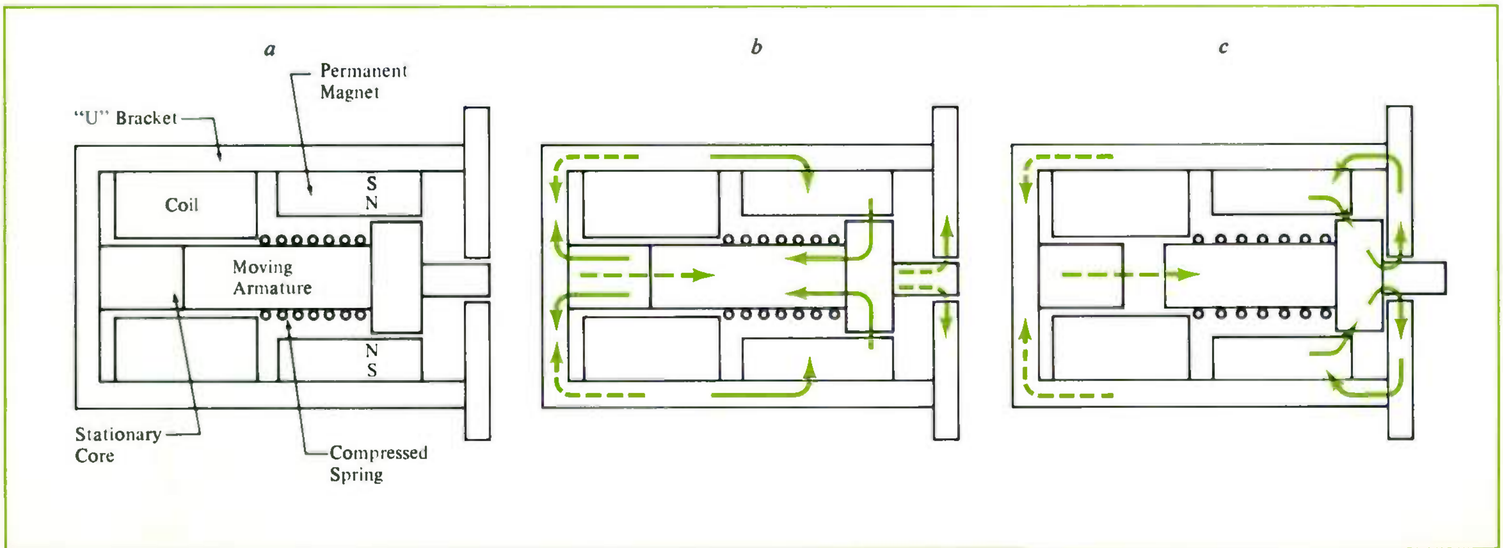
A mechanical interlock trips the breaker if an attempt be made to remove the plug with the breaker in the "on" position. With the plug removed, the breaker remains in the "tripped" position and cannot be accidentally closed.

Flux-Transfer Shunt Trip—All tripping operations are performed by a shunt trip device operating on the flux-transfer principle. Operating power is obtained directly from the overload or fault current itself, via the current monitors, so the device requires no external control power and/or stored electrical energy.

The term "flux transfer" refers to the magnetic principle by which the shunt trip operates (Fig. 7). Two permanent magnets are oriented so that their flux lines go into the moving armature, through the stationary core, through the "U" bracket, and back into the magnets. This flux holds the moving armature against the stationary core by overcoming the force of a compressed spring. If a pulse of current from the solid-state sensor passes through the coil, it establishes a flux that opposes the permanent-magnet field and thus weakens the magnetic force holding the armature to the stationary core. The force of the spring now exceeds the magnetic force holding the moving armature, so the spring drives the armature to the right to operate the breaker trip mechanism.

The shunt trip has a bistable characteristic because, as soon as the armature moves to the right, the resulting air gap greatly reduces the permanent-magnet flux passing into the stationary core. The flux then transfers to a path from the right side of the moving armature through the front plate and back to the permanent magnets (Fig. 7c). The magnetic force holding the moving armature to the stationary core is now drastically weakened, so the spring moves the armature positively and rapidly to the limit of its travel.

As in conventional breakers, the handle must be reset before the breaker can be reclosed after it has tripped. When the



breaker handle is brought back to the reset position, it engages a lever that automatically resets the moving armature and compresses the spring inside the shunt trip device in readiness for a subsequent trip operation.

Ground-Fault Protection

Ground-fault protection can be added to a Seltronic breaker by use of an external Ground Fault Protection System (GFP). The GFP has a current monitor (a zero-sequence current transformer) that surrounds all conductors of the system to be protected and feeds a solid-state ground sensor supplied from an external source of power. On detection of a ground fault, the sensor energizes the flux-transfer shunt trip in the breaker. Conventional thermal-magnetic breakers require an additional shunt trip attachment for this type of ground-fault protection, but the Seltronic breaker does not.

Testing in Service

A red "push-to-trip" pushbutton in the front of the breaker can be used to mechanically check the tripping mechanism. It is also used for rapid manual tripping of the breaker.

In addition, and for the first time in molded-case breakers, a means is provided to test the breaker electrically while it is in service and under varying load conditions including phase unbalance. Test receptacles on the front of the breaker are used to input a calibrated signal from a small portable test unit (Fig. 8). The test unit operates on ordinary 115-volt 60-Hz power, and one unit is adequate for testing all frame sizes of Seltronic breakers. Operating instructions and a chart of calibration check times are mounted inside the test unit's cover.

The test input is shown in Fig. 6 as current I_T. It simulates a fault on the breaker and causes it to trip with a long delay or instantaneously, depending on the magnitude of the input.

Current I at any instant is equal to the highest of currents I_A, I_B, I_C, or I_T. If I_T, which is a dc current, has a value larger than the peak of any of the other three currents, the intelligence voltage across the rating plug is proportional to the test signal alone and not to the currents flowing through the breaker. The significance of this is that the breaker can be tested not only without having to remove the main conductors from it but also without having to remove load.

Considerable time savings result. In a typical situation, a Seltronic breaker might be used to feed several smaller breakers to control lighting in a large building. An electrician tests the Seltronic breaker by merely plugging in the hand-held test unit, adjusting it for the desired setting, and waiting for the breaker to trip. There are two tests—one to check long-delay operation and one to check instantaneous tripping. The breaker can be reclosed immediately after tripping, thus minimizing loss of service. No opening and closing of downstream breakers is required, and no time consuming cable disconnections are involved. There is no hazard because the electrician is never exposed to live conductors.

Conclusion

The design advances described in this article have been proved reliable and useful in the Seltronic line of breakers. Consequently, they are being extended to other Westinghouse molded-case breakers.

REFERENCE:

[1]R. O. D. Whitt and Thomas W. Slebodnick, "Static Sensor Makes Compact Circuit Breakers More Capable and More Flexible," *Westinghouse ENGINEER*, May 1969, pp. 80-84.

7—(Left) *A shunt trip unit* (a) *is used to open the breaker contacts. It operates on the flux-transfer principle. In the untripped condition* (b), *magnetic flux (solid lines) from two permanent magnets overcomes the force of the compressed spring and holds the moving armature against the stationary core of the electromagnetic coil. If a pulse of current from the breaker's solid-state sensor passes through the coil, magnetic flux (dashed lines) from the coil opposes that from the permanet magnets, allowing the spring to drive the moving armature to the right to trip the breaker. The permanent-magnet flux then transfers to the path shown in* (c).

8—(Right) *A portable test unit can be used to test Seltronic breakers without taking them out of service. It introduces a calibrated signal into the breaker's solid-state sensor to simulate a fault signal.*

Modular EHV Power Circuit Breakers Simplify Installation While Retaining Proven Reliability

The type SF interrupter module has provided many years of reliable service since its use on the first domestic 550-kV circuit breakers and on early 362-kV breakers. Its capabilities have since been extended to reduce the number of interrupter modules required on 550-kV breakers. The higher capacity interrupter, designated type SFA, has found further application on an 800-kV breaker and, most recently, on a simplified repackaged 362-kV circuit breaker.

The first 550-kV breakers installed in this country in 1964 employed type SF interrupter modules, which were filled with sulfur hexafluoride (SF_6) gas as a dielectric and interrupting medium. Since that time, over 80 of the 550-kV breakers with three SF modules per phase and 180 breakers rated 362 kV with two SF modules per phase have been installed throughout the country. The field experience gained with those breakers helped in the development of a higher capacity interrupter module, the type SFA. Like its predecessor, the SFA module has two series breaks, but its dielectric strength and interrupting capability have been increased by using larger contacts, greater contact travel, and increased SF_6 gas pressure.

Consequently, later 550-kV breakers have only two SFA modules per phase instead of the three SF modules formerly required (Fig. 1). The first Westinghouse 800-kV breaker has three SFA modules per phase (see Fig. 2 and back cover). Since 1970, there have been 126 of the 550-kV SFA breakers installed; the second 800-kV SFA breaker will be installed this fall.

Recent testing has shown that a single SFA interrupter module meets all individual phase requirements for a 362-kV breaker. Thus, the latest addition to the SFA circuit breaker line is a repackaged 362-kV breaker made up of only three interrupter modules, all mounted on a common frame (Fig. 3).

Breaker Components, Systems, and Features

SFA circuit breakers incorporate all the inherent advantages of the field-proven SF breakers[1] in addition to many refinements.[2] As with the SF design, insulation for the SFA line is provided by low-pressure SF_6 gas, and interruption is performed by flow of high-pressure gas through a blast valve into a low-pressure system.

The *interrupter module*, the basic breaker component, has two sets of serially connected contacts (Fig. 4). The moving contacts, mounted on opposite ends of a rocker arm, engage and disengage stationary contacts as the rocker arm is rotated about its axis. With the breaker closed, current enters the module from the bushing conductor, passes through the side wall of the tubular stationary contact into a set of fingers in the moving contact assembly, travels across the rocker arm through the second set of contacts, and then exits through the other bushing conductor.

Replacement of SF interrupter modules by a smaller number of SFA modules on 362- and 550-kV breakers has produced somewhat higher voltage stresses across each contact break. Therefore, additional dielectric strength is provided by greater

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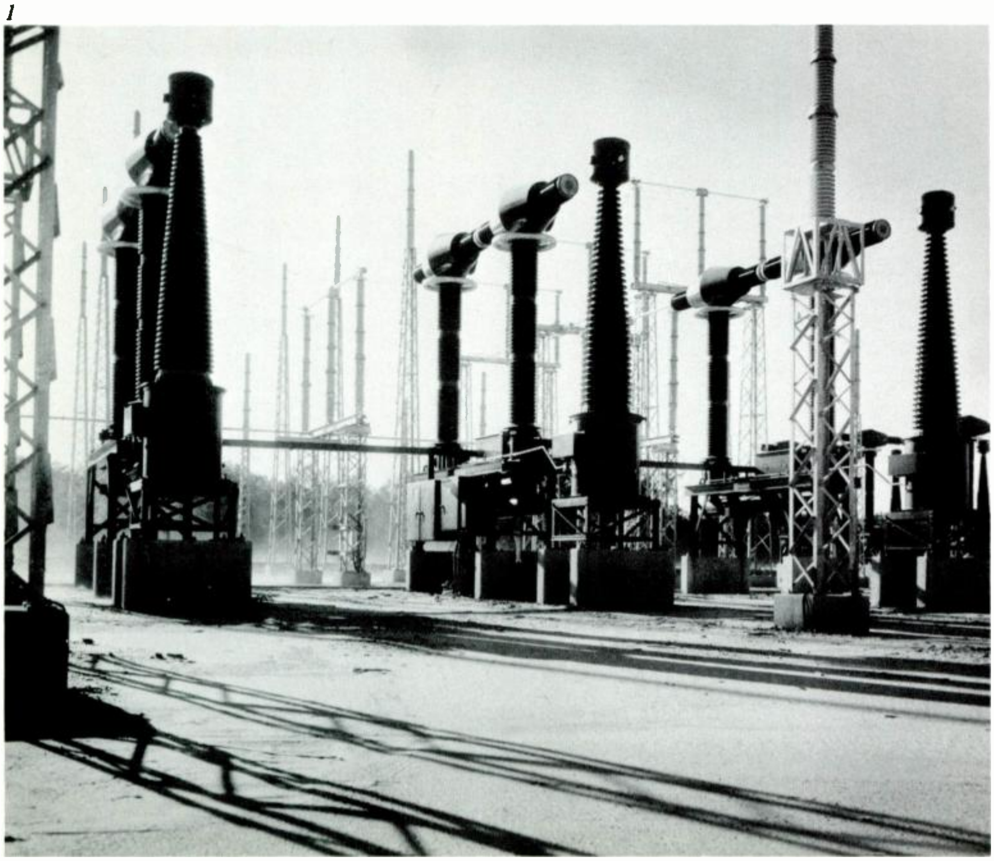

1—The expanded capability of the type SFA interrupter module has made possible a 550-kV circuit breaker with only two modules per phase. Earlier 550-kV breakers required three type SF interrupter modules per phase.

2—This 800-kV power circuit breaker, serving the American Power System, is installed at the Maryville substation of Ohio Power Company. The two-cycle SFA breaker has 40-kA interrupting capability and 3-kA continuous current rating.

3—The repackaged 362-kV breaker is shown being prepared for mechanical testing. It employs three SFA interrupter modules, one per phase, all on a single frame. The simplicity and small size of the new design offer many important benefits including greater reliability, shorter installation and maintenance times, and lower operating costs.

open-gap distance per break, increased contact parting velocities, improved contact configuration, and increased SF_6 gas pressure. The pressure of the low-pressure gas in the module surrounding the contacts has been increased from 45 psig to 60 psig. High-pressure gas (240 psig) is stored in an auxiliary reservoir in the module and is released to the low-pressure area during interruption. Voltage-dividing capacitor assemblies are connected across each break to help equalize the voltage distribution across each pole unit.

The rocker arm assembly is linked to the breaker mechanism by an operating rod. When the breaker is in the closed position, the operating rod is held in tension by a charged torsion bar in the module and a latch in the mechanism. The force of a permanent magnet keeps the mechanism latched. When the high-speed trip coil is energized, the resulting flux decreases the holding force of the permanent magnet, thereby unlatching the mechanism and allowing the charged torsion bar to rotate the rocker arm assembly.

This action simultaneously opens a gas blast valve mounted in the hub of the rocker arm. High-pressure SF_6 gas is released from the auxiliary reservoir, through the hollow rocker arm, through the tubular moving and stationary contacts, and into the module tank. As the contacts of each break separate, an arc is drawn initially between the stationary contact tip and the moving contact fingers. The gas flow quickly transfers the arc from the fingers to an arcing horn to minimize arc erosion of the members that carry continuous current. The electronegative SF_6 gas absorbs electrons from the arc discharge stream and extinguishes the arc. As the arc is extinguished, the blast valve is reset for the next opening operation. The entire sequence, from energizing the trip coil to extinguishing the arc, is carried out in less than two cycles.

Pressurizing the pneumatic mechanism transmits a force through the linkage system and operating rod that recloses the breaker contacts. This force also recharges the torsion bar for the next opening operation. (The blast valve does not open during contact closing.)

During a contact closing operation, two series resistors are first inserted into the circuit to reduce the resulting switching surge. The resistors, located in the module around the inner portion of each bushing, have a toggle-lever contact that is met by a projecting contact on the rocker arm as the arm is rotated toward the closed position. For most systems, the single-step pre-insertion resistors limit switching surges to 2 per unit or less.

After about one-half cycle of resistor insertion, the continuing rotation of the rocker arm engages the main contacts, shorting out the resistor elements. The toggle-lever resistor contacts are spring biased so that, during an opening operation, the resistor contacts open before the main contacts part, thus taking the resistors out of the opening operation. The rapid dielectric recovery of the surrounding SF_6 gas eliminates the need for resistor insertion to control the transient recovery voltages produced during main contact open-

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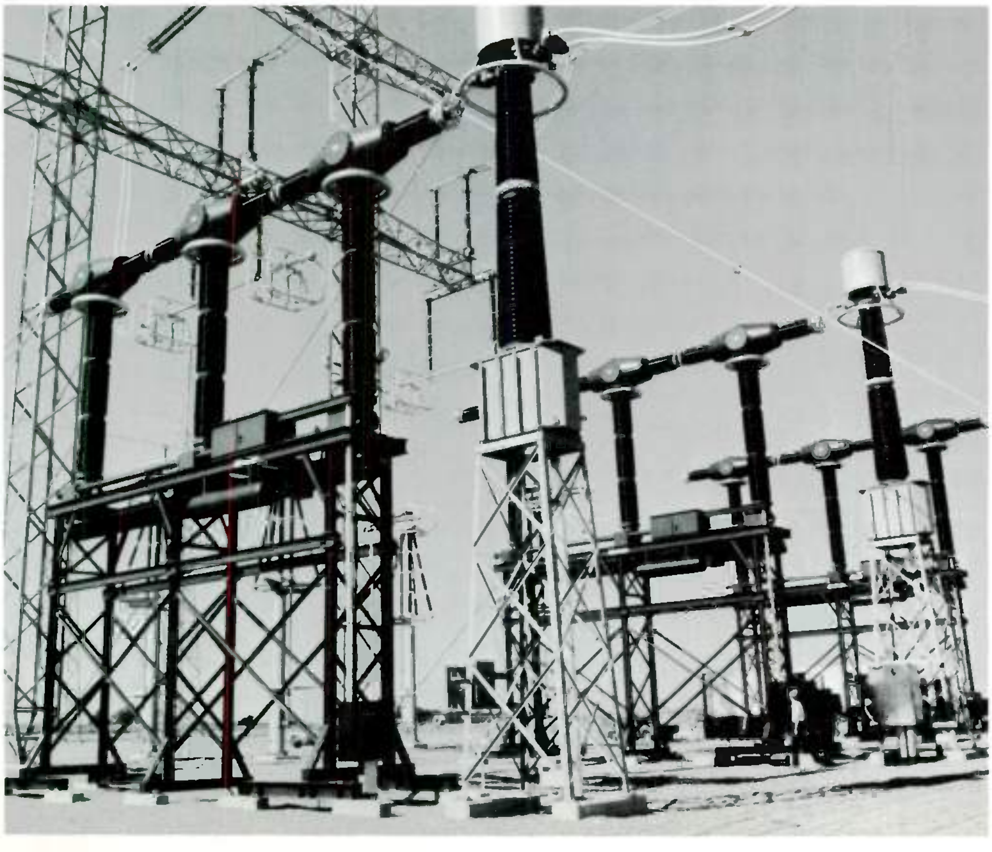

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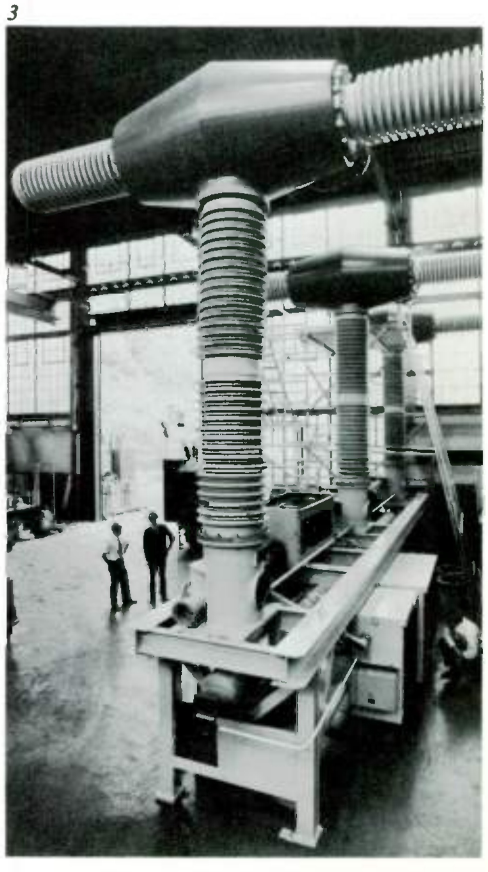


ing. Therefore, there are no opening resistor arcing contacts to be maintained in the SFA module.

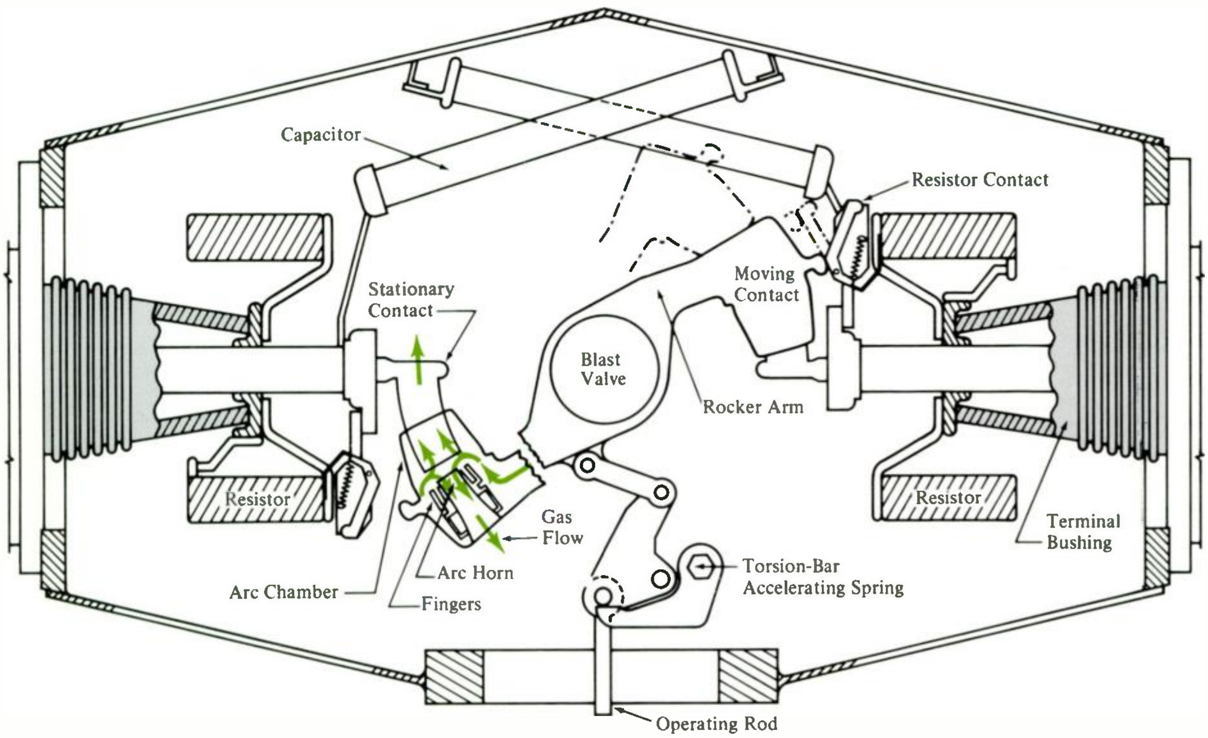
The *SF_6 gas system* for the 362-kV SFA breaker, shown schematically in Fig. 5, illustrates the basic features of gas systems used on SFA breakers of all ratings. As described earlier, during interruption, high-pressure gas is discharged from the auxiliary reservoirs, through the breaker contacts, and into the low-pressure system, which is essentially made up of the interrupter modules and support columns. The auxiliary reservoirs are connected to a main high-pressure reservoir by reinforced epoxy feed tubes that extend through the support columns. Full pressure is maintained in the high-pressure reservoirs by a compressor that pumps in gas from the low-pressure system after each interruption. However, the main and auxiliary reservoirs contain sufficient gas pressure for up to four interruptions without compressor operation.

The main high-pressure reservoir, located on each support frame at ground level, supplies all interrupter modules on that frame. Thus, one main reservoir supplies all three phases on the single-module 362-kV breaker, whereas three reservoirs, one per phase, supply the 550- and 800-kV breakers. Since SF_6 gas at 240 psig starts to liquefy at about 48 degrees F, heating elements are incorporated on the main reservoir to maintain the temperature well above the liquefication point. The heaters are energized automatically at 70 degrees by thermostats attached to the underside of the reservoir. Warm gas flows upward through the feed tubes to the auxiliary reservoirs in the modules to replace gas that has cooled.

A certain amount of moisture enters the breaker during installation or maintenance. This moisture, which is absorbed into the SF_6 gas, is effectively removed by the gas drying system (Fig. 5). The gas is circulated through the drying system constantly during the first few weeks after installation or maintenance, because a manually controlled bleed orifice allows slow leakage of gas from the high to the low-pressure system. The leakage causes operation of the compressor to maintain proper gas pressures. A bag of desiccant in the base of each support column helps remove moisture from gas leaving the interrupter modules and support columns. The gas is further dried by a desiccant filter located at the low-pressure inlet of the compressor. As the gas is pumped into the high-pressure system, it passes through an oil filter to remove any oil carryover from the compressor, and then through a second desiccant filter. After a few weeks of gas circulation, the moisture admitted into the breaker during installation or maintenance is completely removed and the bleed orifice can be closed.

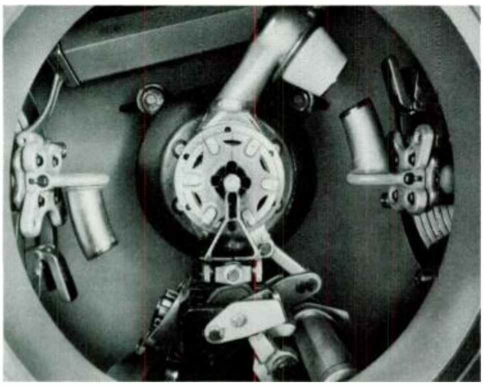
Although most of the gas decomposition products formed during arc interruption recombine into SF_6 immediately upon extinction of the arc, an extremely small percentage remains. This remainder is removed by the desiccant filter at the low-pressure inlet of the compressor.

Use of SF_6 gas as both the insulating and interrupting medium in Westinghouse live-tank circuit breakers affords several



important side advantages. The entire gas system is closed to the atmosphere, so that when the breakers are properly installed they remain free of moisture contamination. This eliminates continual maintenance of costly high-pressure air supply and dryer systems required by air-blast breakers to remove condensate that causes rust and corrosion and is susceptible to freezing. Air-blast breakers also require special sumps in the earth and external piping to handle moisture and oil residue from the compressor blowdown; such requirements, however, are eliminated with SF_6 breakers. Further advantages of the use of SF_6 in power circuit breakers are given in reference 3.

The closed gas system also prevents the breakers from exhausting the interrupting medium to the atmosphere; thus, interruption is reasonably quiet without the use of mufflers. Operating pressures of SF_6, at 240 and 60 psig, are low compared with those of air for air-blast breakers, which inherently affords greater safety to personnel and equipment in the event of malfunction.



4—Internal photo and diagram of the SFA interrupter module show the locations of the major components. Both of the two series breaks are operated simultaneously by the rotation of the rocker arm on which the moving contacts are mounted. In the diagram, the moving contact in the upper right quadrant is shown fully engaged with the stationary contact. The dashed outlines indicate the fully open position and the position where resistor insertion first occurs on closing. The contact set in the lower left quadrant is shown partially open to illustrate the flow of gas from the blast valve through the contacts.

Pneumatic mechanisms provide the power for operating the interrupters. The mechanisms are of the type "AH" design and use many features of the "AA" family of pneumatic mechanisms, proven reliable over many years on oil breakers. The 362-kV breaker is available either with one mechanism serving all three phases or with one mechanism per phase for independent pole operation. Each of the three pole units of the 550- and 800-kV breakers is operated by a separate mechanism. All contacts of each pole unit are mechanically linked to their respective mechanism, and all three mechanisms are tied together electrically to insure synchronous operation.

A *compressed air system* provides power for operating the pneumatic mechanisms. Each mechanism is equipped with a separate air reservoir, and, to insure uniform operating pressure, all reservoirs are supplied from a single air compressor. Only one air reservoir is required by the standard 362-kV breaker, whose single mechanism operates all three phases.

The *control equipment and compressors* for the SF_6 gas and air systems are located in a common housing mounted at ground level on the 362-kV breaker frame (the middle phase frame on 550- and 800-kV breakers). The lines connecting the breaker with the gas and air reservoirs are controlled by valves that can be closed to permit servicing of the breaker.

External insulation between adjacent interrupter modules and between the modules and ground is provided by the porcelain bushings and support columns. Dielectric strength is maintained within the porcelain structures by low-pressure SF_6 gas. The gas is admitted to each horizontal module bushing through the internal tubular conductor (Fig. 6). An inlet filter prevents passage of solid arc products into the conductor. An orifice at the bushing end of the conductor provides a throttling effect to any sudden gas pressure surges that might shock load the porcelain as the gas passes to the outer area surrounding the conductor.

The terminal end of the module bushings is an improvement over conventional bushing designs in that a single top plate replaces the spring bowl. By nesting the complete spring cluster and flexible diaphragm cylinder within the porcelain weather casing, the outer end of the porcelain is electrostatically shielded from high-voltage gradients in air. The toroid-shaped top plate further adds to this shielding complex, thus producing a bushing not only free of corona at maximum line-to-ground voltage but also capable of effectively shielding most line terminals.

The possibility of flashovers occurring across the module bushings when moist or contaminated is greatly reduced by the unique exterior configuration of the porcelain. The "dog-bone" cross section separates successive ionized air paths from each other, and thereby prevents formation of partial arcs that could otherwise combine to create a single arc flashover (Fig. 6).

The porcelain configuration also prevents flashover caused by accumulation of moisture that has been made conductive through contact with surface contamination. Moisture has no chance to collect on the bushing surface because the droplets are forced to run around the insulator circumference in grooves at the crest or base of each shed and drop to the ground. Droplets that roll over the edge of a shed instead of running around its crest groove drop off the sharp undercorner onto the base groove and then to ground without wetting the protected undersurface. The overhanging skirts below each crest groove protect about 46 percent of the total creepage distance.

The porcelain support columns for SFA circuit breakers have been simplified by elimination of the guy supports used on earlier 550-kV type SF breakers. This has resulted not only in improved appearance but also in reduced voltage gradient to ground, which has enabled simplification of the grading ring at the top of the column. Sufficient cantilever strength is attained by using larger diameter columns to provide greater support area. Additional stability is provided by increased tension on the tie rods within the columns. The column structure is capable of withstanding forces produced by a 90-mi/h wind or an earthquake shock of 0.2 g. The forces are in addition to a terminal loading force of 300 pounds, which may be applied in any direction. These capabilities have been verified by various cantilever-load and seismic tests made on a pole unit.

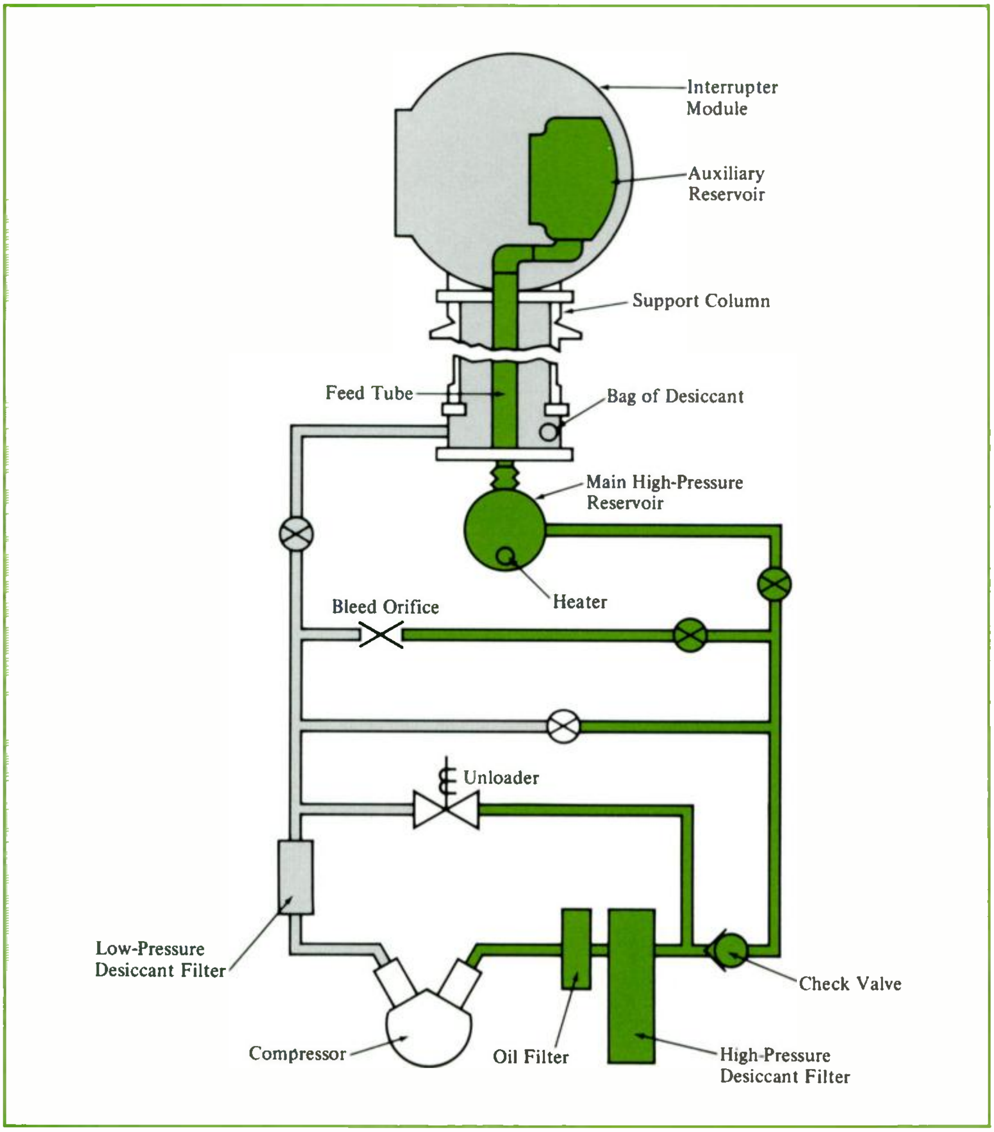
Test Program

A rigorous test program was conducted to demonstrate the SFA interrupter's capabilities as a single-module breaker at 362 kV. The SFA interrupter meets or exceeds all interrupting requirements determined by ANSI standards for 362-kV application. While the standard interrupting rating of SFA circuit breakers has been 40 kA symmetrical, the tests have verified that the 362-kV breaker is also capable of 50-kA interruption by increasing the gas operating pressure less than 10 percent.

The most frequent duty for a power circuit breaker is switching unloaded transmission lines. When an energized transmission line is disconnected by the breaker, a recovery voltage is generated across the opening contacts that can be more than double the maximum rated phase to neutral voltage. To prevent the arc from restriking, which could cause even more severe transients, the breaker must build up dielectric strength across its contacts more rapidly than the recovery voltage builds up.

The *line charging current test* verifies a breaker's dielectric recovery for switching energized transmission lines. Tests on the 362-kV interrupter module are made on one break, which normally carries 52 percent of the rms rated phase-to-neutral voltage, or 108 kV. A test voltage of 1.2 times the rms rated single-break voltage (1.2×108 kV$=$130 kV) is used to provide the required peak recovery voltage of 2.4 times E_{max}, the maximum rated single-break voltage (2.4×154 kV$=$370 kV). The standards also specify that the tests be made at minimum interrupting time, maximum interrupting time, and at 30-degree intervals over the current loop. The minimum interrupting time tests are made with the circuit breaker contacts adjusted to part within ± 6 degrees of current zero, which assures maximum recovery voltage occurring at minimum contact separation. Tests are made at 250 amperes and 75 amperes, which is approximately equivalent to the charging current of 250- and 75-mile transmission lines on 362-kV systems.

For certain fault switching operations with one phase unfaulted, recovery voltage can reach 2.6 E_{max}. The interrupter was able to switch without restrikes at both 250 and 75 amperes at the 2.6 E_{max} peak recovery voltage, which was obtained with a test voltage of 141 kV. Additional tests without any restriking were made at 25 amperes with test voltages up to 150 kV, which produced a 2.76 E_{max} peak recovery voltage (Fig. 7). Due to the 5 to 10 percent regulation of the laboratory circuits for the 75- and 250-ampere tests, and the high test



5—(Left) *Shown schematically is the SF_6 gas system for a 362-kV SFA circuit breaker. The colored areas indicate portions of the system at high pressure (240 psig), and shading represents areas of low pressure (60 psig). The main high-pressure reservoir supplies gas for all three phases.*

6—(Right) *Dielectric strength is maintained within the bushing of an interrupter module by low-pressure SF_6 gas, which passes from the module through the hollow conductor, through an orifice, and into the bushing. The porcelain bushing has circumferential weather sheds of "dog-bone" cross section for high resistance to external flashovers.*

voltages used for the 25-ampere tests, the interrupter's ability to switch line charging current has been proven to considerably exceed the present requirements of ANSI standards.

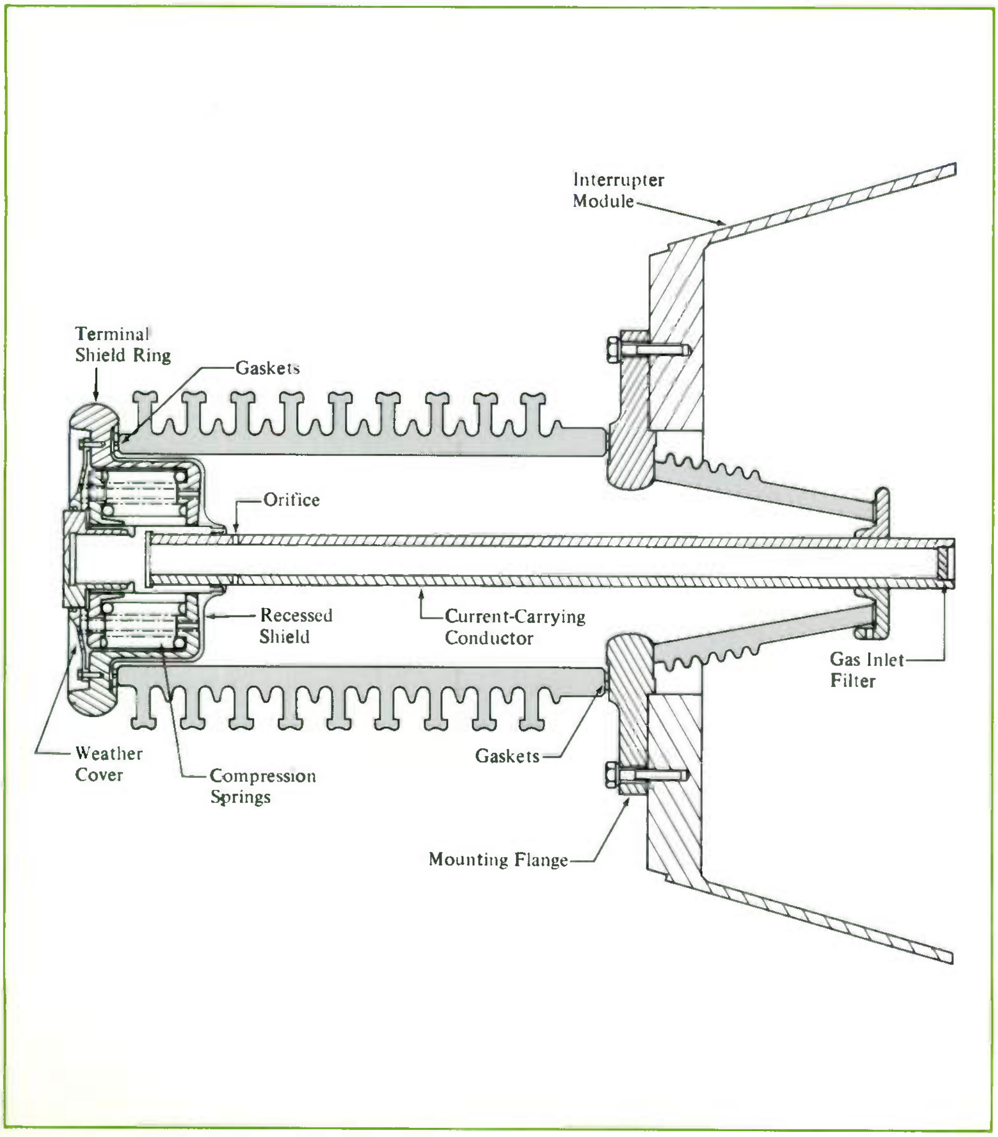
The most severe test of a breaker's fault interrupting capability is interrupting *short-line faults* (faults occurring on the transmission line ½ to 1 mile from the breaker). The recovery voltage that appears across the opening breaker contacts consists of two major components—a sawtooth transient produced by the shorted transmission line and a transient generated from the bus side of the breaker.

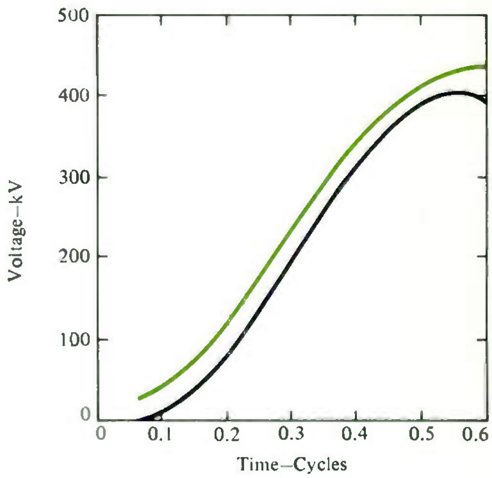
The transient voltage components and high currents required to verify the interrupter module's short-line fault interrupting ability were obtained with synthetic circuit techniques. Similar techniques, in addition to two-part testing, verified *bus-fault* interrupting capability. Recovery voltages employed for the short-line and bus-fault tests are described in *Fault Testing the SFA Interrupter* on page 118.

Duty cycle tests were made to demonstrate the interrupting ability, standard interrupting duty, and serviceability (contact life) of the circuit breaker. The breaker was closed on peak currents up to 123 kA and interrupted currents ranging from 4.8 to 67.4 kA rms. Voltages were varied from 132 kV for the lower current tests to 44 kV for higher current tests.

To meet serviceability requirements, the breaker must be able to interrupt 400 percent KSI* with the resulting contact resistance increasing less than 200 percent from its value when new. It must also be able to carry rated continuous current. (Available continuous current ratings for SFA circuit breakers are 2000 and 3000 amperes.) The cumulative interrupting duty for the entire open and close-open test series was 506 kA, or 778 percent KSI, and the final contact resistance had increased only 45 percent. Thus, the serviceability requirements have been exceeded.

*The KSI for the 362-kV SFA breaker is 65 kA, where K is a breaker constant equal to 1, S is a function of the breaker's maximum interrupting time of 2 cycles and is equal to 1.3, and I equals 50 kA, the breaker's maximum interrupting rating.





7—The recovery voltage at which a 362-kV circuit breaker must perform restrike-free switching for the standard line charging current test is indicated by the black curve. The capability of the SFA interrupter, however, has been proven to be beyond that requirement (colored curve).

SFA Advantages at 362 kV

The SFA interrupter module has not only demonstrated interrupting duty capability at and beyond the requirements for 362-kV applications, but its use affords many important benefits for the 362-kV breaker. Since only one interrupter module is needed per phase, all three phase poles are mounted on a single support frame, which contributes significantly to space and foundation savings. (In contrast, other live-tank breakers require three frames, one to support the two or more interrupting modules needed for each phase.) Moreover, external flash paths to ground are minimized since only three insulating columns are required.

Fault Testing the SFA Interrupter

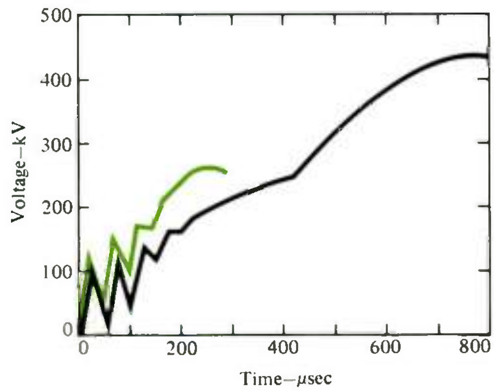
The new 362-kV circuit breaker employs only one SFA interrupter module per phase. The SFA module's interrupting capability for this application has been proven by short-line fault and bus-fault tests. A short-line fault produces a recovery voltage that is initially made up of a sawtooth line transient superimposed on a (1 – exponential) component contributed from the bus side of the breaker. The latter region of the recovery voltage is dominated by a (1 – cosine) bus-side component. The total short-line fault recovery voltage that the module must withstand to satisfy standards requirements is indicated by the black curve in Fig. A.

As shown by the colored curve, the module has been tested at or beyond the requirements for the initial recovery voltage region, which includes the sawtooth line component and (1 – exponential) bus component. The interrupter's dielectric strength in the latter recovery voltage region, made up of the (1 – cosine) bus component, has been verified with the (1 – cosine) component generated for the bus fault tests (Fig. B, curve 3). (Compare with curve 4, the total bus component required for the short-line fault test.) Short-line fault interrupting capability has been verified for both the 40- and 50-kA ratings of the SFA interrupter.

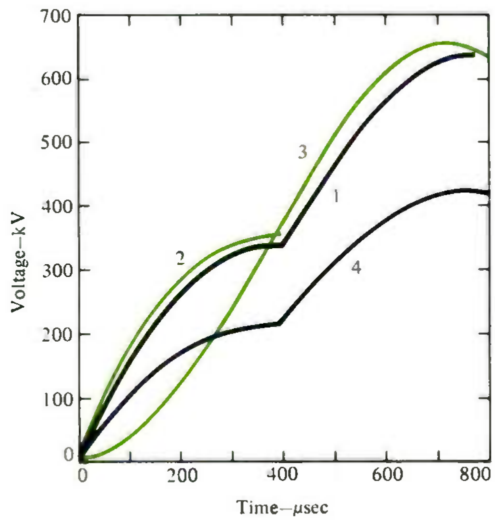
The recovery voltage required for the bus-fault test, shown by curve 1 in Fig. B, is made up initially of a (1 – exponential) component and later by a (1 – cosine) component. Each recovery voltage component was applied to the interrupter in separate tests. Bus fault interrupting capability at the interrupter's maximum rating of 50 kA has been verified at test recovery voltages at and beyond the standards requirements, as shown by the (1 – exponential) component in curve 2 and the (1 – cosine) component in curve 3.

The full-pole recovery data shown in Fig. B has been extrapolated from tests made on a single break of the interrupter. Additional bus fault tests were made with a (1 – cosine) recovery voltage at 15 kA to 18 kA in accordance with standards for testing at 30 percent of maximum rated current. Still others were made with a (1 – exponential) recovery voltage at 30 kA to 39 kA, which exceeds requirements for testing at 60 percent of rated current.

A



B



With fewer interrupting modules, the breaker requires less SF_6 gas, which is supplied by a single main reservoir. In addition, only a single gas heater system is needed to prevent condensation of the SF_6 at low temperatures, which reduces power requirements by about one-half.

Having fewer breaker components also reduces shipping costs and minimizes unloading and installation time. An important feature in minimizing installation time is that no interphase mechanical or electrical connections need be made in the field; since all three phases emanate from a single support frame, the connections are made at the factory. Total field assembly time is about 20 man-days, as compared to about 60 man-days for two-module-per-phase breakers.

In addition to the interrupter module, the 362-kV breaker's major components are essentially the same as those used on all other Westinghouse live-tank breakers. Similarity of breaker components reduces maintenance training for service personnel and shortens production lead times.

REFERENCES:
[1]R. C. Van Sickle, R. N. Yeckley, C. F. Sonneberg, and J. J. Brado, "A Modular SF_6 Circuit Breaker Design for EHV," *Westinghouse ENGINEER*, March 1965, pp. 44-9.
[2]R. N. Yeckley and C. F. Cromer, "New SF_6 EHV Circuit Breakers for 550 kV and 765 kV," IEEE Winter Power Meeting, January 25-30, 1970, Paper No. 70 TP 111-PWR.
[3]W. M. Leeds, R. E. Friedrich, T. E. Browne, Jr., and C. L. Wagner, "New Goals for EHV and Future UHV Power Circuit Breakers," *Westinghouse ENGINEER*, July 1970, pp. 120-4.

Coal Gasification for Electric Power Generation

Sylvester Lemezis
David H. Archer

The ultimate goal of the coal-gasification power system project is the demonstration on a commercial scale of an economic and environmentally acceptable electric generating plant that links a coal-gasification system with a combined-cycle plant adapted for burning low-Btu fuel gas. The project will be carried out by a six-member industry/government partnership comprising the U.S. Department of Interior's Office of Coal Research, Public Service Indiana, Bechtel Incorporated, AMAX Coal Company, Peabody Coal Company/Kennecott Copper Corporation, and Westinghouse.

The work will progress in phases, beginning with the development of a small-scale fluidized-bed gasifier to demonstrate the process described in this article. From this and other government-funded development work, a conceptual gasification process will be chosen for final scale-up to prototype size. Once the scale-up procedures have been verified, a commercial-size gasifier plant will be constructed for operation by Public Service Indiana at its Dresser Station.

The research and development effort will be accomplished on a cost-shared basis; the industry team will assume 30 percent of the research and development costs and the remainder will be borne by the Office of Coal Research. The industry team will provide the commercial situation and apparatus needed for an operating demonstration.

In addition to the six-member partnership, the following utilities are sponsoring the program as associate members: Northern Indiana Public Service Company, Tennessee Valley Authority, Consumers Power Company, Union Electric Company, Duke Power Company, New England Electric System, Columbus & Southern Ohio Electric Company, Pennsylvania Power & Light Company, The Montana Power Company, Tampa Electric Company, and Iowa Power & Light Company.

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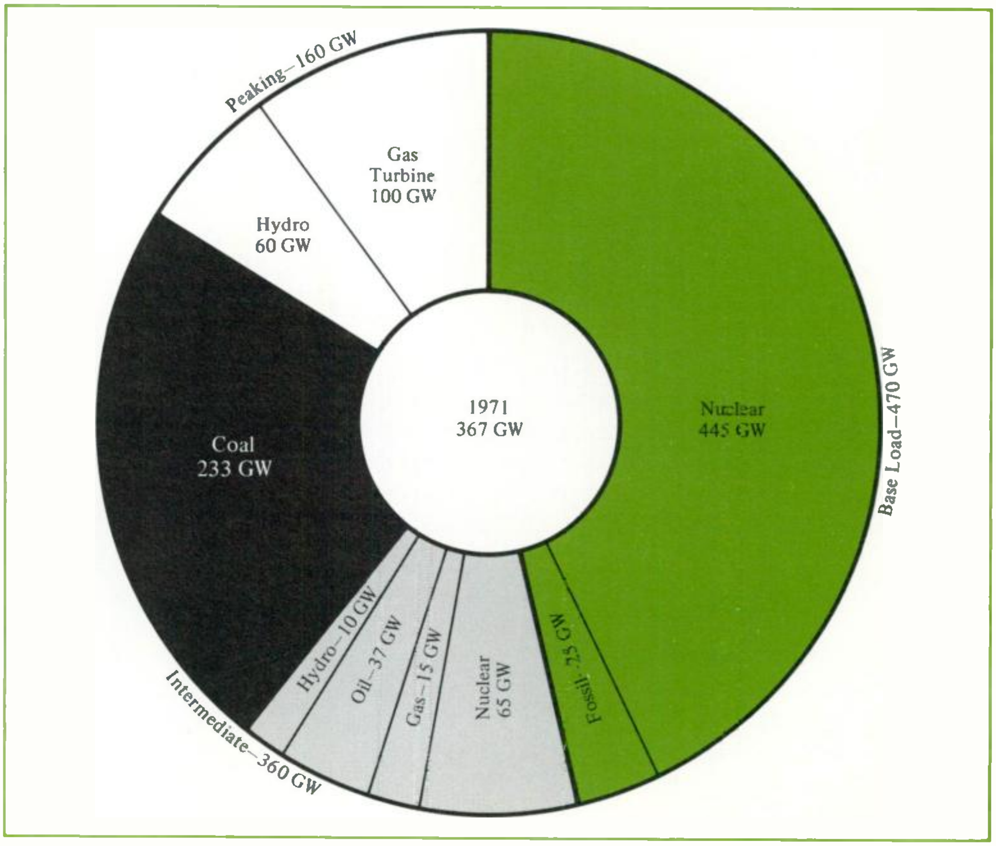
The gasification power system project is an acknowledgement by both government and industry of the potential deficiency in fossil-fueled electric generating capacity that the United States could face in coming years. That shortage would not be due to a basic lack of fuel resources; even though natural gas and oil are in short supply there are ample coal reserves. The real problem is the inability to economically convert coal to electricity in a manner compatible with the environmental constraints now being written into law. The most logical approach to solving the problem is joint industry-government effort—combining the research and development activities presently carried out by federal agencies with industry's know-how and experience—to more rapidly arrive at feasible solutions.

When the predicted availability of fuels within the contiguous 48 states over the 1973-1990 period is integrated with expected generation costs and with predicted load requirements, a pattern of new generation additions emerges. The methodology applied in such forecasting has been described.[1] With that approach, the current forecast of generation additions through 1990 segregated by fuel source and duty cycle is shown in Fig. 1. However, when that pattern is linked with the pollution control technologies becoming available, one salient fact appears: there is no technology available today to provide the 233 GW of coal-fired intermediate-duty-cycle generation that does not add substantially to generation cost. Any add-on device for removing sulfur oxides from stack gas adds significantly to plant costs. Therefore, the real service that research and development effort can render to the utility industry is to devise a new kind of coal-burning power plant that is capable of meeting the new environmental standards and that has

1—Estimated electric load growth for the next two decades will require generation capacity additions totaling about 1000 GW. Of this, 233 GW is expected to be provided by coal-fired plants designed for intermediate-load service. The fluidized-bed coal gasifier is being developed for use with plants serving that load sector.



been optimized for intermediate-duty service by minimizing capital costs and at the same time keeping operating costs as low as possible.

The preengineered highly packaged combined-cycle plant previously described[2] is designed to provide the capital cost economies required for such service. However, its long range success in satisfying intermediate generation requirements also depends on the availability of an economic fuel supply.

Since coal is by far the most abundant of all fossil fuel reserves, the development of a process for producing clean fuel gas from run-of-mine coal as well as a gas turbine/steam generator plant capable of burning that gas would permit the utilization of an economic fuel supply.

The Gasification Process

The basic process for converting solid coal to a fuel gas comprising principally carbon monoxide, hydrogen, and nitrogen is well known. In fact, the "city gas" commonly used before the general availability of natural gas was manufactured with earlier versions of present-day equipment. Basically, oxygen (or air) is supplied to fuel in a quantity insufficient to complete the conversion of its carbon and hydrogen to carbon dioxide and water.

Four basic sequential reactions occur in the gasification process. The principal heat-producing reaction is *oxidation*, which results when oxygen reacts with the fuel to form carbon dioxide and water (steam):

$$C+O_2 \rightarrow CO_2$$
$$H_2+\tfrac{1}{2}O_2 \rightarrow H_2O.$$

The *gasification* reaction is the greatest absorber of heat; this reaction occurs when unburned carbon from the fuel reacts with steam and carbon dioxide to form hydrogen and carbon monoxide:

$$C+\left(\begin{matrix}H_2O\\ \\ CO_2\end{matrix}\right) \rightarrow CO+\left(\begin{matrix}H_2\\ \\ CO\end{matrix}\right).$$

A third reaction, *hydrogasification*, occurs when hydrogen reacts with carbon from the fuel to form methane:

$$C+2H_2 \rightarrow CH_4.$$

This reaction is moderately exothermic; i.e., some heat is released. And finally, the fuel when heated also undergoes *devolatilization*:

$$\text{Coal}+\text{Heat} \rightarrow C+CH_4+HC,$$

where C is carbon in the form of char and HC consists of higher hydrocarbons and tars. This reaction may be thermally neutral or it may yield heat depending on coal type and process conditions.

In the overall gasification process, these four basic reactions can occur simultaneously throughout a reactor, or each reaction may be localized to a region of the reactor or in a separate reaction vessel. In any case, most gasification processes are designed so that the heat released by oxidation, hydrogasification, and devolatilization matches the heat required by the gasification reaction (plus the sensible heat in the reaction products). The overall heat balance is achieved by adjusting the amount of air (or oxygen) and steam added to the process. If the reactions are carried out in separate regions or reactors, some means are required to transfer heat between regions.

The fuel gas product composition produced by a gasification process depends primarily on the nature of the fuel and on the temperature, pressure, and gas composition in the regions where gasification, hydrogasification, and devolatilization occur. These quantities determine the kinetic rates and the thermodynamic limits of the reactions. When H_2O, CO, H_2, and CO_2 coexist at high temperature, they can also undergo the shift reaction,

$$H_2+CO_2 \rightarrow H_2O+CO.$$

However, this reaction has a negligible effect on process heat balance. While the reaction's equilibrium does affect product gas composition, it has little effect on gas heating value.

Power Plant Fuel Is Not Pipeline Gas

The specter of dwindling natural gas supplies and rising costs for this clean and convenient fuel has created tremendous interest in converting coal into a fuel gas that can be freely substituted for the natural product in the existing pipeline and distribution network. However, since the economics of natural gas supply and usage is keyed to a fuel containing 950 to 1000 Btu per standard cubic foot, a manufactured gas that can be substituted freely for the natural one must have a heating value in that same range.

The basic gasification process that has been described up to this point generates a product gas whose heating value comes primarily from the carbon monoxide and hydrogen provided by the gasification reaction, because the hydrogasification and devolatilization reactions contribute only small quantities of methane (CH_4). To upgrade the mixture into methane to match the heating value of natural gas would require further relatively expensive process steps—essentially, additional hydrogen must be produced and reacted chemically with carbon monoxide to form methane.* Furthermore, the oxidation reaction should be fed pure oxygen rather than air so that the product gas will not be diluted with inert nitrogen.

On the other hand, if the purpose of gasifying coal is solely to remove ash and sulfur so that the fuel gas is nonpolluting to the environment and nonerosive to gas turbines, the heating value need only be sufficiently high to maintain a stable flame in the gas turbine combustor. It happens that air-blown gasifiers performing the four basic process reactions described can produce a gas mixture with a heating value of 120-160 Btu/scf, which is adequate for a gas turbine fuel. Eliminating the needs for pure oxygen and for methane production makes such gasification systems less expensive than ones that strive to produce a natural gas substitute. Thus, the plants being developed for the production of pipeline gas and for power fuel gas differ markedly in complexity. In general, pipeline gas processes employ either pure oxygen or

*For example, carbon monoxide can be converted to methane by a two-step reaction. Additional hydrogen is produced by injecting steam to react with carbon monoxide, and the hydrogen produced is then made to react with carbon monoxide to generate methane:

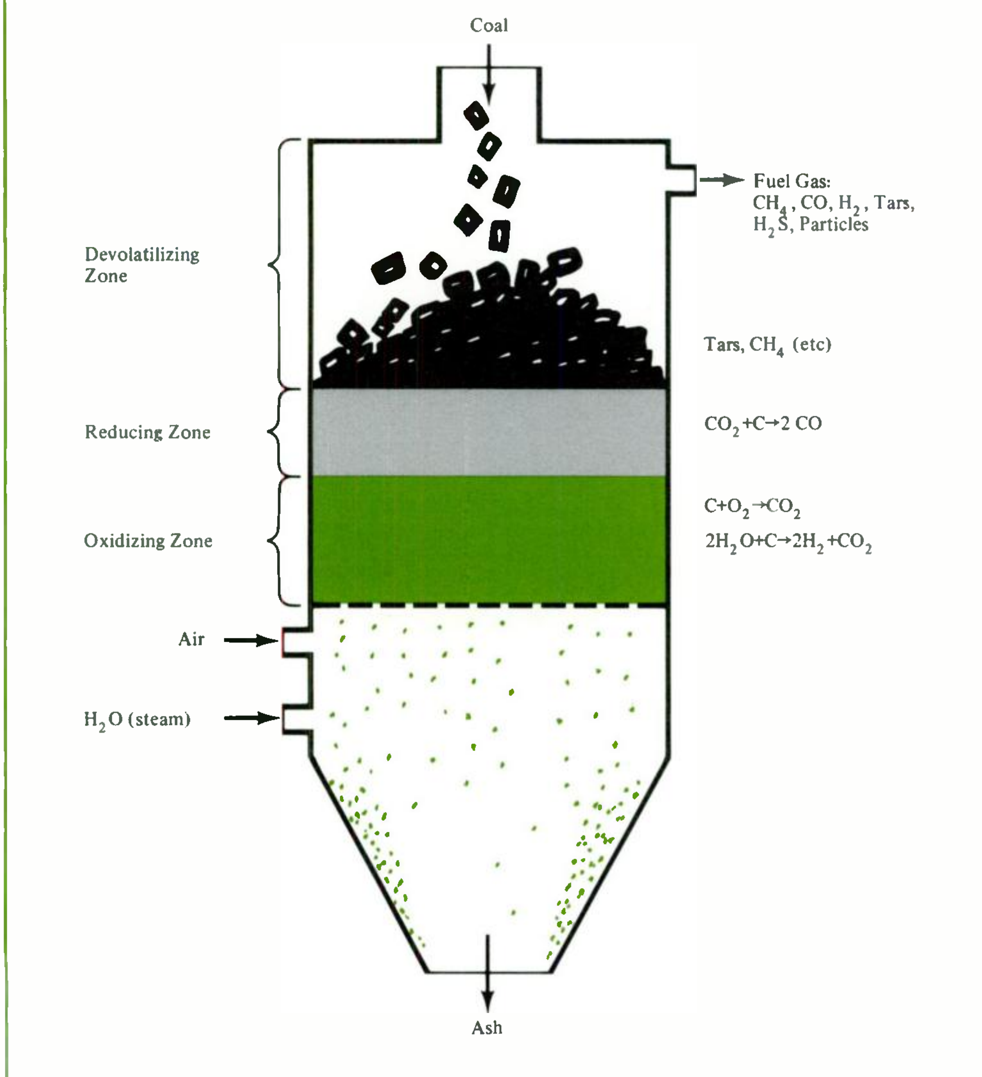
$$H_2O+CO \rightarrow H_2+CO_2$$
$$3H_2+CO \rightarrow CH_4+H_2O.$$

2—The conventional fixed-bed gasification process originally developed for manufacturing "city gas" in the 1920's utilizes a counterflow of gases and coal to effectively divide the bed into reaction zones. Typical reactions are indicated.

Table 1—Fuel Gas Properties Required for Pipeline Gas and for Combined-Cycle Power Plant Fuel

	Pipeline Gas	*Power Plant Fuel*
Heat Content, Btu/Standard Cubic Foot	~1000	>120
Pressure, Atmospheres	>30	10-20
Temperature, °F	~70	70-1800(a)
Composition	Primarily CH_4	CO, H_2, N_2, CO_2, H_2O, CH_4
Cleanliness		
Sulfur	<1 ppm(b)	1.2 lb $SO_2/10^6$ Btu (~550 ppm)(c)
Particulates	≪0.01 lb/10^6 Btu(b)	0.1 lb/10^6 Btu(c)

(a)A high temperature is advantageous and may be necessary if the heating value of the gas is low.
(b)Limits established by process requirements.
(c)Limits established by either gas turbine materials or laws regulating emissions (both subject to change with time).



hydrogen together with steam at pressures ranging from 30 to 60 atmospheres to produce a product gas high in methane. Processes for power fuel gas use air and steam at 10 to 20 atmospheres to produce a much lower-cost, lower-Btu-content product. The basic differences in the characteristic properties required of these two product gases are summarized in Table 1.

Potential of Fluidized-Bed Reactors for Coal Gasification

Pressurized fixed-bed gasifiers similar to those originally developed for producing "city gas" are the only type commercially available for power plant application. In this form of reactor, gases pass through a bed of solids at a velocity so low that the solid fuel particles are neither disturbed nor blown from the bed by the flowing gases. Coal particles rest primarily upon other particles that make up the bed and are ultimately supported by some type of grate.

Typical pressurized fixed-bed gasifiers are counterflow designs that receive raw coal in batches at the top and discharge hot ash from the bottom (Fig. 2). A blast of steam and air (or oxygen) is introduced at the bottom of the bed, and product fuel gas is bled off continuously from the top. The devolatilizing, gasification (or reducing), and oxidizing zones corresponding to the basic gasification reactions form naturally as a result of the counterflow relationship between coal and blast gases. The transfer of solids between zones and ash removal from the bed are by gravity.

Unfortunately, this practical device has several inherent limitations as a base for a new coal-burning power generation technology. First, its operability has been demonstrated commercially only on selected noncaking coals of limited particle-size distribution. Operating problems have been encountered in processing coals that tend to cake or swell, such as those mined in the eastern United States. Caking coals cause irregularities in the flow of solids and gases through the equipment, so fuel gas quality is erratic. Coals with any appreciable quantity of fines under 1/16 to 1/8 inch in size also tend to plug the bed and cause irregularities in gas flow. Although ingenious stirring devices have been used in small-scale experimental fixed-bed gasifiers to minimize these difficulties, none have been proven in commercial operation.

Another limitation is that individual commercial fixed-bed reactors have low capacity—equivalent to 30 to 50 megawatts—whereas new power plants will be in the 250- to 600-megawatt range. Thus, while two or three gasifiers operating in parallel might increase plant reliability, more than that could introduce control complications and add to both capital and operating costs.

And finally, fuel gases emerging from fixed-bed gasifiers at 900 to 1000 degrees F contain a sizeable content of the tars formed at low temperatures and hydrogen sulfide (H_2S). Both pollutants must be removed before the fuel gas is burned in a power plant; otherwise, tars would deposit and foul plant equipment and sulfur dioxide (SO_2) would be exhausted in the stack gas. Although low-temperature (220 to 250 degrees F) wet scrubbing processes are available for both tar and hydrogen sulfide removal, such processes add to the complexity and cost of the plant and decrease total process efficiency.

Because of these problems inherent in fixed-bed gasifiers, this coal-gasification power system project has been oriented toward fluidized-bed technology. In fluidized-bed reactors, gases flow through a mass of particles at a sufficiently high velocity to support the fuel particles but not high enough to carry them out of the bed. Thus, the fluidized bed intensifies the interactions of the fuel particles with air and steam and prevents agglomeration and clinkering through its roiling motion. Higher gas velocity and more uniform gas flow enables the fluidized-bed reactor to handle the fine particles that tend to plug fixed-bed reactors.

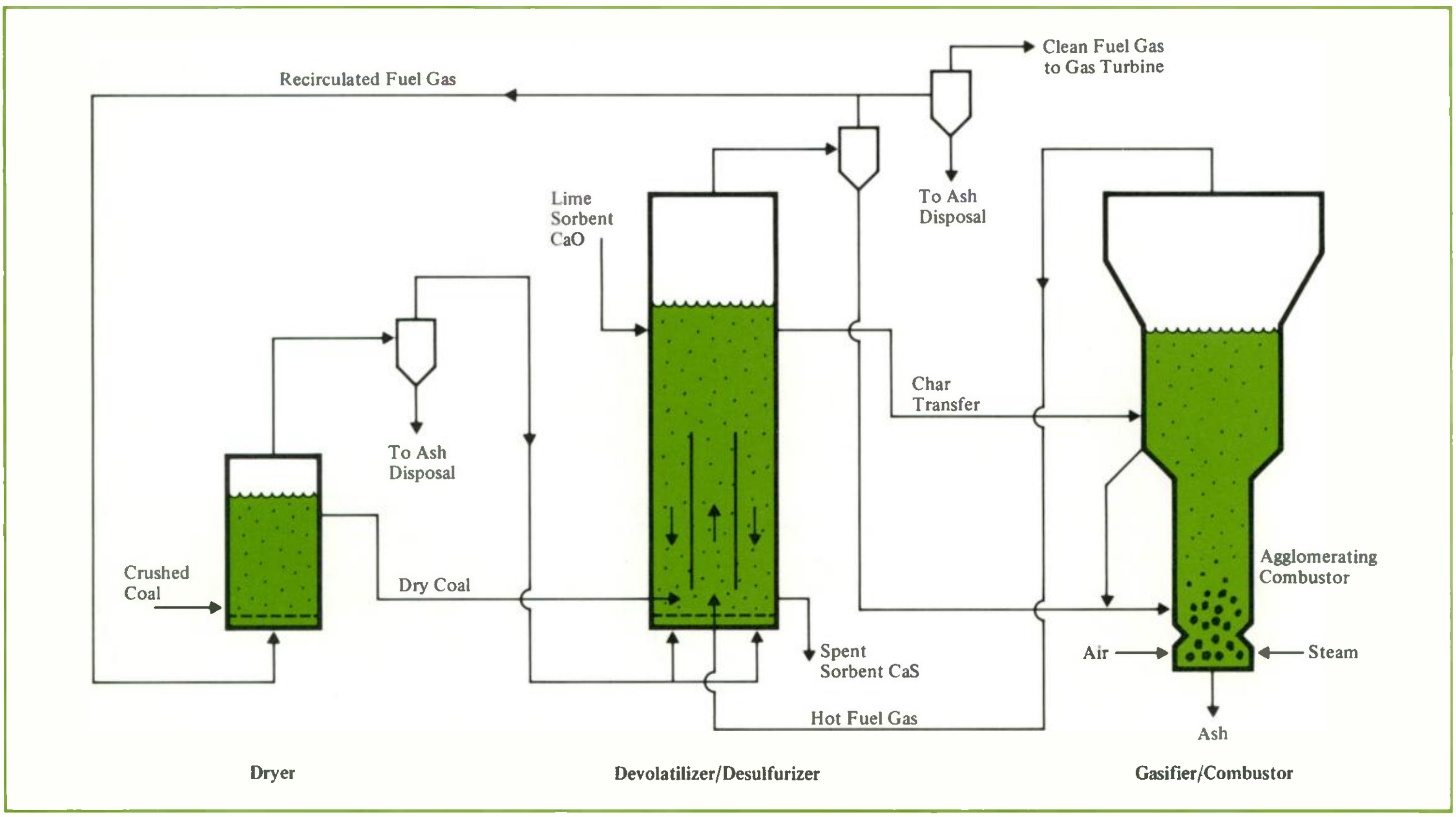
The other major anticipated advantage of the fluidized-bed reactor is its potential capability to remove sulfur within the gasification process. This capability stems from the ease and versatility a fluidized bed provides in handling solids. Solid materials can be readily added or selectively removed because particles can be segregated by their relative size and density. Gas velocities can be chosen to promote particle mixing in the bed or to cause separation between particles of different size and density. This versatility in control of solids flow permits a controlled stream of limestone particles to be introduced and to flow through the bed. As sulfur in the coal is converted to hydrogen sulfide, the limestone sorbent* removes this pollutant from the fuel gases, adding another major reaction to the process:

$$\left(\begin{matrix} CaCO_3 \\ CaO \end{matrix}\right) + H_2S \rightarrow CaS + H_2O + \left(\begin{matrix} CO_2 \\ - \end{matrix}\right).$$

The relatively dense calcium sulfide particles that result can be tapped off. The fuel gas bled from the top of the bed contains very little hydrogen sulfide and requires further cleaning only to remove particulates and any high-temperature tars that remain.

Although fluidized-bed gasification re-

*More specifically, a mixture of high-calcia limestone ($CaCO_3$) or dolomite ($MgCO_3 \cdot CaCO_3$) and lime (CaO).



actors have not been applied commercially, at least five fluidized-bed units are currently under development to produce pipeline gas and/or liquid fuels from coal. Other fluidized-bed processing units have been developed to produce pipeline gas from oil, and fluidized-bed reactors are now used commercially in the catalytic cracking of oil, roasting of sulfide ores, incineration of oily wastes and sludges, production of organic chemical monomers, making of cement, and conversion of nuclear materials for fuel elements.

Proposed Coal Gasification Process for Electric Power Generation

The proposed multistage coal gasification process consists of three process units—a dryer, a devolatilizer/desulfurizer, and a gasifier/combustor, as shown in Fig. 3. The process arrangement capitalizes on the potential advantages of the fluidized-bed reactor, but at the same time realizes the thermal efficiency inherent in the fixed-bed gasifier's counterflow of gases and solids.

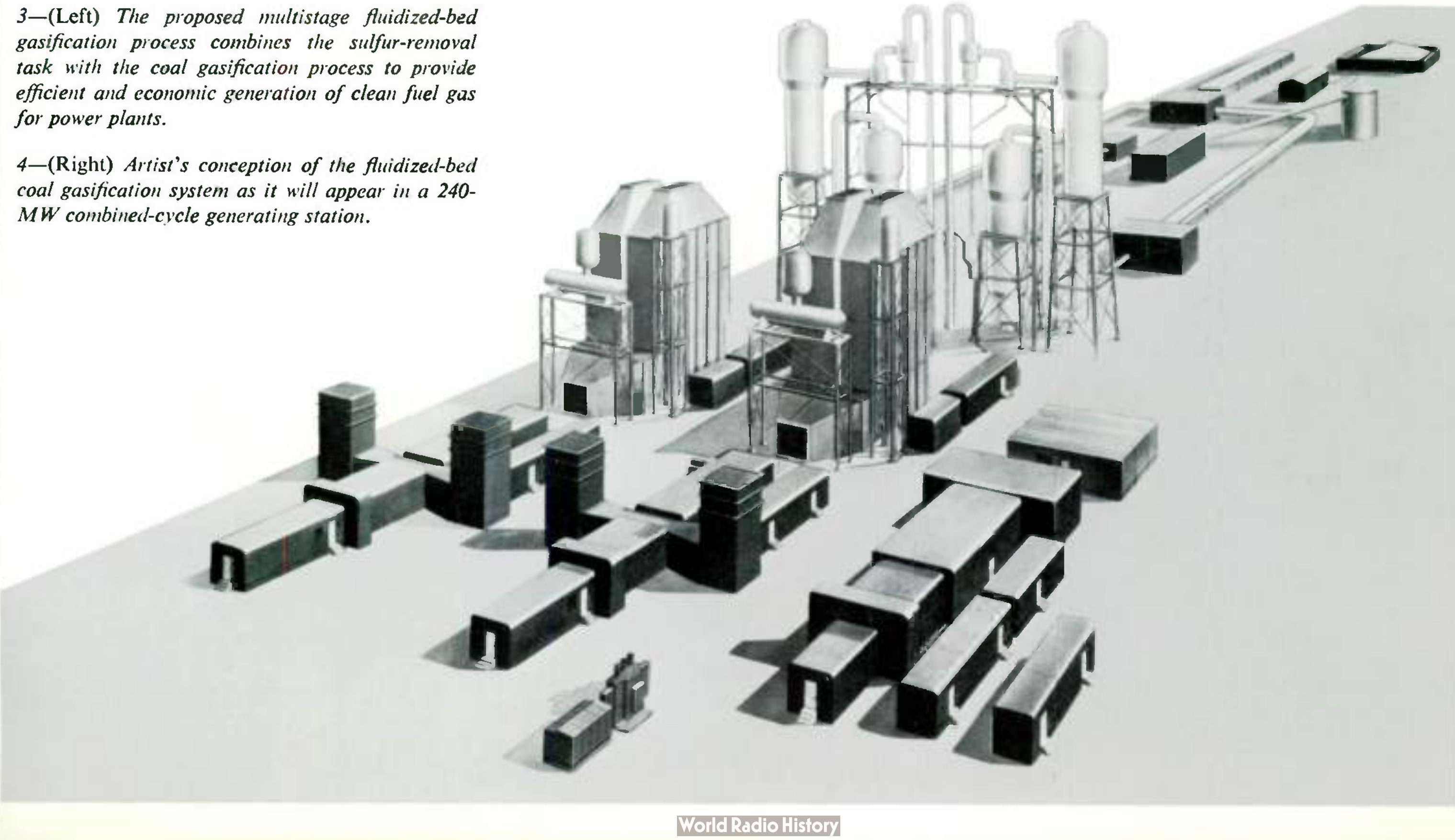
Crushed coal is fed to a fluidized-bed dryer where the coal's water content is reduced so that particles will flow freely and thus be more readily transported and introduced into the devolatilizer/desulfurizer unit. There the devolatilization, desulfurization, and partial hydrogasification functions are combined in a single recirculating fluidized-bed reactor operating at 1300 to 1700 degrees F. Dry coal is introduced through a central draft tube in this reactor. Inside this tube, the raw coal and large quantities of recycled solids—char and lime sorbent—are carried upward by gases flowing at velocities greater than 15 ft/sec. The recycle solids that continually dilute the coal feed and temper the hot inlet gases descend in an annular downcomer—a fluidized bed surrounding the draft tube. The recirculating solids, which flow at weight rates up to 100 times the coal feed rate, effectively prevent or control agglomeration of the coal feed as it devolatilizes and passes through a phase in which it becomes sticky. Volatile products are driven off the coal in an atmosphere containing hydrogen, which reacts with the coal and char to form methane and higher hydrocarbons and release heat. The dry char that results from devolatilization has a particle size and density that cause it to concentrate in the top section of the fluidized bed where it can be withdrawn.

Lime sorbent is added near the top of the bed and mixes with the recirculating solids, removing hydrogen sulfide from the fuel gases. Spent (sulfided) sorbent is withdrawn from the reactor after stripping out the char, either in the char transfer line or in a separator of special design. Although some heat is provided by the hydrogasification and devolatilization reactions, much of the heat required is supplied by the high-temperature fuel gas fed from the gasifier/combustor unit. Some heat is also transported by solids carried over in the gases from the gasifier.

The gasification of low-sulfur char is conducted in the upper section of the fluidized bed in the gasifier/combustor unit. Steam reacts with char, absorbing heat and forming fuel gases (hydrogen and carbon monoxide). The gasification section oper-

3—(Left) *The proposed multistage fluidized-bed gasification process combines the sulfur-removal task with the coal gasification process to provide efficient and economic generation of clean fuel gas for power plants.*

4—(Right) *Artist's conception of the fluidized-bed coal gasification system as it will appear in a 240-MW combined-cycle generating station.*



ates at temperatures of 1800 to 2000 degrees F. The lower leg of the unit serves as the combustor. Char fed from the devolatilizer/desulfurizer unit is burned with air, forming normal combustion products (steam and carbon dioxide) and releasing the major portion of the heat required by the total process. Combustor temperature is 2100 degrees F. Heat is transported from the combustor to the upper gasifier section by combustion gases and by solids that flow between the combustor and gasifier sections.

At the 2100-degree combustion temperature, ash agglomerates and segregates in the lower bed leg for removal.

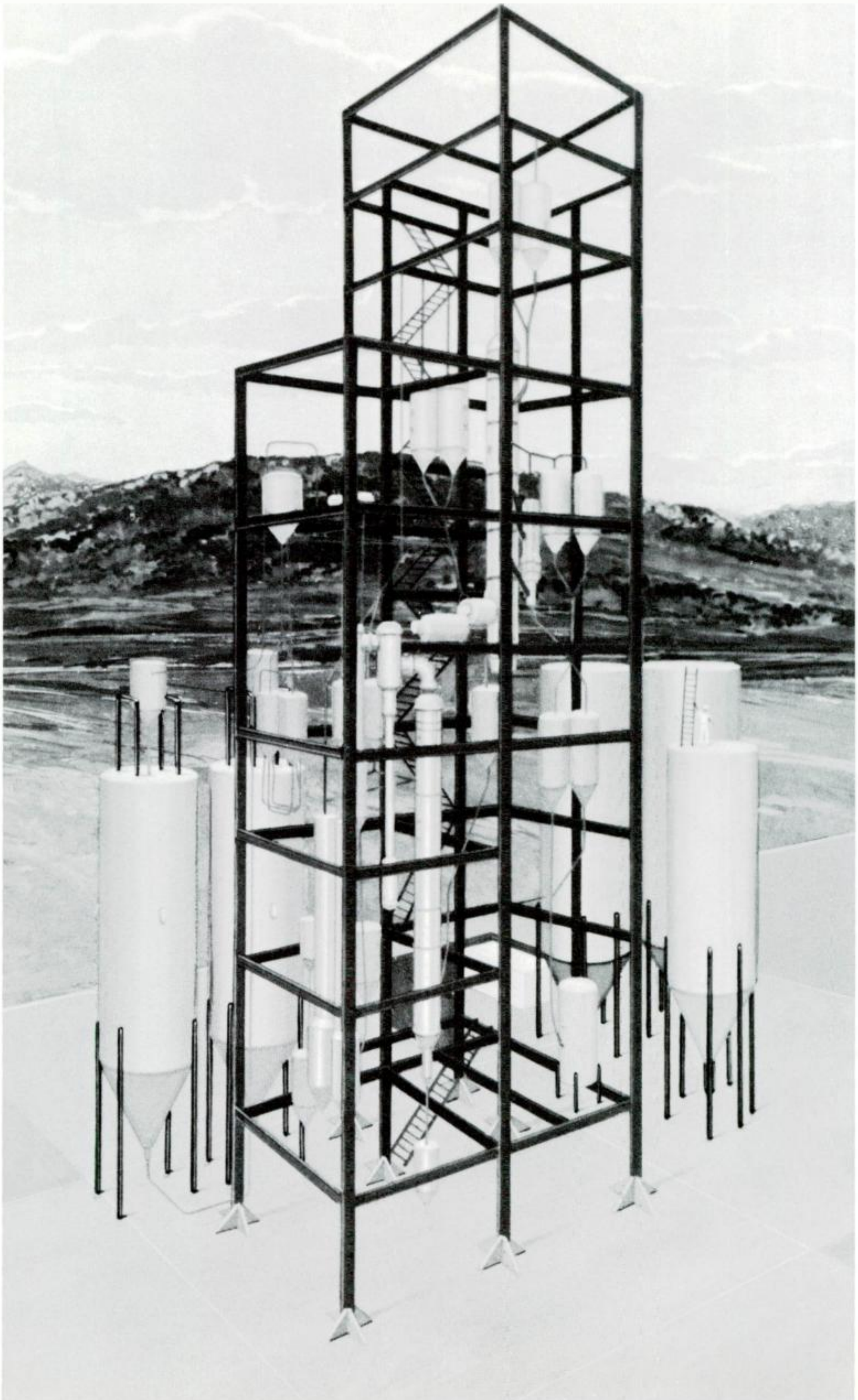
Advantages of the New Process

This new multiple fluidized-bed concept has the potential for overcoming the inherent limitations of other gasification processes and providing an economic gasification system for power plants.

A wide variation in fuels including caking coals and high-ash coals can be used without costly and inefficient pretreatment. This flexibility will allow power plants to utilize local coal resources and minimize transportation costs.

A wide variation in coal particle size, ranging from ¼-inch diameter down to fine dust, can be accommodated. Since mechanically mined coal may contain as much as 20 percent fine particles, the ability of a gasifier to use coal as crushed without extraction of fines will provide a further economic benefit.

Good process heat economy is realized through the countercurrent movement of gases and solids between stages. The multistage arrangement provides the long residence time required for high carbon conversion with good temperature control in both stages of gasification. The proposed design also minimizes loss of carbon in ash. Fluidized-bed agglomeration of coal ash with low carbon loss (1 to 2 percent)



5—The first step in the coal gasification power system project is this miniature process development unit, designed to convert 1200 pounds of coal per hour into sulfur-free fuel gas. Ground was broken for the installation at Waltz Mill, Pennsylvania, in late 1972.

Table 2—Schedule for Gasification Project

	Completion Date
Develop and Operate Multiple Fluidized-Bed Process Development Unit	March 1975
Select Gasifier Concept for Further Development	April 1975
Scale Up Concept and, if Necessary, Build and Operate 5 Ton/hr Gasifier Pilot Plant	September 1977
Complete Design of Generating Pilot Plant for the Dresser Station	September 1978
Complete Construction of Generating Pilot Plant	August 1979
Operate Combined-Cycle Plant with Coal Gasifier	May 1981

has been demonstrated on both small- and large-scale equipment.

Clean fuel gas can be produced without the heat loss that would occur if the fuel gases had to be passed through scrubbers, because the fluidized-bed concept permits fuel gas desulfurization by limestone or dolomite at process temperature. Since this temperature is above the range in which tars condense, these should pass on out of the gasifier with no harmful effects.

Although this advanced gasifier concept is unique, it is composed of subsystems that have been successfully demonstrated in other processing systems. The development task thus becomes one of testing these processes in combination and of learning to design and build economic and reliable apparatus.

The Industry/Government Goal

A gasifier that is insensitive to the size distribution and caking properties of feed coal, that removes sulfur and ash particles from the product gas, and that is economical to build and easy to operate is the key to applying economic combined-cycle apparatus in coal-fired generating plants. The proposed fluidized-bed gasification process has this potential. An artist's concept of the end result, a coal-burning generating station rated at approximately 240 MW, is shown in Fig. 4.

The surest way to implement economic coal gasification for power plants is to embark on a comprehensive development program that leads directly to a commercial-scale demonstration on a utility system—the goal of the gasification power system project now under way. Briefly, the total program consists of the following steps, which interlock and overlap in both timing and scope:

1) Design, construct, and operate a process development unit—a miniature fluidized-bed gasifier capable of converting 1200 pounds of coal per hour into clean, sulfur-free fuel of 120 to 160 Btu/scf heating value. An artist's concept of the process development unit as it will appear at Waltz Mill, Pennsylvania, when ready to operate early in 1974 is shown in Fig. 5.

2) Create a preliminary design for a commercial-size gasifier based on the design concepts of, and experience gained with, the process development unit.

3) Conduct laboratory investigations on material properties, chemical reactions, coal and sorbent characteristics, fluidized-bed performance, gas cleaning, and low-Btu-gas combustion to support and extend data provided by the process development unit.

4) Review all operating experience and performance data generated by the process development unit and by pilot plant gasifiers of other types now being developed by others, either Government-funded or privately sponsored. Develop a final conceptual process design for a commercial power plant gasifier incorporating all that has been learned from these programs.

5) Translate the conceptual gasifier process into detailed plans for a plant of commercial size. Further laboratory testing and possible pilot plant confirmation may be required to validate all conceptual details and verify design procedures used for scale-up of pilot gasifier designs to commercial size. Present plans call for construction of a gasifier pilot plant having a capacity of some 5 tons of coal per hour. The need for this interim pilot plant will be determined by results obtained from the preceding steps.

6) Construct a combined-cycle generating plant that operates on distillate oil to supply firm power, but has the capability for burning gasifier product gas in the gas turbine and heat-recovery steam generator. Public Service Indiana has designated its Dresser Station, near Terre Haute, Indiana, as the site for this plant.

7) Construct at the Dresser Station a commercial-size gasifier system for 55 to 60 tons of coal per hour, arranged to supply fuel gas to the combined-cycle generating plant.

8) Operate the gasifier/combined-cycle plant through a planned test program to provide operating experience and cost data so that the true characteristics of this new type of power plant can be established.

Work on the first three steps listed above is already under way. Target dates for completion of the program's principal milestone events are listed in Table 2. As indicated, the program will cover a time span reaching into 1981. Accomplishments will be reported from time to time as the project progresses.

REFERENCES:
[1]P. N. Ross and L. G. Hauser, "Some Future Dimensions of Electric Power Generation," *Westinghouse ENGINEER*, Jan. 1971, pp 2-7.
[2]P. A. Berman and F. A. Lebonette, "Combined-Cycle Plant Serves Intermediate System Loads Economically," *Westinghouse ENGINEER*, Nov. 1970, pp 168-73.

Top—*Three of the glass-walled elevators in the new Hyatt Regency Hotel in Houston are on the outside of the building, giving guests a view of the city's skyline.* Bottom—*The other four face the lobby.*

Standard Design Minimizes Cost of Observation Elevators

A new approach in the design of glass-walled observation elevators saves money by using standard construction instead of trying to conceal the operating apparatus, such as counterweights and rails. Those parts, and the elevator shafts, are merely painted a dark color to make them unobtrusive.

An example of this approach is in the seven observation elevators installed in the new Hyatt Regency Hotel in Houston, Texas (see photos). They whisk guests to the hotel's 33 floors while providing an unobstructed view of the skyline of the South's largest city or of the hotel's atrium, a park-like lobby.

The Westinghouse gearless elevators, which travel at 700 feet per minute, are located at the juncture of the hotel's two wings. Three elevators face the street and four overlook the atrium. At meal times, two of the elevators provide express service to the revolving restaurant-lounge atop the structure, taking less than 30 seconds for the trip from lobby to top. Each cab has a capacity of 3000 pounds.

The elevators have the Selectomatic Mark IV computer control system that sends cars on the most efficient traffic routes to minimize waiting time. The system dispatches by demand rather than by anticipation, so elevators move only when there is a real need.

Reverse-Osmosis System Facilitates Disposal of Used Cutting Oil

The cutting oils used in machining are generally diluted with water in a ratio of about 20 to 1, so disposal of used oil usually requires the tanking and hauling of large volumes of liquid by scavengers. Moreover, recent environmental legislation has imposed more severe regulations on the disposal of cutting fluid and has made the manufacturer liable for the acts of the scavenger.

Disposal costs are reduced, and liability avoided, by a new disposal system that removes about 95 percent of the water and most of the additives from the cutting fluid. The concentrated oil can then be disposed of by burning in the plant's heating or process furnaces; it has a heating value of 5000 to 10,000 Btu per pound and so provides a fuel credit to the plant. The water and additives that are extracted can be used as makeup for new batches of cutting fluid, resulting in a substantial cost saving.

The main component of the system is a reverse-osmosis module. It consists of tubular semipermeable membranes supported in a porous matrix of resin-bonded sand, with a protective shell that supports the assembly and collects the product water. The rest of the system includes a feed pump, strainer and filter, mounting frame, piping and associated valving, back-pressure valve, product-water collection system, and instrumentation.

As hydraulic pressure is applied to the cutting fluid on the feed side of the reverse-osmosis membranes, water and most of the additives are forced through the membranes to the product side, leaving concentrated cutting oil behind. The applied hydraulic pressure is sufficient to reverse the natural osmotic flow of water from the dilute to the concentrated side—hence the term "reverse osmosis."*

The usual system configuration is a batch type in which the cutting fluid is recirculated through the reverse-osmosis module until the oil reaches the desired concentration. The product water is used as makeup for new cutting fluid or, if desired, can be released into most sanitary sewers. An alternative configuration is a once-through system, which requires more reverse-osmosis modules than does the batch system. The systems are made and marketed by the Westinghouse Heat Transfer Division.

The systems are shipped as self-contained units that require only external piping and electrical connections, and they

*J. B. Wright, "Reverse Osmosis: A New Tool for Water Purification," *Westinghouse ENGINEER*, July 1971, pp. 108-13.

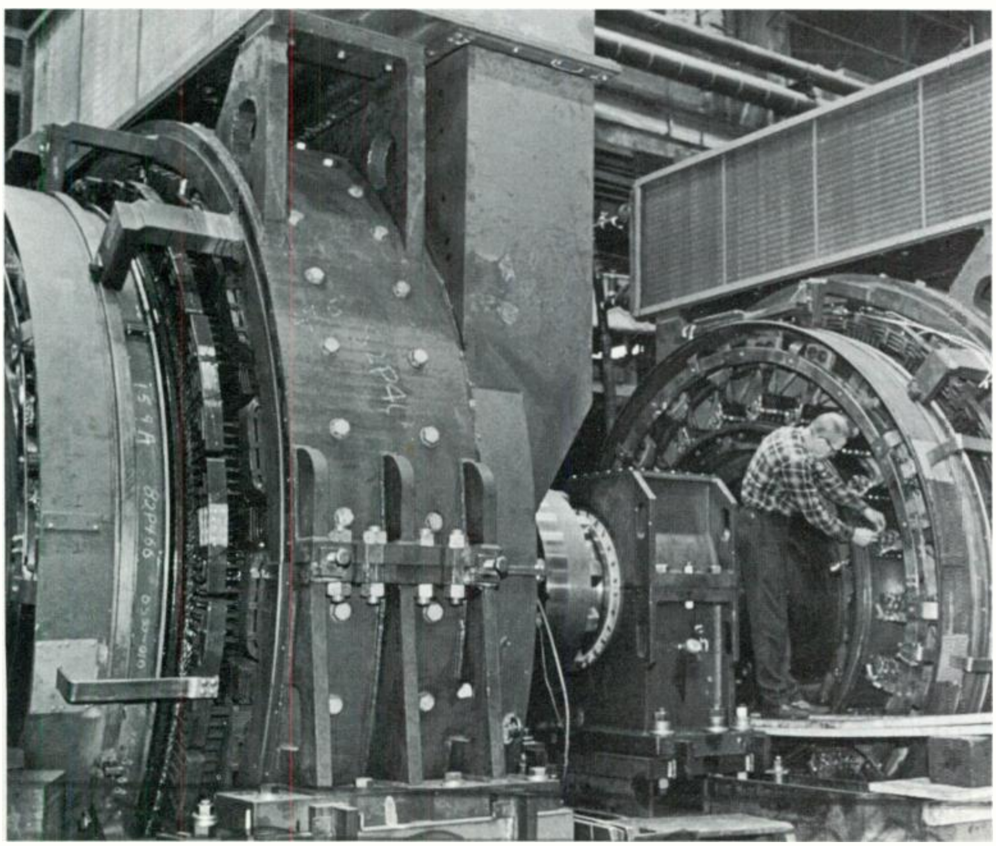
can be easily expanded after installation. A booster feed pump is required in the larger systems to maintain the required pressure of 450 to 500 pounds per square inch on the feed side of the reverse-osmosis membranes. Performance monitoring and periodic cleaning are the only operator functions required.

Propulsion Equipment Supplied for Large Icebreaker

Three 6000-horsepower 900-volt dc propulsion motors will power the WAGB-10 *Polar Star* icebreaker being built for the U.S. Coast Guard. Each of the 105/130-r/min motors will drive one of the 400-foot vessel's three propellers in normal operation. (For breaking ice, the propellers will be driven by gas turbines.)

Electric power for the propulsion motors will be supplied by six 2600-kVA diesel-driven ac generators, with the six-phase ac-to-dc conversion made by silicon rectifiers. The motors and generators were built by the Westinghouse Large Rotating Apparatus Division, which also supplied three 937-kVA ship-service generators. The rectifiers and control equipment were made by the Power Electronics Department of the Industrial Equipment Division.

A second Coast Guard Polar icebreaker will be powered by a duplicate set of Westinghouse equipment. That order includes a spare propulsion generator and a spare ship-service generator.



Propulsion motors for the Polar Star *icebreaker were fully tested at the manufacturing plant before shipment.*

Emergency Beacon for Miners Being Field-Tested

An experimental emergency beacon is being developed to tell rescuers on the surface the exact location of miners trapped underground in accidents. It uses ultra-low-frequency radio waves that, unlike the waves used in commercial broadcast radio, can penetrate as much as a thousand feet of earth.

The device is being tested by the Westinghouse Georesearch Laboratory in Boulder, Colorado, where the prototype equipment was built under a contract from the Bureau of Mines, U. S. Department of the Interior. Results have been encouraging in field tests conducted so far.

Two versions of the beacon have been tested. A portable type is powered by the battery in the miner's cap lamp, using as the antenna a length of metal tape stored in his belt. In an emergency, the miner would unreel the tape and form it into a 30-foot loop on the floor. Switching the transmitter on would send a simple signal to the surface, where a man with a portable receiver on the ground or in a helicopter could determine the exact point under which the miner was trapped. Then rescuers could drill down to the miner or try to reach him through the mine itself.

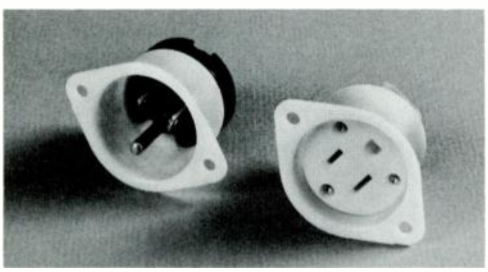
A stationary type would allow men underground to hear speech transmitted from the surface, and its transmitter would let them send back three kinds of pulses corresponding to "yes," "no," and "don't know." Rescuers could ask questions to determine the number of men at the beacon, their condition, and other information. The system's battery would be constantly charged from the mine's power circuit, and its antenna would be looped around a mine pillar.

Bureau of Mines engineers are considering the possibility of integrating the stationary beacons with a mine's telephone system. The two systems would share certain components, such as speakers, as an economy measure and as a way to ensure that those components are in constant working order should they be needed for emergency use.

Products and Services

Low-voltage distribution switchboards in the Pow-R-Line Type WR line have been redesigned so that breaker, main bus, and cable sections can easily be isolated from each other for safety. Also new in the rear-accessible switchboards is a modular design that gives much more layout flexibility, and recessed front covers that eliminate shipping damage to protruding breaker handles. The molded-case breaker modules are standardized, so specifiers can arrange breakers in a variety of ways without having to check with the factory to see if the layout is electrically and mechanically feasible. The type WR is available in ratings up to 4000 amperes at 600 volts or below. In a related change, the main bus capacity of the Pow-R-Line Type WF model has been increased from 2000 to 3000 amperes. The Type WF is a smaller front-accessible distribution switchboard with panel-mounted devices for applications with floor-space limitations. Both it and the Type WR meet requirements of NEC, OSHA, NEMA, and Underwriters' Laboratories, Inc. *Westinghouse Distribution Equipment Division, 1040 Laidlaw Avenue, Cincinnati, Ohio 45237.*

Flanged inlets and outlets for electrical equipment have casings made of nonconducting and impact-absorbing nylon instead of metal. Besides preventing possible shocks caused by accidental energizing of metal casings, the nylon devices are stronger and corrosion-free. Prices and catalog numbers remain unchanged. The line includes ratings of 15, 20, and 30 amperes in the various NEMA configurations. *Westinghouse Bryant Division, 1421 State Street, Bridgeport, Connecticut 06002.*



Flanged Inlet and Outlet

Style-Tone vapor lamp provides light with the warm pleasant effect of incandescent illumination but retains the high efficiency and long life of vapor lamps. It is useful in many indoor applications where vapor lamps formerly were not considered because of their characteristic color. The lamp is available in 175-, 250-, and 400-watt sizes. Average rated life is in excess of 24,000 hours. *Westinghouse Fluorescent and Vapor Lamp Division, 1 Westinghouse Plaza, Bloomfield, New Jersey 07003.*

Testing service for steam turbine-generators applies nondestructive test methods as part of a scheduled maintenance program to protect power plant equipment by detecting flaws before they become stress or fatigue failures. Field engineers and technicians check all components subjected to stress, including turbine blades, diaphragms, shafts, tubes, pipes, and bolts. Tests can also be run on plant lifting equipment such as crane hooks, cables, and chains. Among the testing techniques used are wet and dry magnetic-particle analysis, liquid dye-penetrant inspection, ultrasonic testing for flaw detection and thickness gauging, Brinell and Rockwell hardness measurements, and inspection of weld structures with etchants. *Westinghouse Power Generation Service Division, P.O. Box 9175, Lester Branch, Philadelphia, Pennsylvania 19113.*

Light-source system for atomic absorption spectroscopy significantly improves ability to detect such difficult metallic elements as arsenic, selenium, and tellurium. The electrodeless-discharge light source (EDL) system is adaptable to all existing atomic absorption spectroscopy equipment of the hollow-cathode type. It thus enables existing equipment to detect, quickly and easily, elements previously difficult to detect because initial light output was so low and deterioration so rapid with hollow-cathode sources. EDL sources currently available are arsenic, selenium, tellurium, antimony, phosphorus, and iodine; mercury, lead, cadmium, and tin sources are under development. The system operates at 915 MHz from a 120/240-volt 50/60-Hz power source. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902.*

Submersible switching cubicle is a sectionalizing, tapping, and fusing device for underground distribution systems. The Switch Pak cubicle is available in single- and three-phase designs for grounded wye and delta systems, and its small size (diameter 27 inches, height 31 inches) and cylindrical shape permit installation in low-cost bituminous-fiber vault enclosures. The device uses a Type LBOR oil switch with a spring-loaded overcenter toggle mechanism and double-break contact assembly that extinguishes the arc in three cycles or less. It has a standard stainless-steel tank with welded cover and a high-voltage plug-in or well type epoxy bushing. *Westinghouse Underground Distribution Transformer Division, 500 Westinghouse Drive, Jefferson City, Missouri 65101.*

Dry-type transformer, smaller and lighter than previous models, is made especially for use in high-rise buildings. The Hi-Rise transformer is available in ratings of 37.5 to 10,000 kVA single and three phase, with high-voltage ratings through 34.5 kV. Installation can be in any convenient location, with no vaults, special vents, domes, or other protection needed. A three-fuse chamber can be supplied for protection against excessive overloads, and arrester mounting brackets can be supplied for additional surge protection. Load-break bushings or clamp-type terminals are available for the incoming line. The case has removable panels to further reduce size and weight for rigging in tight locations. *Westinghouse Sharon Transformer Division, 469 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

About the Authors

R. E. Hendrix joined Westinghouse on the graduate student training program after graduation from the University of Maryland (BSEE) in 1963. He attended the Westinghouse Design School and, with further graduate study at the University of Pittsburgh, obtained his MSEE in 1968. He has also done graduate study in Business and Public Administration at George Washington University.

From the graduate student course, Hendrix was assigned to what is now the Systems Development Division at the Westinghouse Defense and Electronic Systems Center. There he has had a variety of radar engineering and development assignments. From 1963 to 1964, Hendrix designed portions of the pulse compression unit of the AN/AWG-10 missile control radar. The next three years were spent on analysis of coherent radar systems with emphasis on spectral analysis and radar detection theory, especially Fourier transforms, sampling theory, and information theory.

Hendrix was made a Senior Engineer in 1967 with responsibility for analysis of electromagnetic compatibility of the AWACS radar system. In 1968, he worked on the analysis and development of a digital simulator for a portion of the AWACS system. Since 1970 he has been assigned to systems analysis and definition of the AWACS radar system, which he describes in this issue.

Alfred E. Maier is a senior design engineer at the Low Voltage Breaker Division. He has ten patents to his credit and has contributed to the design of the Westinghouse DB-75 control relay, motor operators for the MA, NB, and PB circuit breakers, the FB breaker mechanism, and the Seltronic line of molded-case breakers.

Maier joined Westinghouse in 1948 as a drafting apprentice in the Power Circuit Breaker Division, and he graduated from the Westinghouse Technical Night School. He left in 1957 to work for Federal Pacific Electric Company, where he progressed from design engineer to Engineering Manager. He returned to Westinghouse in 1965 in the former Standard Control Division, the predecessor of the Low Voltage Breaker Division.

Alan B. Shimp is a senior design engineer in the Power Electronics Research Department at the Westinghouse Research Laboratories. He graduated from Purdue University in 1955 with a BSEE degree and from the University of Pittsburgh in 1968 with an MSEE degree.

Shimp joined Westinghouse in 1955 on the graduate student training program and went to work for the Switchgear Division, where he designed circuits for generator voltage regulators. He left in 1962 to join Magnetics, Inc., and then Norbatrol Electronics, working in circuit design for solid-state power control for both companies.

Shimp returned to Westinghouse in 1968 at the Research Laboratories, working first in the Electronic and Electrical Systems Department in circuit design. He assumed his present position last year.

Sylvester Lemezis joined Westinghouse in 1946 after serving three years in the U.S. Navy as a ship repair and engineering officer. His first assignment was in the design of gas turbines at the Westinghouse Steam Division in Lester, Pennsylvania. By the mid-50's he had switched to the design and application of steam turbines.

In 1959, Lemezis moved to California as the Steam Division's representative to serve utility and industrial customers in the Los Angeles area. He returned to Philadelphia in late 1962 to be Manager of the Heat Transfer Development Engineering Section. He is presently Manager of the Coal Gasification Project, which he describes in this issue. Incidentally, his interest in improving the environment is more than just a professional interest in coal gasification—he spends his spare time sailing on Chesapeake Bay.

Lemezis is a graduate of Marquette University (BME, 1943) and the University of Pennsylvania (MSME, 1951).

D. H. Archer is Manager of Chemical Engineering Research at the Westinghouse Research and Development Laboratories. His 20 years of experience includes 7 years teaching chemical engineering and 13 years of research in such varied fields as combustion, fluid flow and heat transfer, thermodynamics, process dynamics and control, and coal gasification, the subject on which he writes in this issue. More specifically, his work at the Research Laboratories has included development work on the Westinghouse Opcon control, solid-electrolyte fuel cells, water purification systems analysis, fluidized-bed combustion boilers, and coal gasifiers. He presently directs development work on new chemical processes for materials manufacturing, power generation, and gas cleaning.

Dr. Archer obtained his BS and PhD degrees in chemical engineering at the University of Delaware. He participates actively in the American Chemical Society and the American Institute of Chemical Engineers.

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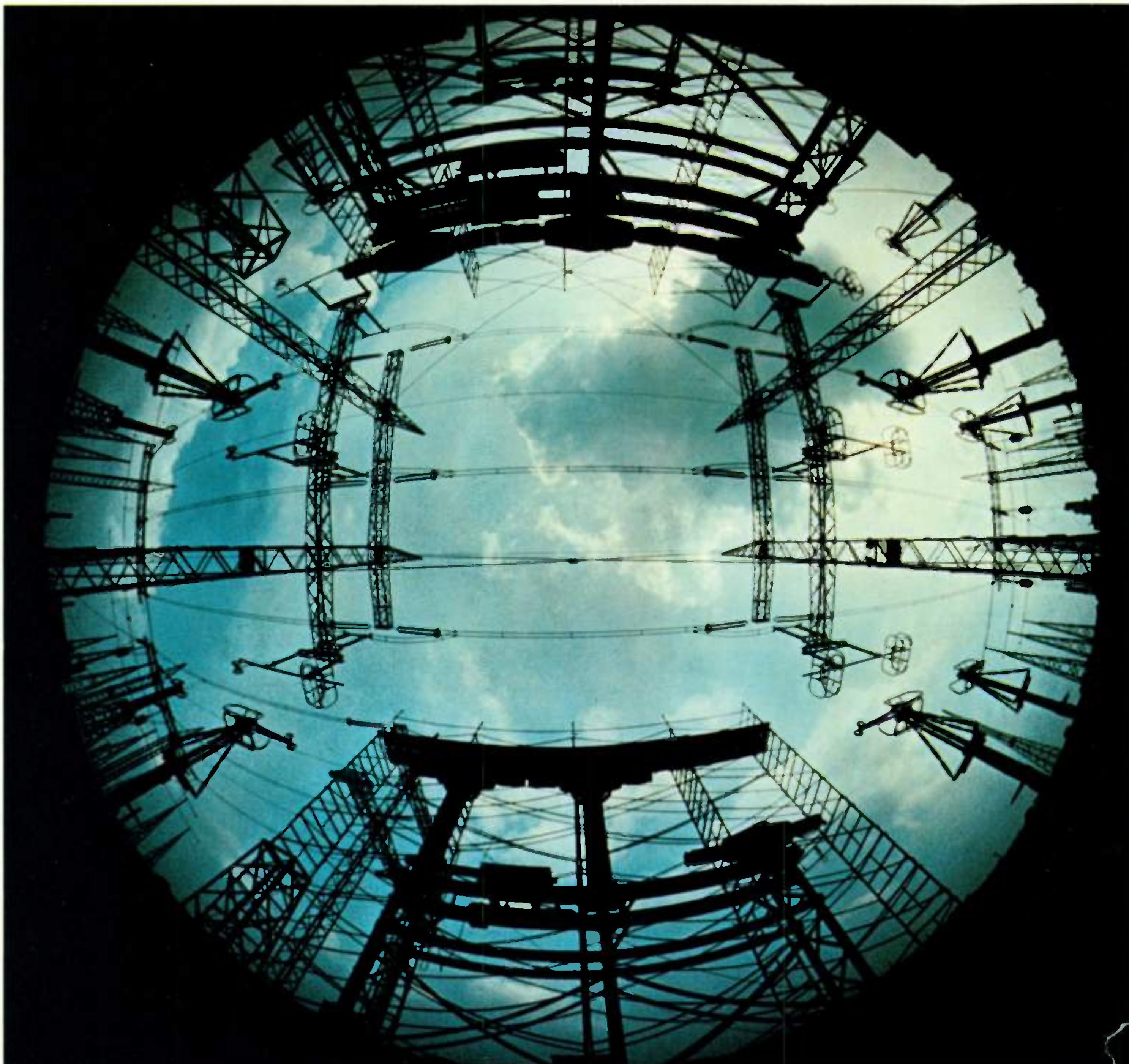

This is an 800-kV SFA power circuit breaker as an astigmatic gopher might see it. Actually, the photographer lay on his back in the middle of the unit and used a fish-eye lens. *(See page 112.)*