Westinghouse

Centennial Edition

ENGINEER

> "If someday they say of me that in my work I have contributed something to the welfare and happiness of my fellow men, I shall be satisfied."
>
> George Westinghouse

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Cover Design:
The engineering grid frames George Westinghouse as the focal point, symbolizing him as the origin of 100 years of engineering and scientific achievements.

Introduction

With the help of a few brilliant and dedicated engineers, George Westinghouse set out 100 years ago to apply technical knowledge and inventive genius to harness energy. The achievements of the Company since that time are a tribute to the engineers and scientists who have led the way in achieving our present success.

Our continued success will depend on our ability to unlock still-unknown treasures of knowledge—and to transform this knowledge into greater value for society.

To me, these efforts mean:

- Expanding the knowledge and expertise in current technologies to improve the value of our present businesses; and
- Developing new technologies in areas beyond our current needs to create opportunities for continuing self-renewal and a firm foundation for future growth.

These current and new technologies have just one ultimate purpose: to grow the total value of our businesses.

In this Centennial edition of the Westinghouse ENGINEER, we focus on a representative few of the technologies in which we provide world leadership. Also, to provide a flavor of our rich engineering tradition, we've included a "Historical Album" of some significant past achievements of Westinghouse engineers and scientists.

This Centennial edition is dedicated to the Westinghouse engineers and scientists who are continuing to develop and apply technologies that help to insure the future success of Westinghouse.

DDDanforth

D. D. Danforth
Chairman

Centralized On-Line Diagnostics Using Artificial Intelligence

R. L. Osborne
C. A. Weeks

The human mind is the last frontier; locked within it is the vast majority of knowledge needed to solve man's everyday, real-world problems. Artificial intelligence (AI) transfers this knowledge into computers so it can be shared with and used by others.

The first commercial application of AI-based, on-line diagnostics puts the combined diagnostic knowledge of turbine generator experts in the hands of utility personnel so they can continuously have a better understanding of the health of their equipment.

From a Central Diagnostic Center, it is possible to monitor any power plant in the world, on-line, around the clock and diagnose turbine generator conditions as they develop.

A centralized Diagnostic Center in Orlando, Florida (Fig. 1), where the diagnosis is actually performed, is presently connected to power plant data centers through telephone lines and a packet switching network to transmit digital data.

The data centers receive signals from hundreds of sensors located on the turbine generator being diagnosed. This data is stored in the data center's computer, then transmitted to the Diagnostic Center. There, the data is analyzed, and the resulting diagnosis is sent to the power plant and displayed for use by operating personnel.

1–Engineers at a central Diagnostic Center are armed with computer diagnostics based on artificial intelligence. Capturing the thinking of turbine generator experts inside a powerful computer allows engineers to diagnose the causes of problems in distant operating plants—in minutes instead of hours or days.

Artificial Intelligence/ Expert Systems

This is one of the few practical commercial applications of artificial intelligence. In particular, this is an application of one branch of AI called expert systems.

Expert systems specialize in placing experts' knowledge in computers. While expert knowledge can be written into conventional software, the input process requires not only domain experts, but programmers as well. Using AI software, non-programmers can create and modify expert systems through interactive input sessions with experts.

An expert system stores knowledge in the form of if-then rules. For example, in a medical diagnostic system a typical if-then rule might be: "*if* the patient has stomach pains and nausea, *then* the patient has appendicitis, with a confidence factor of 20 percent."

In the expert system at Orlando, there are thousands of such rules which interconnect the data (e.g. nausea, stomach pains) with the diagnosis (appendicitis). The rules and the way they are related and interconnected represent the knowledge.

This knowledge by itself, however, is not enough. The expert system, like its human counterpart, must have adequate input data so that the knowledge can perform a useful service; namely, make a diagnosis. The portion of the program which applies the rules to the data is called an inference engine.

If the inference engine generates a diagnosis from information flowing from the input data, it's called a forward-chaining expert system. If the system assumes a diagnosis, then goes back to determine if the data supports the diagnosis, it's called backward-chaining.

Expert systems have several advantages over other computer-based approaches:

1) A conventional decision-tree analysis will not indicate the validity of the diagnosis, while an expert

system does this by providing a confidence factor with each condition diagnosed. This is important because the data does not always strongly suggest a specific condition.

Confidence factors can have values from −1 to +1. A −1 confidence factor indicates absolute certainty that the condition does not exist, while a +1 value indicates absolute certainty the condition does exist. Values near zero indicate uncertainty.

2) Expert systems can seek out or ask for specific additional data to improve the quality of the diagnosis. If we assume in our medical example that the original data given the computer included only how nauseated the patient was, his temperature and that he had a stomachache, the system would give the following diagnosis:

Condition	*Confidence Factor*
Gastroenteritis	0.8
Duodenal Ulcer	0.4
Appendicitis	0.2

If a more precise diagnosis were desired, the computer might request such information as "age, sex, white blood count and test for rebound tenderness." If the patient were a young man, his white blood count normal and the test for rebound tenderness negative, the diagnosis would be revised to show gastroenteritis with a confidence factor of 0.95.

3) An expert system can reach decisions in seconds which, due to the complexity of the situation, could otherwise take hours. These decisions, such as taking a unit out of service, can involve millions of dollars.

4) An expert system can display how it reached its decision, clarifying the diagnosis and providing an excellent training tool for new personnel.

Process Diagnosis System

The Process Diagnosis System (PDS) is an artificial intelligence tool developed initially at the Research and Development Center and Carnegie Mellon University. It can be used for the on-line diagnosis of a wide variety of complex equipment, not just turbine generators.

PDS is a forward-chaining, rule-based system. It is an "empty" expert system; i.e., it defines a generic set of concepts such as sensors, rules and hypotheses for representing expert knowledge. The knowledge engineer uses these concepts to create a rule base which contains the expert knowledge for diagnosing a specific process.

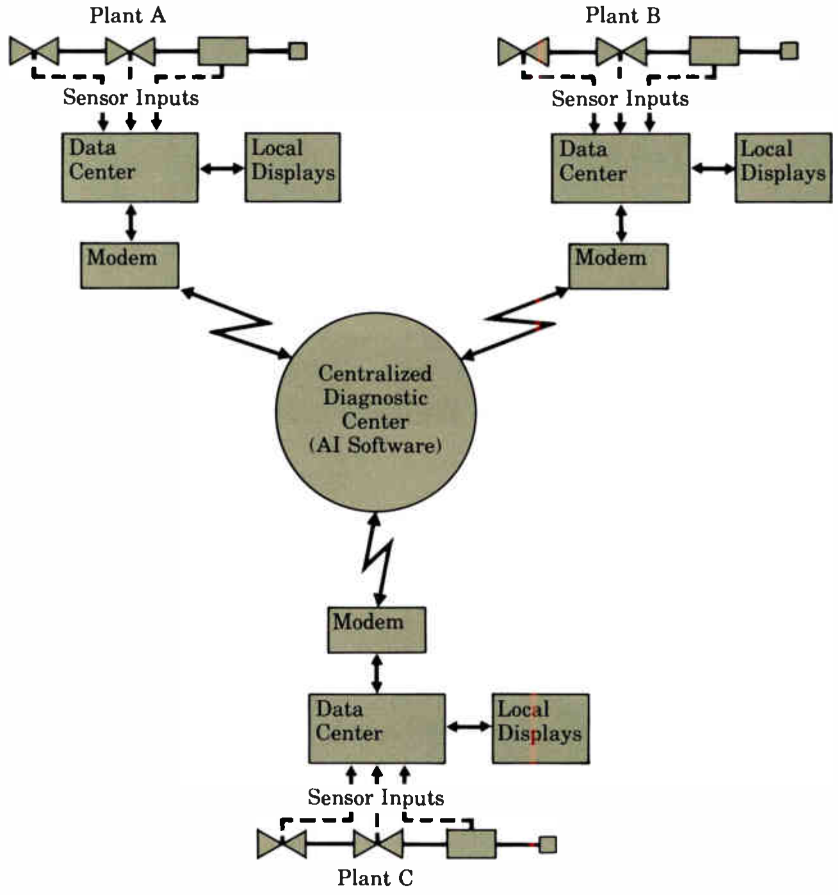
Once the rule base is defined, the PDS inference-engine software will use the rule base and the sensor inputs to compute the actual diagnosis. The representatives and propagation of belief are similar to that found in MYCIN, a medical expert diagnostic system.

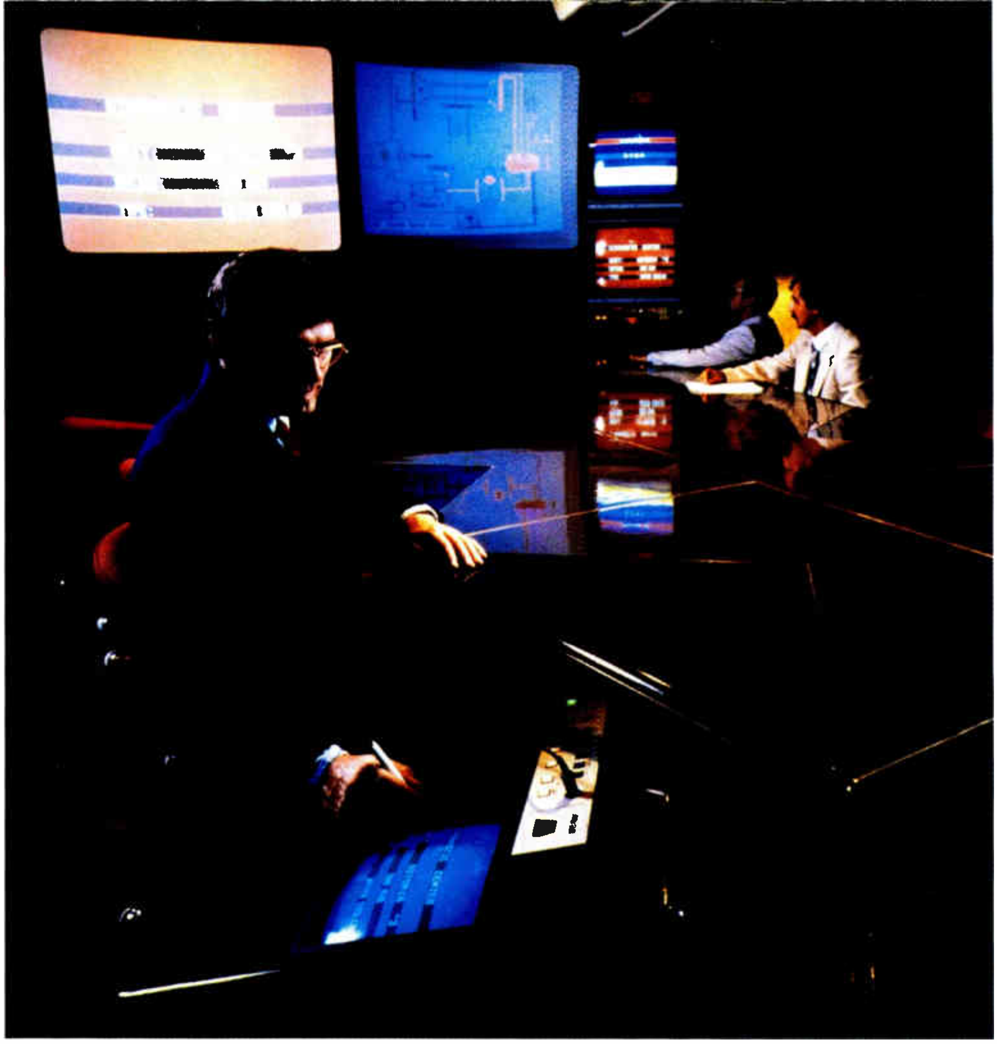
For each rule, there are schemata describing each constituent part of the rule's antecedent (or evidence), a schema describing the rule's consequent (or hypothesis), and a schema describing relationships between the rule's evidence and hypothesis.

In most applications, it is just as important for the expert system to question the "truthfulness" of the data it receives as it is to perform a diagnosis on the equipment itself.

The correct diagnosis of any equipment condition requires knowledge of the condition and accuracy of the sensors themselves. If a sensor is known to be completely failed (e.g., an open thermocouple), its reading should be ignored. Or, a sensor may be slowly

2–Centralized on-line diagnostic system.





3–Engineers a thousand miles from a troubled operating generator can use on-line diagnostics to help determine the health of a customer's equipment. Since this is a centralized system, the diagnosis benefits not only from the knowledge of experts but also the combined experience of many users.

deteriorating so that its reading is still useful, but to a reduced extent (e.g., a drifting sodium monitor).

PDS provides a method for handling both situations. The knowledge engineer can write rules which will determine a sensor's present condition. These rules can be based on redundant sensing, physical or logical tests, or on expert knowledge of the behavior of a failed or failing sensor.

These are called sensor diagnosis rules and are executed before the set of rules perform the actual equipment diagnosis.

Another special class of rules exists, called "parameter alteration rules," that will dynamically alter the equipment diagnosis rules according to the results of the sensor diagnosis.

The Diagnostic Center

The expert system computer is located at the Diagnostic Center rather than at individual power plant sites (Fig. 2). The centralized approach allows the expert system to improve its knowledge based on experience gained from all power plants using the system. This global data base of experience is greater than any single plant could possibly attain—and thus an isolated system would generally have less potential for improvement.

The Diagnostic Center consists of three functional areas:

1) Two Artificial Intelligence Laboratories are used to facilitate the transfer of knowledge from experts to the engineer who is putting the knowledge into the computer.

The system takes advantage of the synergy of using multiple experts to create the knowledge. The knowledge is put into the computer and then the experts are called back to verify that the diagnosis is in agreement with their judgment and experience.

The knowledge to allow the computer to supply confidence factor values is obtained from the experts in the form of necessity and sufficiency functions. Thus if the human experts who provided the knowledge were given the same data as the computer, they should diagnose the same conditions with approximately the same confidence factors.

The rules can be tested using internal functions that allow the manual entry of sensor values and the setting of specific contexts—in lieu of actual data. An edit function allows the study of the effects of small modifications in sensor values on the propagation-of-belief process.

The first step was the creation of a small "root" system. This began with ten sensors and used forty-four rules and twenty-nine intermediate hypotheses to indicate seven malfunctions. This was used to elicit information and stimulate thinking by the experts.

The system presently in operation can identify more than 200 conditions, using about 2,300 rules, through 110 sensors.

2) The Operations Center is staffed 24 hours a day, every day, by a diagnostician who reviews all on-line diagnoses being made on customer equipment, updates rule bases and communicates with operators at the utilities.

The real measure of the success of the centralized diagnostic system is the quality of the rule bases produced by constant feedback from the field. Each time an improvement or correction to the rule base is identified and implemented, it is used to immediately improve all rule bases of the same type.

3) In the Diagnostic Center Conference Room (Fig. 3), engineers can interact in problem-solving sessions and have direct communications with division personnel, the Research and Development Center or field locations. This "paperless" conference room is itself an experiment in people stimulation and data delivery to arrive at better decisions in less time.

Data Centers

At the user end of the system are the data center and monitors located within the power plant. The data center is an advanced, in-plant data monitoring system and an extension of the Diagnostic Center. The diagnosis is displayed at the data center, along with direct recommendations on what actions the operator should take.

The diagnosis is presented in the form of a list of "candidate conditions." The condition (malfunction) with the highest confidence factor is at the top of the list.

The electronic-mail capability built into the data center allows the power plant operator to send messages to the human diagnostician at the Diagnostic Center and vice versa. Since the Center at Orlando is manned 24 hours a day, assistance can be obtained beyond the on-line diagnosis. To provide aid, the diagnostician has access to data bases on equipment histories and detailed engineering design information.

Field Experience

The diagnostic system has been used at the Texas Utilities Generating Company (TUGCO) since the summer of 1984. It monitors and diagnoses seven generators in East Texas having 4 gigawatts of power output.

Phase I of the project, which began in July 1984, included modifying the existing generator monitoring systems at each plant to permit them to transmit data reports hourly as well as whenever an alarm condition occurs.

If a developing abnormal condition is diagnosed, Diagnostic Center engineers contact the plant operators with the diagnosis and potential courses of action.

Phase II, which is now being completed, involves the installation and verification of the complete data centers.

A number of incidents were correctly diagnosed during Phase I. These ranged from sensor failures to broken conductors in a stator winding.

The most important result of this phase of the project, however, was the updating of the original system based on inputs from utility personnel and an evaluation of performance by the experts. This has resulted in an on-line diagnostic rule base of unequaled quality.

The value of the diagnostic system is illustrated by an incident on one of the monitored units in January, 1985. Broken phase-coil conductors caused the unit to be taken off-line. The diagnostic expert system correctly diagnosed the situation 2-1/2 hours before any variable reached the alarm level. The unit was removed from service before serious damage occurred and was back on turning gear ready for synchronization four days later. The utility avoided a potentially costly event by early recognition of the condition and an appropriate response.

The system can discriminate between false alarms and real emergencies. In February 1985, correction-factor inaccuracies in a temperature-normalizing algorithm caused temperature deviations to be displayed. These could have been interpreted as broken conductors on the generator stator winding. However, the diagnostic system correctly diagnosed the situation as bad correction factors. An unnecessary unit shutdown was avoided.

The diagnostic system can be used as a predictive maintenance tool or to plan maintenance priorities during regular shutdown periods.

In September 1984, the expert system made use of a sophisticated temperature comparison scheme to identify a sensor malfunction which could not be identified through more conventional range checks.

Also in that month, the system diagnosed a conductor discontinuity at a particular location. Since the severity was not high, a recommendation was made to continue running for the remaining three weeks before a planned outage, but to be ready to repair the problem at that time.

Inspection of the generator three weeks later proved the diagnosis was correct.

The diagnostic system is also used to issue a monthly report to TUGCO listing recommended maintenance items.

Looking Ahead

The next commercial application will not only provide AI diagnostics for the generator, but also for steam chemistry and thermodynamic performance. This system will be the first application of AI diagnostics combined with the new turbine generator control system, DEH III.

Turbine AI diagnostics will be the most difficult to develop because of the need for dynamic analysis of higher frequency signals such as shaft vibration and acceleration measurements.

The next step in the development program is the creation of AI diagnostics for the steam supply system and the balance of plant components.

The use of the PDS diagnostic program is not limited to power plant equipment, but can be used to diagnose virtually any piece of equipment or system.

Using field experience, the existing 24-hour Diagnostic Center and the capabilities of experienced personnel, applications as varied as diagnosing communications systems, space stations and submarines are being explored.

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Gallium Arsenide–Key to Future Radar Systems

H. C. Nathanson, M. C. Driver, R. N. Thomas, W. R. Harden and D. Alexander

Gallium arsenide is an emerging semiconductor material which is key to the development of future radar and electronic warfare systems. Because of its high electron mobility, it can be made into integrated circuits having useful output power and radio-frequency gain in the frequency bands from 2 to 100 gigahertz.

A new and exciting semiconductor, gallium arsenide, is already having a dramatic impact on future generations of many high-frequency defense applications, such as radar and electronic warfare (EW) antennas.

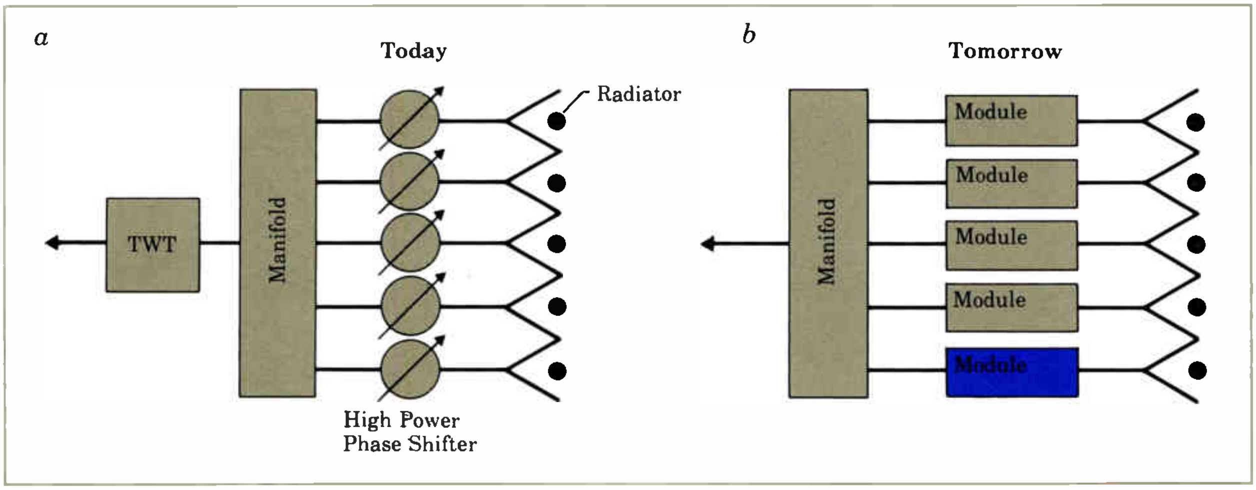
To appreciate the importance of gallium arsenide (GaAs), however, it's helpful to review the difference between conventional radar and what is required for the future.

Figure 1 shows the contrast between the radar of today, which uses the so-called "big bottle" approach, and the radar of tomorrow. Current radars use a high-powered electronic traveling wave tube (TWT) to generate a large pulse of radio-frequency (RF) energy (Fig. 1a).

The power in the pulse of this transmitter is typically from five kilowatts up to megawatts for some large ground-based radars. This power is distributed to the slots or radiators of the antenna face through a device called a manifold. Each radiator emits from 1/2 to 10 watts in a typical "big bottle" airborne radar. Phase shifters between the manifold and the radiating elements electronically steer the beam, eliminating the need to mechanically rotate the antenna.

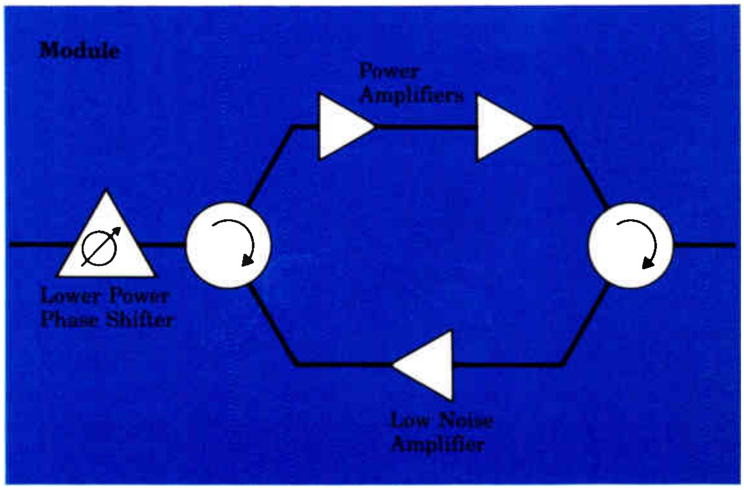
Radars that have a phase shifter on each radiating element of the array are called "phased-array" radars.

The ability to steer the beam electronically by changing the electrical phase of each radiator is a powerful feature of any radar, since mechanical antenna rotation is slow. In contrast, a phased-array radar can change the



1a–Big-bottle approach. One high-power tube supplies power to all the radiators through individual phase shifters.

1b–Active-aperture approach. The high-power tube is replaced by individual power sources in each radiator module. Circulators route the reflected signal to a low-noise amplifier and back to the same phase shifter before it's returned to the manifold.



direction in which it points many thousands of times a second. This increases its flexibility of application.

In addition, future radars will have "active apertures"; that is, each antenna radiator will have a "built-in" active source of power, eliminating the need for the TWT (Fig. 1b). The manifold will feed a reference signal to each active aperture or module. The modules themselves will amplify this signal and transmit it out of the antenna. As before, the transmitted signal can be steered by internal phase shifters within each module.

Besides providing an extremely fast scan, active apertures provide increased reliability—because the output signal is made up of hundreds of independent RF power sources instead of just one.

Also, such an active-aperture radar can point in literally hundreds of directions simultaneously, greatly increasing target-tracking capabilities.

A single airborne radar must replace several current radars in the future to save space and weight, so each must perform multiple functions—such as surveillance, terrain follow and avoidance, mapping, and fire control.

The combination of improved performance, multifunctions, electronic scan, active aperture and acceptable cost constitute the main drivers for the development of gallium-arsenide technology.

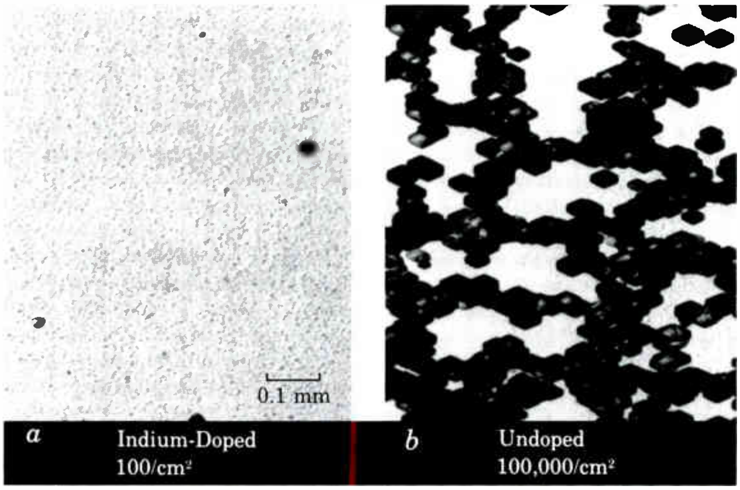
To meet all these needs, the propagation of signals through electronic devices must be much faster. That is, electron velocities must be higher, devices smaller, electronic paths shorter, frequencies higher, and operating bandwidths wider.

Fortunately, GaAs provides just these characteristics—higher electron velocity leads to higher frequencies, broader bandwidth, higher RF efficiency, and reduced power requirements. (Silicon as a microwave material is just too slow.)

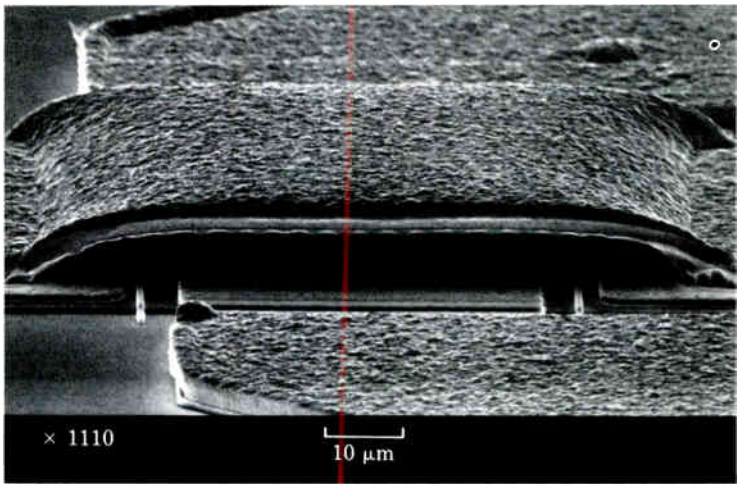
Also, as inexpensive gallium arsenide monolithic microwave integrated circuits (MMIC's) become available during the next five years, their costs should drop significantly.

Wideband low-noise amplifiers and power amplifiers as well as broadband

2–Finished GaAs boule ready for slicing and polishing into 3-inch wafers.



3–Improvement in dislocation density of 2-inch-diameter GaAs wafers—doped and undoped (above right).



4–Scanning electron micrograph: portion of a GaAs monolithic RF integrated circuit (lower right).

phase-shifter chips and electronic attenuators are all being worked on.

Besides being applied to linear power and signal devices, GaAs is being used for digital logic ICs and functional gate arrays for memory applications, to permit the integration of digital and linear functions on a single chip.

GaAs Technology Base

Much research effort in the U.S. is aimed at the routine and reproducible fabrication of GaAs MMICs for defense applications. There are two key technologies: the development of large-diameter, uniform wafers, and the development of fabrication methods to produce complicated microwave ICs.

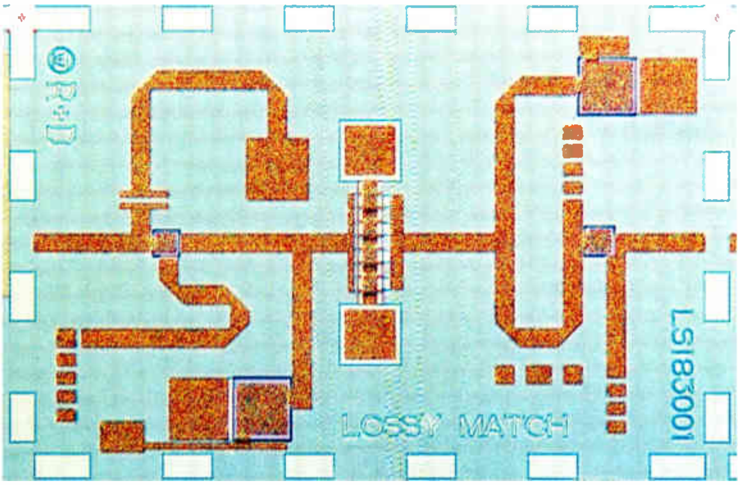
Large GaAs wafers (3-inch-diameter or more) with acceptable purity and uniformity are necessary to make multiwafer runs of monolithic ICs. Such wafers can lower costs through the use of processing equipment like that used for the silicon IC industry.

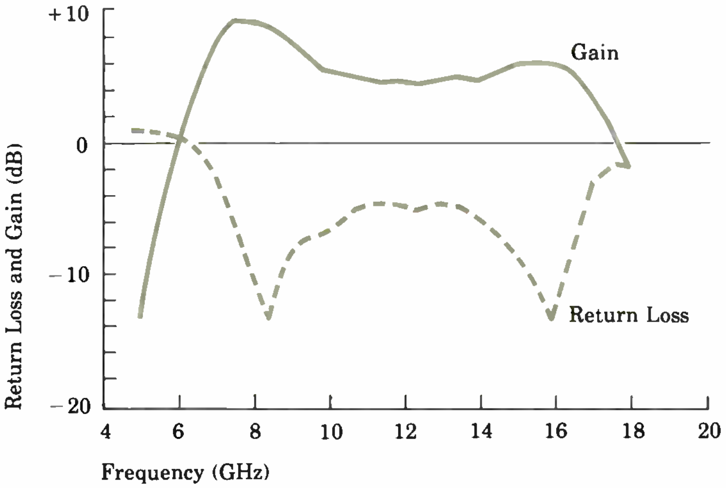
Single-crystal GaAs is much more difficult to grow at high purities than silicon. However, large GaAs boules are now being produced in a special high-pressure Czochralski furnace that can melt and grow crystals in high-purity crucibles using single crystal seeds (Fig. 2). Such a seed provides the atomic template for the whole crystal.

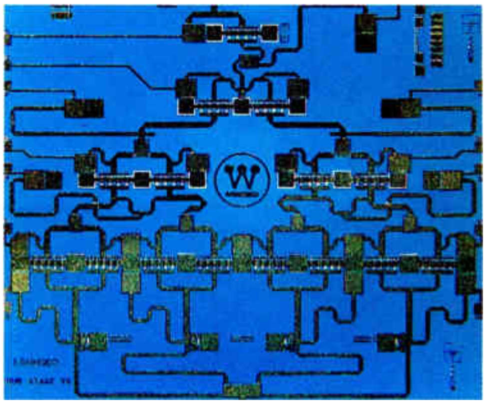
GaAs is a binary material, formed of equal numbers of gallium and arsenic atoms. Much R&D over the past five years has dealt with the critical effect of small differences in the number of gallium and arsenic atoms on the resistivity and mobility of the crystal.

Since most GaAs wafers of interest to MMIC fabricators require extremely high resistivity and high mobility, the critical adjustment of composition during growth is one key to successful wafer production. Recent research has determined that a precise ratio of gallium to arsenic of 0.98 is required for the production of stable material.

Another key problem is that crystal dislocations occur more easily in GaAs than in silicon. Dislocations cause strains in the lattice which cause nonuniformities in the electrical properties of the RF circuits formed in the substrate wafer.







5a–Recent 8 to 18 GHz 250-mW 4-dB power amplifier MMIC (actual size: 1.5 x 2 mm) for active array (upper left).

5b–(Lower left) gain and return loss versus frequency.

6–(Above) GaAs four-stage 2.5-watt power amplifier (actual size: 6.3 x 6.9 mm).

Recently, materials such as indium have been added to the GaAs melt. These materials strengthen the lattice, and the growing crystal can undergo thermal stresses without dislocations.

The dislocation count can be reduced by a factor of 1,000 by adding three percent indium, without degrading the desired mobility and resistivity of the GaAs substrate (Fig. 3). This significant reduction in distortion increases the electrical uniformity of transistor parameters by a factor of five.

The second key area is the fabrication of linear monolithic microwave devices. Fabricating GaAs linear ICs lags about 5 to 8 years behind silicon technology where digital circuits now have millions of components (e.g., a 256,000-bit random-access memory).

Linear power GaAs MMICs involve exotic concepts such as source and drain ohmic contact regions and micron-size gates for high frequency performance. In Figure 4, a scanning electron micrograph of one part of an MMIC shows the features of a modern GaAs IC: semi-insulating substrates, low-capacitance airbridge crossovers to interconnect cells of power field-effect transistors, and ion-implanted conducting layers for precise localized control of transistor characteristics.

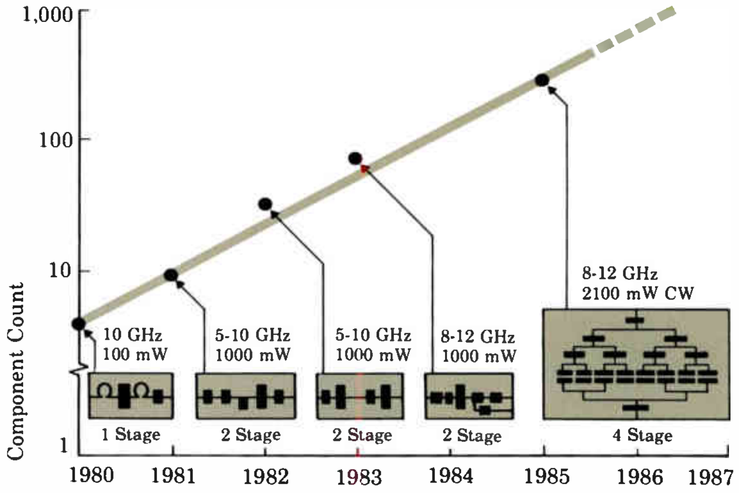
The ability to fabricate power amplifiers with multi-octave bandwidths (Fig. 5) is an extremely attractive feature of monolithic GaAs chips.

Another four-stage MMIC for the power amplifier on a radar has an exceptionally high output power of 2.5 watts over a frequency band from 8 to 12 GHz with a 25-dB gain (Fig. 6). It was developed under contract with the Defense Advanced Research Projects Agency.

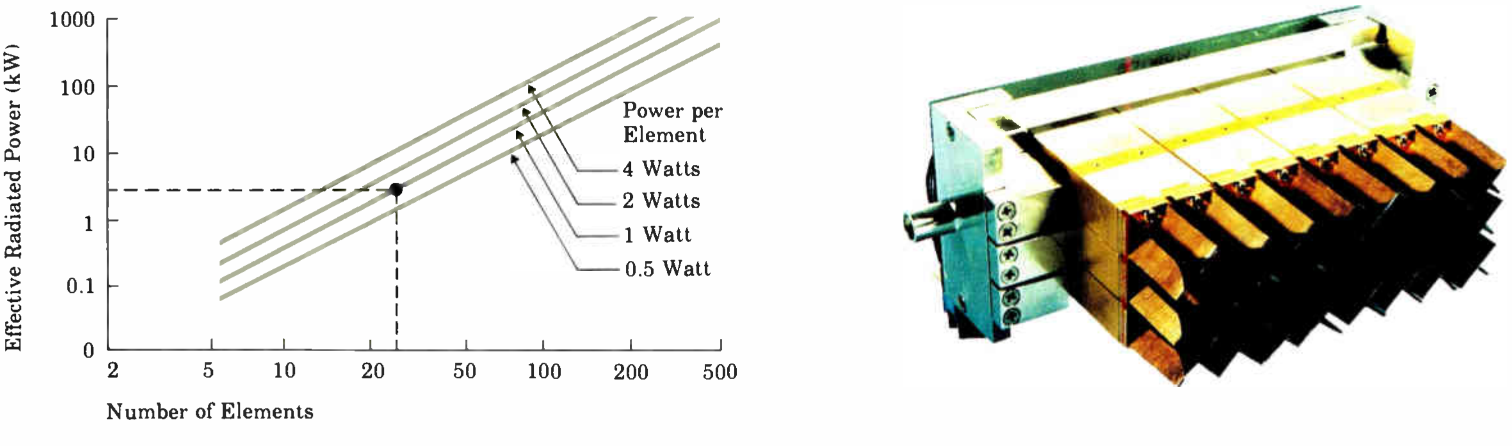
This chip represents a size reduction of over a hundred times compared to a conventional hybrid RF amplifier. Chips like these are key to significant reductions in weight, volume and cost of future radar and EW systems.

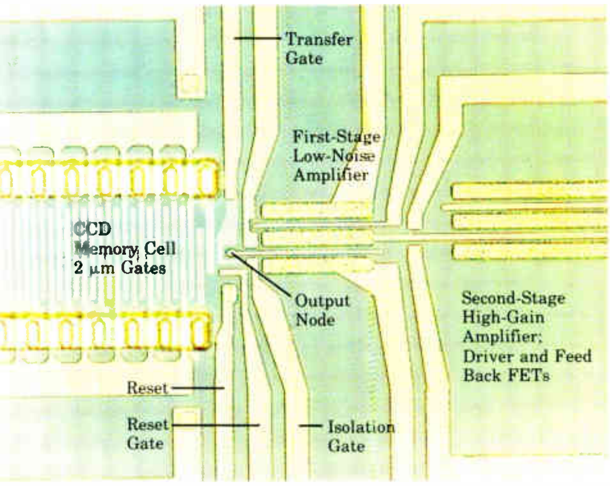
The precise geometric tailoring of the capacitors and inductors in these circuits by the photographic fabrication method allows the reproducible broadband results. The ability to batch-fabricate such complicated RF circuits without post-fabrication trimming promises to reduce cost dramatically.

7–Linear component count vs. time for GaAs power integrated circuits (right).

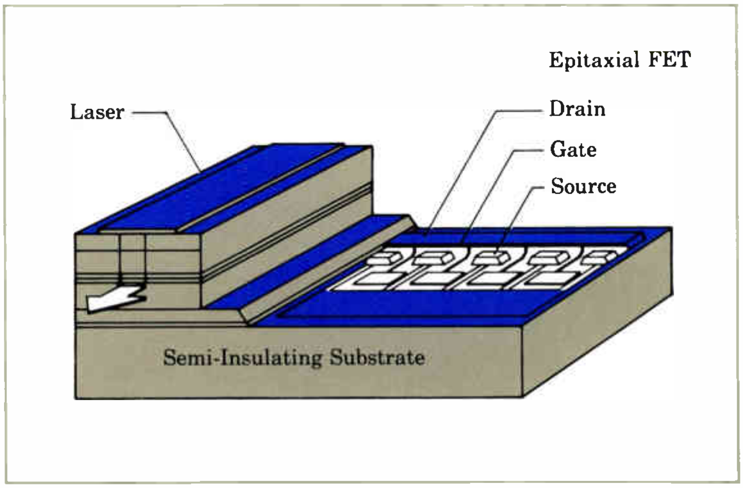


8–Experimental active-aperture EW array, and chart showing effective radiated power (below).





9a–Output section of GaAs charge-coupled device.



9b–GaAs field-effect transistor and GaAlAs laser.

The complexity of power monolithics in GaAs is evolving rapidly, doubling about every nine months (Fig. 7). Therefore, increasingly attractive power functions, including digital synthesis of power-output signals at radar frequencies, soon may be possible.

A GaAs System Example

Figure 8 shows an experimental electronically scanned EW array containing 24 modules. Each module has a power amplifier producing over one watt of RF power over a bandwidth from 8 to 12 GHz. Each module also contains a low-noise amplifier, electronic phase shifters and transmit/receive switches to separate transmitted and received signals. By exciting the 24 elements of the array in various phase combinations, the beam can be electronically steered over almost a full hemisphere.

The 24 one-watt elements can produce a jamming signal equal to a hemispherically isotropic TWT-powered jammer having a power of 2.5 kW.

This high effective radiated power is due to the "gain" or directionality of the 24-element antenna, and makes the array an attractive competitor to much larger pod-like EW jammers presently wing-mounted in modern aircraft.

One advantage of the active array is that the failure of several of the 24 elements does not result in catastrophic loss of antenna function, but only in a smoothly decreasing center-to-sidelobe degradation of about 3 to 4 dB. Such small and steerable high-effective-power antennas are expected to revolutionize the EW protection function of modern aircraft.

By increasing the number of elements from 24 to 1000 or more, a broadband radar function can be achieved. These new shared-aperture combination radar/EW systems promise to be extremely attractive for simultaneous aircraft search and protection.

Future Directions

Several technological barriers must be overcome before inexpensive GaAs MMICs are routinely available. Problems lie primarily in the field of materials, particularly in the control of defects and electrical uniformity in the GaAs wafers.

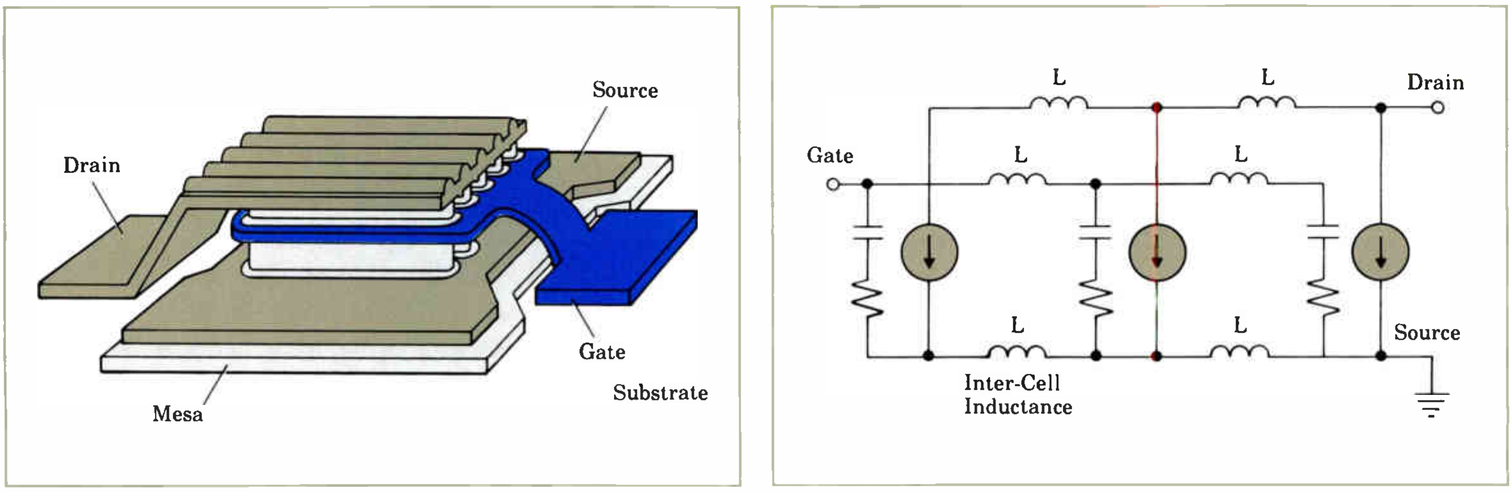
Low-cost manufacturing methods are also important, and large government programs are underway to "come down the learning curve" on GaAs MMIC fabrication.

Other important issues include the need for sophisticated microwave design and packaging techniques. Finally, reliability is always key to the acceptance of a new product for a military system.

In the near future, emphasis on GaAs MMIC technology will lie in three main areas: manufacturing methods, device technology and materials technology.

For manufacturing technology, improved understanding of material and device interactions and increased use of "hands-off" processing will lead to higher yields as larger uniform wafers appear. A $20-million manufacturing technology contract to address material and fabrication issues was recently awarded to Westinghouse by the Department of Defense.

Also, "systems-on-a-wafer" will be available as yields increase. The use of RF redundancy on wafers will help alleviate the full-wafer yield problem and lower overall system cost. Ultimately, a single four-inch wafer may be used to fully populate a flat 24-element EW array with all required active elements. This offers profound cost-saving appeal.



10–Vertical field-effect transistor for higher power and efficiency, and its equivalent circuit.

In the near future, new device technology will become important in MMICs.

Self-scanned devices offer opportunities for increased information processing in GaAs MMICs. GaAs charge-coupled device memories (Fig. 9a) offer the possibility of on-chip electronic image storage and scan conversion in combination with MMIC high-speed processing.

New concepts for integrating very-high-speed lasers on the same chip with microwave driver amplifiers (Fig. 9b) may permit modulating light from the laser at extremely high rates (approaching 20 GHz in one recent experiment.)

This opens the door for reference phase distribution from MMIC to MMIC by light pipes rather than microstrip—a more covert and less massive approach. At Westinghouse we have shown that the laser-to-laser emission from proton-isolated monolithic on-chip lasers has remarkable uniformity.

Also, there's need for very-high-efficiency field-effect transistors (FETs), so prime radar power can be generated without need for excessive heat removal.

Work continues to increase the efficiency of MMICs, including the use of special doping profiles in FETs, use of high-quality contacts and use of low-parasitic multicell transistor configurations.

One novel transistor promises to minimize extra inductive parasitics between cells—the vertical power transistor (Fig. 10). Its effective current-carrying "channels" are very close together, minimizing inter-cell inductance.

The finished device is 20 times smaller than an equivalent conventional periphery FET and offers higher power performance due to more efficient power-combining. Recent small-signal-gain results show promising RF behavior through 24 GHz.

In fact, the future of high-frequency, high-efficiency power generation on a single chip probably lies in the novel use of three-dimensional fabrication.

Finally, vertical-crystal-growth material techniques such as molecular-beam epitaxy and organometallic-chemical vapor deposition have the unique ability to grow 100-Angstrom-thick layers of mixed-crystal GaAs-like compounds. These techniques will further revolutionize device function in the next ten years.

Conclusion

As manufacturing methods for GaAs monolithic chips become more refined, and as material problems disappear, a variety of increasingly attractive RF integrated circuit functions will be used in important military radar and EW systems. These circuits will have low noise, high bandwidth, acceptable power and efficiency, and low size and weight. Most important, GaAs will provide cost-effective performance.

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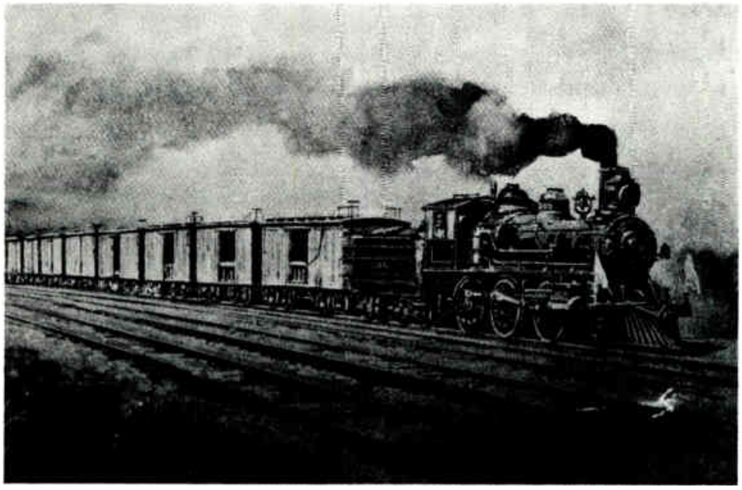
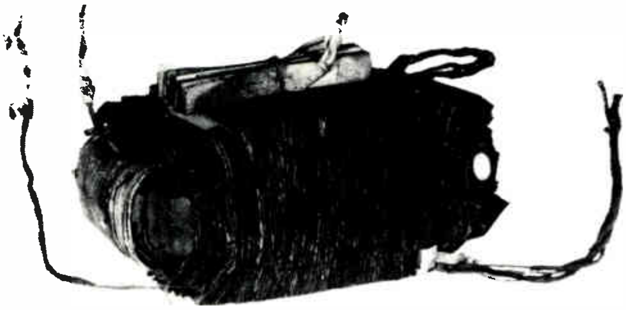
Grateful acknowledgment is given for the valuable technical contributions of L. Whicker and D. Yaw of the Westinghouse Defense and Electronics Center in providing material for this article, and to Dr. Richard Reynolds of DARPA for his continued support.

Historical Album–Part 1



Air brake for trains

Admission Ticket



Transformer

Great Barrington, Mass.

1867

George Westinghouse invented the compressed air brake for trains. He was 21 years old.

There wasn't a good way to stop trains in those days. The "down brakes" whistle was sounded a mile or so before the train's scheduled stop. The locomotive coasted while the brakeman on each car worked a handwheel to force heavy brake shoes against the wheels. Since some cars slowed down faster than others, there was a lot of bumping and jostling.

The Westinghouse brake was operated by compressed air controlled from the cab, and could be used on any length of train. A later version was also "fail safe"; air held the brakes open—any loss of air pressure automatically applied them.

1885

The first transformer was built in the United States by William Stanley. With a 500-volt primary and 100-volt secondary, it was used for a lighting system.

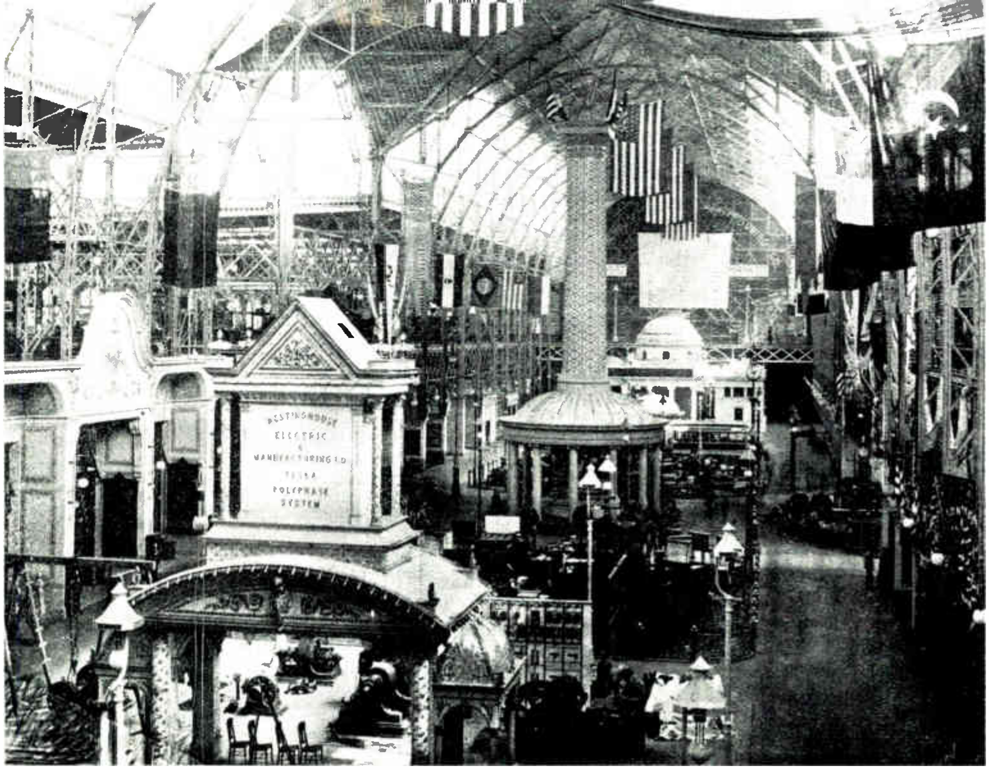
In those days the idea was new that with alternating current a counter-voltage of 500 volts could resist the flow of current through a coil having a resistance of only an ohm. It was so plainly a violation of Ohm's Law, it was almost beyond the comprehension of the electrician who was familiar only with direct current.

1886

First successful demonstration of lighting in the United States by the alternating-current system.

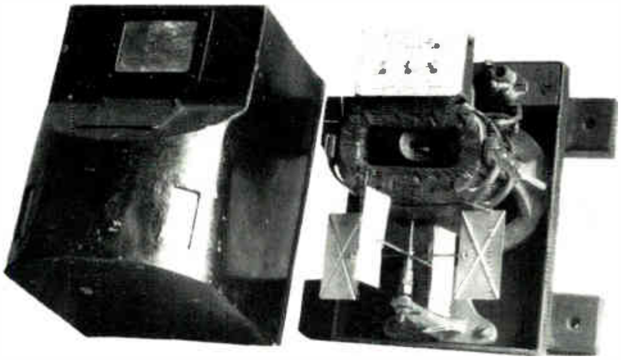
(Letter to George Westinghouse from William Stanley at Great Barrington, Mass., March 17, 1886):

"I am pleased . . . that the [single-phase ac] system is being rapidly completed. I have . . . run wires from the laboratory to the village and have placed a converter [transformer] in my cousin's store . . . to test the commercial necessities . . . The lamps in the store were running last night . . . I might say a great deal about the system, but briefly, it is all right."

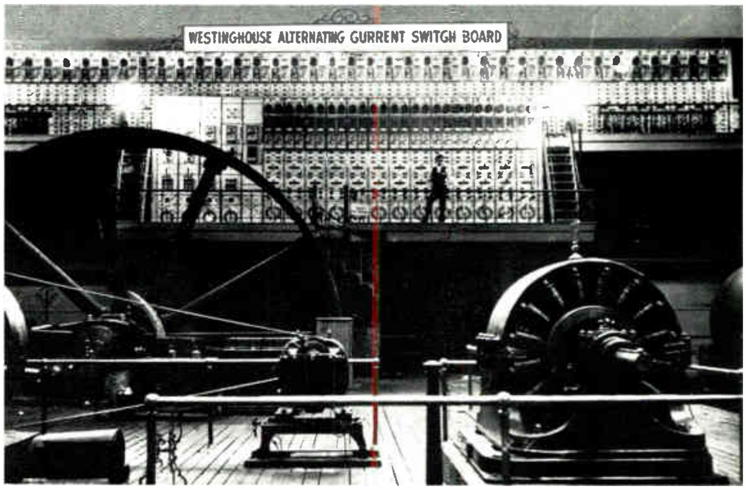


Columbian Exposition

Polyphase induction motor



Ampere-hour meter



Switchboard, Columbian Exposition

1888
The first polyphase induction motor.

On May 1, 1888, patents were issued to Nikola Tesla, a citizen of Austria-Hungary, covering the polyphase induction motor. Exclusive rights were secured by George Westinghouse nine weeks later.

Tesla's discovery probably did more than any other one thing to advance the use of electricity in industry.

1888
While Oliver B. Shallenberger was testing an ac arc lamp, he accidentally dropped a small spring on the spool of a magnet coil —and it started slowly rotating in the magnetic field.

Observing this phenomenon, within a month he had developed the first ac ampere-hour meter. Four years later it was modified to measure kilowatt hours.

It's now the cash register of the electric utility industry, with one (or more) on virtually every house and building.

1890
First ac power transmission in the U.S. at Oregon City, Oregon by the Willamette Falls Electric Company.

Energy from a 100-hp Westinghouse generator was transmitted at 3000 volts, 133 Hertz from Oregon City to Portland, 14 miles away. In Portland, transformers reduced it to 1000 volts for local distribution and again to a lower voltage to operate lamps.

1893
In a gala display, George Westinghouse lighted the grounds of the 1893 Columbian Exposition in Chicago and demonstrated a complete polyphase system for power and light.

The project called for building and installing some 250,000 lamps, 385 transformers, generator capacity of nearly 10,000 kVA, switchboards and all cable and wiring.

Westinghouse owned the patent rights to a two-piece bulb invented in 1880. He transformed the bulb into the famous two-piece "stopper lamp," with a ground-glass stopper that fit into the base of a glass globe like a cork.

He set up a glass factory, designed machines for grinding the globe and stopper, and in less than a year built the 250,000 stopper bulbs.

Taking Technology to the Customer's Doorstep

K. C. Chang, S. S. Palusamy and J. D. Gibbons

Trailer-mounted computer facilities put broad experience, a complete engineering data base, and computer-aided analysis capability at the plant site—where it's needed most—during construction and startup of a nuclear power plant. This speeds construction and plant startup testing and also improves quality and reliability.

Getting a nuclear power plant on line, on schedule, is vital. Every day of delay can cost upwards of a million dollars in lost revenue.

A nuclear plant is complex, and many changes are necessary during construction. That causes delays.

Consider this: A typical 1000-megawatt plant contains—

- 50 miles of Class I piping.
- 20 miles of electrical raceways.
- 6 miles of heating, ventilating and air conditioning ducts.
- 5,000 valves and hundreds of tanks, heat exchangers and pumps.
- Up to 30-thousand pipe supports.

Making even a minor change in pipe routing or support configuration during construction can be complex and time consuming.

Clearances must be reverified, and dynamic and static stresses in pipe and loads on supports regenerated using the revised information.

Normally the computer facilities, data bases and analysis expertise to make these studies are not located at the site. So from the time a problem occurs, changes identified, and systems analyzed, qualified and approved by all parties, weeks or months may easily elapse.

To minimize this time delay, trailer-mounted computer facilities, along with experienced engineers and computer experts, now put the data bases and analysis capability right at the construction site—where they're needed.

This provides fast turnaround service to analyze, verify and recommend solutions to construction and startup problems as they occur.

The mobile units provide on-site minicomputers, supporting equipment and software to perform all modeling, design, analysis and testing required for piping and pipe support qualification, as well as system verification through preoperational and initial startup testing (Fig. 1).

An electronic link ties the mobile units to multi-process mainframe computers at the central office and minicomputers at other sites to quickly handle overflow and particularly complex structural analyses and evaluations.

Piping and Support Analysis

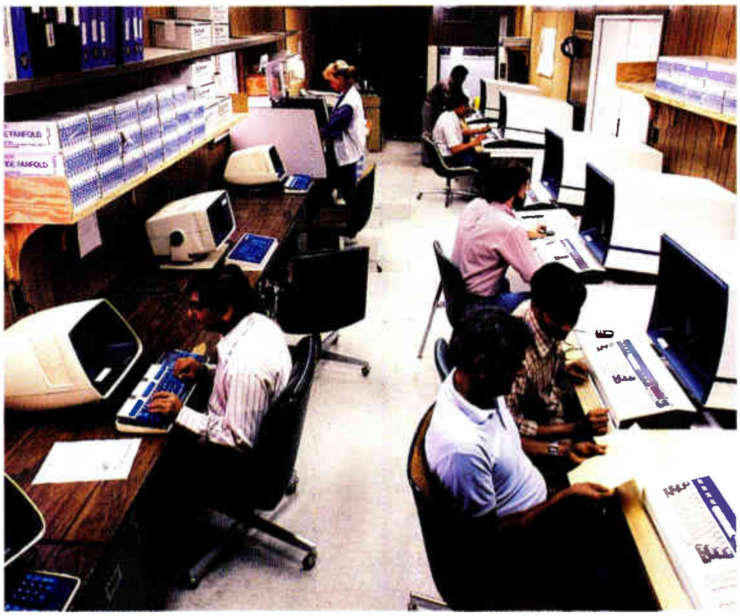
The Structural Analysis Mobile Unit (SAMU) offers a complete piping and support design and analysis capability (Fig. 2)—with fast turnaround time.

This keeps the piping and pipe-support efforts off the critical path during construction.

By using this on-site computer and engineering capability, piping and supports are installed right the first time over 80 percent of the time. The industry average is only 40 percent.

All the information for a complete piping analysis model, including support configuration and multiple loading conditions (such as deadweight, thermal, and dynamic loads), is input and maintained at the mobile unit's minicomputer.

The analyst constructs a 3-D mathematical model of the various piping systems from engineering drawings, using a light pen.



1–Interior of Structural Analysis Mobile Unit shows array of computers and terminals for on-site design, analysis, and modeling as well as to interface with main-frame and minicomputers at remote locations.

2–Functional description of Structural Analysis Mobile Unit during a typical plant construction phase.

The analyst selects the information to build the model from various menus. For example, pipe size is selected from a menu of standard sizes and schedules; valves from a library of over 1500 premodeled valves.

Where valves or flanges are unique to a plant, they can be included in the standard menu for future use and documentation.

Lumped masses, representing the weight distribution of the piping system required for dynamic analyses, are automatically calculated and inserted in the model.

The data base generated is available both in the central office and at the site for later re-analysis, reconciliation of as-designed versus as-built, or to provide base-line performance information for the future.

This data base is used in several ways:

1) It gives a permanent record of the piping model.

2) It generates full-size engineering drawings of piping systems to check against the as-built configuration during the plant walkdown prior to testing.

3) It determines optimum support locations and configurations to eliminate unnecessary supports.

For instance, small-bore piping in nuclear plants traditionally has been qualified by using inherently conservative spacing tables.

For a typical 150-foot line, computer analyses call for 5 to 7 fewer supports than spacing tables. This represents about 50 percent fewer supports.

Also, excessive use of dynamic supports in piping systems design is of growing concern to both utilities and the Nuclear Regulatory Commission. These devices permit free thermal expansion of pipe while providing restraint for dynamic loads. They require periodic visual inspection and functional testing, which adds significant operating cost and concern about occupational radiation exposure.

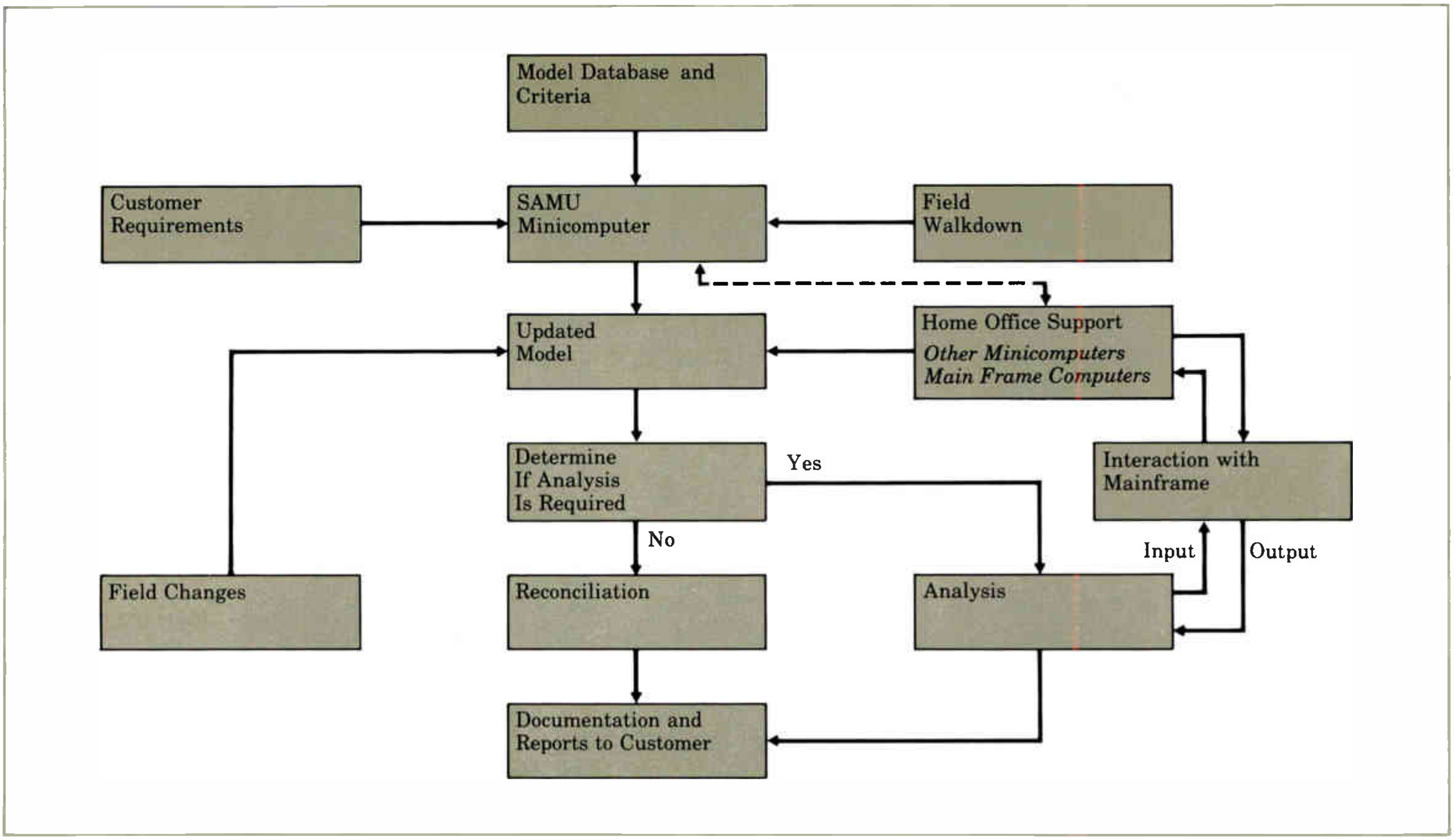
On a recent job, an on-site analysis of 17 subsystems resulted in a reduction of dynamic supports from 177 to 30. For a typical 1000-megawatt plant, this can mean a savings of more than $32 million over the life of a plant.

4) The data base can quickly incorporate as-built changes or develop and evaluate design modifications.

Test Analysis

A second on-site computer facility, the Test and Analysis Mobile Unit (TAMU), provides support for pre-operational and startup testing.

Pre-operational tests of piping systems (including thermal growth, vibration, water hammer, structural integrity and leak tests) take about



3–Section of piping in nuclear plant.

six weeks. They are run with all systems operating, but before the reactor core is installed.

In a pre-operational test, thermal growth measurements may be made at over 150 points, with a similar number of temperature and vibration measurements. These measurements are taken at temperature increments of about 100 degrees F.

The startup tests can take six months and include tests on systems that did not reach full design temperature and pressure during pre-operational testing. These tests are made at increasing power levels from 10 percent to full load.

Previously, all these measurements were taken manually and returned to the office for correlation and analysis —which might require days before moving to the next level. And if a retest was necessary, it had to be rescheduled with further delay to other work.

Remote sensors now transmit readings directly to the mobile unit, and computers tabulate, correlate and analyze all the data. Any variations from pre-programmed acceptable levels are identified and corrected within minutes or hours, so testing can proceed without delay.

This eliminates uncertainties in test data, reduces retesting and minimizes delays between temperature plateaus. It also provides data on baseline structural performance for plant maintenance and upgrading.

Plant Life Extension

The mobile units can also acquire data for plant life-extension studies; a plant can be modeled to match its future needs. The models also provide for modifying and expanding a plant later to take advantage of advances in life-extension technology.

A Look Ahead

Mobile computer systems are being expanded to provide analysis, design and layout aid, and to track construction activity for entire plants.

Piping and support analyses can be applied to cogeneration, solar, fossil, petro-chemical and other non-nuclear plants. They can also be applied to conduit and cable trays.

In the near future, on-site computerized systems will continuously monitor the entire plant construction and operating process, and track and record all desirable steady-state and transient data.

They will also monitor operating cycles to determine remaining life of power plant components, and will improve plant heat rate by tracking and evaluating key process and mechanical variables.

Also, for unanticipated occurrences, the system will provide information, including a detailed sequence of events, to identify the cause and aid in corrective action.

Conclusion

Engineering should always lead construction to insure that work can be done right the first time. An on-site automated computer and engineering capability helps to avoid unnecessary rework with its excessive cost in time and money.

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Improved Protection for Perishable Cargo

Len Vercellotti, Rob Colclaser and Dave Christiansen

Millions of people around the world enjoy fresh food and the benefits of life-saving medicines, chemicals and other temperature-sensitive necessities brought to market by modern transport refrigeration. Now a microprocessor-based controller for over-the-road and shipboard refrigeration provides more precise temperature control and remote monitoring of these perishable goods.

Until the late 1950s, cargo was transported by ships in "break-bulk" form; cartons and crates were individually loaded into a cargo net and stowed in the hold of a ship.

The introduction of standardized containers revolutionized the shipping industry. A shipping container resembles a semi-trailer without wheels. It can be put on a semi-trailer chassis for cross-country delivery or stacked six-high in the hold of a ship, on deck or in a staging yard. Once loaded, the cargo is not touched again until it reaches its destination.

The cargo is kept from spoiling by a portable refrigeration unit installed within each container. The refrigeration system operates whether the container is on the deck of a ship or speeding across country (Fig. 1).

Providing a Cold Environment

The proper cargo temperature is maintained using a reciprocating compressor, fluorocarbon refrigerant, air-to-fluid heat transfer coils, electric heaters and motors. Power is provided by shipboard generators, by a local utility or by a portable generator that travels with the containers.

Temperature control has (1) several levels of refrigeration, (2) heat when ambient temperatures are too low for the cargo and (3) a defrost function to maintain good heat transfer on the refrigeration coil surfaces.

Temperature is maintained by using valves in the suction line of the refrigeration system to provide modulated changes in cooling capacity.

Until recently, temperature was controlled by an electronic thermostat using analog operational-amplifier/comparator circuitry and relay logic to operate solenoid valves, condenser and evaporator fan motors and the compressor motor.

A new microprocessor-based controller (Fig. 2) provides precise temperature control (based on unique algorithms) as well as diagnostics and digital datalogging. It also allows for a future link with a remote monitoring and control system.

More Precise Temperature Control

Temperature sensors in the air stream feed data to the thermostat to maintain close control (within plus or minus 0.25 degrees F). This is done automatically since the cargo is left unattended much of the time.

The controller provides thermostat functions, temperature display and recording, defrost control, operational indicator light control, status recording and input/output relay control. Previously, each of these required a separate control component.

More than 10 million tons of perishable cargo a year are transported internationally in cargo containers.

1–Whether on the high seas, the open road or hot, dusty city streets, modern refrigeration systems keep perishable goods cool and safe from spoiling in constantly changing weather conditions. Containers are packed where food and other goods are produced, sent over long distances—by ship, train or truck—and unpacked at remote markets or plants, without ever touching the cargo along the way.

2–The controller (far right) has a ten-digit vacuum fluorescent display, a six-key tactile feedback membrane keypad, three LED's that indicate display status, an incandescent alarm light and a serial port used to transfer data and communicate with computers.

A multiplexed analog-to-digital converter transmits evaporator return and discharge air temperature readings. Additional temperature reference and calibration inputs are used to check and set temperatures. Digital input signals (e.g., from relay contact closures and limit switches) enter the microcontroller through digital input/output ports.

The operator uses a digital keypad to establish temperatures, select the sensor to be used for temperature display and read alarm codes.

Both the digital and analog output circuitry interface with the transport refrigeration system. The digital outputs operate the compressor motor, heater, fan motors and solenoids on the liquid and suction lines. The analog output generates the microcontroller demand signal for the modulating valve and for the display and communications outputs.

Control Algorithms

The software for the controller provides improved control and monitoring. It is structured around nine algorithm modules known as "asynchronous independent state machines." This allows individual debugging of each module. Algorithm constants in look-up tables permit the addition of enhancements or customizing for particular applications.

Four of the control algorithms are in memory and are activated when the controller is installed.

Individual modules handle (1) keyboard and other digital inputs, (2) analog inputs, (3) display routines, (4) control sequencing, (5) analog and digital outputs, (6) serial communications and (7) data recording. The data recorder has an EPROM (electronically erasable programmable read only memory) that stores operational parameters such as temperature-setpoint values and calibration constants.

To maintain an accuracy within 0.25 degrees F, the software has calibration routines that compensate for temperature-sensor errors. A digital filter also reduces circuit errors after analog-to-digital conversion.

Monitoring and Diagnostics

The software maintains the setpoint temperature for the load. A systems-state sequencer scans input states of switches and the output demand from the temperature control algorithms. The software monitors temperature-sensor performance and, if there's a problem, switches automatically to a second, back-up sensor without shutting down the system.

The controller signals an alarm in the event of such faults as low oil pressure, evaporator over-temperature, return or discharge air sensor problems, high refrigerant pressure and out-of-range temperatures. Also, an expanded list of controller fault codes are derived from on-line diagnostic software.

Data Logging

The controller not only displays data and codes, it can also store information in a data-record logging memory. A data snapshot is taken every hour or half-hour which includes return

and discharge air temperatures, new setpoints that have been entered and faults that may have occurred.

This history can be accumulated over a forty- or eighty-day period so a shipper has a complete record for each load. It also can be used by service technicians to analyze causes of faults.

These logs can be printed directly from the computer or transferred to a larger computer for storage or inclusion in a larger data base.

A Look Ahead

In the future, the controller will be integrated with other systems and functions. The serial communications protocol includes commands for virtually all internal and external control and recording operations. Work is underway to provide a power line carrier communications system for ship and dockside remote monitoring. This will permit a shipper to keep in constant touch with several hundred containers dispersed over a large yard or ship area and in many different weather environments.

The use of power lines will provide shippers the information they need without introducing an additional set of conductors and connectors. Data can be gathered at a central personal computer and stored on disk. The data can be transmitted to a mainframe computer, and shippers will have a system-wide data base for all their ships and yard locations.

Several shippers currently use satellite data transmission and can benefit from the remote monitoring and diagnostic capabilities of the microprocessor controller. Direct and immediate monitoring of food conditions will be possible throughout the entire packing, shipping and delivery cycle.

Also on the horizon are high performance processors, with digital closed-loop algorithms to provide many more control functions and advanced diagnostic tools. These will "exercise" the refrigeration system through specially constructed routines to yield timely maintenance and repair information for service technicians.

Conclusion

All perishables are not alike. Today's sophisticated refrigeration technology and microprocessor-based controllers maintain constant temperature—and constant vigil—on the sea or over the road. The result: goods are delivered fresh to the far-flung markets of the world.

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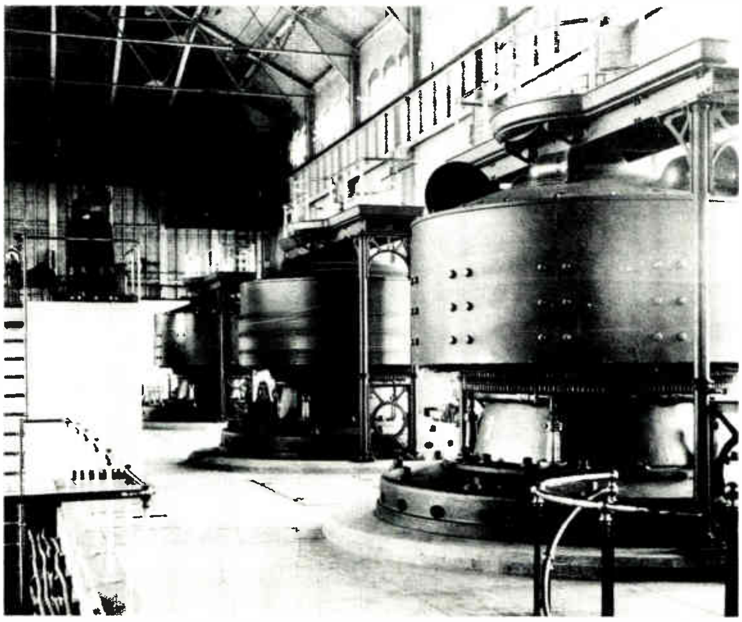
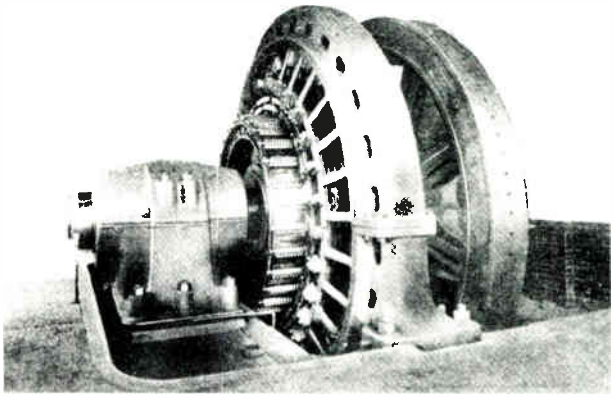
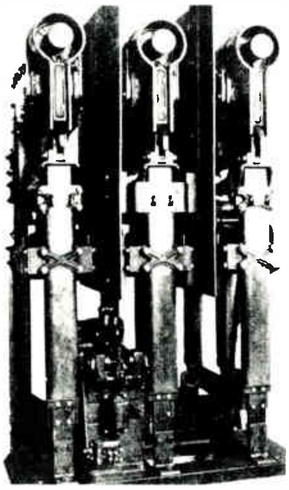
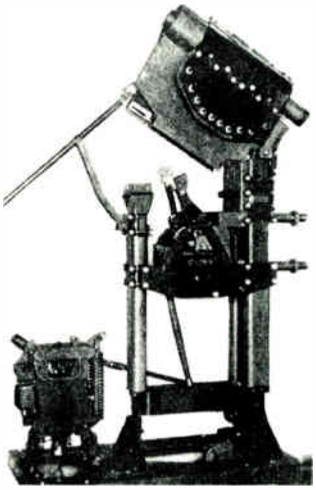
Historical Album—Part 2


Niagara generators


Steel-mill motor


De-ion circuit breaker



1895
In October, 1893, Westinghouse received an order for the first three generators for Niagara Falls. Each unit was rated 3750 kVA, 2200 volts, 25 Hertz.

In November, 1895, power was delivered to local businesses, and in November, 1896, to Buffalo, 20 miles away.

These first three generators, plus seven more, operated continuously for 26 years.

1901
First central-station turbine-generator installed in the United States.

Built for the Hartford Electric Light Company, Conn., the Westinghouse 2000-kW, 1200-rpm turbine was coupled to a 2400-volt, two-phase generator.

The turbine had about four times the capacity of any turbine built up to then.

1905
First installation of motors for steel mill main rolls in this country—at the Edgar Thompson Works of the Carnegie Steel Company near Pittsburgh, Pa.

This non-reversing mill had two stands of rolls, each driven by a 1500-hp, 250-volt dc motor, directly connected to the rolls. The principal product of the mill was rerolled rails.

1920
In November, 1920, Westinghouse broadcast the Harding-Cox election returns from KDKA, its experimental 100-watt radio station at East Pittsburgh, Pa. It was radio's first scheduled broadcast by a commercial station.

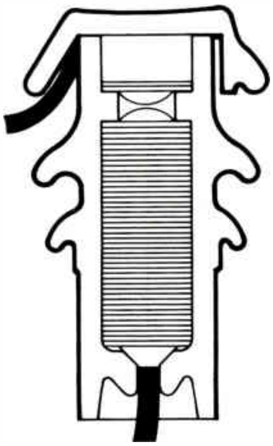
This was soon followed by a regular evening program. Programs consisting of music, news and announcements were listed in advance in most newspapers within a 200-mile radius of the station.

The broadcasts were received as far away as Texas, Kansas, Canada and on ships hundreds of miles at sea.

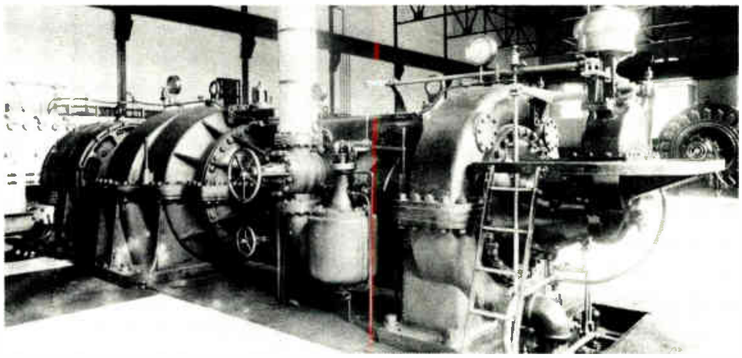
Now using a power of 50,000 watts, KDKA remains the leading radio station in Pittsburgh. The Company also has 10 other AM and FM radio stations and five TV stations throughout the United States.

1922
The modern autovalve lightning arrester is based on the principle announced by Dr. Joseph Slepian.

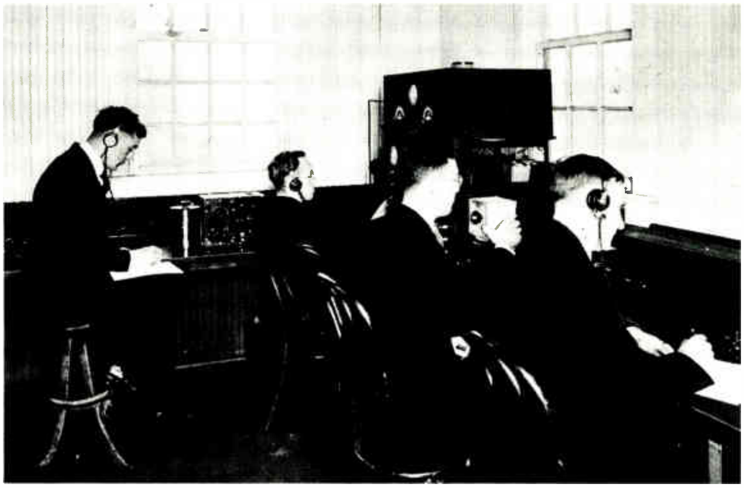
Failures of service, due to surge voltages produced by lightning and other causes, frequently occurred on a power



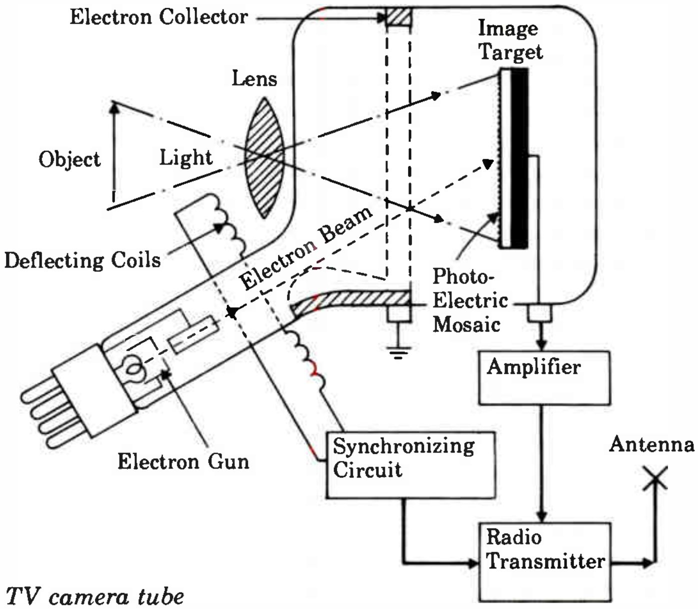
Autovalve arrester



Hartford turbine generator



Radio broadcast



TV camera tube

system. The “autovalve” arrester not only permitted more nearly continuous service, but eliminated the heavy cost of replacing transformers, fuses and other equipment under emergency conditions.

The “autovalve” consisted of many thin disks of material separated by even-thinner air gaps. Lightning could jump through; the feebler power current, spread thinly through the disks, could not follow.

1927

The de-ion circuit breaker was born. Modern circuit breakers still use the principle.

It did not *break* the arc at all, as did previous breakers—it simply *stopped* it the first time the ac current went to zero.

Researchers had found that during arc conditions, there was a thin space next to the cathode which deionized almost instantly when the current passed through zero, providing a definite voltage gradient to be overcome before the arc could be restruck.

By chopping the long arc into many short arcs by insulating plates—each short arc no longer than the width of the thin cathode layer—the entire arc path became a succession of cathode layers which reached their full insulating value almost instantly when the current passed through zero.

1928

Doctor Vladimir Zworykin of the Westinghouse Research Laboratories laid the foundation for modern television systems by inventing the iconoscope, the first practical TV camera tube.

In this camera, an image of the illuminated scene is focused onto a plate in the evacuated iconoscope tube. This plate is covered with a mosaic of tiny photosensitive elements, each insulated from its neighbors. The light falling on an element continuously discharges it as the light ejects photoelectrons. A beam of electrons from a gun is scanned over the plate, recharging each element by replacing the charge it has lost. This recharging current is the video signal, which is amplified, transmitted and used to recreate the picture in the receiving television set.

World-Class Manufacturing Focuses on Quality and Productivity

Leading-edge technology and radically new ways of thinking are not only dramatically changing the look of today's plants and factories, but literally altering the manufacturing culture itself. The result is an environment that encourages people to strive for technological excellence and achieve new levels of quality and productivity.

Here are a few examples that illustrate how modern technology has transformed the factory floor.

1. Machining the Tough Jobs . . .

In 1971, the largest direct numerical-control (DNC) system in the world controlled 60 NC machines manufacturing huge turbine blades.

Fifteen years later, this facility remains at the metalworking forefront; and the DNC system has since been revamped with up-to-date machine-interface units.

It includes the first computer-driven, automated forging/swaging cell. A host computer serially communicates with the six computer-driven machine tools in the cell.

A new commercially available cell management language (CML) controls the software to schedule the cell, sequence the machine functions, up- and down-load NC programs and perform all operator interface functions.

The cell includes several firsts:

- The first application of a non-contact gaging station for medium-tolerance parts at over 1000 degrees F. An industrial vision system and a two-axis computer-numerical-control (CNC) machine tool form the gage package which is fed by a CNC industrial robot.
- The first application of CNC, electric drive robots in a high-temperature, large-payload, forging environment. Two of these robots handle parts weighing up to 500 pounds in temperatures ranging from 1200 to 2200 degrees F.
- And the first computer-driven, precision-indexing rotary furnace. All monitoring, controlling and indexing functions are directed by an on-board computer.

2. For a Space-Age Electronics World . . .

To assure the high quality demanded by the electronics industry, copper-clad laminate, the base material for

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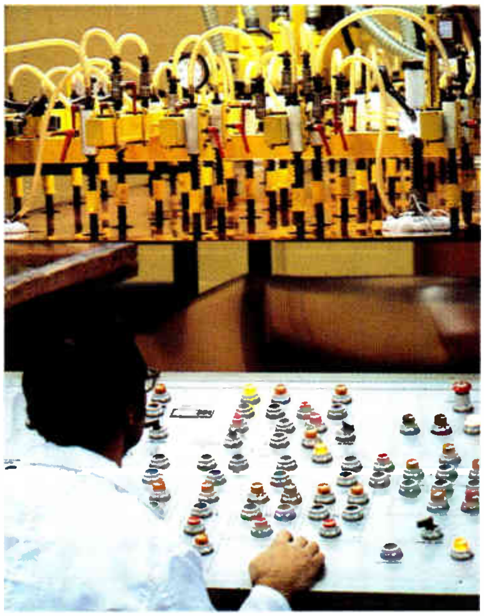


printed circuit boards, is assembled, pressed and cut to size virtually untouched by human hands.

The process starts in a clean room where robots alternately add large sheets of copper foil to pre-assembled sheets of glass cloth to form a multilayer stack. Each stack is moved from robot to robot by small, flat-bed cars operating from an overhead tramway. A Numalogic programmable controller synchronizes three overhead cars as grippers reach down, slide under each growing sandwich of layers and moves it to the next position.

Each thin stack, which may be as large as four-by-twelve feet, is then moved by conveyor to a huge automatic laminating press with 30 openings, each capable of pressing up to 10 laminates. From a control console, the operator sets values for pressure, temperature and sheet size and the stack is compressed and bonded together into circuit-board stock.

From there each sheet is transported to a large cutting machine and automatically slit into standard sizes for printed circuit boards used in everything from TV sets to satellites.

3. Staying a Step Ahead . . .

Extensive development work at several laboratories is focusing on new manufacturing technologies using lasers.

Advanced laser metalworking technology is investigated at the Westinghouse Research & Development Center. The main workstation houses an 18-kW CO_2 laser. It's one of seven workstations and four laser systems used to develop new products and techniques.

Another powerful metalworking laser at the Industrial Laser Center in Sunnyvale, Calif. is used to prove that lasers are reliable and practical tools for the factory floor.

The carbon dioxide industrial laser is controllable from 1 to 15 kilowatts. It produces an intense beam of continuous radiation at a wavelength of 10.6 microns, far into the invisible, infrared region of the spectrum.

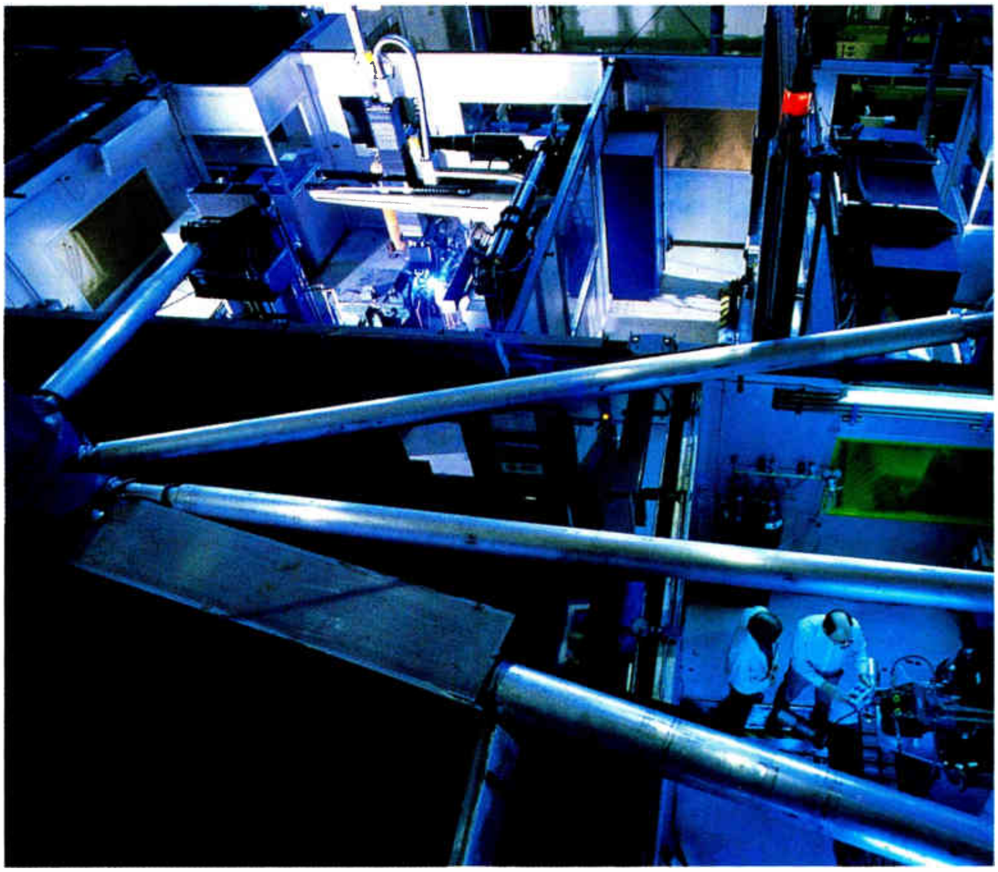
The beam is sent through a system of nitrogen-cooled ducts and water-cooled turning mirrors to any one of five work stations that share the laser's beam.

At one station, the laser welds on an NC worktable that handles pieces weighing up to 12,000 pounds.

At another station, the beam is rechanneled and used to harden the surfaces of large gears.

And at a third, multi-purpose work station, a 10-foot-tall robot delivers the laser beam anywhere within its 108-cubic-foot work area so that it can work with components of many different shapes and sizes.

3a



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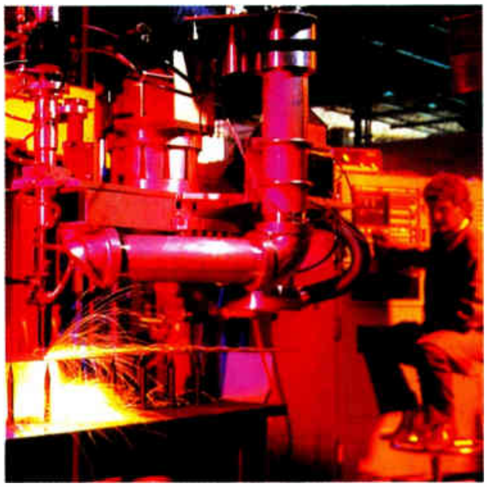


4

A laser-based flexible manufacturing cell developed at the Quality and Productivity Center consists of an industrial laser, an optical-beam delivery system, and a precision robotic positioning system. The system positions and moves the laser beam in three or five axes of motion along a stationary work piece. It can be coupled to rotary tables and material-handling robots or conveyors.

4. Change Goes Without Saying . . .

Flexible manufacturing systems (FMS) combine the technologies of management, engineering, manufacturing and robotic systems with planning and production-control software.

For example, a sheet metal FMS, which converts raw sheets into punched, marked and sheared components faster and more economically than conventional methods, uses just-in-time production philosophies and software techniques that integrate the total business system.

A customer's order and the date it's needed triggers the manufacturing cycle. The planning system uses this information to retrieve numerical-control (NC) programs, group parts according to thickness and due date, and to integrate programs to optimize material use and the punch path. Sheets are loaded by a robot with an extended forty-foot X-axis and rotary waist, which can select from any of six material stacks depending on size, gauge and type of material required.

Material use is maximized through random nesting of parts on each sheet. A second robot transfers the sheet to a marking head and onto a right-angle shear.

The software provides production planning and control, interfaces with the host business system, provides off-line programming and an interface with CAD/CAM functions.

5. The Plant Itself Becomes a Flexible Manufacturing System . . .

A new plant where printed circuit boards for defense systems are assembled has been called the aerospace factory of the future.

New technologies are introduced as they are developed. For example, guided by a two-camera vision system, robots precisely insert axial- and radial-lead components into printed circuit boards.

The plant has adopted the group technology process-flow concept and generic modular work stations; it has 181 work-in-process assembly and test work stations.

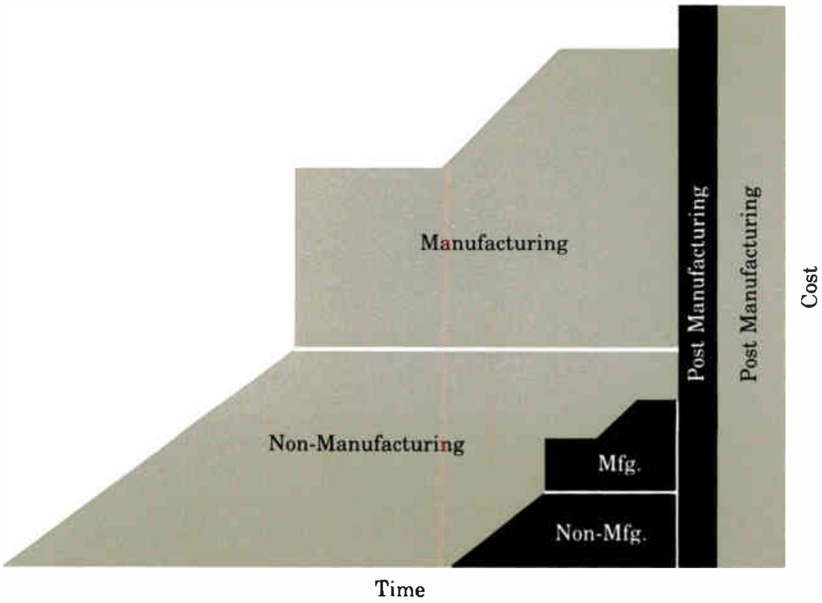
In effect, the entire factory is a flexible manufacturing system. The factory includes automatic material-handling systems, robots, process controllers, mechanized assembly equipment, and a networked data base. Information and material is provided automatically to teams of multiskilled technicians who schedule their own work to best meet daily or hourly needs.

5a

A pay-for-skills program has boosted productivity and created an attitude that welcomes the introduction of new technology. Each team is responsible for its own performance; there are no shop supervisors in the conventional sense.

This factory of the future has reduced the average production cycle from 12 to just 2 weeks. And yields (first time through) have gone from 33 percent two years ago, to more than double that today.

6. Total Business Cost-Time Profile



6. Reconsidering Traditional Philosophies . . .

Many plants are using new manufacturing philosophies to enhance customer service, improve quality, lower costs, reduce inventories and shorten cycle times.

Traditional approaches are giving way to totally new ways of thinking: just-in-time scheduling and production; kanban and other work-in-process systems to follow work flow; development of parent styles that can be modified quickly to customer specifications; group technology; and value engineering that addresses the functions a product performs.

5b

A recent philosophy called OPTIM (Operating Profit Through Time and Investment Management) diagnoses the health of the organization. This approach graphically illustrates the relationship between cost and time. It can be used to analyze the causes of problems, and set priorities among many manufacturing and non-manufacturing improvements. It can lead to solutions which improve total quality within a single product line, a department or an entire business.

For example, a manufacturer of transportation equipment and systems reduced assembly cycle time by 90 percent, cut work-in-process inventory by 90 percent and reduced labor costs by 50 percent.

At another location, revising procedures and improving communications techniques dramatically reduced the time for engineering drawings to reach the factory floor—from 174 to just 11 days.

In yet another case, a business providing services for electric utilities reduced order-entry and engineering cycle time from 22 days to 1 day, and reduced costs by at least 50 percent.

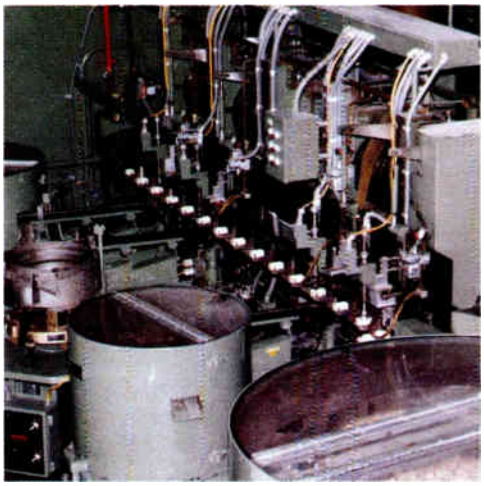
7. Designing for Producibility . . .

Automated assembly machines improve the overall quality of a product: they reject substandard components that don't meet close tolerances and eliminate such routine causes of human error as omitting parts or assembling them in the wrong sequence.

Hard-automated assemblers can be designed to produce families of products and, in many cases, the products themselves are redesigned to meet the requirements of automatic assembly.

Switch-assembly equipment consists of two machines connected by an automatic conveyor transfer. The two-machine system automatically feeds and assembles 19 different parts . . . producing 6 types of switch assemblies.

7



Each machine, with its own controller, assembles one-half of the product. Machine #1 assembles and automatically inspects base subassemblies.

Machine #2 accepts these subassemblies and completes switch assemblies at the rate of 40 per minute, a 188-percent increase in daily production. It's programmed to assemble, inspect, test and date-code the products. A total of 16 built-in inspection points and two test points reliably and continually monitor product quality—rejecting any product not passing all check points.

8. Precision Machining 400-Ton, 70-Foot-Long Giants . . .

Internal components for nuclear reactors are machined in a shop with tight temperature and humidity controls to assure consistent production of both small and large precision parts.

The plant handles components up to 70 feet long and 15 feet in diameter, weighing up to 400 tons. Yet tolerances are maintained to plus or minus one-thousandth of an inch.

Machine tools include large automated horizontal and vertical boring mills, deephole drills, and vertical machining centers that can machine 25-foot cylinders inside and out.

9. Advanced Technologies, Artificial Intelligence Fine-Tune a Process . . .

A new nuclear-fuel manufacturing process is totally automated from the admission of uranium gas to completion of welded fuel rods.

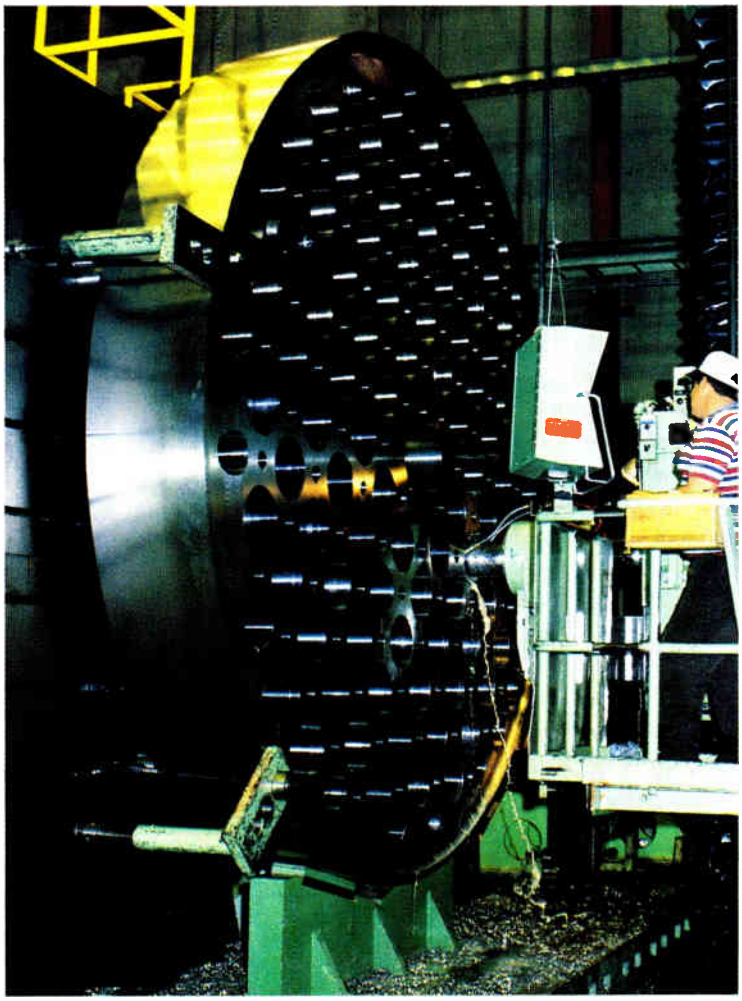
The line uses a dry conversion technology which minimizes chemical wastes, a unique pneumatic transport system for fine powders, automatic gentle handling of fuel pellets and rods, inspection robots, vision machines for automatic dimensional and visual inspection, and improved environmental controls.

In the kiln, where the gas is converted to powder, extensive instrumentation provides computer monitoring, data logging, data display and control of the process, permitting analyses of a large number of variables. These are used by an artificial intelligence system that learns from past experience.

This extensive instrumentation and control, coupled with artificial intelligence, fine tunes the process to optimize product quality.

The management information system ties together all elements of fuel rod production. The system relies on automated data input to minimize paperwork and human error. From a central control, a single operator monitors the entire process, receiving and coordinating signals from microprocessors throughout the facility.

8



10. Direct-Dialing the Factory or Warehouse . . .

Using an advanced negotiation system, a salesman in a field office can enter data on many products to work up a bill of material. This information is transferred to the division electronically—in seconds rather than days, and the price is sent directly back to the sales office.

Moving in parallel, the same data is channeled through an engineering logic pattern, producing approval drawings and manufacturing information.

The total cycle time for a typical panelboard negotiation is reduced from 130 to just 55 hours—and the actual work time from 25 to 10 hours.

Another answer to a just-in-time world is Speedline. This direct customer-order-entry system uses computer terminals at high-volume customer locations so they can reach directly and electronically into stock records. The customer can inquire about the availability of stock, standard products and call up prices. He can enter an order or check on one.

11. Transforming the Classic Machine Shop . . .

A modernization program at one facility reduced manufacturing floor space by 58 percent, increased plant capacity sixfold and cut average product cycle time from 26 to 3 weeks.

This was accomplished by moving from a classical machine shop to a fast-response assembly operation. It proved more efficient to source parts from suppliers throughout the world, get them delivered on time, then assemble and ship. One-hundred-percent inspection ensures that materials reach the assembly floor in perfect condition.

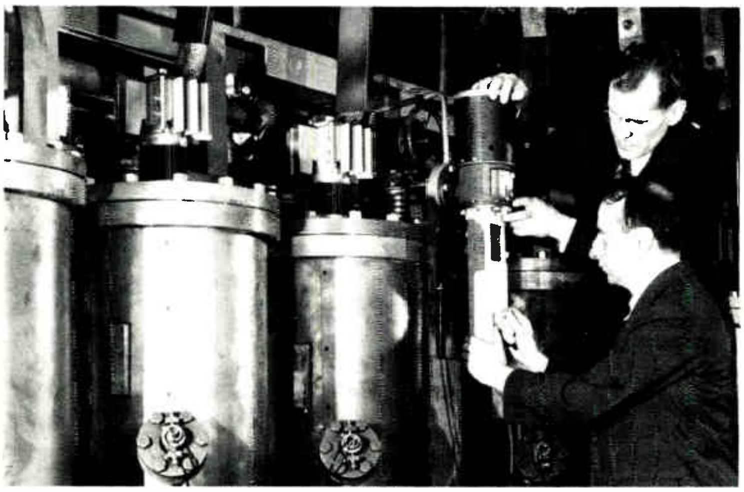
The very plant culture was altered. The organization is based on team concepts and matrix management. Workers have been retrained and upgraded. As an example, 650 computer terminals serve 1000 employes. Virtually all employes are computer-literate and process their own data.

9

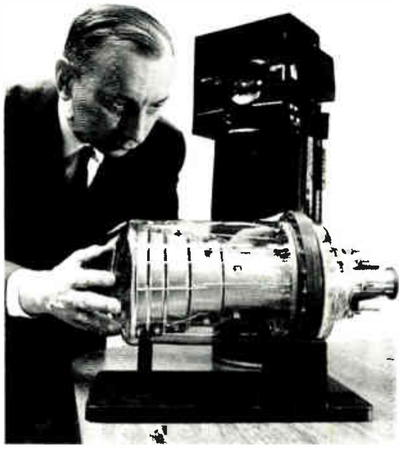
10

11

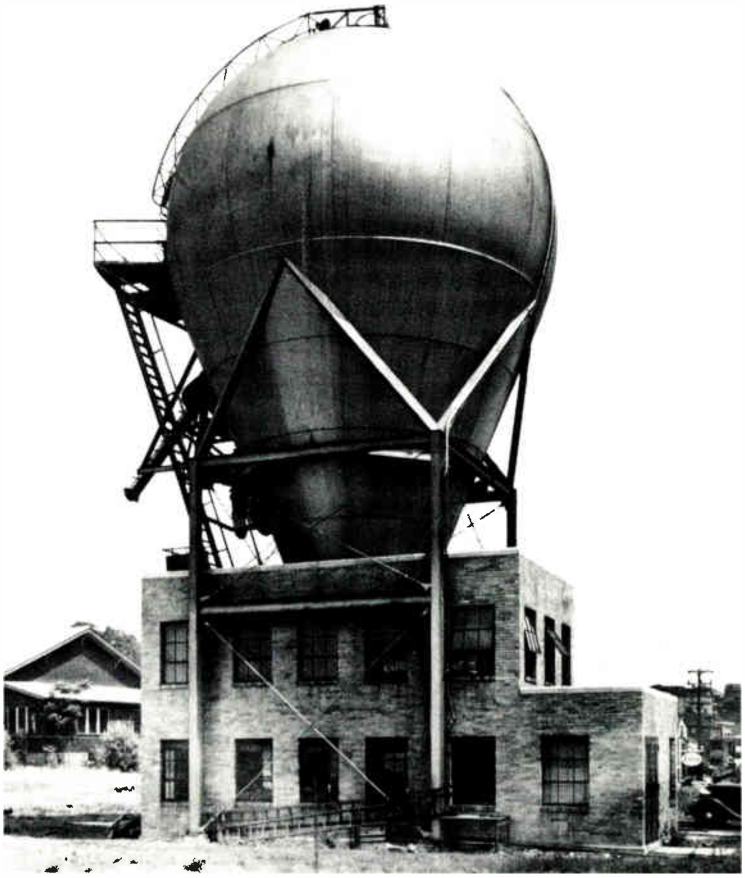
Historical Album–Part 3



Ignitron rectifier



X-ray image amplifier



Atom smasher

1932
Invention of the ignitron rectifier to convert ac to dc.

The ignitron rectifier had the advantages of previous systems, with few of their disadvantages. It could carry power current, had high overload capacity and could start conduction at any point in the positive half cycle.

1937
First atom smasher in industry—5,000,000 volts—constructed by Westinghouse Research Laboratories for a fundamental research program in nuclear physics.

The largest of its kind at the time, it enabled the Company to become familiar with an entirely new field of science. This initial step helped Westinghouse gain a leadership position in the production of nuclear energy for peaceful purposes.

1940
First long-range search radars ordered from Westinghouse in 1940 by the U.S. Army Signal Corps. Six of these were shipped to Hawaii in the summer of 1941.

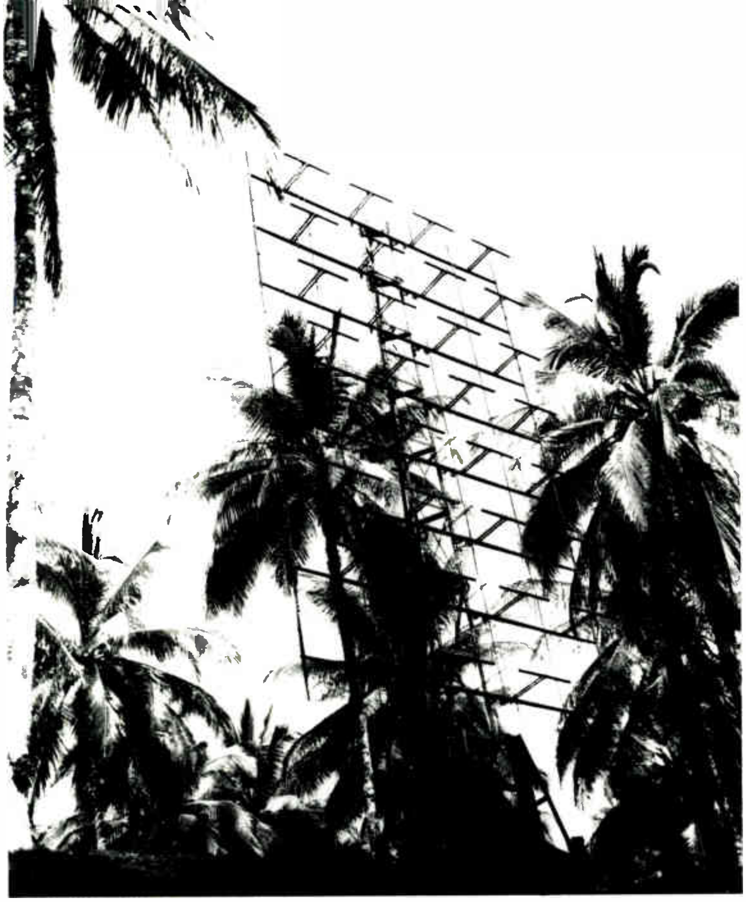
As a radar operator on Oahu watched his scope on Sunday morning, December 7, 1941, a formation of planes began to appear, coming from the north.

He checked the direction and called the aircraft warning center. There, the officer assumed (incorrectly) that the large flight of planes were B-17's arriving from the United States.

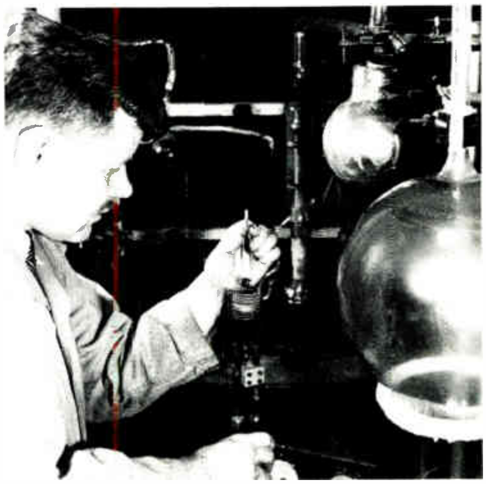
A few minutes later, the attack on Pearl Harbor began.

1941
Westinghouse research metallurgists working with ARMCO developed Hipersil, a high permeability grain-oriented magnetic steel.

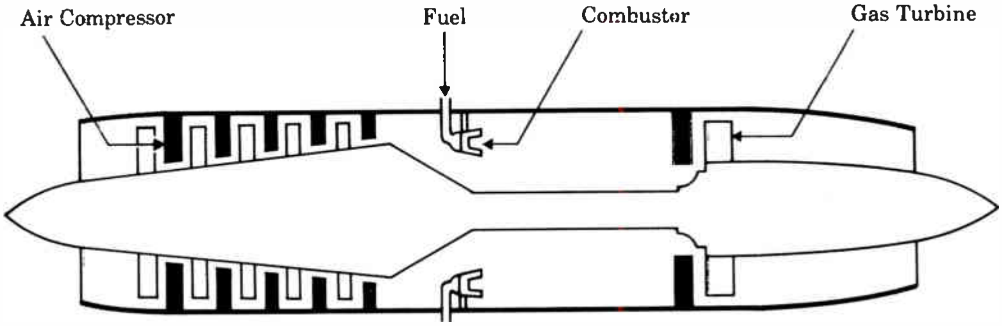
Because crystals were all aligned in the same direction, this silicon steel had one-third more flux-carrying capacity than the previous best grades of silicon steel. This meant transformers could be smaller, lighter and more efficient.



Early radar



Uranium for lamp filaments



Axial-flow jet engine

1941

In 1939 scientists and government officials of the United States were in a dilemma: they had become aware that an atomic bomb was a possibility. Worse, it was possible that our enemies were well on the way to achieving it!

They decided to embark on the trail of atom splitting, lacking only two things—time and the main ingredient, uranium.

It would be months before pure uranium was available from new plants, and all the pure uranium ever made in this country could be placed in a small shoebox.

And all of it came from a small-scale process in the Westinghouse Lamp Research Laboratory—a process developed years earlier in a search for a better lamp filament.

By 1941, Westinghouse daily production was in one-pound lots; at the end of 1942, 500 pounds daily.

In December, 1942, the University of Chicago began operating the first experimental atomic "pile," using several thousand pounds of uranium—most of it from the Westinghouse "emergency" uranium factory.

1945

First American-designed aircraft jet engine powered the McDonnell FH-1 "Phantom."

The Phantom used two Westinghouse 19-XB axial-flow engines, each delivering 1600 pounds thrust.

1949

Introduction of the first electronic amplifier for x-ray images, ushering in the use of electronics in medical imaging.

A revolutionary development for medical x-ray diagnosis and now used for all x-ray fluoroscopes, it greatly increased diagnostic ability and decreased patient x-ray doses. The first commercially practical tube intensified the original image by 500 times.

The tube does its work after the x-rays pass through the subject. They impinge on a fluorescent screen, releasing a stream of light rays. These, in turn, strike a photoelectric surface coated on the screen. The electrons emitted are accelerated by a high-voltage field across the evacuated space within the tube and are focused by electrostatic lenses on a second fluorescent screen at the end, where light rays are produced to form the image.

Solid-State Spectroanalysis of Stack Gases

Robert L. Nelson

Environmental considerations and economics are the drivers in the search for better ways to analyze stack gases. A new solid-state in situ analyzer now makes it possible to measure virtually all stack gases reliably, continuously and accurately.

The measurement of flue gas content from combustion processes has become essential to control fuel-air ratios, evaluate burner performance and monitor emissions to meet environmental regulations.

Major improvements have been achieved in stack gas measurement by using in situ analyzers. In situ analysis is performed on the gas as it exists in the stack. In situ analyzers are installed across the stack or use a measuring cell inserted directly into the flue gas stream.

In 1972, the in situ zirconium-oxide oxygen analyzer (see box) revolutionized combustion control. The ability to measure the excess oxygen content of combustion flue gases, on line, made it possible to control the fuel-air ratio by measuring the net result of the combustion process.

The development in 1984 of a potassium sulfate solid electrolyte cell combined with a zirconium-oxide cell permitted highly accurate in situ measurement and monitoring of sulfur dioxide.

Absorption Spectrometers

A second measurement method used for flue gas analysis involves absorption spectroscopy. This technique uses infrared (IR) or ultraviolet (UV) radiation and determines gas concentrations by measuring the absorption of radiation based on the Beer-Lambert law (see box).

The most common extraction absorption spectrometer is the nondispersive type (Fig. 1). The source radiation is not dispersed by a prism or diffraction grating to separate out the wavelength of interest.

Infrared light from an IR source passes through two gas cells, a reference cell and a sample cell. The reference cell generally contains dry nitrogen gas, which does not absorb light at the wavelength of interest. As light passes through the sample cell, stack gas molecules absorb some of the infrared light.

As a result, the light emerging from the sample cell has less intensity than the light from the reference cell. The difference is determined by a detector or detector/filter pair that is sensitive to the particular infrared frequency of interest.

Current In Situ Spectrometers

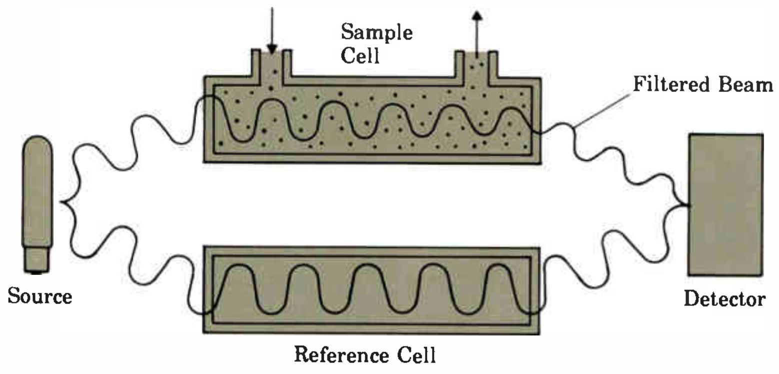
In situ spectrometers do not compare absorptions within reference and sample cells. Instead, they measure the degree of absorption by one of three techniques: differential absorption, gas filter correlation or second derivative spectroscopy.

1) Differential Absorption Spectroscopy measures absorption at a wavelength in the absorption band of the molecule of interest and compares it to the absorption at a reference wavelength where the gas of interest has minimal absorption.

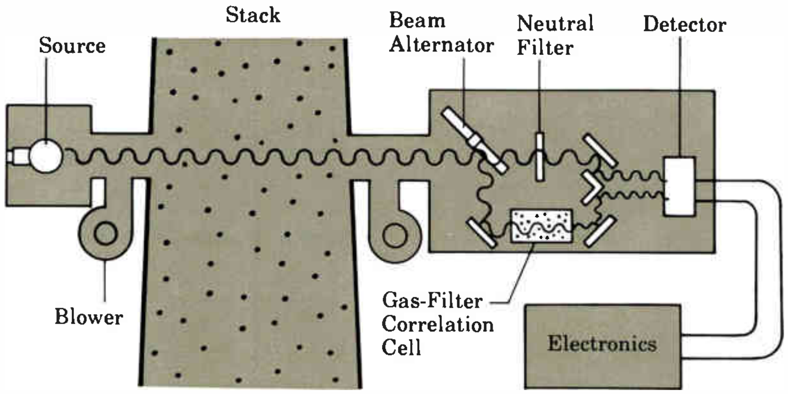
The wavelengths are selected by a dispersive device like a diffraction grating or by narrow-band optical filters. The ratio of the absorptions produces a signal that is related to the pollutant concentration.

2) Gas Filter Correlation Spectroscopy (Fig. 2) uses a filter made from a cell filled with the gas of interest. An infrared source radiates light through the stack to the detector assembly where the beam is alternated between

1–Nondispersive infrared analyzer.



2–Gas-filter correlation spectrometer.



a neutral filter and the gas filter correlation cell. When there is no pollutant gas in the stack, this cell contains enough of the gas being analyzed to remove most of the energy contained in the individual absorption lines of the gas. Light of wavelengths not absorbed by the correlation cell gas passes on to the detector.

The neutral filter reduces the energy from all wavelengths in the beam so that when there is no pollutant gas in the stack, the amount of energy reaching the detector from each beam is the same.

When there is pollutant gas in the stack, no change in the light passing through the correlation cell occurs since the absorption for the lines of interest are already complete.

The beam passing through the neutral filter, however, will have less energy since light was selectively absorbed by the pollutant gas in the stack. The difference in energy between the two beams is related to the pollutant concentration and is monitored at the detector.

3) Second Derivative Spectroscopy differs from differential spectroscopy in that instead of just sitting on a specific wavelength, a scanner or moving slit of a diffraction grating scans back and forth across the central wavelength.

The scanner modulates the light at wavelengths across the width of the absorption peak. Maxima will appear at the detector at double the frequency of the scanner. By tuning to a frequency which is double that of the frequency of movement of the scanner, strong signals indicate strong absorption. The amplitude of the detector signal at twice the frequency is proportional to the second derivative of the absorption with respect to wavelength.

Acousto-Optic Tunable Filter Spectrometer

Recent developments in single crystal materials have opened the door to the development of a solid-state, multigas spectrometer for stack gas analysis. Such materials exhibit different light velocities depending on the direction of propagation within the medium (Fig. 3).

Principles of In Situ Analysis

The Nernst Equation:
Zirconium oxide (ZrO_2) operating at high temperature conducts current when oxygen ion concentrations across a cell are unequal or when a differential voltage is applied. If different concentrations of oxygen are exposed to electrodes, the output voltage follows the Nernst equation:

$$\text{emf} = \frac{RT}{4F} \ln \frac{P'(O_2)}{P''(O_2)} + C$$

where:
emf = cell output, volts
R = gas constant
F = Faraday constant
$P'(O_2)$ = reference gas (oxygen partial pressure)
$P''(O_2)$ = process gas (oxgyen partial pressure)
C = cell constant
T = absolute temperature

The output voltage is inversely proportional to the logarithm of the oxygen concentration on the process gas side of the cell.

Similarly, potassium sulfate (K_2SO_4) conducts current by means of potassium ions when oxygen or SO_2 concentrations across a cell are not equal; it also follows the Nernst equation:

$$\text{emf} = \frac{RT}{2F} \ln \frac{P'(SO_2)}{P''(SO_2)} + \ln \frac{P'(O_2)}{P''(O_2)} + C$$

where:
$P'(SO_2)$ = reference gas (sulfur dioxide partial pressure)
$P''(SO_2)$ = process gas (sulfur dioxide partial pressure)

The output voltage is inversely proportional to the logarithm of the SO_2 concentration when O_2 variations are canceled by a ZrO_2 cell output.

The Beer-Lambert Law:
Absorption of light follows the Beer-Lambert law. This law states that the transmittance (T) of light through a medium that absorbs light is decreased exponentially by the product of the attenuation coefficient (a), the concentration of the gas (c) and the distance the light beam travels through the gas (l):

$$T = \frac{I}{I_o} = e^{-acl}$$

where:
I = intensity of light leaving the gas
I_o = intensity of light entering the gas

The attenuation coefficient (a) is dependent on the wavelength of the radiation and the properties of the gas molecule.

The coefficient tells how much light energy a molecule will absorb at a given wavelength. If no absorption occurs, (a) will be zero, and the transmittance would equal one or 100 percent. If the gas absorbs energy at some wavelength, (a) will be greater than zero, and the reduction of light energy across the path (l) will depend upon the gas concentration (c) and the original intensity (I_o) of the light beam.

In the case where the reference cell is filled with dry nitrogen, the attenuation coefficient (a_{ref}) equals zero; and the detector reading for the reference cell is:

$$I_{ref} = I_o e^0 = I_o$$

The ratio between I_{sample} and I_{ref} then becomes:

$$\frac{I_{sample}}{I_{ref}} = \frac{I_o e^{-acl}}{I_o} = e^{-acl}$$

Taking the logarithm of both sides:

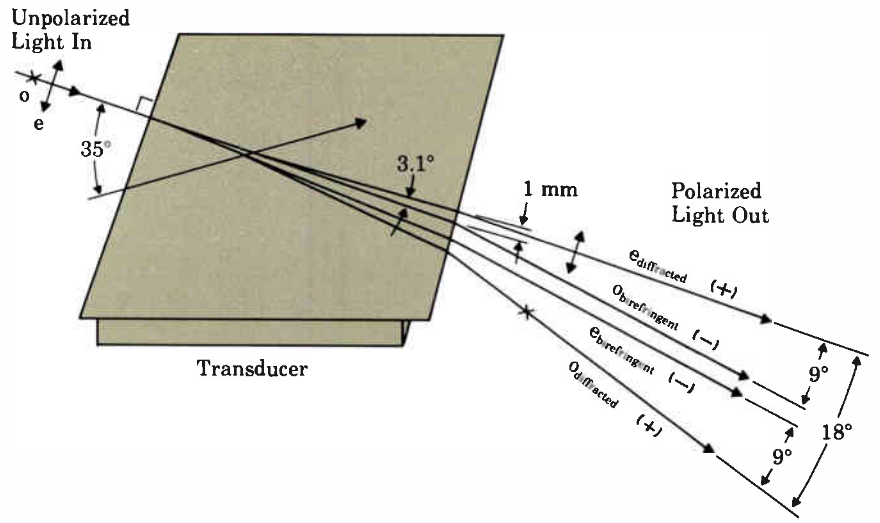
$$\ln \frac{I_{sample}}{I_{ref}} = -acl$$

$$c = -\frac{\ln \frac{I_{sample}}{I_{ref}}}{al}$$

where:
l = known length of path
a = known value or instrument calibrated to account for the value
$\frac{I_{sample}}{I_{ref}}$ = ratio of intensities detected by the detector

The (a) for the gas being measured is that for the absorption band center of the gas of interest.

3–The AOTF as a tunable source of infrared radiation.



When light passes through such a material, it splits into two refracted paths. One of these follows the ordinary laws of refraction and is called the ordinary ray (o-ray), while the other deviates somewhat and is called the extraordinary ray (e-ray). These two beams are plane-polarized at right angles to each other.

Certain birefringent materials, termed acousto-optic materials, can be used as a filter in a spectrum analyzer. In such acousto-optic materials, a light beam propagating as a polarized e-ray can be converted into an o-ray and be spacially separated from the original e-ray by interaction with, and diffraction from, an acoustic wave propagating through the same medium.

This phenomenon has been used to make narrow-band optical filters, whose peak transmission wavelength can be selected by properly choosing the frequency of the acoustic wave. Such filters are known as acousto-optic tunable filters (AOTF).

A new, efficient infrared transmissive acousto-optic material called thallium arsenic selenide (TAS) provides excellent operation as an AOTF over near-to-mid infrared wavelengths from about 1 to 16 microns.

Even more recently, the ability to grow production quantities of high-quality single crystal TAS has made it possible to build an AOTF on a commercial basis for operation over the 2 to 5.5 micron band. Such a filter with integral ultrasonic transducer can be used in place of mechanical filter wheels, spinning gas cells, moving mirrors, diffraction gratings and mechanical light choppers.

The TAS AOTF produces an electronically controllable narrow-band infrared filter that can be tuned to any infrared frequency. It can direct a chopped and tuned IR source across the stack on any combustion process to simultaneously measure the concentrations of CO, CO_2, SO_2, CH_4, NO, NO_2, H_2O, or other gases.

The AOTF is ideally suited to a form of differential absorption spectroscopy. It is not limited to two absorption frequencies by narrow-band optical filters or mechanically driven diffraction gratings; the AOTF can be tuned to any selected frequency in a matter of microseconds.

The AOTF is ideally suited for the design of real-time spectroscopic sensors:

- Small and rugged, it can be remotely controlled through a single RF cable.
- The aperture times the acceptance angle (etendue) for the AOTF can be extremely large. This large light throughput results in an extremely fast optical sensor. The high optical speed permits real-time optical monitoring with an excellent signal-to-noise ratio.
- Unlike conventional monochromators, optical speed is independent of the optical resolution.
- The AOTF can operate with random spectral access since changing the acoustic drive frequency changes the center passband of the device. Access time to any given frequency is limited only by the acoustic transit time through the crystal (a few microseconds). Random spectral access together with high optical speed permits sequential monitoring under computer control to analyze multiple gases in a stream.

The Optical Analyzer

A commercial multi-stack-gas analyzer (OPTAN for Optical Analyzer) is now under development using the TAS AOTF technology.

Its overall design is shown in Figure 4. It consists of three major functional systems: the optics, stack-mounted electronics and control-room electronics.

1) The optical subsystem is essentially an infrared solid-state spectrometer that operates over a relatively wide spectral range. A heated infrared source provides a broad band of infrared radiation. A portion of the output is collected and focused on the AOTF. After passing through the AOTF, the radiation is collected and collimated. The collimated beam then passes through the process stream or stack and is collected and focused on the detector.

The ability to rapidly select any number of infrared wavelengths for analysis permits the measurement of all infrared absorbing gases in the range of interest, eliminates interactive effects by proper algorithms and provides zero and range checks without beam splitters or moving elements.

2) Stack-mounted electronics interface with the optical subsystem at the detector and at the AOTF. The stack electronics impresses selected-frequency RF power on the AOTF. The detector microcomputer uses the optically filtered infrared signals to determine the absorption of selected gases in the process stream.

The source microcomputer controls the output frequency and amplitude from a frequency synthesizer, much as a quartz tuner selects a television channel. The AOTF functions not only as a rapidly tunable narrowband infrared filter, but as a solid-state optical chopper as well.

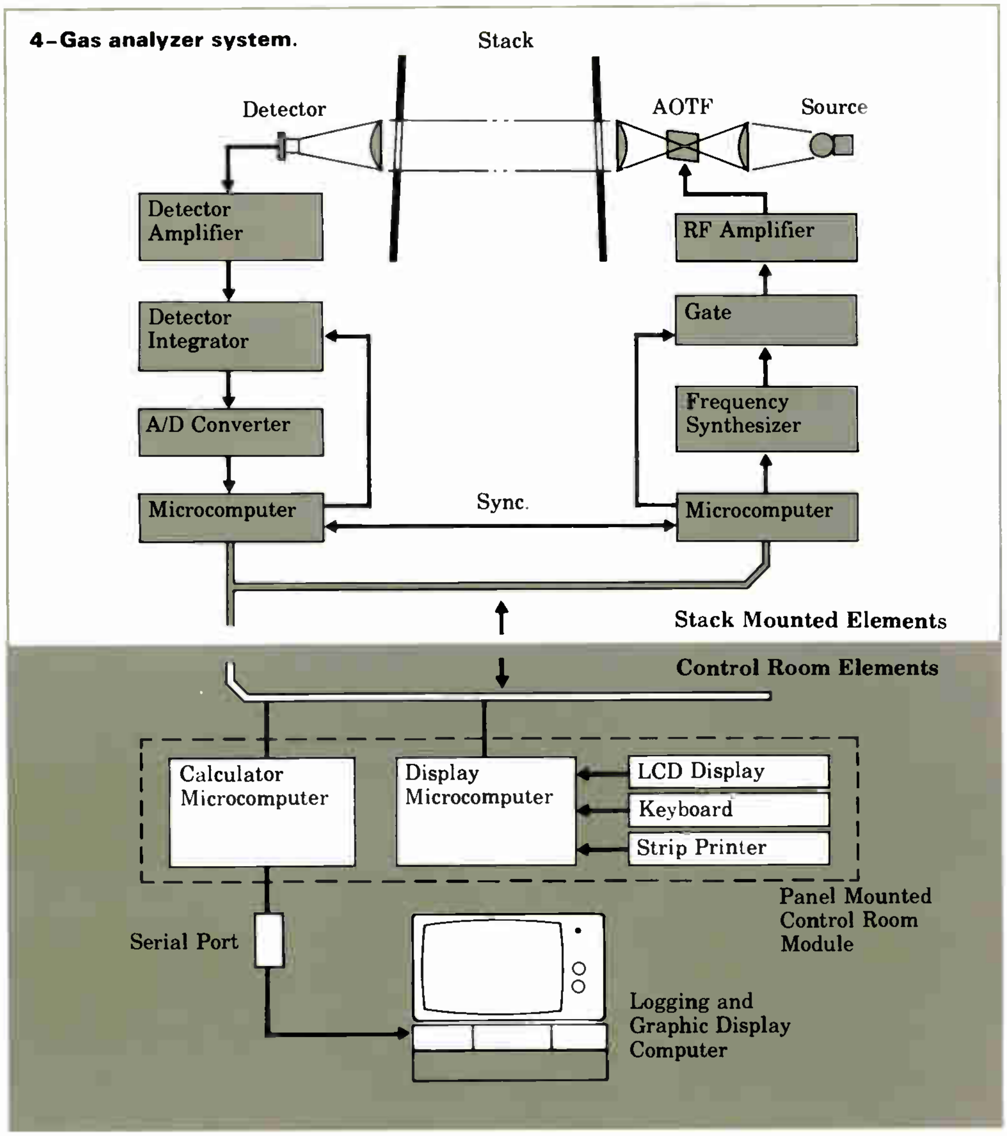
The detector output is integrated over the time the acoustic wave is passing through the filter to measure the radiation received during the entire period that the filter is open. This analog value is converted to digital form, and the detector microcomputer establishes an absorption value for each frequency selected.

3) Control room electronics convert the absorption information into gas concentrations. Although the simple algorithm described above illustrates the classic differential absorption technique, more complex algorithms in the microcomputer can account for special interference conditions, or additional gases can be analyzed by simply developing new software.

The normal mode of operation is to test on a real-time basis only the wavelengths related to the specific gases of interest. However, it's also possible to program a scan mode of operation so the frequency synthesizer will incrementally scan through a range of frequencies, a step at a time, to produce a plot of absorption versus frequency. This allows study of the total absorption spectrum of a given process. It's particularly useful in developing new software, studying interference effects between gases or studying changes in absorption at various gas temperatures or pressures.

The ability to measure virtually all combustion gases with a single solid-state, in situ analyzer adds a new dimension to the development of future combustion control systems.

4-Gas analyzer system.



Robert L. Nelson is Engineering Manager, Westinghouse Combustion Control Division, Orrville, Ohio.

Evolving Technology of Airborne Radar

H. E. Schrank
B. A. Sichelstiel

Airborne radar is undergoing dramatic changes from the present technology to future systems with antennas built into the aircraft skin to reduce drag and increase "stealth." In addition, these new systems must be more reliable and provide more functions in less space.

Early airborne radars used paraboloidal "dish" antennas which were scanned by moving the entire antenna mechanically, either in continuous rotation for 360-degree azimuth coverage or back and forth for limited coverage (Fig. 1a). The antenna's mechanical inertia and gimbal structure limited the scanning rate.

To provide faster beam scanning to track many targets at once, phased-array antennas were developed. In this technique, an array of many closely spaced radiating elements (radiators) forms a directed beam, which scans electronically by using a phase shifter behind each element. Thus the antenna need not move (Fig. 1b).

Phased arrays allow much faster scanning and provide other important advantages, including more precise control of the amplitude and phase distributions across the antenna aperture. This allows suppression of antenna pattern sidelobes, which is important both to reduce clutter (unwanted ground reflections) and for jamming interference.

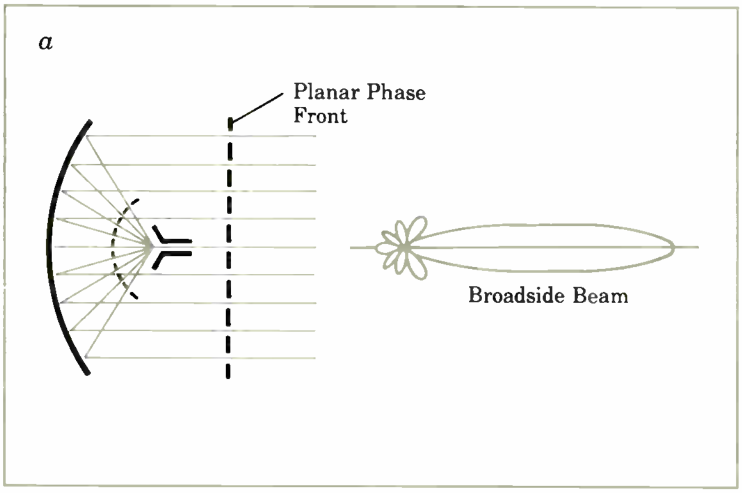
Changing the phase of the radiators steers the beam, while tapering the amplitude of the signals reduces the sidelobe pattern.

One example of a phased-array antenna is the Airborne Warning and Control System (AWACS). This planar array of slotted waveguide radiators (Fig. 2) is about 25-feet long and 5-feet high and forms an electronically steered beam with sidelobes that are lower by orders of magnitude than previous antennas.

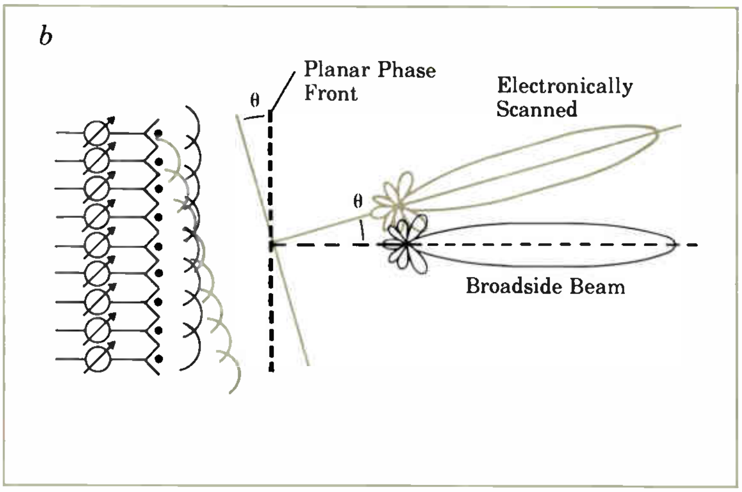
These ultralow sidelobes were necessary so the radar could detect low-flying aircraft targets in the presence of strong ground echoes (clutter). The combination of low sidelobes with pulse Doppler technology made the AWACS system extremely successful as a "downlook" radar (see box).

The AWACS antenna is enclosed in a large radome which mechanically rotates with the antenna for 360-degree-azimuth scanning. While the rotating radome and antenna scans the beam in azimuth, the array scans electronically in elevation using precision ferrite phase shifters. In effect, the antenna scans one dimension electronically and a second dimension mechanically.

Because of space limitations on modern aircraft, current radars must perform multiple functions as well as adapt to changes in environment. Such a multifunction radar, known as the Electronically Agile Radar (EAR), was built in the late 1970's and successfully demonstrated several functions—ground mapping, terrain avoidance and follow, and target detection and tracking.



1a–Early airborne radars used a mechanically scanned antenna.



1b–Electronically scanned antenna.

The EAR antenna is a circular-aperture (39-inch diameter) array of circular waveguide elements. It forms a low-sidelobe beam which electronically scans in two dimensions (azimuth and elevation) and can switch from linear to circular polarization for operation in a rain environment.

A more recent application of multiple-function, adaptive technology is the radar now being produced for the B-1B aircraft. It not only performs multiple functions but in addition has "low observable" characteristics to reduce its radar echoing cross section (RCS)—that is, it's harder to detect by enemy radar.

One way to achieve low RCS is to avoid having the flat face of the array normal to the line-of-sight of an enemy radar. By tilting it down (Fig. 3), it reflects the beam from an enemy radar toward the ground rather than back to its source.

Figure 4 shows a partially assembled B-1B array with some phase control modules (PCM's) plugged into the multilayer board and waveguide feed manifold. Each PCM is a dielectric-filled, circular waveguide containing a ferrite phase shifter and polarization switch. The small circuit board attached to the side of each PCM controls the phase and polarization of the module's radiated beam.

The radar includes a computer to control the functions and process the signals received by the array. The transmitter is a high-power traveling-wave tube RF amplifier (9 to 10 GHz), referred to as a "bottle" transmitter to distinguish it from the more advanced transmitters under development.

Tomorrow's Technology

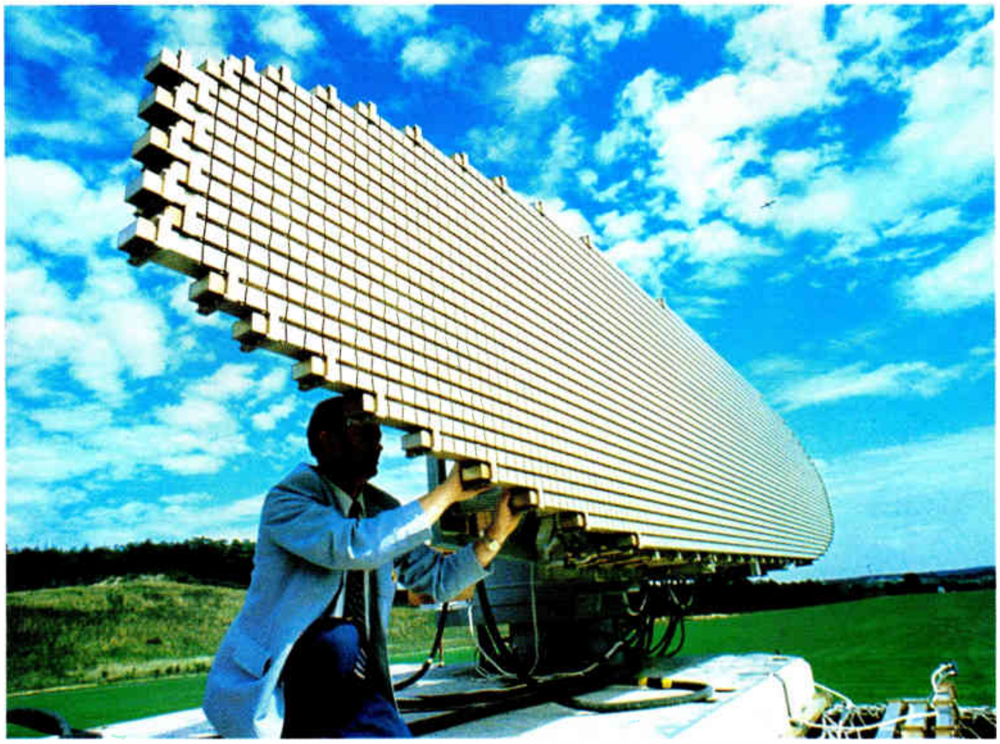
Future airborne radars must be agile (steered electronically), adaptive, multifunction, low-observable, conformal and resistant to jamming.

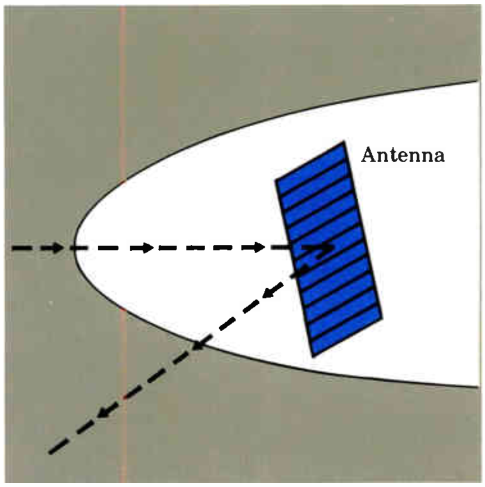
To meet these challenges, the cost of aircraft avionics may approach 50 percent of the total fly-away cost. To stem a disproportionate growth in this cost and still provide the necessary functions, future designs must focus on three areas: (1) high reliability, (2) multifunction, and (3) low observability (stealth).

Reliability

The need for high reliability leads radar technology toward solid-state "active" phased arrays. In these, each element will contain its own transmitter in the form of an RF power amplifier. In effect, this will distribute the transmitter function over thousands of array elements instead of generating all the RF power in a single transmitter tube, or "bottle." This results in much higher reliability because several elements can fail without seriously degrading radar performance, as compared to the catastrophic failure of a bottle transmitter.

Each module also contains a low-noise RF amplifier to function in the





2–AWACS airborne planar-array antenna (left) with electronically steered beam.

3–(Above) tilted airborne antenna to reflect enemy radar signals to ground.

receiving direction, along with phase shifters to electronically steer the beam (Fig. 5).

Multifunction

Multifunction radars are needed because of the scarcity of space for antennas on advanced aircraft, with their sleek, "stealthy" shape.

Earlier aircraft used separate antennas for radar, communication, navigation, electronic countermeasures (ECM) and target identification friend or foe (IFF).

In general, multifunction radars will operate at higher frequencies and over wider bandwidths with specific bandwidths allocated to each function.

Antenna design is important in integrating the many functions of future radars. Fewer separate antennas that serve more functions and offer larger fields-of-view can both reduce costs and reduce the surface area needed for antennas on future aircraft.

One key to integrating these functions is the rapid advance in technologies concerned with gallium-arsenide integrated circuits and very-high-speed integrated circuits (VHSIC).

Gallium-arsenide (GaAs) integrated circuits (ICs) can provide both power and low-noise performance over much broader bandwidths and at much higher frequencies than is possible with silicon technology, so the integration of functions can be more easily carried over to the antenna subsystem level.

Pulse Doppler Radar

Pulse radars measure the distance (range) to a target by transmitting a pulse and noting the elapsed time for the reflection to return. Since electromagnetic waves travel at the speed of light, the range can be calculated:

$\text{Range} = \frac{ct}{2}$, where c is the speed of light and t is elapsed time.

Pulse Doppler radar combines the pulsed operation with the Doppler principle to measure both range and velocity of the target. More important, it can discriminate between a moving target and stationary background objects (or clutter) which also reflect waves.

The Doppler effect is the apparent change in frequency of radio waves that occurs when the source of the wave and its target are in motion relative to each other—the frequency increases when the source and target approach each other and decrease as they move apart.

Figure (a) shows the Doppler effect on a stationary target, which results in no frequency change between transmit and receive waves.

Figure (b) shows a closing target, resulting in a higher frequency for the reflected wave than the transmitted wave.

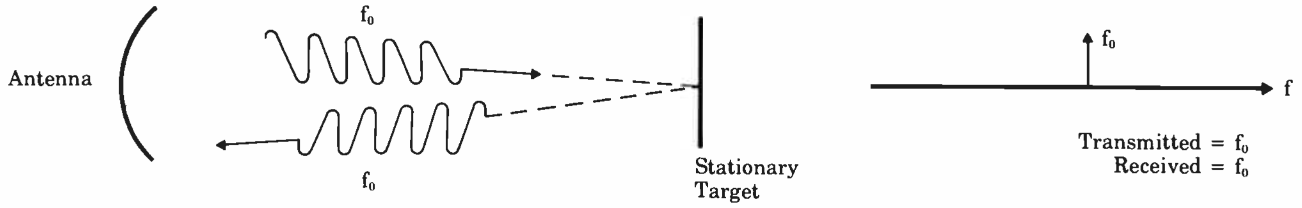
And Figure (c) shows an opening target, with the reflected wave having a lower frequency.

The change in frequency is measured by electronically subtracting the two frequencies.

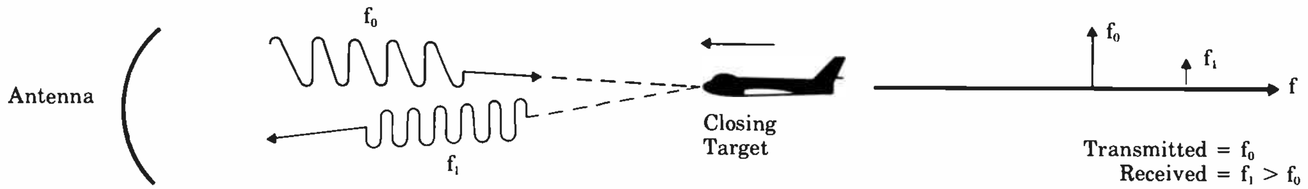
Knowing both elapsed time and the frequency change between transmit and receive waves, both range and velocity can be determined.

Also, by filtering out any return waves with unchanged frequency, the unwanted reflections from stationary objects can be screened out.

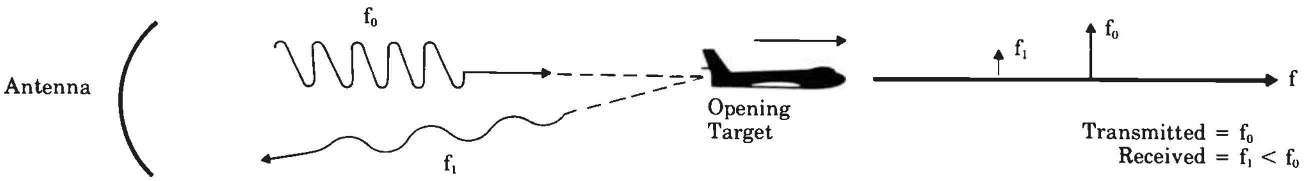
a



b



c



GaAs monolithic ICs operating in the microwave frequency band provide the technology base for future solid-state or "active" phased-array antennas. The distributed-amplifier approach would be much more expensive without these advances in lower-cost, high-yield IC processes.

Stealth

The need to be less observable means that radar and other antennas can no longer have large echoing surfaces. This leads toward antennas that are flush with the aircraft skin (Fig. 6), rather than being flat or protruding. These flush antennas are called "conformal" because the arrays of elements conform to the curved surfaces of the aircraft fuselage or wings.

The radar cross sections of earlier aircraft were dominated by three principal reflecting sources—the engine duct, the cockpit, and the radar antenna/bulkhead area. The first two sources have been reduced by treating the materials and shaping the geometry, leaving the antenna problem as the most serious. Engineers have now demonstrated they can reduce the radar cross section by using conformal electronically scanned antennas.

In summary, reduced cost, reduced radar cross section, functional integration and enhanced performance can all be achieved through the use of emerging technologies and techniques.

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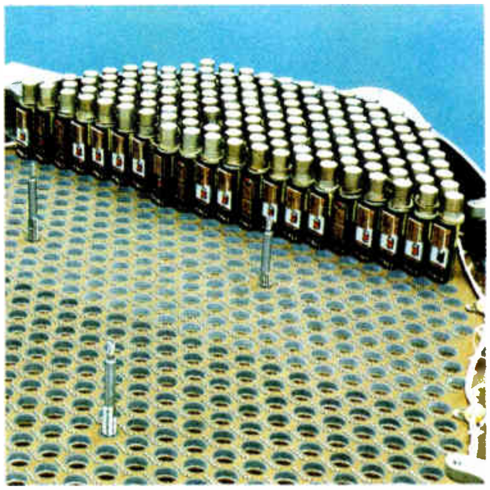
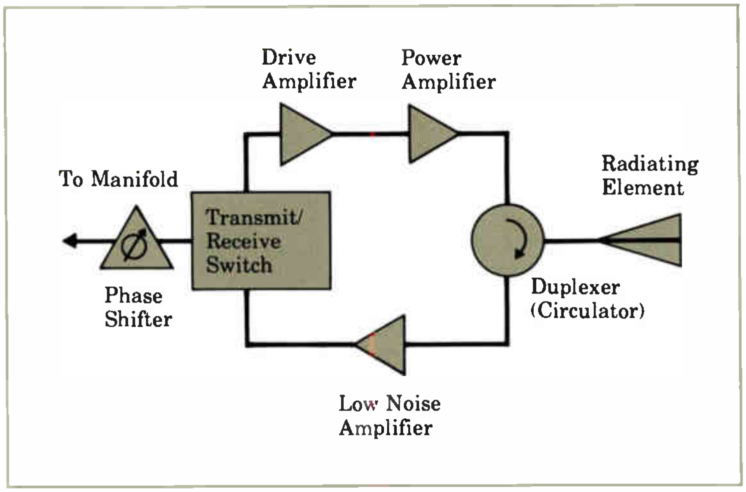
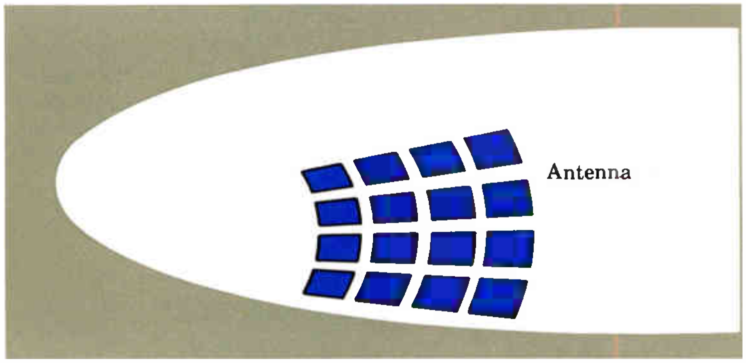


4–Antenna array for B-1B bomber with individual radiating modules, each with its own phase shifter circuit mounted on the module.





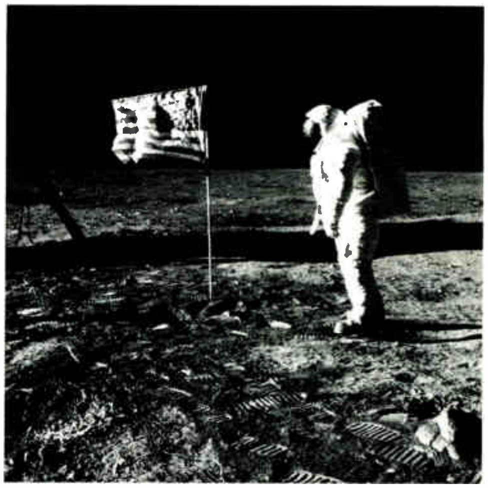
5–Typical transmit/receive circuit in each antenna module (above).

6–Conformal array for future airborne radars to reduce detection by enemy radars (below).

Historical Album – Part 4

Nuclear submarine

Automatically defrosted refrigerator



Lunar camera

1950
First automatically defrosted refrigerators introduced.

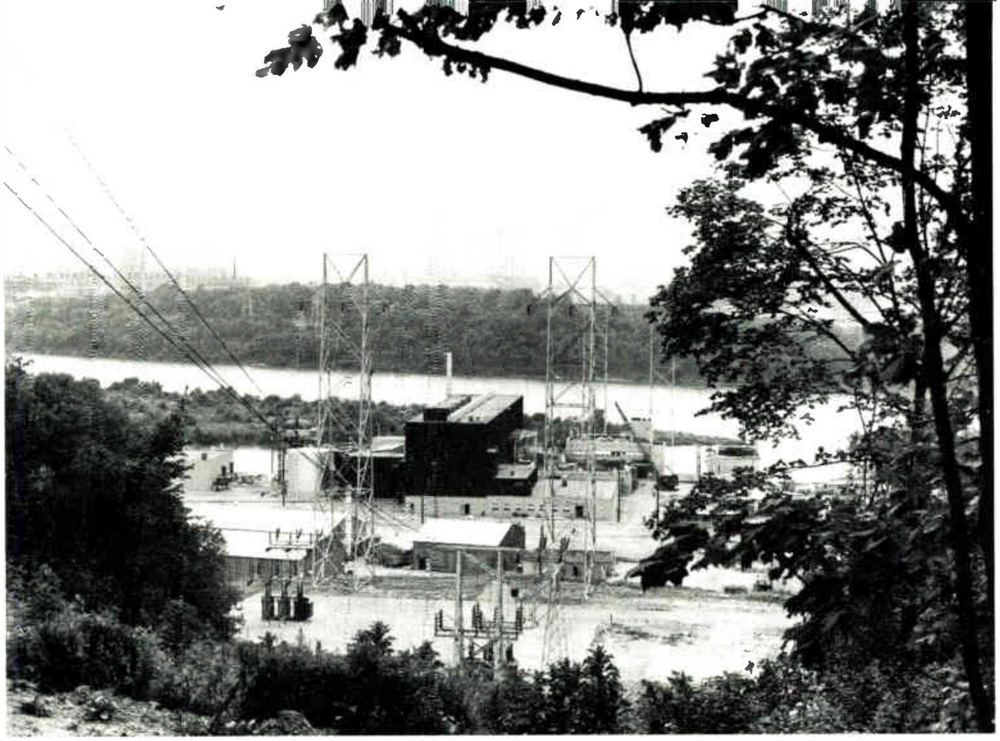
The automatic defroster did the job in minutes. A heating element warmed the refrigerant flowing through the coils, melting the ice but leaving food frozen.

1951
First inner-cooled coils (using hydrogen) increased the output of large generators by at least 50 percent.

1953
Invention of pulse Doppler radar revolutionized modern radar technology. The Doppler effect is the apparent change in frequency of radio waves that occurs when the source of the wave and its target are in motion relative to each other—the frequency increasing when the source and target are approaching each other and decreasing when they move apart.

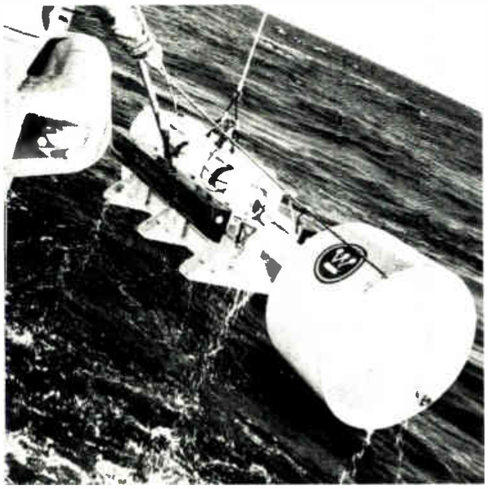
This Doppler "shift" is measured to detect the velocity of the target. More important, it separates the moving target from stationary background objects (or clutter) which also reflect waves back to the source.

1955
First nuclear submarine—the USS Nautilus—went to sea. It was powered by a Westinghouse pressurized-water nuclear power plant. Its highly successful career ended in 1985, when it was towed to its final berth in New London, Conn.



Nuclear power plant

Molecular electronics



"Photographing" the ocean floor

Airborne radar

1957
Nation's first nuclear-electric power plant put in operation—the Shippingport station of Duquesne Light Company, near Pittsburgh, Pa.

The 60,000-kW plant was powered by a Westinghouse pressurized-water nuclear reactor.

1959
Westinghouse first demonstrated successful molecular electronics devices (integrated circuits). This technology revolutionized the electronics industry.

Integrated circuits provide the ability to combine many individual circuit functions on a single integral block of material.

1964
New sonar was announced for "photographing" the ocean floor.

A sonar vehicle towed under water behind a surface vessel continuously scans the ocean floor with beams of high-frequency sound waves. Reflected energy is picked up and produces sharp clear pictures on a TV screen or recorder.

1969
Westinghouse lunar camera enabled millions of television viewers on earth to watch man's first walk on the moon.

1971
First in situ commercial oxygen analyzers to directly measure the oxygen in combustion stack gases.

This instrument allows quick, reliable and continuous monitoring and control of the results of combustion processes.

1972
First flight tests were conducted on a new and versatile Airborne Warning And Control System (AWACS), which provides an instant overview through a range of more than 300 miles. It detects, identifies and tracks all high- and low-flying aircraft within that radius.

The Power of Computer-Aided Engineering

Doug Drumheller

The evolution from pencil and paper to the slide rule and on to microprocessor and computer technology has greatly improved the engineer's ability to solve complex problems. Computer-aided engineering is completely changing the way products are designed and manufactured.

Computer-aided engineering covers a very broad area: it includes any application in which an engineer uses a computer to help do a job.

To date, computers have been used to help with two basic engineering tasks: quickly performing difficult mathematical calculations involving large amounts of data; and visually portraying complex or conceptual design information for analysis, manipulation or documentation.

They have a single purpose: to increase the engineer's productivity by performing tasks faster and by doing things right the first time.

The following examples—among many—give a flavor of the great diversity and scope of computer-aided engineering applications in industry.

Analytical Power

The invention of logarithms in 1614 made possible the slide rule—the first tool to enhance the engineer's mathematical productivity. The "slip stick" remained the primary means of calculation until well into the 1960s when it was replaced by the widespread use of computers (Fig. 1).

Among the first uses of engineering computers in industry was the calculation of complex reactor neutron interactions.

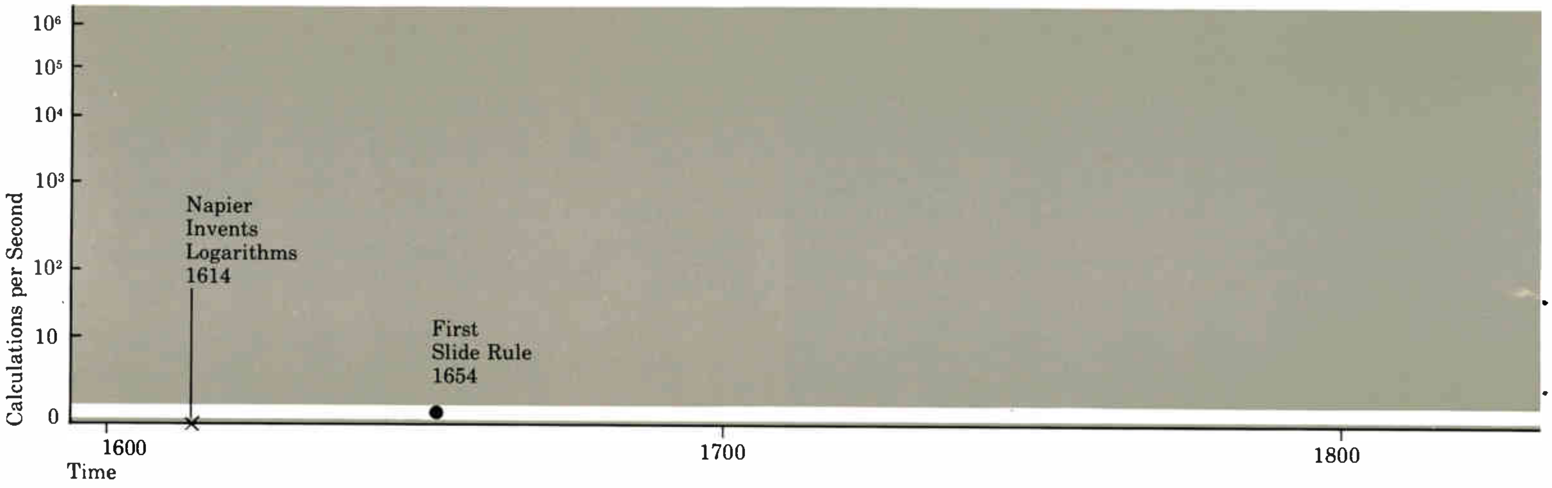
As early as 1953, engineers and scientists designed the first commercial nuclear power station at Shippingport, Pa., using an early UNIVAC computer. And in 1967, the first of many supercomputers was used not only to design nuclear reactors but also to perform realistic simulations of nuclear operations.

Today, supercomputers are involved in such large number-crunching problems as nuclear fuel management, thermal-hydraulic studies, simulated transient performance of nuclear steam systems under hypothetical accident conditions, stress analysis of components, simulation of electronic circuits and fluid dynamics.

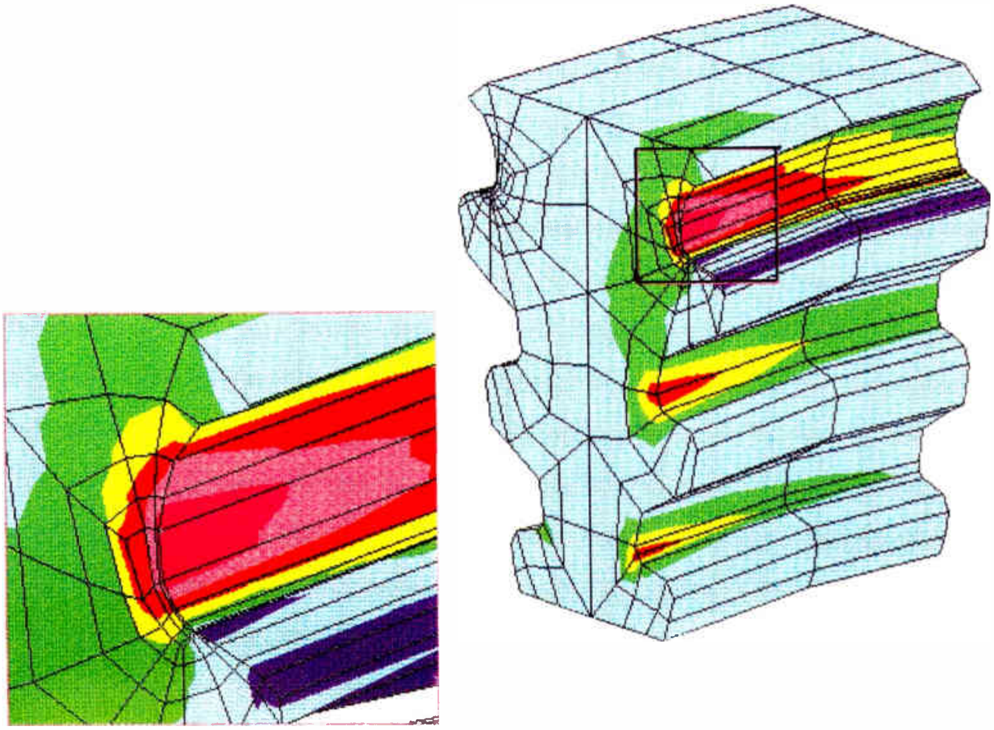
For example . . . the development of finite element software has revolutionized structural analysis.

One such program (WECAN) is used by structural engineers to perform a wide range of static, dynamic and heat conduction analyses. It is used to compute the structural behavior of a wide variety of structures including those representing two- and three-dimensional models, shell structures, axisymmetric bodies of revolution, beam and truss structures and piping systems.

The system performs static elastic and inelastic analyses, computes natural frequencies of structures, explores steady-state and transient thermal conditions, represents dynamic behavior of a structure due



1–The dramatic growth in engineering productivity in recent years is illustrated by the number of instructions per second engineers can execute. This number remained virtually unchanged for centuries. Today, it approaches one million in an engineering workstation.



2–Analysis and modeling programs allow engineers to perform many traditional design tasks mathematically by computer. Here, a finite element analysis highlights areas of principal stress on a turbine blade root.

to time-dependent loadings, or predicts the response of a structure to seismic loadings.

The program has been used to design, analyze and evaluate turbine blades and rotors, huge nuclear reactor pressure vessels, reactor coolant pumps, the effects of temperature distribution on the silicon web-growing process and the analysis of tiny solder droplets on electronic circuit boards.

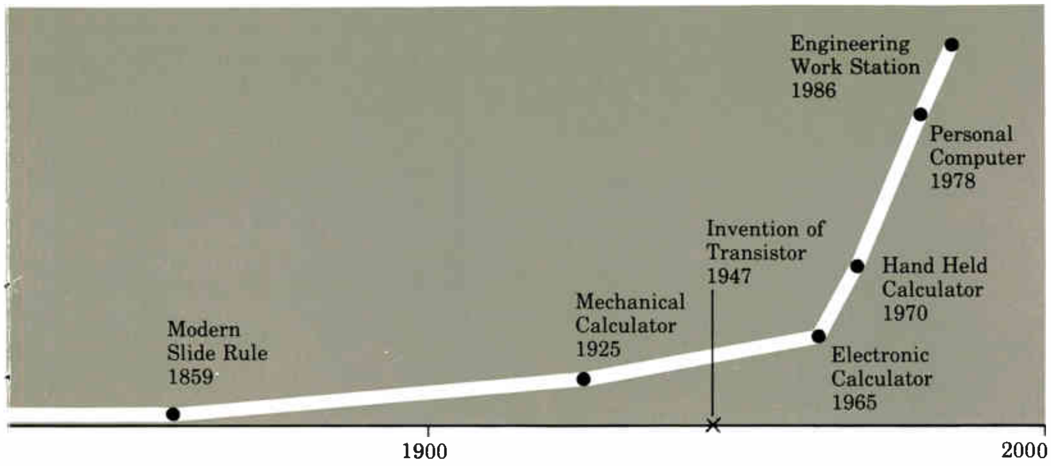
A companion software product (FIGURES) has advanced graphics capabilities. Complex pictorial, interactive models can be constructed from the data. Contour stress plots, deformed shapes and time-dependent plots give graphical representation of structural behavior. A typical analysis might involve the stress levels on the surface of a rotating turbine blade airfoil or turbine blade root (Fig. 2).

The speed and power of computers are continually increasing (see box). The newest supercomputer can perform 840 million calculations a second. Such computers are used by corporations and universities to solve a wide range of practical scientific problems.

Speed is important because complex problems require human interaction, interpretation and decision making between computer iterations.

For example . . . a fuel reload pattern is often designed after a power plant has been shut down for refueling. Replacement power may cost more than 500,000 dollars a day—so speed is vital.

For example . . . a finite element analysis of a large structural piece may involve calculations known as non-linear simultaneous equations—and 180 billion arithmetic operations. Until recently, even giant computers



took 148 hours to perform this analysis. Today, it can be done in just one hour.

For example . . . the Westinghouse Energy Systems Computer Center was chosen by Carnegie Mellon University and The University of Pittsburgh through a National Science Foundation grant to establish a National Supercomputer Center in Pittsburgh for basic research in science and engineering.

This is one of five national centers and includes the most powerful machine of its kind in the world.

Picture Power

At the other end of the spectrum, minicomputers and personal computers have brought low-cost computing power—and graphics capabilities—to virtually every engineer.

There's a quantum difference between pencil and paper—or pen and ink drawings—and the graphics capabilities of today's minicomputers.

With pencil and paper, the designer is limited to a two-dimensional or isometric view of a part. Computer-aided design and drafting (CADD) makes possible a three-dimensional model, along with the ability to view the design from any angle.

In addition, changes can be made directly on the computer in a fraction of the time it would take otherwise and allows several iterations of a design. CADD increases the engineer's productivity and improves the quality of the design and ultimately, the manufacturing of the product.

For example . . . one CADD system used to design coolant pumps and other mechanical products is integrated with many aspects of the engineering and manufacturing cycle—including drafting, manufacturing and testing, planning and inspection.

The total pump design layout, including three-dimensional models of the impeller and diffuser, is developed in the CADD data base.

The iterative, interactive data base is used by engineers for stress and thermal finite element modeling,

3–Workstations combine—through a readily accessible personal computer—the tasks needed for engineering with those jobs performed by other office workers.

Super-Fast Computers

Supercomputers are an extremely valuable tool for many high-technology applications.

The recently established National Supercomputer Center in Pittsburgh contains the fastest computer in the world. There are three primary reasons for this speed.

1) The super-fast computer uses a type of semiconductor chip known as a bipolar chip, which is faster than other chips. And to enhance its speed, each chip is asked to perform fewer functions. There are nearly 600,000 chips in the four main processors and 150,000 more in the extended memory.

2) Because computers operate on electricity, the ultimate limit to their speed is the speed of light. Since the Supercomputer is designed to handle a new instruction once every 9-1/2 billionths of a second, the transmissions between the circuits have to take even less time than that.

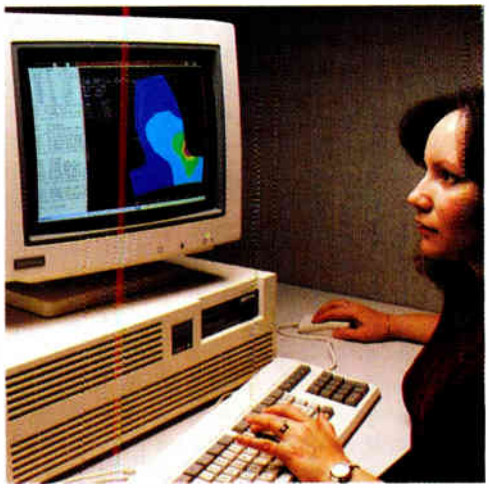
Since light travels about one foot in one-billionth of a second, no wire inside the computer is longer than three feet—which accounts for the computer's cylindrical shape, with connecting wires running only on the inner side of the cylinder.

3) The Supercomputer's problem-solving architecture involves vector processing and pipelining.

Vector processing allows the computer to perform a string of calculations based on a single instruction and then combine the result with other strings of calculations.

Pipelining lets the computer break an operation like addition into several parts so that it can start working on one part of the problem before finishing another part.

The Supercomputer Center is connected to a worldwide data communications network for use by the national scientific research community.



finite element dynamics modeling and hydraulic component design and modeling. And the final CADD data base is used to generate manufacturing drawings, and tool and test designs.

More recently, the graphics system has been used to develop new products and processes including the generation of tool paths for machining impeller vanes from a solid forging, and three-dimensional verification of laser optics to eliminate fixture interference with the laser beam.

For example . . . engineers have developed special routines on a graphics system to move a 3-D representation of a radar antenna array through various degrees of displacement to check for possible interference. In addition, they have substantially automated the design, documentation, manufacture and inspection of many parts of a phased-array antenna assembly to reduce delivery lead time.

A mechanical engineer enters the geometric and size requirements of the antenna array into the generic antenna design program. Simultaneously—and independently—an electrical engineer enters the performance specifications.

The mechanical and electrical data are processed by a mainframe computer and the results fed into an interactive graphics station. Here a design engineer generates a prerequisite design before moving on to the detailed design of the full complement of radar manifolds (used to distribute RF power to the antenna array).

Manually designing each of the 58 manifolds for a typical antenna takes 150 hours. Now it takes just minutes—and there are no errors.

This system is now being augmented with additional information that includes other components of an antenna. The process performs an entire conceptual antenna design in four hours (versus 80 hours using conventional techniques).

The design data is transferred to the production floor where a numerically controlled machine mills the aluminum manifolds. Then an automated inspection machine checks to make sure they meet specifications.

For example . . . computer graphics perform the layout and artwork generation for printed wiring boards and are used to design custom (application-specific) integrated circuits used in automation equipment, robots, broadcasting, elevators, energy management systems and other products. Many of these microprocessor chips are more powerful than early computers.

An engineer creates a computerized schematic of the chip in terms of primitive cells. The schematic shows transistors, resistors, diodes and capacitors for bipolar linear circuits; or gates, flipflops and other cells for digital circuits. This electronic data base is then used for simulation, layout and design verification. Test vectors (specifications) are simultaneously developed for use by the semiconductor manufacturer.

Computer Power at the Engineer's Fingertips

Individual computer workstations combine the high resolution screen for drawing and the mathematical processing capabilities needed by the engineer, plus the office automation, spreadsheet, filing and electronic publication capabilities normally associated with the knowledge worker (Fig. 3). Studies show that an engineer spends less than 30 percent of his time on product design, thus explaining the value of a system that combines both office automation and engineering functions.

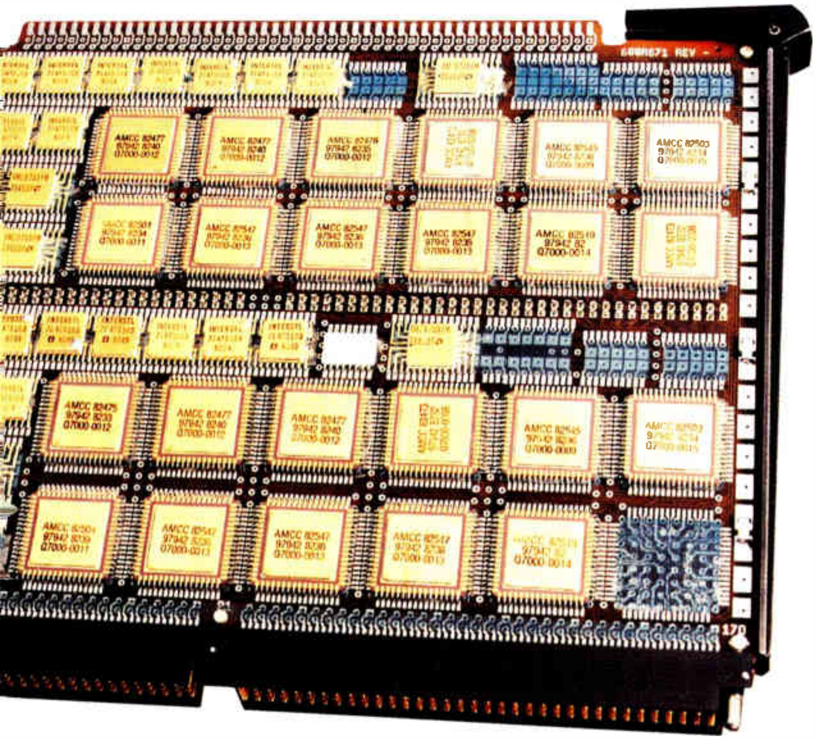
In addition, the engineer at the workstation has access to larger, more powerful computers from his individual terminal.

The integration of the functions of the engineer and other knowledge workers through a personal desk-top computer results in a major functional change in the way products are designed and manufactured.

For example . . . powerful 32-bit microprocessor-based engineering workstations are already in use for the design of large-scale integrated circuits, very-large-scale integrated (VLSI) circuits and printed wiring boards (Fig. 4).

A typical workstation includes a microprocessor with 4 to 16 megabytes of memory and a high-resolution display, and allows the engineer to subdivide the viewing area into multiple windows for quick access to menus and closeup views of graphics or text which is otherwise too large to fit on the screen. A disk with a 170-megabyte capacity, a keyboard and a cursor-control mechanism complete the workstation.

The connection of each workstation to a network or ring allows access to large data-storage centers, printers, plotters, mainframe computers and other resources.



4–An engineering workstation is used to design the digital portion of a circuit board from top to bottom.

The engineer enters the system requirements and extends the design level by level. At each level, he selects the appropriate logic symbols from the data-base library and interconnects them to achieve the desired logic flow.

The logic diagram is then used for formal engineering documentation and for service manuals.

During the design process, the tool set on the workstation advises the engineer of potential omissions and design inconsistencies, such as overloaded circuits or failure to connect necessary inputs and outputs.

Further, the workstation provides design verification. It activates the circuit's input ports with a combination of signals and checks to see if the output signals are behaving correctly. Logical models of the circuit reside in the workstation library.

In some cases, the workstation has an auxiliary port so actual devices can be plugged in during the simulation. The engineer can "probe" the circuit during simulation to examine the state of various nodes at different points in time.

Six VLSI gate arrays and two static RAM designs containing a total of 77,000 gates were simulated in less than four minutes—at a detailed gate level. Previously, using higher order languages like FORTRAN, such simulations took several hours and could not be performed at a detailed gate level.

Once the design is complete, the workstation sends bills of material and manufacturing process data electronically to the factory floor.

The Decade Ahead

Computer-aided engineering has reduced product-development cycle time and enhanced product quality. However, while much has been accomplished using computer technology, the traditional design process itself remains virtually unchanged.

Although we have replaced the drafting board with an electronic screen, the output is still paper. This paper drawing is then placed in a system essentially unchanged since the days of George Westinghouse. The drawing and documentation is delivered to manufacturing to develop necessary manufacturing drawings and operational process information such as routings, NC tapes and process specifications needed in the factory.

To achieve the next quantum jump in productivity, industry must radically change the way it designs and manufactures products.

There are two elements in the equation for change: technology and culture. The technology now exists; what's lacking is the human interface necessary to make this technology easy to use without extensive training. In other words, we need a substantial change in design philosophy and engineering culture.

In the future, teams of design and manufacturing engineers working with dynamic, high-resolution workstations and powerful computers will develop accurate computer models of their designs—and reduce the design/manufacturing cycle by 50 percent.

One state-of-the-art workstation—foreshadowing things to come—has a highly accurate, user-friendly modeling system where engineers are working together to design and manufacture a product from a single knowledge base (Fig. 5). The accuracy of the system allows machining of the part directly from the model data base. The basic intent is to develop a highly interactive team to design and manufacture a quality product in minimum time.

By combining the modeling system with a multifunction, high-power networked engineering workstation, the tools will be in place to permit a major functional change in the methods currently used to design and manufacture a product.

This combination of technology and culture will result in major cycle-time reductions and marked improvements in product quality.

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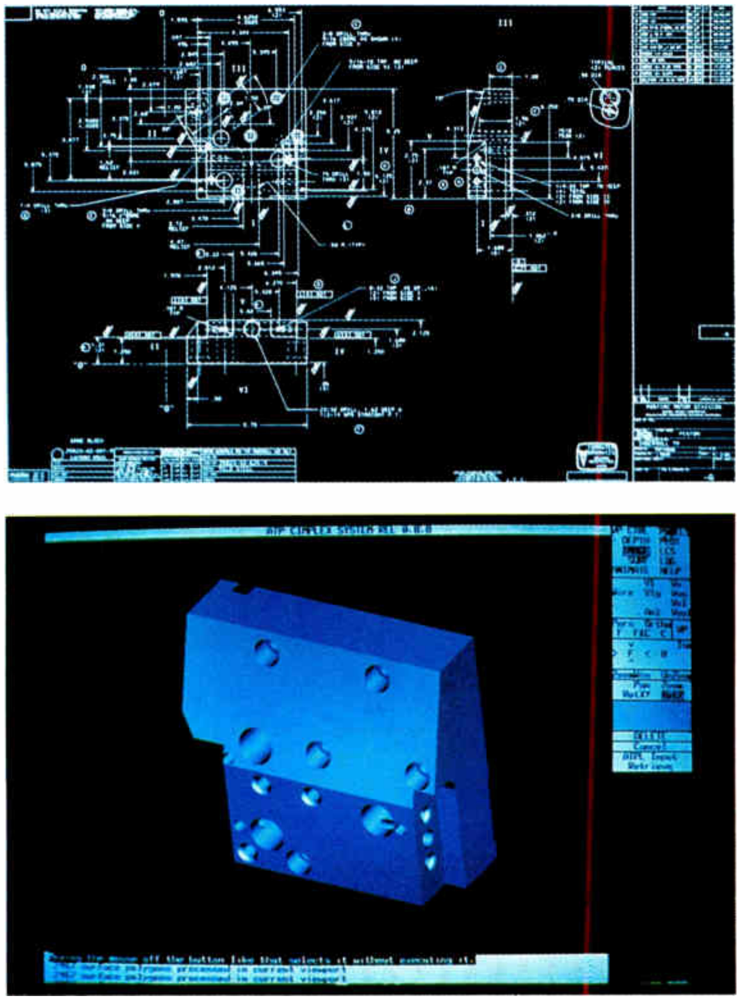
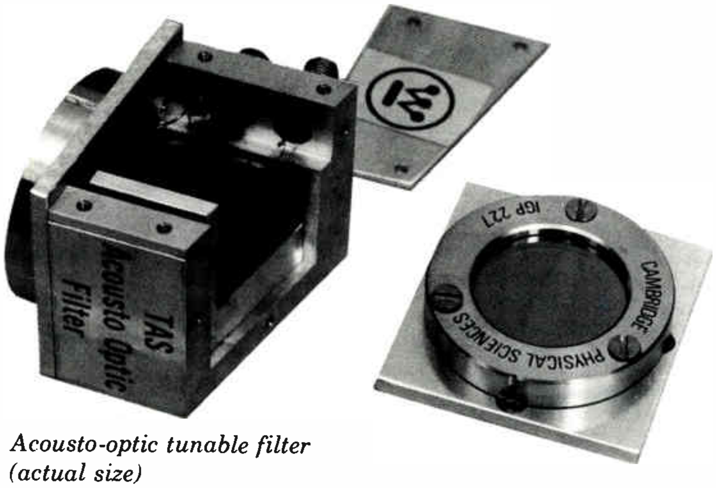
Grateful acknowledgement is given for the valuable technical contributions of R. Clanton, Westinghouse Defense and Electronics Center, Baltimore, Md.; S. Gabrielse, Westinghouse Research and Development Center, Pittsburgh, Pa.; A. Hribar, Westinghouse Electro-Mechanical Division, Cheswick, Pa.; J. Kasdorf, Westinghouse Energy Systems Computer Center, Pittsburgh, Pa.; and A. Szabo, Westinghouse Research & Development Center, Pittsburgh, Pa.



5–A solid model replaces a detailed design drawing. It's an accurate mathematical representation of the part and is so precise it can be used for analysis or manufacturing. Data can be fed directly to machine tools or test equipment.

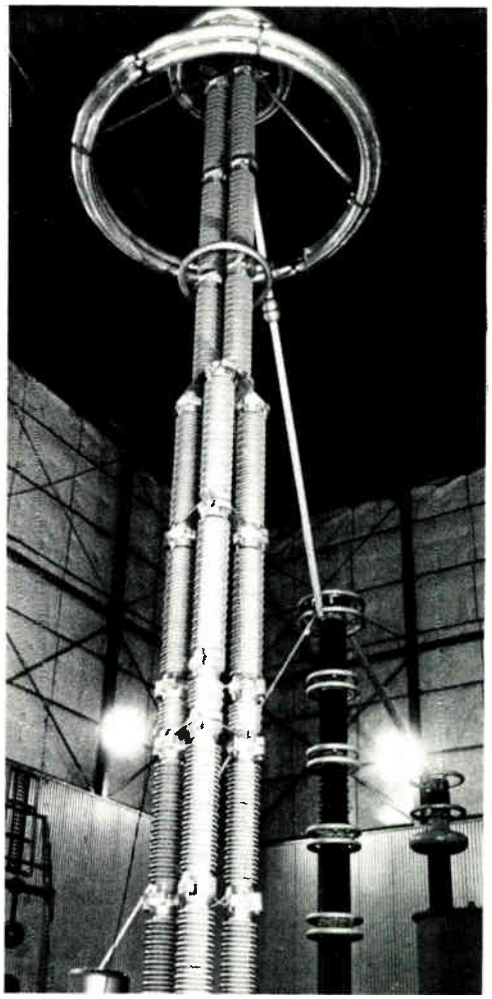
This is a workable system that does not demand that the user understand a computer language. Rather, it "talks" in terms of drill bits, set-ups or other shop variables.

Historical Album–Part 5



Acousto-optic tunable filter (actual size)

Electronic mail



Metal-oxide arrester

1975

Introduction of a solid state acousto-optic tunable filter.

The thallium arsenic selenide filter can continuously monitor a portion of the electromagnetic spectrum (from about 1.5 to 16 micrometers) and can determine the frequency of up to 20 applied signals simultaneously to an accuracy within one percent—in just microseconds.

Applications include infrared spectroscopy, combustion analysis and control, infrared spectral imaging and defense electronics.

1976

Development and application to solar cells of the dendritic web process which forms ribbons of single-crystal silicon.

The ribbon is formed by the solidification of a liquid film supported by surface tension between two silicon filaments, called dendrites, which border the edges of the growing strip.

The process has several advantages for solar cells: The ribbons are free from contamination; they grow with mirror-smooth surfaces that are essentially ready for fabrication; they use only one-fifth of the silicon required for conventional processes; the ribbons are only 5 to 6 thousandths of an inch thick; and they have a conversion efficiency of 17.0 percent.

1978

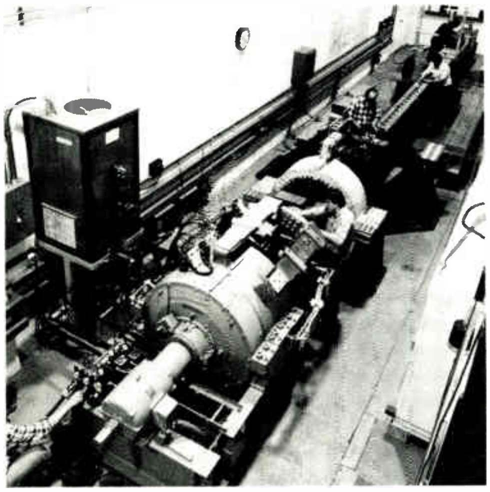
Development of a metal-oxide arrester to limit power surges on transmission and distribution systems.

All earlier surge arresters (since the 1920s) used non-linear resistors (silicon carbide) in series with power gaps to protect electrical equipment. The metal-oxide arrester is completely gapless—eliminating the weakest link in conventional arresters.

The new arresters have quicker response time, are less affected by contamination and are smaller and lighter. Development work was supported by the Electric Power Research Institute.

Microprocessor control for transit cars

VAR generator controls



Electromagnetic launcher

Dendritic web

1979

As one step in its use of office technology, the company introduced the use of electronic mail to replace conventional letters.

Currently more than 8500 employes and customers use the system, sending over 20,000 messages per day worldwide—with significant improvements in service, and major reductions in time, paper, mailing and filing costs.

1979

First microprocessor control for rapid-transit cars.

Just 10 years after transit cars began using solid-state controls, Westinghouse added microprocessor control—first used on the Rio de Janeiro Metro Transit System.

1982

Development of an electromagnetic launcher that may be able to fire projectiles more than 10 times the speed of sound.

Using technology common to electric motors and generators, the launcher currently generates a pulse of 2.1 million amperes to propel a 10-ounce projectile over 10,000 miles per hour.

Future applications may include new metal-forming processes, the firing of pellets with enough mass and velocity to create nuclear fusion, and defense systems.

1985

Completion of the largest installation of solid-state reactive volt-ampere (VAR) generators in North America to precisely control and regulate line voltage on a utility transmission system.

Using both thyristor-controlled reactors and capacitors, the microprocessor-based system provides continuously variable reactive power from minus 250 megavars (inductive) to plus 250 megavars (capacitive).

VAR generators replace traditional rotating synchronous machines and mechanically switched capacitor banks, which are too slow to follow system voltage fluctuations and present cost, maintenance and reliability problems.

Integrating Distributed Plant Control and Monitoring Functions

Richard Colborn

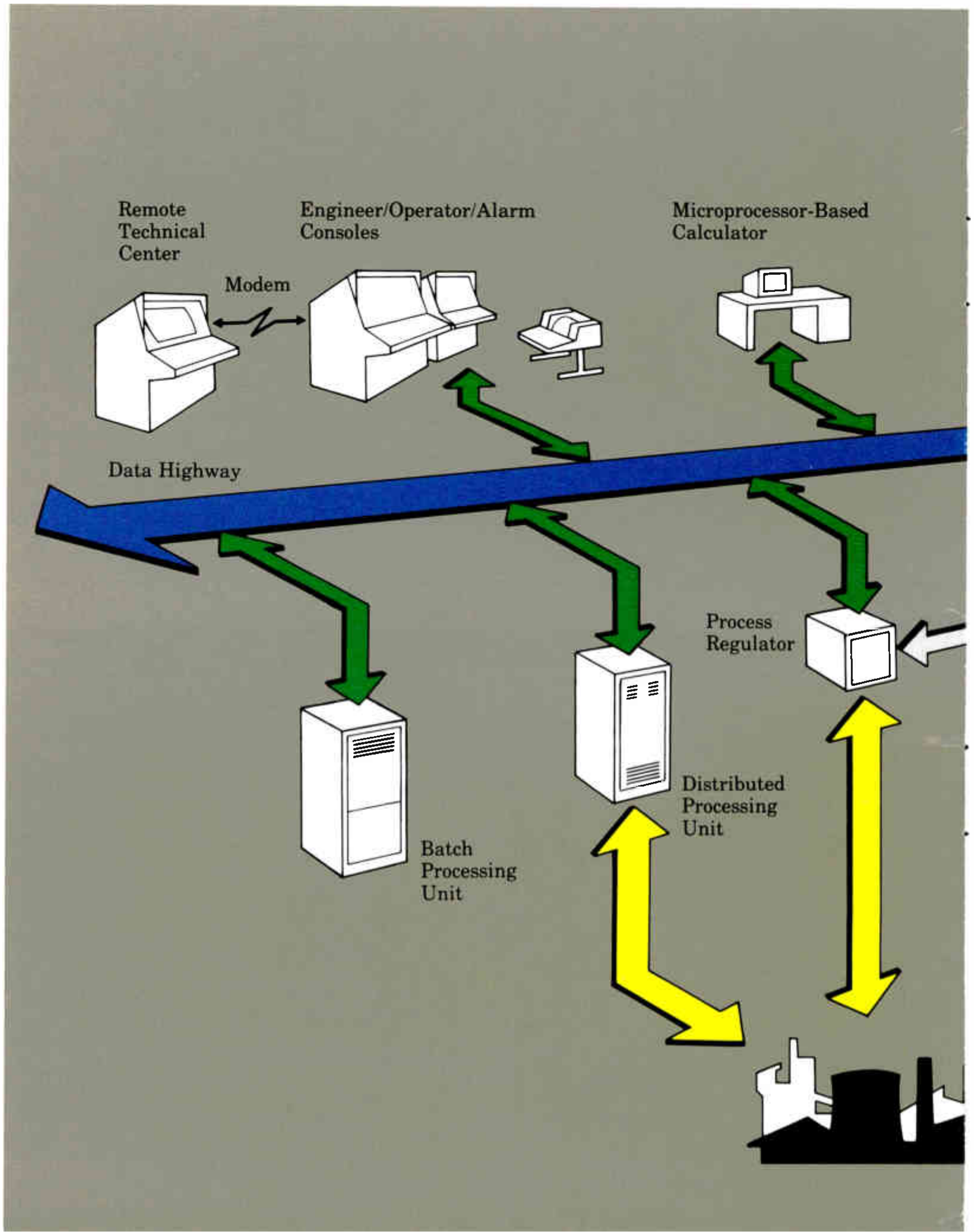
A state-of-the-art process control, data-acquisition and monitoring system links up to 254 microprocessor-based functional modules distributed along a 6-mile-long coaxial cable communications highway. Each module has continuous access to information generated at every other control and monitoring station, thus providing a global data base.

A powerful process management system called WDPF can integrate monitoring and process control of all of a plant's operations in a two-square-mile area. This became possible as the microprocessor, with its low price, small size, computing power and ruggedness, ushered in radical changes in both sequential and process control.

Previously there were essentially three independent systems—a system for sequential control, one for process control and a central computer system for data acquisition and plant optimization. None of these were designed to be tied together.

In the new system, sequential control, continuous control, data acquisition and optimizing functions are distributed to independent microcomputers, all operating simultaneously and all tied into one system by a common communications highway.

This common highway links as many as 254 independent microcom-



1-WDPF is a collection of functionally distributed modules that individually monitor and/or control some part of the plant. Each drop performs different tasks —interface for process input/output, display or log plant data, alarm out-of-limit values, store long-term data on plant operations and make specialized plant performance calculations. The system can include as many as 254 intelligent modules which "plug into" the communications highway.

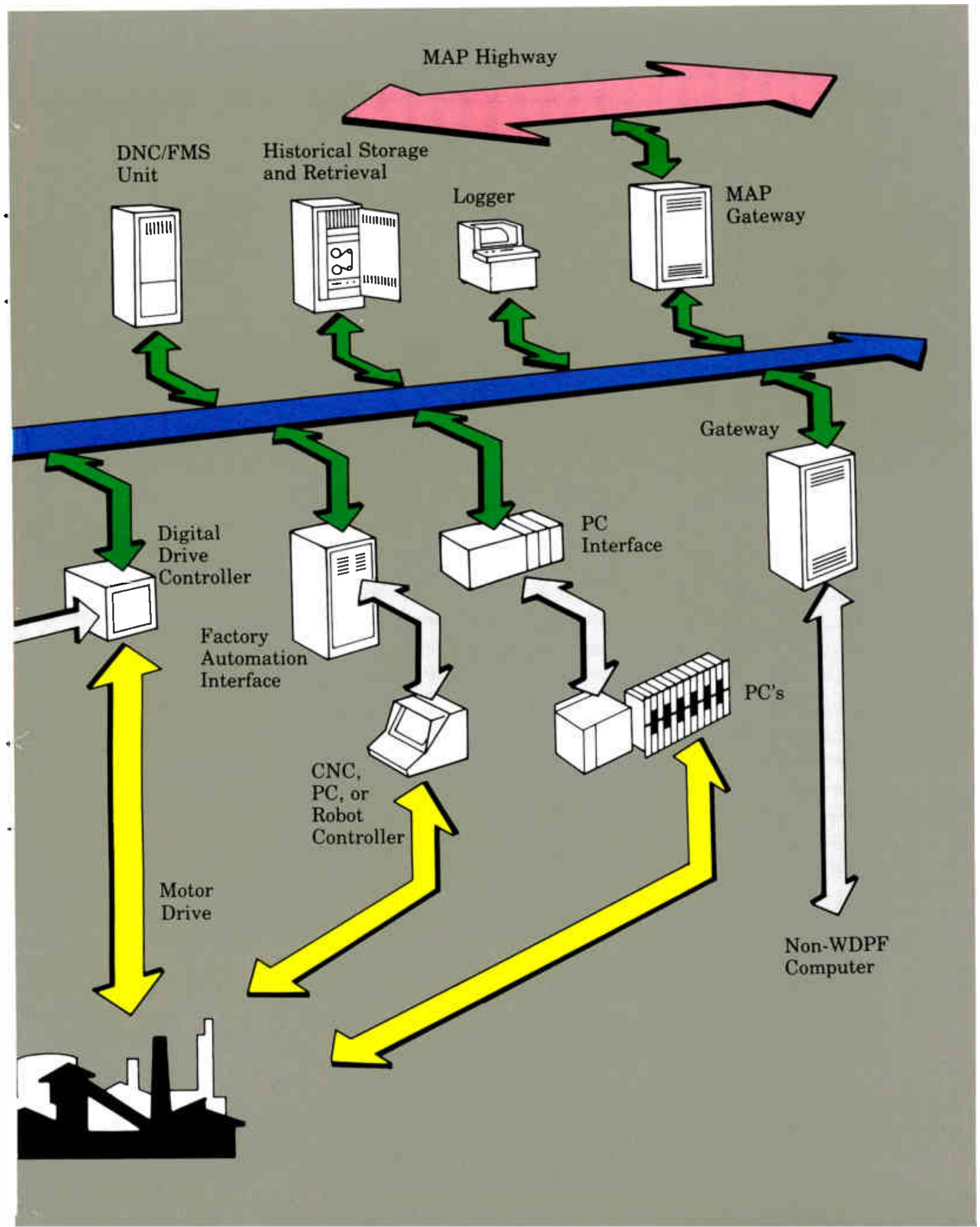
puter-based modules. Each independent module or drop (see box) on the highway is dedicated to a specific task and runs simultaneously and in parallel with other drops. Since all process control and host computer functions are distributed among independent drops, new functions or additional capacity are obtained by merely adding drops.

With parallel and simultaneous processing, adding drops not only increases the system's functional capabilities but also increases its computing power. Each drop has dual microprocessor intelligence: one to communicate, and one to perform specific control functions.

The failure of one drop has no effect on other drops tied to the data highway. Adding redundant highways and redundant microprocessors to the distributed processing units responsible for control eliminates critical single points of failure.

Highway Communications

The highway ties together from 2 to 254 independent processing units (or drops)—each performing a particular function (Fig. 1). Each drop has instant and continuous access to up-to-date information from anywhere in the system and under all plant conditions. In other words, through the system's communications highway, tasks executed at all drops always have instant, simultaneous and transparent access to the plant's global process data base.



Control/Monitoring Modules

WDPF consists of standard microprocessor-based building blocks (or drops) integrated by a common communications highway.

Typical drops include:

- The Distributed Processing Unit handles data acquisition, continuous (modulating) control and sequential (Boolean and ladder) logic customized to particular applications with 100-percent redundancy and card-level diagnostics.
- The Operator Console and Graphics Printer is a communications window linking operators with the process. With this "picture power," over 300 displays stored in nonvolatile bubble memory (including graphics on specific processes) can be built into each unit. Graphics can be as general as an entire mill area or as specific as a single pressure gauge. Information is updated each second.
- The Engineer Console initiates and maintains all data-base software and provides access to all display and control process information. Control programs and graphics developed at the engineer console can be down-loaded over the data highway to drops located anywhere on the network.
- The Batch Processing Unit controls and monitors pumps, valves and other final control elements in a predetermined sequence. As many as 10 recipes (out of a selection of 10,000) can be run simultaneously.
- The Gateway permits any non-WDPF computer facility to communicate with any drop on the data highway. This provides an interface between WDPF, the management information system and data processing centers to give complete information to management.

Each drop can recognize which bits of information racing around the data highway are pertinent to its job. All process values obtained or calculated by every drop are automatically broadcast onto the highway as frequently as every 0.1 second, but at least every second. Each drop's highway controller listens to the broadcast of all such data and identifies each source.

As the highway interface at each drop hears the address of those points in which it's interested, it stores their values in shared memory for use by the microprocessor that performs the functions unique to that drop.

The highway runs at two megabaud (2 million bits per second) over the coaxial cable. A process data base as large as 16,000 analog values, or 256,000 digital values, or a combination of both, can be broadcast onto the highway every second.

As an option for electrically noisy, chemically hazardous or other difficult environments, a fiber-optic highway communicates with as many as 64 microprocessor drops in a star configuration.

Besides automatic process-point broadcasting, WDPF also provides demand peer-to-peer communications for the transfer of data files.

Time is sliced into 100 millisecond segments. Starting with the automatic broadcast of points, the remaining 100 milliseconds in each segment is available to every drop for communications demanding needed information. The boundary between broadcast and demand communications modes is dynamic and depends on the number of broadcast points. In a typical system, with 4,000 analog points and 4,000 digital points being distributed every second, in excess of 350,000 bits (44 kilobites) can be transmitted on demand every second.

If there is a redundant data highway, broadcast transmissions on both highways occur simultaneously; the intelligent highway controllers at each drop listen and obtain data from either highway.

The distribution of all functions and the transparent interface between functionally different drops provided by the highway allow the integration into one unified system of previously independent sequential control, continuous control, data acquisition and optimization functions.

New Applications

WDPF is in use in many industries from chemical plants, paper mills and food processing to steel mills, utility power plants and wastewater treatment facilities.

While it was initially designed for process control in utility and industrial plants, it has now been enhanced for application in other areas such as the following:

Factory Automation

WDPF is now being used in a flexible manufacturing system (FMS) that makes parts for jet aircraft. The FMS system consists of: six 5-axis machines that cut parts from metal castings; two coordinate measuring machines for automatic inspection of parts and tools; an automatically guided vehicle to move parts around the factory; and a storage and handling system for both parts and tools.

A WDPF drop called a Station Interface Unit (or Cell Controller) can simultaneously connect the programmable controller, CNC and robot controller to the highway and control the sequence of their operation. For example, the interface can receive and buffer data that represents the program for the part to be cut by the machine tool. At the proper time, it can then load this program, bring in the materials and tools and start the CNC. With the use of other drops, it can control over 100 machine tools for flexible manufacturing and distributive numerical control.

The WDPF data acquisition and control system forms part of a $200 million upgrade of the City of Los Angeles' massive Hyperion wastewater treatment plant. It is an integral part of the facility's energy recovery system, which combines modern sanitary engineering with state-of-the-art power generation automation.

In addition to controlling the factory, the system also collects data on the parts produced and on equipment performance. It also schedules the factory to level the workload and use resources most effectively.

This application required the development of new hardware drops and a software language appropriate to discrete parts manufacturing and transfer line operations.

Drive Control Systems

Another application area for this system is in drive systems for hot and cold rolling mills, continuous casters and process lines in the metals, paper and mining industries.

Modern, high-speed mills, with increased throughput and higher percentages of on-gauge production, require high-speed digital regulators, with control loops in the 5- to 10-millisecond range, closely coupled sequential and modulating control and extensive diagnostic capability.

The WDPF-controlled drive system has digital regulators as standard drops on the highway, uses a computer for supervisory functions and has increased diagnostic capability.

The main interface to the drive system is via a controller which is used in three different variations:

- As a programmable controller for auxiliary control functions, equipment

sequencing, protective logic and interface to desks and panels;

- As a process regulator providing high-speed coordinated control for control of tension looper, hydraulic gap, automatic gauging and process speed;
- As a digital regulator for control of speed, position or torque of dc motors.

The drive's architecture includes a second high-speed "control" version of the highway, called the "V" channel. Data acquisition, alarming and logging are handled on the primary highway with a one-tenth-second resolution, and critical data and control commands between various controllers and process regulators are transmitted on the second highway with an update rate of a few milliseconds.

Software Production

Ninety percent of the development effort for WDPF is software; the remaining 10 percent is hardware.

Application-specific software is programmed by engineers using high-level languages at specially designed application engineering work stations.

The engineer writes the software program at the work station and examines the process graphics. All software is debugged before it is loaded into the system on the factory floor.

Once the system is installed and running, help is a phone call away. Using a Remote Technical Center, an engineer at the plant site can be tied directly by telephone with WDPF master control equipment. From there, engineers can trouble-shoot, fine-tune or perform remote diagnostics.

Diagnostics

The plant operator knows the instant that a drop has gone off-line or a component has failed. With the aid of system and drop status displays, the problem can be quickly identified down to individual printed circuit cards.

The Future

As new functional drops are developed, they become members of the WDPF family.

One recently developed drop is an interface to a powerful computer which connects directly to the highway for instant access to the entire system data base. It can perform scheduling, modeling and other calculation-intensive functions.

Improved graphics, higher speed communication, artificial intelligence and wireless communication may well be incorporated into future systems.

WDPF is a total process management system integrating plant monitoring, continuous control, sequential logic and batch control into one network.

E. R. Colborn is Manager, Process Control Systems Department, Westinghouse Automation Division, Pittsburgh, Pa.

Technology In Progress

Modern People-Mover Technology

Automated people movers are quiet, smooth-running and pollution-free. They can be used wherever congestion or long walking distances are a problem, such as central business districts, commercial areas, university campuses or new and expanding airports.

Taking the Walking Out of Flying
At Tampa International Airport, travelers never have to walk more than 700 feet. Baggage is checked, cars parked and tickets issued at the main terminal. Then travelers take a comfortable, 40-second ride to one of four satellite terminals. A people mover is available every 70 seconds.

The Tampa airport system has carried more than 130 million passengers and traveled nearly 4 billion miles with a system availability rate exceeding 99.8 percent.

These systems are also used at airports in Seattle, Atlanta, Miami, Las Vegas, Orlando and Gatwick, England.

In and Around Town
Metro-Dade County and the City of Miami turned to the people mover to help solve traffic and parking problems and to revitalize the business district. Metromover, the downtown component of Metrorail, is the first U.S. people-mover application in an urban center.

The system runs through inner-city Miami in a three-kilometer loop. It presently has 12 air-conditioned vehicles, and each can carry 90 passengers on a double-lane guideway structure. Each lane handles more than 3600 passengers an hour with an 80-second average travel time between stations.

The people mover in Miami is the first downtown people-mover system to integrate with a rapid transit system. In 1983, a new 27-kilometer automated Metrorail transit system began to carry commuters into the City. The downtown people mover connects with this system at the Government Center Station, one of Miami's main hubs.

Garbage Turned Into Electricity

The Westinghouse O'Connor Rotary Combustor process economically transforms waste into valuable energy.

Boxes and Bags to Ashes
In the Westinghouse O'Connor system, refuse is fed into a slightly tilted barrel which slowly turns and tumbles the burning materials downward. The barrel is constructed from heavy carbon-steel water tubes connected by perforated plates. Preheated air is forced through the perforations in the barrel at pressures high enough to penetrate the burning waste to supply combustion air where it's needed most.

Miami's Metromover (left) enables commuters to transfer from the Metrorail train and continue into the City's business and high-rise office core in the downtown area.

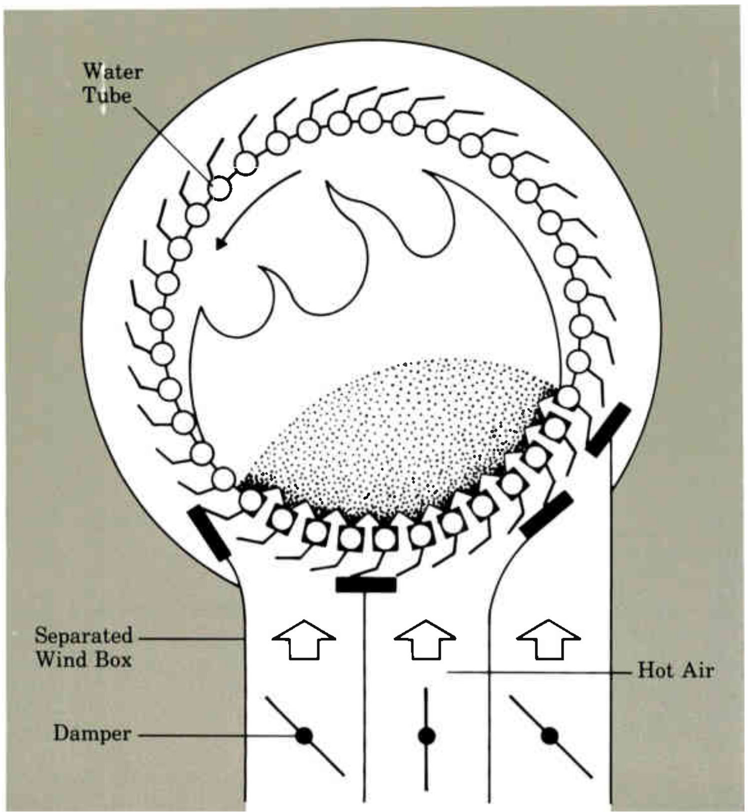
At the heart of the waste recovery system is the patented O'Connor Water-Cooled Rotary Combustor (right) which incinerates a wide variety of wastes, and with a boiler, recovers energy in the form of steam.

Dry materials are burned first, fueling the continuing combustion process; moister wastes are progressively dried and incinerated as they are stirred and spiraled downward toward an afterburning grate at the outlet, where any remaining combustible materials are consumed.

Egg Cartons to Energy
Hot surfaces in both the combustor and boiler transfer heat energy in the form of steam for process use, heating and air conditioning, or to a steam turbine generator for conversion into electricity.

Individual modules provide capacities of up to 500 tons per day; multiple modules afford a wide range of plant capacities.

These highly efficient municipal waste treatment plants can also economically handle as little as 60 tons of waste a day, making them ideal for smaller applications such as industrial parks. The process steam can be used directly by local factories within the area.



Tiny TV

A miniature, high-resolution cathode-ray-tube display monitor has a tube that measures just one inch in diameter.

In spite of its size, the resolution is so good it can display as much legible information as a high-quality 19-inch television screen.

Based on a rugged design presently being used for weapons sighting in modern tanks, the tiny TV has many non-military uses, including phototypesetting and medical applications such as patient monitoring displays and visual assistance during surgery.

Solid-Oxide Fuel-Cell Generator

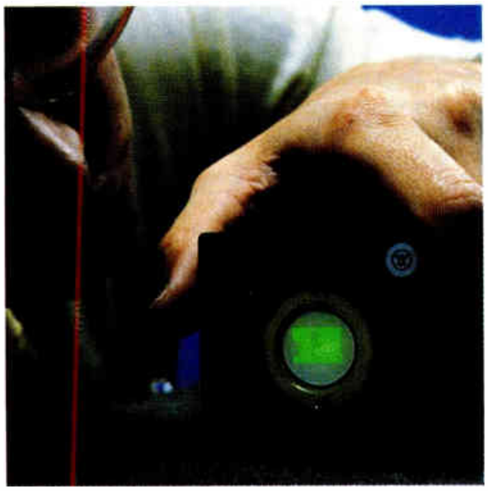
The high-temperature solid-oxide fuel cell generator is a technically advanced power generation system for factories, industrial parks, shopping malls, commercial buildings and utilities.

Fuel-Cell Technology
Fuel cells transform the chemical energy of a fuel into electricity without combustion. The generator contains several bundles of tubular fuel cells. Fuel is fed directly to the bundles and flows among and between the tubes while pre-heated air is injected inside each cell.

When an electrical load is applied to the cell, oxygen ions at the cathode migrate through the solid electrolyte to the anode where the fuel is oxidized to produce electricity.

Individual tubes are stacked together and interconnected in series to provide necessary voltage levels and in parallel to achieve the desired current levels. This dual connection also provides greater reliability. If any tube should fail, the output of other tubes is not affected.

Commercialization
The fuel-cell generator has evolved through years of research at the



A miniature, high-resolution TV screen gives the same quality picture as a typical 19-inch display.

Westinghouse Research and Development Center in collaboration with the U.S. Department of Energy.

The fuel-cell power plant configured with a bottoming plant can have an electrical efficiency of up to 60 percent. This is more efficient than any other power system—and 75 percent more efficient than a modern steam turbine generator.

The fuel cell has excellent ability to follow the load and handle overload situations. Air and fuel ratios are simply adjusted just like using the gas pedal in an automobile.

The cell operates at 1000 degrees C and burns a variety of fuels including natural gas and industrial by-products, such as hydrogen and carbon monoxide, as well as coal gas when coal gasifiers become commonplace.

The generator gives off just four by-products: water vapor, oxygen-depleted air, carbon dioxide and useful heat. The temperature of the exhaust can be as high as 900 degrees C. The exhaust system can be designed to produce steam at temperatures and pressures compatible with all industrial and commercial processes.

Plasma Torch Destroys Hazardous Wastes

A plasma electric arc heats air or other process gases to more than 5,000 degrees C. When organic chemicals or hazardous substances are sprayed into this plasma-heated gas, the chemical molecules are broken apart in a few milliseconds.

Super Heat

A plasma is a high-temperature, ionized, conductive gas created within a plasma torch by the interaction of a gas with an electric arc. The process gas, fed between colinear copper electrodes, is separated into electrons and ions, making it both thermally and electrically conductive.

The conductive property of the ionized gas transfers energy from the arc to an incoming process gas and, in turn, to other materials. The gas exits the torch in a neutral state with super-heated properties.

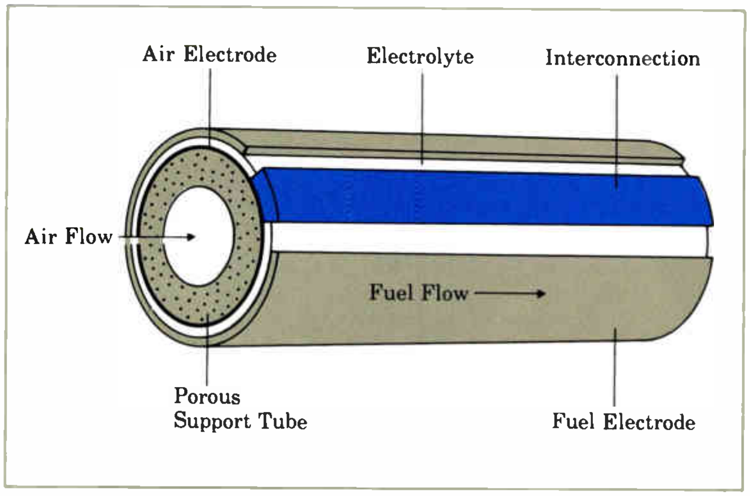
The torch destroys organic hazardous wastes by rearranging their molecular structures as they pass this high-temperature plasma zone.

The Detoxification Process

Wastes are fed into the discharge of the plasma arc and ionized. These separate atoms are forced into the main reaction chamber and, upon cooling, recombine to form non-hazardous compounds.

These compounds pass into a caustic soda scrubber. Rapid quenching of the gas limits the recombination of the compounds to safer, non-hazardous elements such as hydrogen, hydrogen chloride, carbon monoxide and carbon. Sodium ions react with hydrogen chloride to form a solution of water and simple table salt.

Powdered carbon is washed away by lightly salted water. Hydrogen



In the solid-oxide fuel cell, oxygen ions migrate through the tubular structure and oxidize the fuel to produce electricity. At the same time, the hot exhaust gases can be used to produce useful process steam.

Plasma technology is being used in many industrial processes as well as in a new method for destroying hazardous liquid wastes. The Westinghouse Plasma System achieves destruction efficiencies in excess of 99.99999 percent on concentrated hazardous wastes.

molecules and carbon monoxide leave the scrubber as a rich, clean fuel gas, which is a potential new source of combustion energy. This process can produce almost three times as much fuel energy per unit of waste as the energy used to destroy the waste.

Computers Elevate the Art of Utility Planning

The ability of the computer to simultaneously manipulate huge quantities of data and simulate events in the future is now being used to analyze and design generation, transmission and distribution systems for utilities around the world.

For example, the Westinghouse Computer-Aided Distribution Planning and Design System produces an orderly economic plan for both long- and short-range distribution system expansion, and includes everyday operating and design considerations.

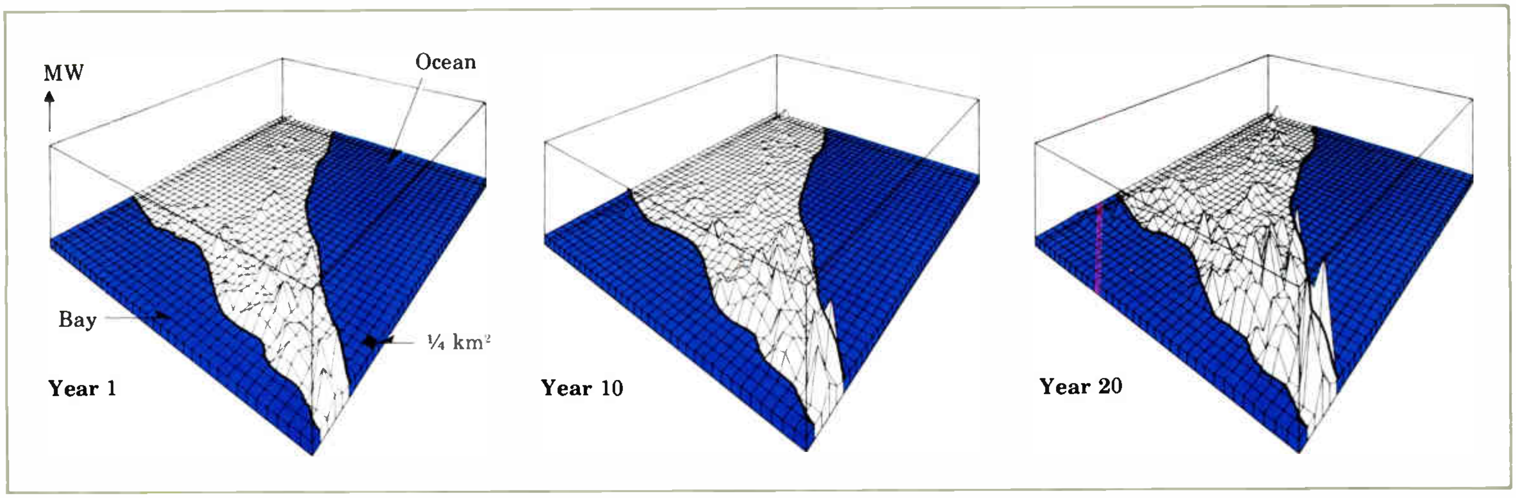
Future load is forecasted by projecting the type and density of land-use development expected in each area, and then translating those projections into electrical demand.

Models based on land use simulate growth by relating it to causal growth factors—the parameters that are really responsible for growth.

Simulation-based load forecasting employs an in-depth simulation of land use and urban growth to project small-area electric load growth. It is particularly applicable to large metropolitan areas and to "difficult" forecast situations.

The system then integrates three distribution planning programs: (1) a program for small-area load forecasting; (2) a special data management program for handling and processing data; and (3) an optimization program for developing minimum-cost radial distribution networks.

Planners can continually optimize the configuration of a system during a study by simultaneously analyzing



A typical distribution planning study begins with a long-range projection of growth. The system is optimized for the horizon year to determine future substation additions. This configuration is then used to guide short-range expansions for feeders, substations and distribution-equipment requirements and to project long-term system requirements.

many substations and feeders, providing a very quick way of searching through many possible redesigns of the distribution system.

Short-range or operational planning is used for detailed analysis of radial feeders for voltage and fault conditions and for other operating investigations. It provides the analytical tools needed to refine and convert long-range economic solutions into practical engineering designs that satisfy short-range operational requirements and budgets.

Here's to the Dreamers

The Westinghouse Science Talent Search (STS) identifies exceptional scientific, mathematical and engineering ability at the high school level. In the past 45 annual Searches, nearly $2 million in scholarships and cash awards have been awarded to 1,800 young scientists and mathematicians.

Since it began in 1942, the Science Talent Search has been remarkably successful in selecting and encouraging gifted scientists at a young age. Five past Search winners have won Nobel Prizes. In addition, the Search has produced two winners of the Fields Medal—the highest award given to mathematicians—and STS alumni have won several MacArthur Foundation Awards in the physical and social sciences.

Twenty-six of the Search alumni have been elected to the National Academy of Sciences. And, chances are, winners of this year's Search will study under one or more past winners. Forty-three percent of former winners are currently teaching at colleges and universities.

The Search has been sponsored since its inception by Westinghouse Electric Corporation and conducted by Science Service, a non-profit organization engaged in furthering public understanding of science.

National winners of the 1986 Search gathered on the steps of the U.S. Capitol Building in Washington, D.C. For more than four decades, the Westinghouse Science Talent Search has maintained an unequaled record identifying and encouraging scientific talent at an early age.

Chip-To-Chip Communications

A newly developed custom integrated circuit—called INCOM for INtegrated COMmunications—has the ability to carry on two-way communications between a personal computer and remote devices.

It is presently being used in the INCOM Lighting and Energy Management System to monitor and control electrical consumption and demand in plants and offices.

It can tie together as many as 128 remote units controlling up to 5,376 circuits. These remote units are controlled by a personal computer which acts as the system master. Both the system master and remote units contain INCOM chips.

The INCOM system monitors actual electrical power consumption, and sheds predetermined, noncritical loads to keep consumption below predefined limits.

The system can be programmed to cycle loads and keep temperatures within a certain comfort range. Or, it can automatically adjust the start-and-stop times of heating and air conditioning equipment according to inside and outside temperature differences and the thermal characteristics of the building.

Dial-up load control via a touch-tone telephone permits employes who work late or come in early to override selected load settings.

The INCOM chip currently communicates via carrier on twisted-pair wires. In the future, it will communicate on power lines, broad- and baseband cable or fiber optics.

Genesis of the Westinghouse ENGINEER

Shortly after the turn of the century, some 200 young apprentices (including many engineering graduates), plus other employes of the Company, were attending weekly lectures on a wide range of engineering subjects. These were presented by the more experienced engineers of the Company.

In 1902 these "working students" organized the Westinghouse Electric Club in Wilkinsburg, near the East Pittsburgh, Pa. plant.

By 1904, the Club had grown to over 500 members, and it was not possible or convenient for all members to attend every lecture.

To make the newest and best information presented at the Electric Club available to members and others in a more convenient and permanent form, the Company began publishing the ELECTRIC JOURNAL.

The JOURNAL continued until 1938. It was succeeded by the Westinghouse ENGINEER, first published in 1941.

Between 1941 and 1975, some 196 issues of the ENGINEER were published for engineers and scientists in Westinghouse as well as other companies.

Westinghouse ENGINEER

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