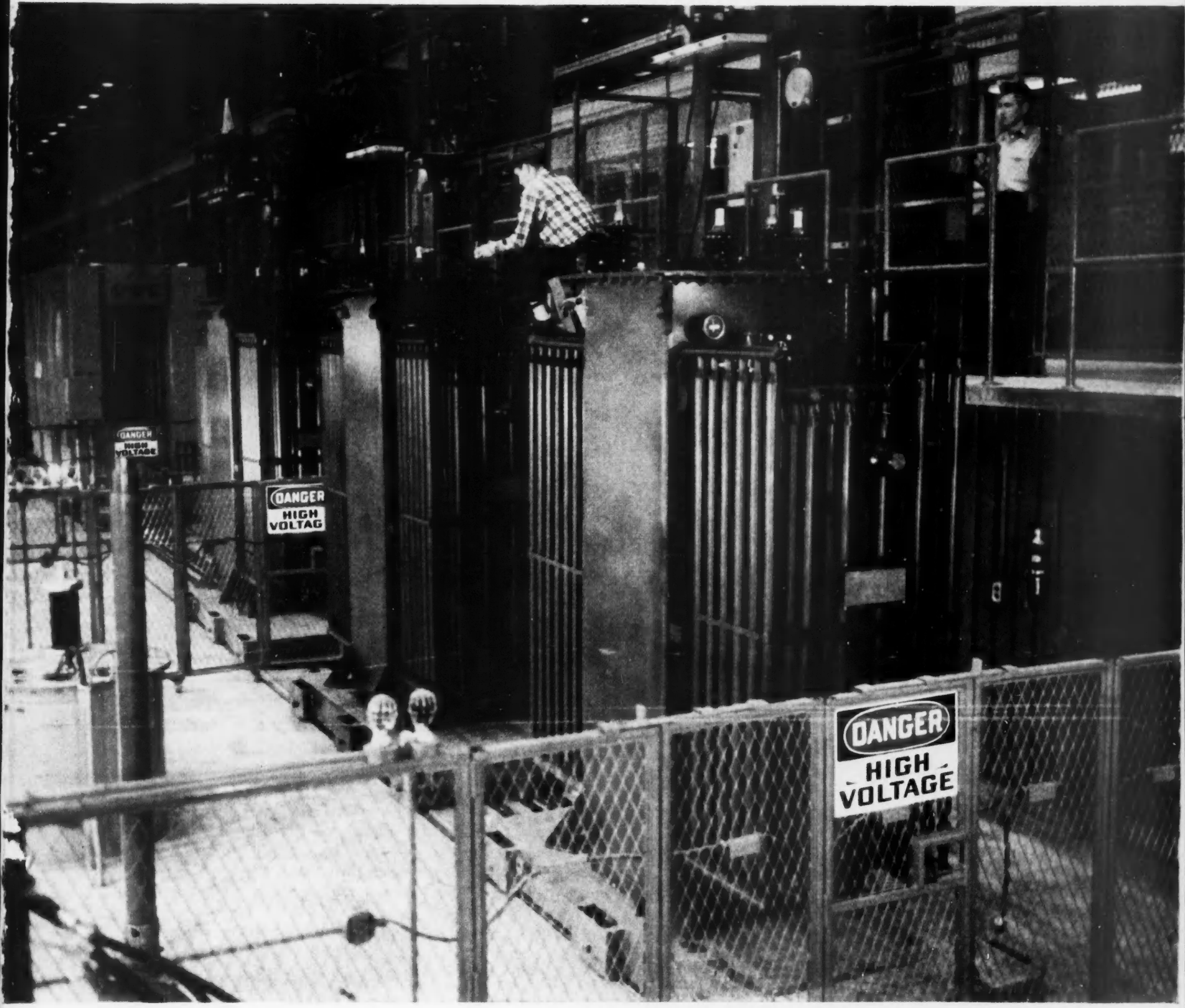
GENERAL ELECTRIC Review



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GENERAL ELECTRIC Review

EVERETT S. LEE • EDITOR   PAUL R. HEINMILLER • MANAGING EDITOR

COVER—At a new G-E plant near Rome, Ga., production-line techniques are used to speed the manufacture of power transformers. In the test area, nine tests can be performed in the seven successive berths. As the transformer stops at each station, the operator runs his particular test, and the unit is then moved into the next berth by the drag-chain conveyor. For other pictures of production highlights at the new plant, turn to page 22. Color photograph by George Burns.

THE GENERAL ELECTRIC REVIEW IS ISSUED IN JANUARY, MARCH, MAY, JULY, SEPTEMBER, AND NOVEMBER BY THE GENERAL ELECTRIC COMPANY, SCHENECTADY, NY, AND IS PRINTED IN THE U.S.A. BY THE MAQUA COMPANY. IT IS DISTRIBUTED TO SCIENTISTS AND ENGINEERS THROUGHOUT INDUSTRIAL, CONSULTING, EDUCATIONAL, PROFESSIONAL SOCIETY, AND GOVERNMENT GROUPS, BOTH DOMESTIC AND FOREIGN. . . . THE CONTENTS OF THE GENERAL ELECTRIC REVIEW ARE ANALYZED AND INDEXED BY THE INDUSTRIAL ARTS INDEX, THE ENGINEERING INDEX, AND SCIENCE ABSTRACTS. . . . SIX WEEKS' ADVANCE NOTICE, AND OLD ADDRESS AS WELL AS NEW, ARE NECESSARY FOR CHANGE OF ADDRESS. . . . ADDRESS ALL COMMUNICATIONS TO EDITOR, GENERAL ELECTRIC REVIEW, SCHENECTADY 5, NEW YORK.

YOU EXPECT THE BEST VALUE FROM G-E FLUORESCENT LAMPS

Invisible coating helps new G-E Rapid Start Lamps light faster

THE film of water that condenses on a fluorescent lamp in wet weather is so thin the lamp hardly feels damp. Still, it can connect the ends of the lamp and set up a miniature short circuit. It doesn't injure the lamp. Just steals enough current so the lamp is slow in lighting.

There's one fluorescent lamp, though, that doesn't get sluggish in moist air: the General Electric Rapid Start Lamp.

It has an invisible coating of General Electric silicone, called Dri-Film*. The photo shows what it does to water on the lamp. Makes it stand up in separate drops. In between are dry areas that break the electrical contact. The short circuit doesn't get started. The lamp does.

G-E Dri-Film* doesn't rub off. It's an example of why you expect the best value from G-E fluorescent lamps. For free booklet, "Facts About Rapid Start", write to General Electric, Dept. 166-GE-7, Nela Park, Cleveland 12, Ohio.

*REG. U. S. PAT. OFF.

GENERAL ELECTRIC

General Electric Predicts . . .

Commercial Atomic Power in 5 to 10 Years

• Nuclear power plants owned by electric utilities will be generating electric power at commercially competitive costs.

• Two types of nuclear reactors offer greatest promise for rapid development and competitive use in the production of atomic power.

A top atomic official of General Electric, Francis K. McCune, has predicted that privately financed atomic power plants will successfully compete with conventional power plants in 5 to 10 years.

Speaking at the Atomic Industrial Forum, in Washington, DC, May 24, McCune said:

"First, we at General Electric believe that electric utility companies will be owning and operating a number of atomic power plants within the next 10 years.

"Second, we believe some of these will be full-scale and, what is most important, they will generate electricity at competitive costs—possibly within five, certainly within 10 years.

"Third, we believe that this will be accomplished without government subsidy for production-plant construction or operation, and with government-supplied fuel priced at cost-of-production levels."

McCune made it clear that he was attempting in no way "to detract from the immeasurable significance of knowledge developed through Atomic Energy Commission contracts."

"Of course, the government's large expenditures for research and development of plutonium production reactors, mobile power reactors, and other power reactors form the base from which private industry can proceed," he went on to say.

He further stressed that G-E studies show that production-size atomic power plants can be made to operate economically.

"They will stand on their own feet," he continued. "They may sell products to the government. They will certainly buy nuclear fuel from the government. But trading with the government need not be a subsidy."

Reactors best suited for "earliest and most effective competition with conventional fuel plants" were described by McCune as: 1) light-water-moderated and cooled boiling reactor; and 2) graphite-moderated water-cooled reactor.

The first type, he explained, would eliminate the need for a boiler system, because water would be boiled inside the reactor to produce radioactive steam that would power a turbine.

The reason that the boiling reactor was chosen by G-E experts in part, he told Forum members, is its similarity in many ways to conventional steam plants.

"Its adoption by the electric utility industry should be relatively easy. The moderator and coolant are both ordinary water which the industry is used to handling. Chemical separations plants are not necessary. The boiling reactor has safety features that have been demonstrated so that operating companies should be able to choose plant sites as available within their systems," McCune said.

"The light-water reactor," he went on to explain, "is one which can become competitive in the higher fuel-cost areas of the country in the near future."

This reactor, according to G-E studies, could produce electricity for 6.7 mills per kilowatt-hour, compared to a cost of 6.9 mills for a conventional coal burning plant. Plants chosen for comparison would each deliver 300,000 net kw of electricity.

The cost figures described were derived "on the basis of coal at $.35 per million btu's, a price paid in a number of sections of this country."

McCune reported, "The fixed charges are higher on the atomic plant. It is estimated that operating costs are slightly more. The big difference is in the relatively low fuel cost, 1.35 mills per kilowatt-hour for long-burn-up fuel."

He said long-burn-up fuel could remain in the reactor over a period of years and still produce sufficient heat to operate the power plant.

Cost of electricity from the graphite-moderated reactor, the G-E official said, would come to 6.8 mills per kilowatt-hour.

McCune derived the numbers in this estimate from actual construction experience. He said emphatically, "We know what it will cost and don't have to guess. The engineering is that which we have developed through many years of technical effort."

He described the graphite-moderated reactor as a direct descendant of the graphite-moderated water-cooled reactors with which we have been producing plutonium at Hanford since 1946.

Forum members were told, however, that both types of reactor depend on development of an adequate long-burn-up fuel element not yet available.

The effort to develop a satisfactory fuel element is a major undertaking "with many aspects and a number of possible avenues of solution," McCune declared.

Costs of the long-burning fuel, he explained, would be linked to the rise and fall of the price of uranium. Further, the Company anticipates that uranium prices are likely to decline during the span of time in which the atomic power industry undergoes its initial expansion.

In his presentation McCune assumed that the government will provide enriched uranium from its gaseous diffusion plants to the electric utility industry for use as fuel at fair prices. "It is my opinion that Congress will make such fuel available to the power industry," he explained.

Size of the graphite reactor chosen for the cost estimate was described as quite large, with a net electrical capability of 700,000 kw. The large size is designed to achieve economy of operation.

"The graphite reactor is not necessarily limited to such large sizes," he commented. "It is possible that it might be cooled by boiling water which would make it economic in smaller sizes."

When describing the capabilities of the graphite reactor, McCune said, "It is our belief from long experience and extensive knowledge of what these reactors can be made to do that they deserve very serious consideration for power."

During his discussion of the graphite-reactor estimate, he said that one of the more important contributions has been to provide the industry with a feeling of certainty that the capital investment will not be too large to preclude competitive atomic power.

"The numbers in this estimate are not speculative," he emphasized. "They are based on years of experience in the construction and operation of a number of high-power graphite reactors which we know can deliver energy reliably with high-capacity factor.

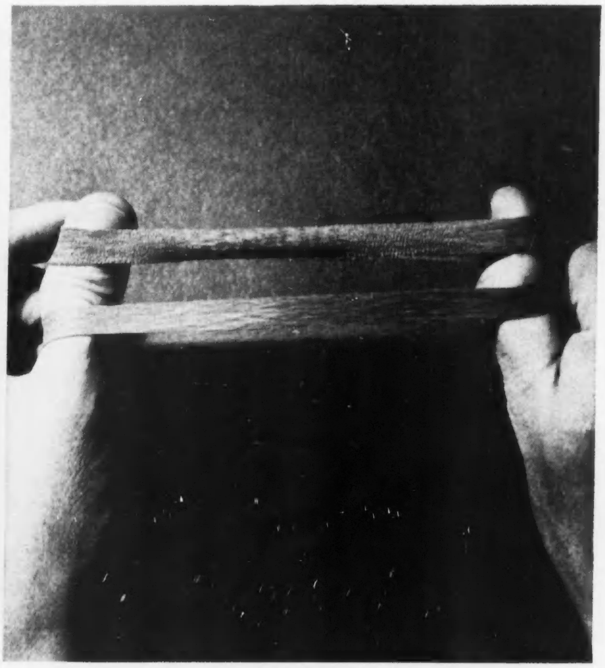
McCune concluded his address by stating, "General Electric feels that the time has arrived when we can look toward definite goals in the area of commercial atomic power—goals that can and will be achieved, and that almost inevitably will lead to expansion into a power age of great proportions with resultant benefits in human well-being." Ω

Francis K. McCune—General Manager of GE's Atomic Products Division—recently announced the Company's official position on harnessing atomic energy to generate electric power at commercially competitive costs. To give you the details of this significant announcement, we present a summary in the space usually devoted to our editorial. —EDITORS

LIQUIDS Many organic liquids become viscous upon irradiation—varying from an insignificant thickening to the formation of a nonflowing solid. Gases also may be evolved.

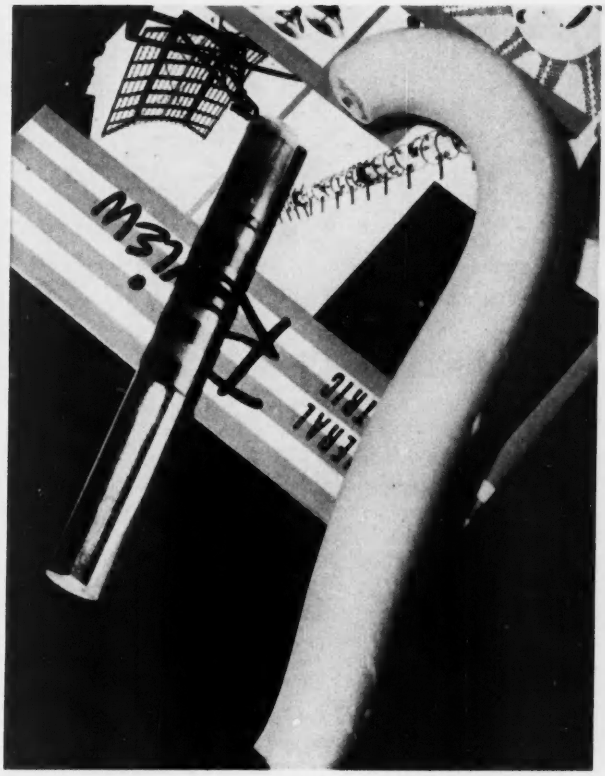
SOLIDS Irradiation breakdown of ordinary paper causes it to become discolored and to break into bits like charred paper; other paper can be made appreciably water-soluble.

PLASTICS After gamma radiation flexible polytetrafluoroethylene, useful as gaskets in chemical systems, is changed to a brittle, crumbling solid.



RUBBER The common office rubber band deteriorates (*top*) after a small dose of gamma radiation, developing cracks and losing its elasticity, particularly under stress.

GLASS Most ordinary types of glasses are quite easily discolored by exposure to gamma radiation. The piece of clear glass has been stabilized against this effect.



PLASTICS Heating some irradiated plastics to 180 F causes trapped gas to expand it. Heating unirradiated plastics (*left*) doesn't alter appearance.

How Radiation Affects Important Materials

By DR. SAMUEL S. JONES

What effect does nuclear radiation have on steel, a rubber gasket, plastics pipe, glass, a piece of paper, or bearing grease?

Is the effect disastrous, insignificant, or perhaps beneficial?

To the majority of REVIEW readers such a question is highly academic, but to the engineers and scientists designing nuclear reactors—and particularly the nuclear power plants for submarines—the questions are of vital importance. (Ionizations, electronic excitations, and atomic displacements may be produced when radiation is absorbed by matter. Radiation damage is said to occur if the resulting physical or chemical effects are such as to interfere with any application involving the material.)

How various materials used in nuclear power plants are tested to determine their behavior under radiation makes a fascinating story.

That radiation can produce changes in matter isn't a recent discovery. In fact, the *effects* of radiation were known even before radioactivity was discovered. Nearly 60 years ago Wilhelm Roentgen, a German physicist, reported that certain highly penetrating rays, which he had discovered, produce images on covered photographic plates. This radiation came to be known as roentgen rays, or x-rays, and was recognized as identical to low-energy gamma radiation. In 1896, Henri Becquerel, a French physicist, reported that radiation from the uranium mineral pitchblende—like x-rays—fogs a covered photographic plate. Shortly afterward, the existence of natural radioactivity was established.

Early workers with radioactive materials observed other effects. Water solutions of certain radioactive materials decomposed and formed gases, and the radiation often discolored and weakened the glass or quartz vessels that contained the solutions.

Controlling Radiation Damage

But the most unfortunate early evidence of radiation damage was the harm

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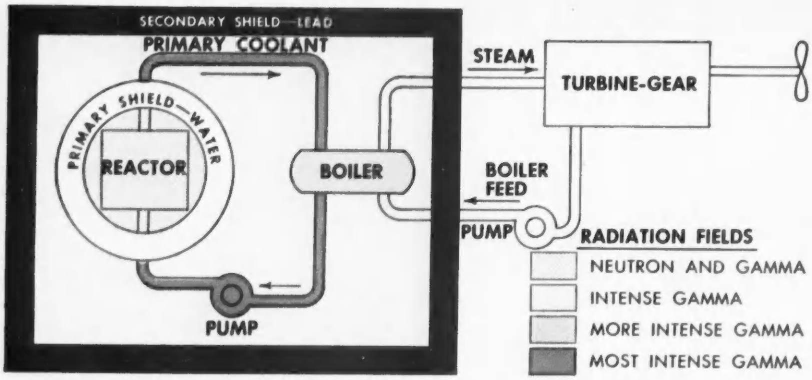
Dr. Jones, a research associate with the Knolls Atomic Power Laboratory, Schenectady, operated by GE for the U.S. Atomic Energy Commission, has been with the Company since 1950. A member of the Chemistry and Chemical Engineering Section, he is involved in the field of radiation chemistry connected with reactor development.



REACTOR'S PRIMARY SHIELD STOPS NEUTRONS; SECONDARY STOPS GAMMA RADIATION.

to the workers themselves. Solutions of certain radioactive materials must certainly have contaminated the laboratory atmosphere, and it's not unlikely that traces of radioactive materials were directly ingested. Such exposures led to cancer or other conditions that were ultimately fatal. Similar radiations, now better understood, are used today in the fight against cancer.

We are now working with quantities of radiation that are many million times greater than ever before. Similarly, our concern about radiation damage to important materials is greater than ever.

Nuclear chain reactions—a source of much radiation—can be made to proceed rapidly, as in the atomic bomb, or at much slower and more controlled rates, as in a power-producing reactor.

An example of the latter is a special type of power reactor now under construction at the Knolls Atomic Power Laboratory operated by General Electric for the U.S. Atomic Energy Commission at Schenectady, NY. The reactor (illustration) will power the submarine *Sea Wolf* and is called SIR (Submarine Intermediate Reactor) because most of the nuclear fission is produced by neutrons traveling at intermediate speeds. Neutrons tend to make radioactive anything they strike and may produce radiation damage as well; so it is best to confine them as close as possible to the reactor by using a neutron shield. Light elements such as the hydrogen in water are effective for this purpose.

Shields Are Essential

But gamma radiation is present around SIR in particularly large amounts because of the intense radioactivity produced in the primary coolant (liquid sodium) used to remove heat from the reactor. To restrict the intense gamma field to a relatively small volume around the reactor, a secondary, or gamma, shield is used to enclose all circuit elements of the reactor's primary cooling system. Dense materials such as lead are especially effective protection against gamma radiation.

The water-filled inner neutron shield is thus subjected to both intense neutron and gamma radiation. However, the volume between the primary neutron shield and the secondary gamma shield is subjected to gamma radiation alone. All equipment located in this space must be able not only to withstand the intense gamma field but also to operate properly for extended periods of time.

To determine the radiation damage that might occur under such conditions, it is necessary to study the effects of gamma radiation on various materials and systems under controlled circumstances. This requires intense sources of gamma rays.

The radioisotope best suited for this purpose is cobalt-60, produced in atomic piles by irradiation of metallic cobalt with slow neutrons. All gamma rays from cobalt-60 have essentially the same energy—about 1¼ Mev. Two gamma rays are emitted for each atom of cobalt-60 that disintegrates—a significantly higher gamma yield than that of most other isotopes considered for irradiation purposes.

Designing a Radiation Source

Certain factors must be considered in the design of a gamma radiation source . . .

- The source must be able to irradiate a sample large enough to be adequately analyzed.
- The sample should be irradiated at such a dose rate that measurable changes of significant properties can be observed in a reasonable length of time.
- If the radiation effect in question depends upon dose rate, it is desirable to have radiation fields of uniform intensity.
- The radiation source must possess a certain amount of flexibility so that it can be used conveniently.

Since early 1952, two high-intensity cobalt sources have been utilized at the Knolls Atomic Power Laboratory. The smaller lead-shielded source was made using 580 curies of cobalt-60; the larger water-shielded installation was loaded with 3400 curies of the isotope. For both, the radioactive cobalt was obtained from the AEC's Isotopes Division at Oak Ridge, Tenn.

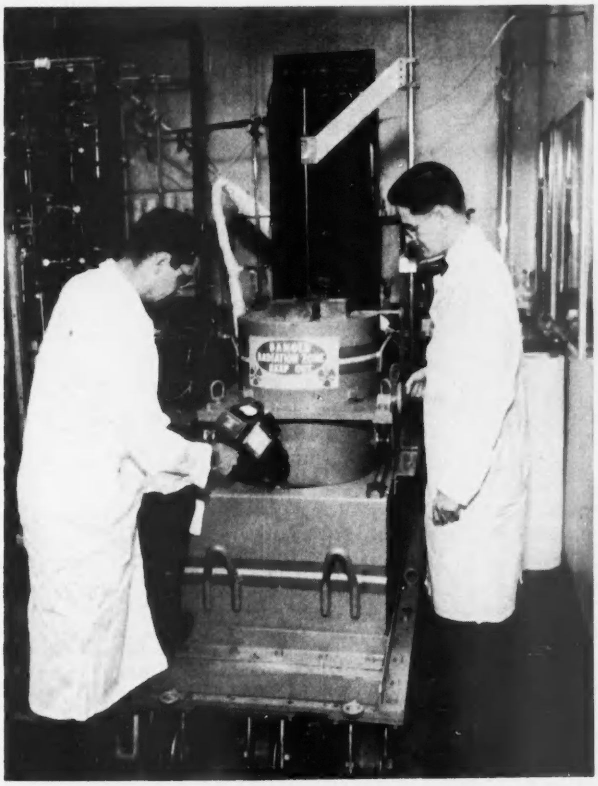
Source Sizes

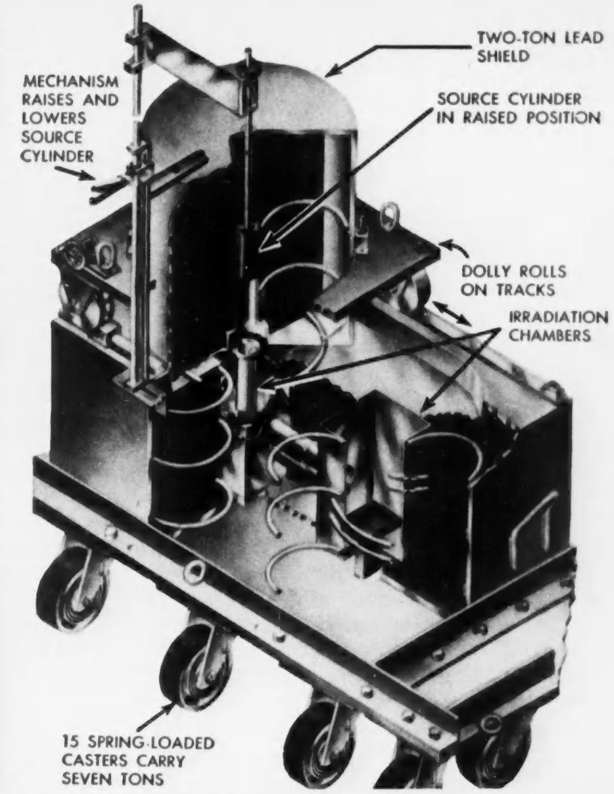
The smaller gamma source is a cylindrical array of cobalt-60 about 2½ inches long and 1½ inches in diameter. The source "building blocks" are pile-irradiated cobalt pellets. About 7 ounces of these pellets is distributed in 5 regularly spaced holes in a hollow thick-walled brass cylinder.

The source is kept in a special lead-filled irradiation unit (photos, top, opposite page) that contains two chambers. For various experiments there are 4 access holes to each of these irradiation chambers. In addition, large square openings are available in the bottom of each chamber through which a radiation beam may be removed. This irradiation unit represents a modified design of a similar one developed earlier at the Oak Ridge National Laboratory.

The total rate of energy output from this unit is only about 9 watts. However, in terms of radiation this amounts to a high intensity of deadly gamma rays: The lowest dose rate in the irradiation chamber is still several hundred roentgens per minute; in the center of the source the dose rate is about 10,000 roentgens per minute. (A dose of 500 is regarded as fatal to humans.) Even though the radiation intensities are high, the 9½-inch-thick lead walls reduce the dose rate to below biological tolerance outside the shield.

The small cobalt gamma source is only one sixth the size of its big brother, the 3400-curie water-shielded source (photos, lower, opposite page). However, the larger unit is made from the same sort of radioactive pellets as is used in the small source. The large source consists of 10 separate cylindrical source capsules, each originally filled with 340 curies of cobalt-60 and each a half inch in diameter and about





MOBILE 580-CURIE LEAD-SHIELDED COBALT GAMMA SOURCE PROVIDES ACCESS TO SAMPLE DURING IRRADIATION; AUTHOR *(RIGHT)*.

LARGE OBJECTS ARE IRRADIATED IN THE 3400-CURIE WATER-SHIELDED COBALT GAMMA SOURCE. IT IS PHOTOGRAPHED BY ITS OWN LIGHT *(RIGHT)*.

IRRADIATION POLYMERIZATION—A mixture of styrene and acrylonitrile in equal quantities produces a solid that often breaks its glass container.

8 inches long. They are made of magnetic stainless steel for convenience in remote handling. Every capsule has a space about 6 inches long that is filled with 4 ounces of radioactive cobalt pellets; a threaded plug at the top closes it. All the capsules have bases designed to provide means for manipulation and support: Special tools can grip the capsule in the rectangular notch around its base end, and for support their bases can be plugged into a steel plate like pegs in a punch board.

The supporting base plate for the large source has a radially symmetric distribution of holes. The 10 source pins can be plugged into these holes in any desired arrangement, and the remaining holes can then be used to support the materials being irradiated.

The base plate and array of source pins are mounted in a concrete tank containing 5000 gallons of water. This covers the source at a depth of 8 feet—an adequate shielding. A mesh of steel rods that covers the top of the tank prevents objects and people from falling in and supports experimental equipment. In addition, an ion chamber constantly monitors the radiation at the surface of the water for health physics purposes.

One technique used in carrying out irradiations utilizes watertight aluminum pipes which have base plugs that fit into holes in the source base plate. Samples in small glass vials are lowered via a simple tube carrier down the pipes into the radiation field. An alternate procedure especially suitable for long irradiations is to place the samples in watertight aluminum cans which also have base plugs that fit into holes on the source base plate. The cans are supported on metal rods and are provided with lead-off tubing for various experimental purposes.

$100 Million vs $17,000

When the 10 source capsules are arranged in a circle of the smallest possible diameter, the radiation intensity in the center of the array is 3 to 4 times that in the center of the small source described previously. When a sample is irradiated under these conditions, each square centimeter throughout its volume is riddled by about 1000-billion gamma-ray bullets every second. To accomplish the same effect would require well over $100-million worth of radium—twice the world's present supply. Yet the radioactivity for this source was bought for about $17,000.

Radiation Effects . . .

What have we learned about radiation effects on different materials?

You must realize that gamma rays are absorbed in materials by giving their energy to the electrons in the materials. The degree to which gamma radiation affects matter therefore depends upon the part the electrons play in the structure of the matter. If the electrons are relatively free to move and are not particularly associated with any one atom, there is very little radiation effect and the radiation damage is negligible. However, if the electrons are directly involved in the chemical bonds of the material, gamma radiation may produce significant effects: the molecules of the matter may be disrupted and the physical structure broken down.

. . . on Gases

Gamma rays knock electrons out of gas molecules and thereby produce ions. Also, about half the absorbed energy goes to excite the gas without forming ions. Some gases such as the monatomic rare gases—helium, neon, argon, krypton, and xenon—are not changed. The gas ions eventually recover enough electrons to neutralize them, and there's no net effect. However, if the gases are composed of complex molecules such as organic vapors or are mixtures of potentially reactive gases, significant chemical changes can result.

. . Liquids

Liquid metals are conductors and have many free electrons. Except for heat generation in the metal there is no net gamma radiation effect in such systems.

Pure water is not appreciably damaged by gamma radiation. Actually, H_2O molecules are disrupted by the radiation, but the decomposition products will recombine to the extent that the net decomposition of the pure liquid is small.

The situation may be quite different if other materials are dissolved in the water because relatively small amounts of certain impurities can cause trouble; the dissolved materials can interfere with the water's tendency to heal itself from radiation breakdown. If this healing capacity is reduced, net decomposition of the water will increase, giving rise to undesirable quantities of water breakdown products: hydrogen, oxygen, and hydrogen peroxide.

But the effect of dissolved materials on water decomposition is only half the story. The materials themselves can undergo changes because gamma radiation converts water—a rather neutral substance under ordinary conditions—into a highly reactive chemical reagent. Much of this reactivity comes from the instantaneous products of decomposition, the H and OH groups. This means that materials initially added to the water for certain purposes may not serve that purpose. In some cases they are converted into corrosive or otherwise undesirable chemicals. For example, many dissolved organic materials are converted into acids; dissolved organics containing chlorine converted to chlorides; sulfites oxidized to sulfates; and nitrates partially reduced to nitrites. Ceric ions can be reduced to cerous ions, while ferrous iron can be oxidized to the ferric state. These last two reactions were studied in considerable detail and are now used to measure the amount of gamma radiation absorbed by dilute water solutions.

Gamma radiation can in many ways break down organic molecules, such as those present in lubricating oils and greases. The molecular structure is so complicated that there's no significant healing reaction of the type that happens in water.

Because the products from the irradiation of organic liquids are numerous and vary from one liquid to another, the effect of radiation upon such systems is not as well understood as it is for water. Usually irradiation produces hydrogen as the principal gaseous decomposition product. The liquid itself may show both increases and decreases in molecular weight. That is, some of the molecules are chopped into smaller molecules, while some of the fragments may combine to produce larger molecules than the original. Certain groupings of atoms in organic molecules produce specific irradiation effects. The most outstanding example of this is the stabilizing influence of aromatic rings such as benzene or napthalene. When these groups are present, the organic material is much more resistant to radiation.

The over-all effect of radiation on many organic liquids can easily prevent them from performing satisfactorily on a given application. Gases may be evolved in substantial quantities. Large viscosity changes may take place (photos opposite page and page 6); sometimes the liquid is converted to a solid. Also, the liquid products of irradiation may interfere with the intended use of the original material.

. . . and Solids

Because metals contain clouds of electrons that aren't attached to any particular atom, gamma irradiation can have no significant consequence except for heating effects. There is, however, an important kind of damage to metals that may be influenced indirectly by gamma rays: corrosion and related phenomena. Corrosion is linked with the effects of various surface films on metals. These films are generally unlike the parent metal and may be damaged either directly by the radiation or indirectly by corrosive chemicals produced by irradiation of the environment. Any such attack on metals by gamma rays is necessarily a secondary act brought about by a "middle man" vulnerable to irradiation.

Among the nonconductors, glass is easily affected by gamma rays in a significant way: Under radiation it discolors so that you can't see through it (photo, page 7). However, the actual physical damage done to the glass is generally minor. Color is produced by the change in state of some of the electrons in the glass. The discoloration can be removed by applying heat or ultraviolet light, thereby getting the electrons back to their initial states. Much larger doses of radiation are required to affect the physical structure of glass.

Radiation damage is important in another group of solid nonconductors—plastics. Polymers of various kinds are the principal structural element of plastics. The relative effect of gamma radiation on a given plastics depends on the type of chemical structure that makes up the links in the polymer chain. The results (photo, page 7) vary widely —sometimes the effects are disastrous, sometimes beneficial in that the physical properties are improved. Here again, as in organic liquids, the presence of aromatic rings increases the radiation stability of the plastics; polystyrene and aniline-formaldehyde polymer are among those most resistant to radiation.

At the other extremity, cellulose and its derivatives, as well as certain halogenated polyethylenes, are easily damaged by gamma radiation. Under irradiation, ordinary paper quickly becomes discolored and brittle, similar in appearance to lightly charred paper (photo, page 6). With continued irradiation, such cellulosic materials can be made appreciably water-soluble.

Polytetrafluoroethylene is noted for its outstanding resistance to corrosive chemicals and high temperatures. However, under irradiation this material is a bad actor. It loses its structural strength, becomes brittle, and may fall apart easily (photo, page 6). You can see that it isn't necessarily true that chemically inert plastics will maintain their resistance under radiation.

A final group of materials of considerable importance for engineering applications are the elastomers, or rubbers, also susceptible to damage by gamma radiation. When rubbers are irradiated they rapidly lose their elasticity and may become badly cracked (photo, page 6). This effect is particularly evident if the rubber is under stress while being irradiated. Under continued irradiation some rubbers become hard and brittle, while others tend to become liquid and as sticky as molasses taffy. This behavior is associated with the breakdown of the chain structures characteristic of the original material.

Stable Materials Are Essential

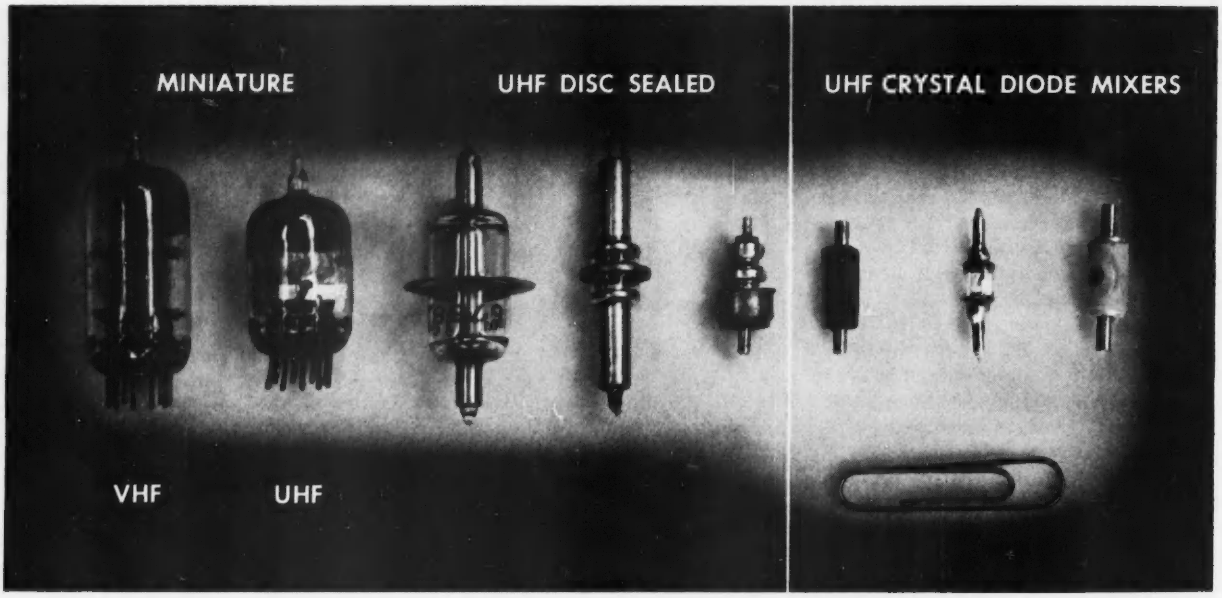
The types of materials whose gamma radiation resistance properties we've discussed are all needed in reactor development. For the SIR many such materials must withstand use in the intense gamma fields between the primary and secondary radiation shields. The shields themselves must also be able to withstand the radiation without being significantly affected. Whenever water or oils are used for shielding purposes, the consequences of radiation damage may be important. For instance, the possibility of releasing sizeable quantities of hydrogen into a closed submarine because the shield decomposed would create a serious explosion hazard.

Another concern is gamma-radiation damage effects to electric insulation located between the primary and secondary shields. The insulation on all coolant pumps must withstand the radiation from the fluid being pumped.

Paint, when used on surfaces in intense radiation fields, is another potential problem. Most paints contain a certain amount of organic matter, the decomposition of which might destroy the paint's usefulness.

So far, we've considered only the effects of gamma radiation on materials and processes in regard to the SIR. However, there are other phases of reactor operation that require our attention. For instance, highly radioactive spent-fuel elements must be processed in shielded enclosures. Transparent liquid shielding for the processing cells often involves the use of concentrated solutions of zinc bromide. This material requires chemical stabilization if it is to perform satisfactorily under intense irradiation. Optical equipment must contain glass that resists radiation discoloration. Such items as electric insulation, rubber, and greases must be radiation resistant. Finally, all chemicals used in reprocessing the spent fuel must be sufficiently stable so that they won't interfere with the process.

Development of the SIR has required attention to a number of aspects of gamma-radiation damage. The choice of optimum materials and operating conditions has been aided by many tests done with the sources. Undoubtedly, in the years ahead they will help to throw more light on this significant factor in reactor development. Ω



DISC-SEALED TRIODE IS MOST SUCCESSFUL TUBE THAT CAN BE USED IN UHF RECEIVER. CRYSTAL DIODE GIVES GOOD NOISE PERFORMANCE.

Is UHF Superior to VHF?

By DR. A. B. GLENN

When the Federal Communications Commission (FCC) lifted its 3½-year ban on the construction of television stations in April, 1952, it allowed a possible 2053 more stations to be built in the United States.

But as the public soon found out, the majority of these stations were to operate in a new and strange medium that bore the somewhat indefinite name of ultrahigh frequency (UHF). The rest of the stations would be in the familiar very-high-frequency (VHF) bands that were already being used. The new setup would have 70 channels between 470 and 890 megacycles, and if your regular VHF set wasn't built to handle UHF, you'd need a converter and a new antenna. The only thing that wouldn't change would be the programs.

Logically and justifiably, the public's reaction was "Why can't we get along with the 12 channels we've always had?"

The "why" had nothing to do with whim. It was simply a matter of necessity: with VHF only, you just can't serve the optimum number of communities in the United States without causing disastrous overlapping of signals. The FCC's original plan didn't work out because, among other reasons, VHF signals (54 to 216 megacycles) traveled a lot farther than anyone had expected. This led to interference between the same channels in distant cities, which led to violent protests, which in turn led to the FCC clamping down on further station construction until a new plan could be drawn up. The solution finally worked out was to open 70 additional channels in a higher frequency area.

When UHF was making headlines, there was a lot of talk among the public to the effect that the UHF channels were "better" than the older VHF channels in that they supposedly would give a clearer picture and would be less affected by interference. UHF was the latest thing. After all, wasn't it "ultra" and "higher" than the old VHF? It just had to be better. The picture is as good and no better, but to do the job you need more precise circuits and more complicated tubes and antennas. "The higher you go in frequency," a laborer in the field remarked recently, "the more difficult life becomes."

Just *how* difficult is outlined in this article: the troubles are concentrated in tubes, circuits, propagation waves, antennas, and transmission lines.

Tubes, for Instance . . .

The allocation of the 70 additional TV channels in the UHF band spurred the development of transmitters and receivers to handle signals in this area. It soon turned out that for *both* transmitters and home receivers suitable tubes are one of the major problems.

The two most important characteristics of tubes used in home receivers are amplification and noise generated within the tube. For transmitting amplifiers the two most important characteristics are amplification and power output. These statements sound innocent enough until you realize that the higher you go in frequency the more amplification drops off and the more the noise increases. And because UHF-TV operates at quite a higher frequency

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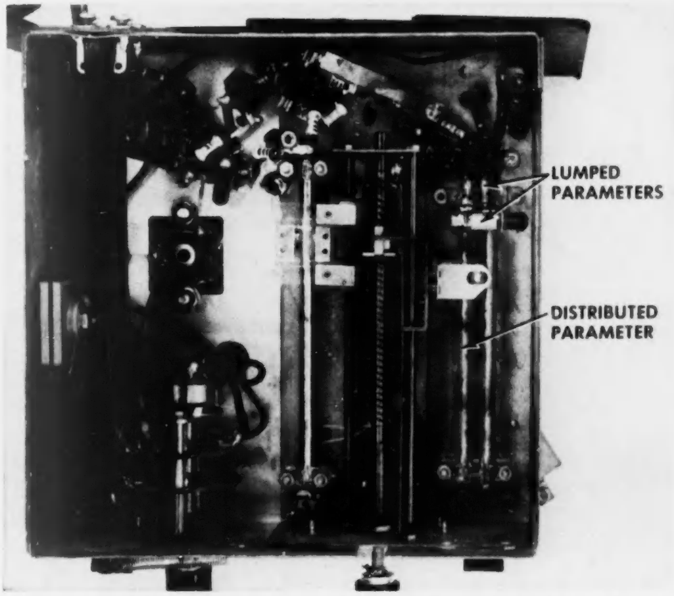
Dr. Glenn—Television Development Engineer—came to General Electric in 1949 and is with the Radio and Television Department, Electronics Division, Electronics Park, Syracuse.



KLYSTRON TUBE SOLVES MANY UHF TRANSMISSION PROBLEMS. PARAMETERS ALLOW CIRCUITS TO BE TUNED OVER ENTIRE VHF-UHF RANGE.

than VHF-TV, the troubles have already begun. Noise shows up on your picture tube as "snow"—a primary limitation of the useful range of television service. (Because of the importance of noise, you'll find a short discussion on page 15.)

Using VHF tubes in UHF equipment won't solve the problem; they just aren't practical at the higher frequencies. For one thing, the length of leads going from the base to the elements of the tube causes uncontrollable feedback that lowers the gain and increases the noise of the amplifier. Another factor is that the socket, plus the leads from the base of the tube to the tube elements, becomes an appreciable part of the amplifier circuit. This makes it difficult to design an efficient circuit.

Transmitting tubes present special problems. In the type of tube used at the lower (VHF) frequencies, the principle of density modulation is used. In short, the signal voltage is applied between two elements of the tube: the control grid and the cathode. This signal voltage will density modulate the electron streams that flow between the cathode and anode of the tube. But as you boost the frequency to UHF levels, the transit time of the electrons between the tube elements becomes comparable to the period of the signal (equal to one over the signal frequency), the amplification starts to decrease, and the noise begins to increase. To overcome this effect, the elements are brought closer together. But this decreases the amount of power the tube is capable of dissipating, which in turn lowers the amount of power the amplifier is capable of amplifying. (To give you an idea of the manufacturing problems, picture the difficulties of spacing the minute elements of a tube 0.001 inch apart under the speeds of today's production lines.)

The solution to the problems of UHF transmitting tubes is the klystron, (photo, left) a tube that actually utilizes the transit time of the electrons. It was developed by Varian Associates under a GE-sponsored program.

Although excellent as a transmitting tube, the klystron is too noisy to be used in a receiver. So far, the most successful type of tube used in a UHF receiver is a planar disc-sealed triode (photo, opposite page), a tube where all the elements—grid, cathode, and anode—are in parallel planes. The "disc" refers to the flat, round piece of metal that supports the grid. Close spacing can be tolerated in a receiving tube because the amount of power to be dissipated is small. At present, however, the difficulty in constructing these tubes results in prohibitive cost for use in home receivers.

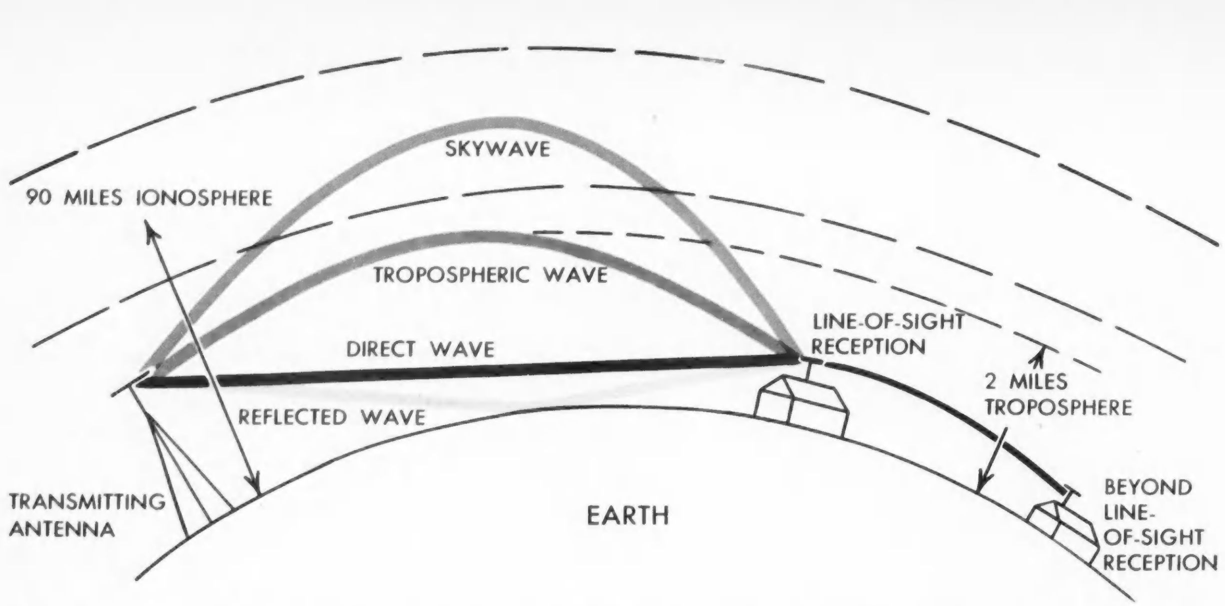
As a compromise, crystal diodes (photo, opposite page) are used in UHF sets. During the last few years their quality has been vastly improved and their cost decreased. Thus the crystal diode today is the most practical method of obtaining good noise performance in a tuner. There's no doubt that the TV tuner of the future will use the same complement of tubes for both VHF and UHF and that the type of tube will probably be of the planar disc-sealed variety.

. . . and Circuits

Another major difficulty confronting the engineer in the UHF region is the development of an efficient circuit that will tune over the entire range. For VHF, lumped constant parameters are used in the circuit; for UHF, distributed circuits are called for (photo, right). This is necessary because the circuit elements that are satisfactory at the lower frequencies radically change their characteristics as the frequency is increased. To confuse the matter even further, the lumped parameters may no longer be lumped but distributed.

As the frequency is increased, you also get increased energy losses due to increased losses in the internal components—usually in the form of heat and also radiation losses. These losses not only lower the gain but also decrease the selectivity of the receiver. And the latter can lead to serious interference from undesired signals.

From all this you can recognize that many of the circuit techniques used at VHF are not satisfactory at UHF, and the circuit problems at UHF are far more difficult than at VHF.



ELECTROMAGNETIC WAVES RADIATED FROM A TV TRANSMITTING ANTENNA MAY REACH THE RECEIVING ANTENNA BY SEVERAL PATHS.

Also, accurate theoretical circuit analysis is difficult, if not impossible, at UHF because of lack of knowledge of the actual components and the circuit.

The Connecting Link

Energy radiated from a transmitting antenna may reach the receiving antenna by several paths (illustration, above) . . .

- Sky waves are reflected from the ionosphere, the region of the earth's atmosphere about 60 to 185 miles above earth.
- Tropospheric waves are reflected from the troposphere, the region of the atmosphere within seven miles of the earth's surface.
- Ground waves propagate energy over all other paths. They are divided into a space wave and a surface wave.

The space wave consists of both a direct wave that travels directly from the transmitter to the receiver and the ground-reflected ray that is received after being reflected from the surface of the earth.

The surface wave is guided along the earth's surface similar to the way an electromagnetic wave is guided by a transmission line. The losses in the ground will absorb the energy of the surface wave; thus the quality of the wave is directly affected by the characteristics of the earth along which it travels.

The surface wave is the primary means of propagation of energy for the standard broadcast waves—500 to 1500 kilocycles. Secondary coverage is obtained by the sky wave, which is of strictly lower quality because it always fades in intensity.

In the frequency range of 1½ to 30 megacycles, moderate and long-distance communication is accomplished by the sky wave; the ionosphere reflects the sky wave back to earth to the receiving point. The propagation characteristics under such conditions will directly depend upon the transmitted frequency and the conditions in the ionosphere.

At frequencies above 60 megacycles—the beginning of the television spectrum—waves are *never* refracted or reflected back to earth by the ionosphere. (Only under special conditions will waves in the range from 30 to 60 megacycles be returned to the earth.)

Thus for frequencies above 60 megacycles, communication is obtained by means of the ground wave. Points well below the line of sight may also receive energy from tropospheric reflections. However, this type of transmission is dependent on the electrical characteristics of the atmosphere, and therefore it is not as reliable as reception within line of sight.

From this it is apparent that electromagnetic waves in the TV bands behave very much like light waves. Any obstacle in the path of the wave will reflect a portion and transmit the remaining portion of the wave much like a light wave striking water. Buildings, mountains, trees, and other obstacles will thereby reflect and transmit the waves, the amount of waves depending on the obstacle. This further complicates transmission because the resultant wave now consists not only of the direct and earth-reflected ray but also of the rays reflected by or transmitted through obstacles in the transmission path. The results of such erratic reflections cause the familiar ghosts in the television picture. If the receiver is behind one of these obstacles in the so-called shadow areas, the signal strength may be unusable. Many times you can get better reception in these areas from a signal that is reflected from a nearby building rather than from the direct signal. If several signals are present, it is important to select one to the exclusion of the others so that ghosts can be eliminated. Directional antennas are necessary under such circumstances.

The reception under these conditions will become more critical as the frequency increases. For example, an antenna was adjusted for best reception on the roof of a house near a group of trees. This was done in the spring when the trees were full of leaves. When the trees lost their leaves in the fall, the field conditions changed so radically that the antenna had to be relocated. This situation is not unusual for UHF reception. Thus mountainous terrain or large cities are better served by VHF than UHF transmission.

It should also be noted that the distance at which a signal can be received beyond the line of sight decreases with an increase in frequency (illustration, page 16). Also, as the frequency increases, the field strength becomes a critical function of the distance from

NOISE . . .

The two sources of noise in a receiver are the noise present in the space surrounding the antenna and that generated in the receiver. The space, or antenna, noise includes atmospheric, cosmic, man-made, and thermal noise. Thermal, tube, and cosmic noise are the fundamental types present in radio equipment because of the atomicity of matter and electricity. Completely without regularity, it is called random noise.

Atmospheric noise, main contribution to antenna noise below 20 megacycles, is produced entirely by radiation from lightning discharges.

Between 15 and 30 megacycles, cosmic noise may be the main contribution to receiver noise. There is considerable speculation regarding the source of cosmic noise. Experimental data show that the center of cosmic noise production is in the direction of the center of our Galaxy, or the Milky Way. Cosmic noise has a continuous spectrum and displays all of the characteristics of random noise.

Man-made noise, which originates from certain electric equipment in the neighborhood of the radio receiver, may be an important part of antenna noise even up to the ultrahigh frequencies. The radio frequencies of this noise arise from the transient effect produced in the equipment by the making and breaking of a current. Equipment noise may be transmitted to the receiver by direct radiation, by conduction through the power cables to the vicinity of the receiving antenna, or sometimes a combination of both these methods.

The thermal motion of charged particles in space is equivalent to random current impulses—the sources of random radiation field that is the thermal noise in space.

Above 50 megacycles the main sources of noise present in a receiver originate there. The receiver noise will include both the random noise generated in electron tubes and the thermal noise generated in the circuits. The antenna noise will mainly consist of the thermal noise in space surrounding the antenna and possibly man-made noise. In 1928 Johnson showed that the currents caused by the thermal motion of the conduction electrons in a resistor can be detected as noise. According to the theory of metallic conduction, any metal has a large number of free electrons moving about in it. When there is no applied voltage, the velocity of the electrons is due to the collisions with the atoms of the metal. The motion of the free electrons are thermal in nature. The electronic flights between the collisions are, on the average, equivalent to current impulses. Thus the thermal motion of the free electrons will cause random or fluctuation currents.

In 1918 Schottky showed that the electron current emitted from a hot cathode of an electron tube is in the form of discrete charged particles. Thus the emission current is never steady but exhibits minute fluctuations due to the finite charge of an electron in combination with its random fluctuations. The random fluctuations arise from the randomness of the electron velocities or energies in the cathode material. Because these energies are random, the number of electrons leaving the cathode will fluctuate in a random manner. The fluctuation noise created by the electrons in the tube current reminded Schottky of the noise caused by a hail of shot striking a target, so he called the phenomenon "shot effect."

As the radio signals applied to electron tubes increased in frequency, the tubes not only showed an increased loading at the higher frequencies that will cause a decrease in amplification but also—and more important—showed a noise increase. In 1941 Bakker and, independently, North and Ferris, discovered the reason for the increase and called it *induced grid noise*. This type of noise increases as the transit time of the electrons between the input electrodes becomes comparable to the period of the applied signal. Hence induced grid noise can be decreased by decreasing the effective spacing between the tube electrodes, which will decrease the effective transit time of the electrons.

The noise factor is a direct measure of the degradation of the antenna signal-to-noise ratio as the signal passes through a noisy system. Because the system will add noise, the signal-to-noise ratio at the output of the system will be less than the signal-to-noise ratio at the antenna. The noise factor, or noise figure, is the ratio of the antenna signal-to-noise ratio to the system output signal-to-noise ratio. The noise in the system will show as snow in the picture. The noise figure of the receiver is one of the primary limitations of the useful range of television service.

The picture quality will be a function of the signal-to-noise ratio applied to the picture tube. This signal-to-noise ratio will depend upon the antenna signal-to-noise ratio and the noise factor of the receiver. A directional antenna will improve the antenna signal-to-noise ratio because the signal field will be directional while the noise field will be non-directional. On the other hand, transmission line loss will degrade the signal-to-noise ratio existing at the terminals of the receiver.

A signal-to-noise ratio of 5 to 1 is about the minimum signal-to-noise ratio considered acceptable for viewing a picture over an extended period of time. A signal-to-noise of 30 to 1 will give a practically noise-free picture.

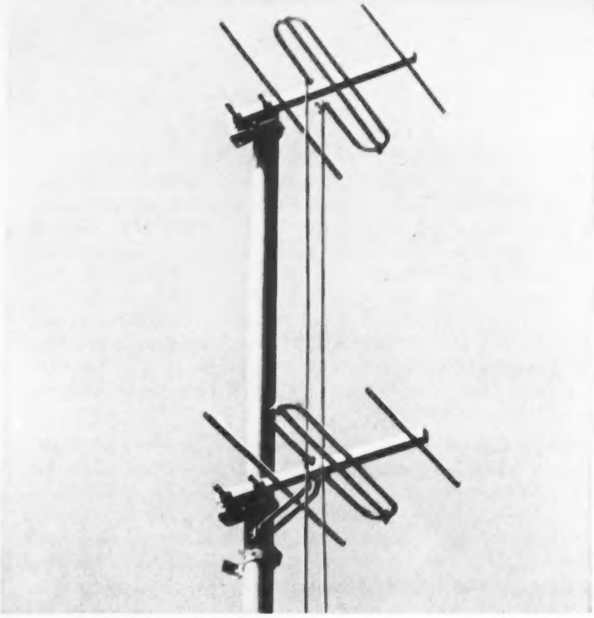
the transmitter. Propagation is far less critical for VHF 50 to 200 megacycles than for UHF 500 to 1000 megacycles.

To help solve the transmission problems at UHF, the FCC permits an increase in the effective radiated transmitted power with an increase in frequency. At the present time it is possible for VHF stations to generate the maximum power allowed by the FCC. It's a different story at UHF because only about one half the maximum permitted radiated power can be transmitted with present UHF tubes. The expectation is that the next few years will see new UHF transmitting tubes developed that will be capable of transmitting the maximum allowable power.

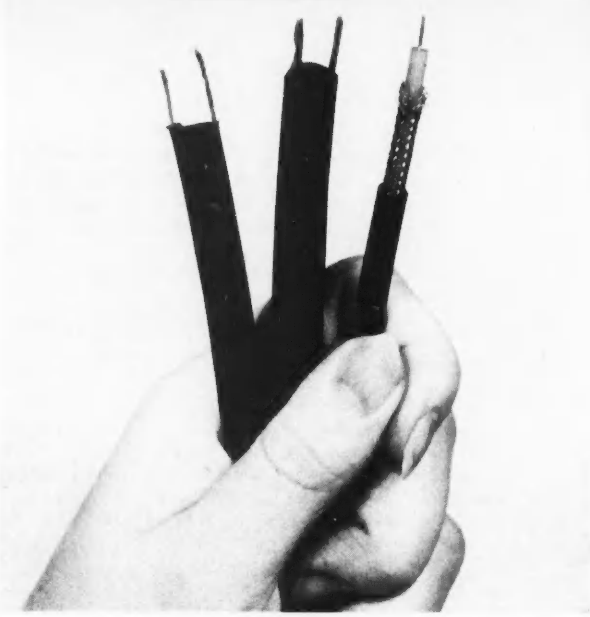
Antennas

The quality of the picture on your TV set is dependent to a large degree on your antenna (photo, left, page 16).

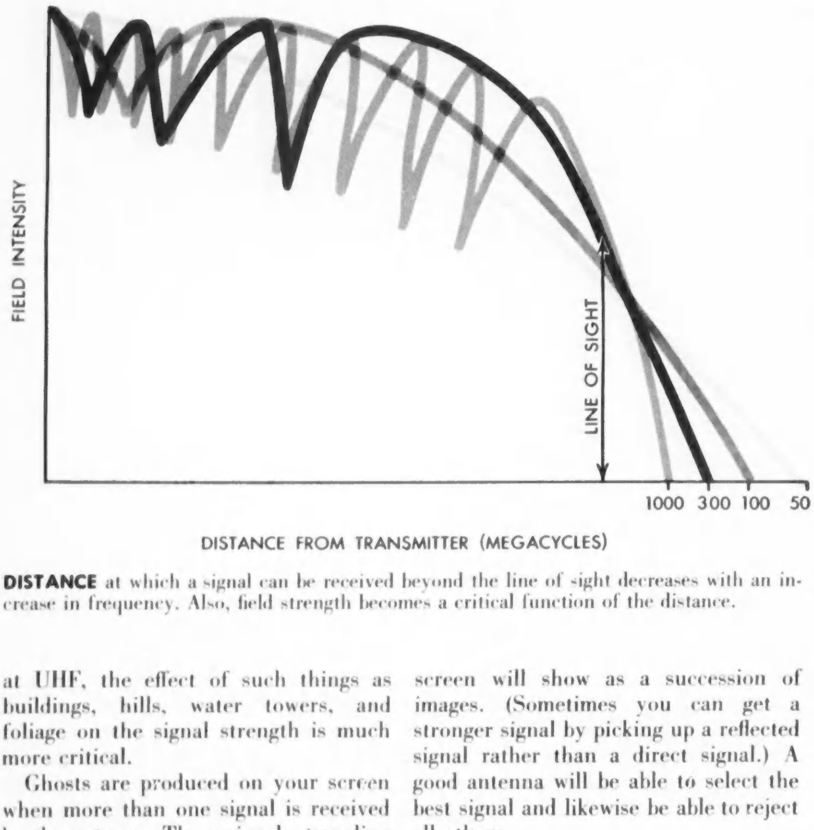
At UHF, transmitted power becomes more difficult to generate, the transmission losses become more severe, and the ability of the receiver to amplify at these higher frequencies is much poorer. Thus the antenna must be more sensitive, and its location becomes more important as the frequency increases. Because the wave length is much smaller



UHF RECEIVING ANTENNA determines to a great extent the quality of a TV picture by selecting the best signal and rejecting all others.



ECONOMICAL TRANSMISSION LINE is flat twin lead. Wet losses are less with tubular lead. Cost of shielded coaxial cable is high.



DISTANCE at which a signal can be received beyond the line of sight decreases with an increase in frequency. Also, field strength becomes a critical function of the distance.

at UHF, the effect of such things as buildings, hills, water towers, and foliage on the signal strength is much more critical.

Ghosts are produced on your screen when more than one signal is received by the antenna. These signals, traveling along different paths, will be out of time phase with respect to each other. Thus the reproduced signals on the screen will show as a succession of images. (Sometimes you can get a stronger signal by picking up a reflected signal rather than a direct signal.) A good antenna will be able to select the best signal and likewise be able to reject all others.

Because of these difficulties, a more elaborate and costly antenna system is needed at UHF than at VHF.

Transmission Lines

The transmission line joins the antenna and the receiver. The most common type is the 300-ohm twin lead (photo, right) because it is economical and its losses when dry are low. But, here again, as the frequency increases, the losses in the line increase—especially when the line is wet and losses may rise as much as 10 times.

A new type of line known as the 300-ohm tubular twin lead is somewhat better in this respect. Its losses only double when the line is wet because a large part of the electromagnetic field exists *inside* the tubular line rather than *outside* as in the flat type. Most of the field is thus protected from the elements.

Shielded coaxial cables are not affected by weather, but their cost is high and their losses for dry conditions are greater than for the 300-ohm line.

The Engineer's Plight

You can readily see that the problems confronting the television engineer are more numerous and more difficult at UHF than VHF. But there were many difficult problems facing the engineer at VHF only a few years ago. These were solved and so will the many UHF problems be solved. The FCC allocation plan to provide television service, in so far as possible, to all the people in the United States will become a reality in the near future. Ω

Observations by Industry on . . .

Educating the Technical Graduate

By W. SCOTT HILL

Industry has many processes whereby the finished product of one plant becomes the source material for another. The education and specialized training given the engineer during his college years become the material utilized by society for an important part of our way of life. Unlike the products of industry, however, the output of the college is a human being with countless combinations of abilities, training, and personal characteristics besides his background aptitude and intelligence level. Because these characteristics appear in endless variations, this subject never loses its interest—or the possibility of improvement.

My work takes me to many a college campus and among many of the best educators in the field of engineering. Often the subject turns to the way engineering students are being prepared by the colleges to meet the requirements of industry or whatever career the graduate selects. Both college and industry recognize that men are being trained to have many choices for the way they can serve society. Like a great hotel, there are countless doors that can be opened. Some lead to spacious quarters or extensive suites, some to narrow confining rooms, and some are simply service rooms or broom closets. What keys are needed for all these rooms? Some say it is best to have a separate key for each room and apartment. Others argue that more flexibility results if the hotel had more passkeys to open the doors of whole floors at once.

It is the business of the engineering educator, together with the counsel of those in industry, to study the best system of keys for our era. If asked, they would probably start by wanting to know what it is that you are trying to do with your keys and rooms. In a hotel the plan of one key fitting a specific door has considerable merit for the guests. When education is the key and industry the multiplicity of doors, the idea of a key for many different doors and opportunities begins to appeal. Suppose we speculate on a few of the factors, aside from specific curriculum subjects, that might profitably convert the single-room key to the more general passkey.

Better Prepared Graduates

If the question were asked "Can the engineer be better prepared for industry?" the answer would be "Yes, he can." If we list the preparation that industry would *like* him to have, this might well include a basic four-year engineering course topped off by graduate work in a specific field, plus the physics or math of a doctorate superimposed on a liberal-arts background with a survey of economics added. Such qualifications may be deduced from the specifications to fill certain jobs. But several things are wrong: Either the average student would suffer privation before he financed all that or industry would hesitate to pay the asking price. A more practical solution is required.

Suppose the question were "Are graduates necessarily poorly prepared?" The answer is "No" because industry makes good use of them right now, and most graduates do astonishingly well. This is a tribute to the educators who have given their lives to this problem over the years.

Such are the extremes. Between them we can find many variations. Some college programs are almost standardized in pattern, with only minor departures. Others in stages between planning and practicing are raising serious questions concerning the established approach. And they are asking if the time has not come for a more general reappraisal and, presumably, some fundamental changes.

These remarks are not to be interpreted as our entering the arena reserved for the professional educator; he is much better qualified to judge how a given educational end can be achieved. However, individual opinions from industry can safely suggest a few avenues that can supplement the literal following of the prescribed professional courses of study. The student may then recognize these viewpoints as signposts to help him in the critical years as he begins his lifework.

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With more than 30 years of experience with General Electric, Mr. Hill is now Manager of Technical Recruiting Services, Engineering Services Division, Schenectady. A vice president of AIEE, he is associated with many technical and professional activities.

Opinions from Industry

Most science and engineering graduates find their first positions through the mechanism of college recruiting, with all its assorted variations. Industry interprets its needs through these recruiting representatives. Their opinions are not final, but they can suggest some of the factors—aside from any special curriculum—that industry takes as its beliefs of the moment.

Take the matter of liberal arts courses in conjunction with a professional course, such as some field of engineering or science. Industry knows that a four- or even five-year course prevents full treatment of the subject matter of a specialty, much less any extensive liberal arts training. Compromises are then made by the college. General Electric's view is that the undergraduate should be led if possible, and prodded if need be, on a course that gives him a reasonably firm foundation in the technical field where he is obtaining his degree. Application can be sacrificed in favor of fundamentals. Next, we urge that space be found to introduce some cultural subject matter to the end that the graduate comes out of school with some of the rough edges smoothed off. This has a threefold objective: The graduate will have some understanding of the meaning of his work in relation to society; some power to select the main issues of the day; and a realization of the influence that he can exert by the wise use of his knowledge, ability, and judgment.

President Griswold of Yale well stated the basic purpose of liberal arts when he recently wrote, "It is to awaken and develop the intellectual and spiritual powers in the individual before he enters upon his chosen career so that he may bring to that career the greatest possible assets of intelligence, judgment, and character." It is desirable that technical graduates be exposed to the important cultural and thinking processes normally associated with the liberal-arts area.

Actually this is now being done to a greater degree than is being indicated here. When professors are alert to these broader horizons and are developed in cultural as well as technical fields, then some of this is caught by their students, often without their being aware of what is taking place. Through various college-living systems students are uniquely associated. When engineering, liberal arts, social sciences, and scientific undergraduates live, talk, and discuss together, some of the attitudes of one group develop in the other through osmosis and inspiration.

Specialization

Society needs to encourage its best minds to take advantage of additional training where this will help to expand the radius of knowledge or contribute to human welfare.

For those with the financial means, intellectual capacity, and time, the graduate schools provide one mechanism for advanced specialization. The alternate is to accept industrial employment in an area where advanced work is available, thereby working and learning simultaneously. Many metropolitan locations and some of the larger industrial firms provide this.

The College Graduate as a Person

For the purposes of these observations, let's assume that colleges are doing a capable academic job, and turn our attention to those aspects of education that are separate from the factual knowledge imparted. Here are a few characteristics that industry looks for and expects in engineering college graduates . . .

Adaptability—With all the varieties of organization structures, products, and personalities in the industrial world, one of the greatest assets for a man is the characteristic of adapting himself to any reasonable environment in which he finds himself. This does not mean sacrificing his long-range objectives or giving up his individual personality but, rather, trying to understand the new situation and promoting suggested changes gradually and diplomatically. In other words, the student should be persuaded to avoid preconceived ideas about his postcollege future so that he won't be upset by any deviations.

Enthusiasm—Placement authorities know that industry recruiters look for signs of keen interest in the future jobs —an easily detected quality. The only problem is that of determining sincerity. Here the college influence is often clearly visible. An inspiring professor, a college program that has stimulated the appetite for world problems, or zest for living fully, all contribute to this attitude. Cultivation of these in the student should be an automatic process of the dedicated professor.

Using Knowledge—Industry expects the graduate to be conditioned to meet new problems and to reason his way to sound conclusions. This means that he should know how to investigate research to find pertinent facts, select and organize them for study, and then use that too-little-employed effort called *thinking* to come up with a decision, conclusion, or reasoned cause of action.

It is of no use to argue the old question of whether the rigors of a scientific training, study of Latin, theories of logic, or mathematics will guarantee this ability to a greater or lesser degree. Industry merely asks that something in his schooling add to his mental stature, not take away or stifle it.

Attitude Toward People—The places in life where the individual can turn his back on people and still make a living are fewer each year. Industry is almost synonymous with some measure of co-operation. Many of our college laboratories provide excellent fields for developing this trait, as do extracurricular activities. A willingness to go more than half way in understanding others is an important asset. A personality that attracts, not repels, others can serve as one of the great cornerstones of a successful life.

Working Habits—We have all seen well-trained people who have never done much with their gifts and opportunities. Modern youth, like all the preceding generations, needs to learn the necessity of doing a job well and of completing as well as initiating programs. Many college courses insist on discipline and exactness. Those remembered with gratitude are often the ones where hard tasks were undertaken, and giving them up would have been the easiest but not the wisest course. Every student should therefore have some contact with at least a few rigorous teachers.

Obstacles are always present. The practice of meeting them and somehow finding a solution is a basic condition of living. Fortunate is the graduate who has developed a pattern to meet reality, overcome its problems, and grow in the process.

Understanding the Economics—Industry frequently encounters graduates who fail to realize the economic relationship of their own efforts to the work of the world. What they do should in some way contribute to the store of knowledge, to production, to the training of others, or—in its broadest sense—to the satisfaction of the lives of others. In the industrial company, this economic measure is often identified as profit.

Administrators ask, "Why can't these graduates have some better understanding of our economic system?" Economics classes are taught to almost every college student. Many are effective. It's up to the educators to see that more of them accomplish the maximum result in the time available.

Summing It Up . . .

What industry is trying to say to educators concerning the engineer and the scientist is this . . .

- Give us well-rounded men.
- Cultivate habits of mind that will enable them to seek out unsolved problems, to systematically explore, and where possible to add to useful knowledge.
- Give them basic tools in the form of fundamental knowledge for this task, but above all show them how to acquire more tools for themselves as they reach the limits of their past training.
- Encourage qualities of initiative and responsibility.
- Make them aware of the economic evaluation society will inevitably put on their contributions.
- Help them toward attitudes of co-operation with their associates in work and community because much of their lives will be spent in working with and for people.
- Prepare them to better adjust to people, situations, and the changing complexities of our society.
- Foster alertness to broad social trends and the implications these have to their field of work. Ω

SUB-ZERO TREATMENT OF METALS

By H. T. GREGG, JR.

LOW-TEMPERATURE TEST EQUIPMENT enables the author to control the behavior of metals in such processes as sub-zero assembling, control of age-hardening, cooling during machining, and stabilization of precision parts. Mr. Gregg, Supervisor of the Metallurgical Unit, Construction Materials Laboratory, Bridgeport, joined General Electric in 1950.

In the early stages of metallurgy, when the village blacksmith was the only practicing metallurgist, heat and the forge hammer were the only tools used to make metals conform to man's wishes. But today many methods transform metals into the implements of modern living. One of the more unusual and recent developments in methods for controlling the behavior of metals is the use of sub-zero temperatures in such processes as sub-zero assembling, control of age-hardening, cooling during machining, stabilization of precision parts, and supplementary treatment in hardening steel.

The first accounts of work done on the low-temperature treatment of metals dates back to the latter part of the 19th century. At that time most of the work was confined to a study of the property changes in metals that resulted from this treatment. Men such as Hopkinson of England, Osmond of France, and the Swedish investigator Benedicks were associated with this early history. More recently Johnson, Luerssen, and Green in America and Tammann and Scheil in Germany were concerned with changes that take place in various steels as a result of having been subjected to sub-zero temperatures. Changes such as increases in hardness, volume, and magnetic intensity plus greater stability were observed—caused by a more complete transformation of austenite to martensite. Austenite is steel's high-temperature phase that appears above 1340 F; it is relatively soft, nonmagnetic, and denser than martensite. The latter is produced upon quenching austenite to room temperature, is very hard and magnetic, and has a density less than that of austenite. This transformation from austenite to martensite enables steel to be hardened. But it's practically impossible to transform 100 percent of the austenite to martensite on quenching. Sub-zero treatment can transform the remaining austenite.

Except for some stabilizing, shrink-fit assembling, and control of aluminum age-hardening, only in the last 15 to 20 years has practical use been made of sub-zero treatments.

Sub-zero Assembling Processes

One of the earliest and most useful applications of sub-zero temperatures was in assembling metal parts, either by the expansion-fit or the expansion- and shrink-fit processes combined.

Shrink-fit assembling involves heating the outside fitting and allowing it to shrink around the center plug, stud, or bushing—a procedure often impractical or even impossible because of damage caused by the necessary high temperature. This is true of certain steels and most aluminum alloys. However, if the internal part is sub-cooled, heating of the external part is either eliminated or reduced to a temperature that will not damage the part.

This method of expansion-fit can frequently be used to replace hydraulic press equipment where a press-fit assembly is being made. Simply by cooling the internal part, an assembly that previously required tons of pressure can now be made by hand. Expansion-fitting also has distinct advantages over press-fitting. It can increase production and lower manufacturing costs as well as prevent unnecessary strains from being set up, and it avoids scoring of the mating surfaces.

Here are a few of the many sub-zero assembling applications . . .

- Assembling cast-alloy valve seat rings in automobile cylinder blocks.
- Placing an alloy-steel ring around coining or cold-forging dies to prevent splitting.
- Assembling case-hardened ring gears without tempering the case.
- Inserting steel ball-bearing races in a cast-iron housing.
- Assembling thousands of bearings and bushings of all sizes and shapes.

Low temperatures are also useful in removing certain assembled parts. With large bushings, for example, it's possible to insert a tight-fitting cup-type container filled with a sub-zero-cooled convection fluid. Under favorable circum-

DIAMETER CONTRACTION OF A TWO-INCH DIAMETER CYLINDER WHEN COOLED FROM 70 F TO SUB-ZERO TEMPERATURES

Rockwell Hardness	Material	−110 F	−160 F	−320 F
C63	High-speed steel 18–4–1	0.0022	0.0028	0.0039
C64	High-speed steel 6–5–4–2	0.0021	0.0026	0.0040
C65	High-speed steel 18–4–2+9 Co	0.0020	0.0026	0.0035
C64	High-speed steel 5–4–4–4	0.0025	0.0032	0.0045
C67	High-speed steel 4–5–4–1+12 Co	0.0020	0.0023	0.0031
C66	Tool steel 1.10 C	0.0024	0.0028	0.0039
C63	Tool steel 0.90 C 1.20 Mn 0.50 Cr 0.50 W	0.0023	0.0027	0.0040
C66	Tool steel 0.50 C 0.90 Cr 1.25 W	0.0024	0.0029	0.0036
C64	Tool steel 2.25 C 12.00 Cr 1.00 Mo	0.0025	0.0027	0.0040
C58	Chrome vanadium steel (SAE6150)	0.0026	0.0029	0.0044
B86	Machine steel (SAE1020)	0.0023	0.0028	0.0044
B85	Cast iron	0.0022	0.0025	0.0037
B82	Stainless steel (18–8)	0.0033	0.0041	0.0057
B60	Brass (66–34)	0.0041	0.0046	0.0072
F82	Copper	0.0036	0.0038	0.0062
F78	Bronze (SAE660)	0.0038	0.0043	0.0065
H64	Aluminum (2S)	0.0043	0.0056	0.0062
E98	Aluminum (24 St)	0.0031	0.0055	0.0080
H79	Magnesium (M)	0.0051	0.0063	0.0094
B78	Invar '36'	0.0003	0.0005	0.0011
C69	Cast alloy 20 Co 8 W 7 Mo 5 Cr 2V 0.7 C 0.7 B Bal. Fe	0.0018	0.0022	0.0029
C58	Cast alloy 44 Co 17 W 33 Cr 2.25 C 2 Fe	0.0020	0.0025	0.0035
A91	Carboloy (Grade 44A)	0.0003	0.0006	0.0015

stances, including low enough temperatures, bushings and similar parts can be removed in this manner.

The Table gives an indication of the range of allowances for sub-zero assemblies. These data were obtained by General Electric's Construction Materials Laboratory, Bridgeport, by using test specimens two inches in diameter and one inch long with a three-eighths-inch center hole. Each specimen was cooled from 70 to −110 F, −160 F, and −320 F. Actual contraction of the two-inch diameter was measured while the test pieces were at the respective sub-zero temperatures.

Control of Age-hardening

The best-known and probably the most important application of low temperatures is in the delay of age-hardening aluminum rivets. Heat-treated rivets of the 17S- or 24S-type aluminum alloys begin to age-harden almost immediately after quenching. To keep the rivets in a soft and satisfactory condition for driving or upsetting, the age-hardening action must be retarded by suitable cold storage. The 17S aluminum alloy begins to harden approximately one hour after quenching, and the 24S alloy starts hardening after about 15 minutes. By storing these rivets at 32 F immediately after quenching, age-hardening can be delayed for about two days; but by using sub-zero temperatures of −40 to −50 F, this hardening action can be suspended for several weeks.

Low-temperature retarding of age-hardening is also suitable for punched and formed parts made from 17S or 24S aluminum alloys. Parts made from these materials can be heat-treated after the blanking operation and stored at sub-zero temperatures until ready for forming. This procedure is especially applicable to thin sections and intricate parts that can become distorted if heat-treated after forming.

Cooling in the Machining Process

Because the efficiency of a machine tool can be measured by its ability to resist wear, tool wear must be small in comparison to wear resistance for an efficient tool. This efficiency can be increased in many ways, but few are of any significance. For example, the improvement gained by changing cutting conditions—such as speed, chip cross-section, or ratio—is limited. In addition, the machinability of materials cannot be considered because these are usually chosen for other properties they possess. The efficiency of a machine tool can be materially increased by the use of coolants because the high heat generated at the cutting edge of a tool is a big factor in lowering wear resistance.

High-speed steel cutters often attain temperatures of 1100 to 1200 F at the cutting edge. These temperatures often cause a welding action between chip and tool as well as a softening of the cutting edge, resulting in excessive tool wear, poor finish, and loss of production. A coolant can reduce these temperatures considerably but frequently will become heated itself to 150 to 160 F, thereby losing its value to a great extent and requiring cooling. This is accomplished by passing the coolant through a refrigerated coil. When extreme accuracy is needed, it is sufficient to keep the coolant at a constant temperature of about 70 F. Longer tool life can be attained by using a coolant at sub-zero temperatures.

We recently investigated the use of low temperatures for cooling cutting tools during operation. The results were excellent. In one test, tool life of small Carboloy (Reg. trade-mark of General Electric Company) milling cutters was increased more than 400 percent by applying a sub-zero-cooled compressed air stream on the cutter edge during the milling operation. This procedure not only increased the cutter life but also made a smoother finish possible.

Further, a sub-zero air coolant makes possible the use of cutters that are successfully made from a tool steel having low "red hardness," such as tungsten finishing steel. Under this coolant, tools made from such steels can be run at much higher speeds than normal without danger of tempering or reducing the hardness.

Stabilization of Precision Parts

Before sub-zero temperatures were readily available, machine-tool castings were often stabilized by subjecting them to outdoor weather conditions for several seasons. Exposure to zero or sub-zero temperatures, plus summer tempering, was sometimes sufficient to produce the required degree of dimensional stability. With the means for readily producing sub-zero temperatures today, much greater stability can be achieved in a matter of a few hours.

Prior to the use of cold treatments, the Bureau of Standards required six years of natural aging before certain precision gages could be certified as stable. This requirement has long since been changed because of employment of sub-zero temperatures in the stabilizing process.

An example of the need for sub-zero temperatures where a high degree of stability is required is a set of plug gages that had worn undersize on one end and had actually increased in size on the opposite end. A −160 F cold treatment for 5 to 15 hours increased the size of several of the gages from 0.0005 to 0.0008 of an inch per inch of diameter. Also, hardness increased two to three points on the Rockwell C scale. It is interesting to note that these were pre-World War I gages aged at room temperature for more than 30 years before being subjected to this cold treatment.

It has been well established that the progressive dimensional changes in hardened steel result from a gradual transformation of retained austenite to martensite. This slow transformation causes a volume increase in the steel and continues to do so until all of the austenite has been changed. Of course, a series of long tempers at elevated temperatures will transform a large percentage of this austenite but at the same time will lower the hardness of the steel. In applications such as precision gages, high hardness, as well as dimensional stability, is required, thus making imperative the use of sub-zero temperatures for stabilization.

A 1944 Massachusetts Institute of Technology research report states that virtually complete transformation of retained austenite can be accomplished by cooling to −250 F, provided the sub-zero treatment is applied immediately after quenching. However, for most applications—including all types of gages and precision gage blocks—a series of sub-zero treatments of about −150 F is adequate to give satisfactory stability. Gage blocks have been stabilized to within 0.000002 of an inch by cooling them from room temperature to −120 F five or six times during the final finishing operation. Each sub-zero cycle is usually followed by a low-temperature draw—low enough to maintain a hardness of Rockwell C65 in the block.

Such a high degree of stability is not necessary for ordinary gages and machine parts. Thus one or possibly two cycles of sub-zero treatment followed by a low-temperature draw is sufficient for most of these applications.

Supplementary Treatment

One of the more recent low-temperature applications is the use of sub-zero temperature treatments as a supplement to standard heat-treating procedures. All steels retain a certain amount of untransformed austenite after cooling or quenching to room temperature, the higher alloyed steels being the worst offenders. With proper heat-treatment the percentage of austenite can be held at a minimum but never completely transformed to martensite. If the quench from the hardening temperature is not stopped at room temperature but is continued down to sub-zero temperatures, progressively more austenite breaks down into martensite as cooling continues down to approximately −120 F. At this temperature the amount of austenite remaining untransformed is negligible, and temperatures as low as −317 F (liquid air) have no further effect.

The results of this conversion of austenite into martensite are increases of both volume and hardness. This means that a tool or die that has been improperly heat-treated and has shrunk when quenched can often be salvaged by sub-zero treatment. It will also increase the hardness and thus the wear resistance.

If such a hardness increase is obtained, it is imperative that the freshly formed martensite be tempered before grinding or using the steel. After the majority of the retained austenite is transformed and the newly formed martensite tempered, the steel will usually exhibit little or no tendency to develop grinding cracks on subsequent grinding operations. One possible explanation is that under heat austenite expands about 50 percent more than martensite. When large quantities of austenite are present in a hardened steel, the heat generated by the grinding wheel will set up stresses that are higher and less uniform than they would be in a part consisting of all martensite because of the greater expansion under heat of the austenite-martensite mixture. The heat and stress that set up also transform a portion of the austenite to martensite which in turn sets up additional stress. The combination of these stresses often exceeds the tensile strength of the steel, causing minute grinding cracks.

The so-called air-hardening steels have a high hardenability and often exhibit a tendency to remain in the austenitic condition after hardening. Thus these steels respond effectively to sub-zero treatment. For example, the hardness of a small sample of air-hardening steel of the 1 percent carbon, 5 percent chromium variety was increased 18 points on the Rockwell C scale by cooling it to −150 F for 3 minutes after it had been overheated in hardening. Of course, this does not usually occur in practice, but it does show the rapid response of this steel to sub-zero temperatures.

Except for carburized steels, the oil and water hardening varieties are little affected by low-temperature treatments.

Ball-bearing steels, such as the SAE-52100 type, exhibit a tendency to remain austenitic after ordinary hardening and tempering. This results in low hardness and dimensional instability, two conditions that cannot be tolerated in this application. However, a sub-zero treatment of −150 F after the first temper usually increases the hardness of this steel several points. In the bearing industry this treatment is used rather extensively today to meet the exacting hardness and dimensional requirements.

It might seem at first glance that sub-zero temperature treatments can be used as a cure-all in the toolroom. This is far from correct, however. For in the final analysis the most important use of low temperatures as a supplement to heat-treatment at present is in salvaging high-alloy steel tools and dies that have received an improper heat-treatment.

The use of sub-zero temperatures in the processing and control of metals, in spite of its many uses, in large measure still remains "an unknown quantity." Of course there is little or no question concerning the merits of the use of low temperatures in assembling processes, control of age-hardening, or even in the machining process. The application of sub-zero temperatures to the heat-treatment of steels, however, remains a controversial issue. Some say it has no useful place in the heat-treatment of steels; others specify it as standard procedure. With the availability of practical low-temperature refrigeration equipment, it is believed that the use of sub-zero temperatures in metallurgical operations will expand and become more and more accepted. Ω

IN 13 ACRES OF MANUFACTURING SPACE, 2249 FEET OF CONVEYORS HELP CUT IN-PLANT HANDLING, SHORTEN PRODUCTION CYCLES AS . . .

New Plant Mass-Produces Power Transformers

Review STAFF REPORT

On an abandoned airport in the red clay and scrub-pine country of northwest Georgia, three miles from the city of Rome, a new plant is turning out medium transformers on highly mechanized production lines.

In the past, power transformers in that range—501 to 10,000 kva, 69 kv—have been built on a more or less individual basis. Parts were handled and rehandled many times from building to building as the work progressed. In the new plant, coils and cores start at one end of the conveyorized assembly line; the finished transformer rolls off the other end.

Planners for the new facilities were given wide latitude: they first laid out their manufacturing lines in three-dimensional models without regard for the shape or size of any of the areas involved. After the many sections were fitted together, the architects were called in and literally told to "design some buildings to enclose these production lines." Cost: $25 million.

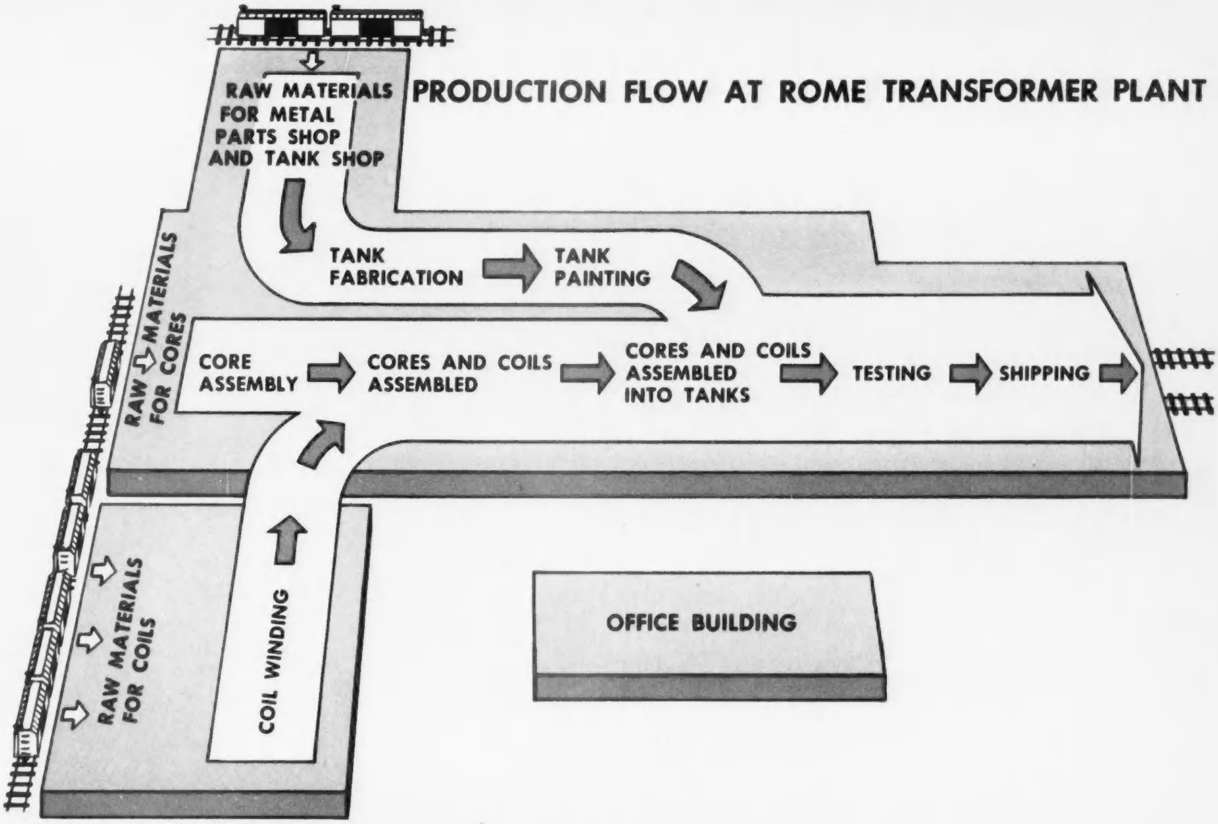
Rome not only is in the booming Southeast but also is close to the geographical center of medium-transformer business. The labor supply is adequate; about 1700 will be employed with an annual payroll of more than $6 million being funneled into the area. Seventy-five supervisory personnel were brought from GE's transformer headquarters in Pittsfield, Mass. "The housing is first rate, and the community is doing everything possible to make us happy," a recently transplanted Yankee told the REVIEW.

A story is related about a new citizen who was working on his lawn one quiet Sunday morning. After awhile he became aware that he was the only one around. All his neighbors were in church. The next Sunday *his* entire family was in church, and soon after he began teaching a Sunday school class.

Wide acceptance by the nation's electric utilities of standardized units—these are known as RM (Repetitive Manufacture) transformers—had a lot to do with making the new plant possible. "Seven years ago we didn't have enough of this type of business to even think about such operations," D. B. Lawton, the plant's manager, told a REVIEW editor. "Today about 63 percent of our output is in the RM range. We're betting on standards."

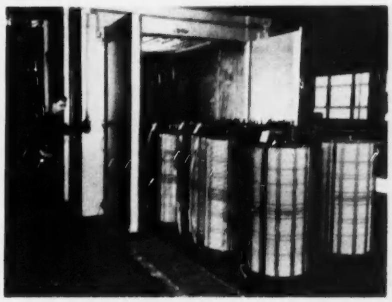
These factors will help the electric utilities in more ways than one: they can get standard units about four to six weeks quicker, and they can save up to eight percent of the cost of specials.

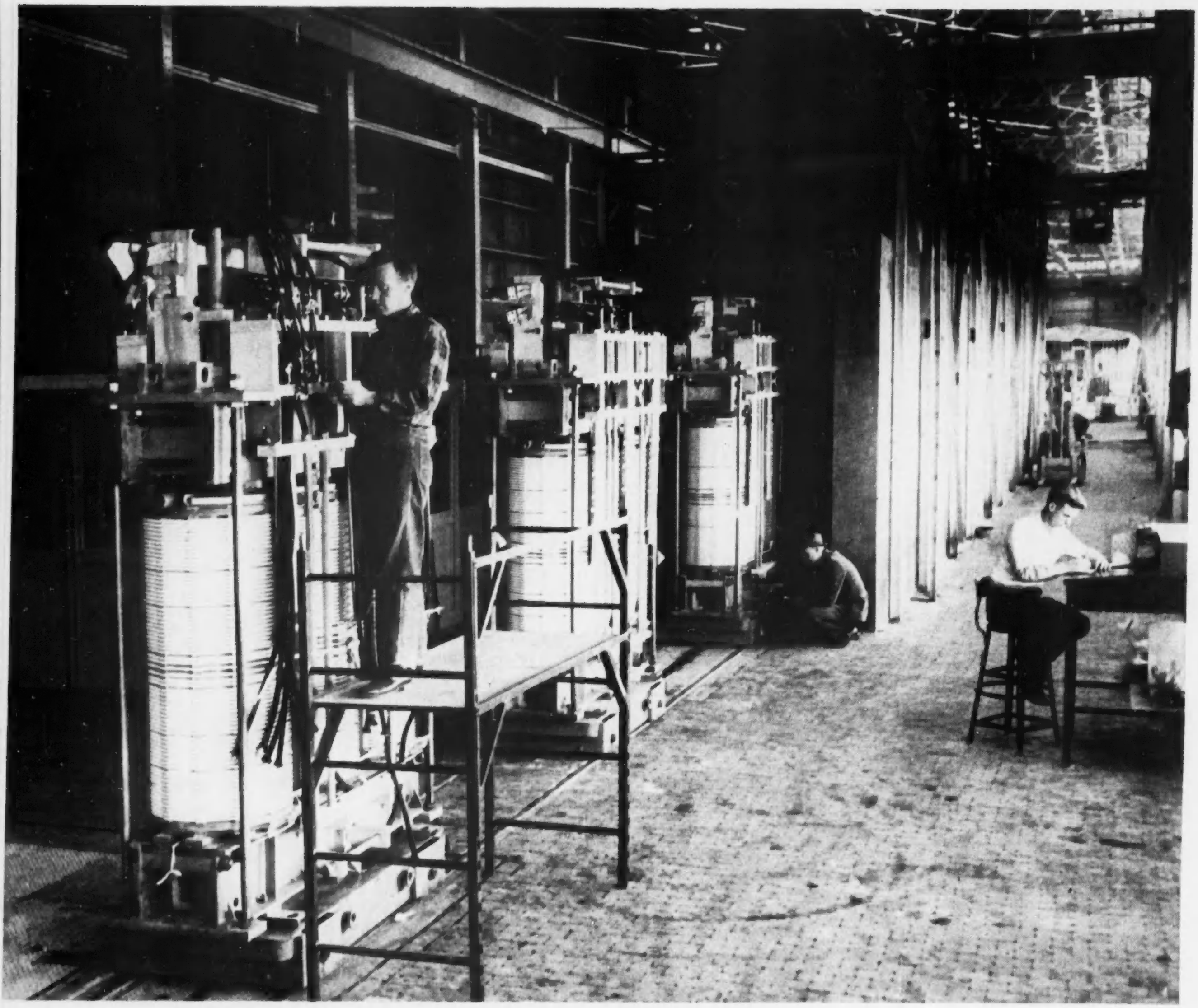
For some production highlights of the new plant, follow photographer George Burns on the next five pages . . .



. . . RAW MATERIALS ARRIVE BY RAIL OR TRUCK AND ARE UNLOADED DIRECTLY AT POINT OF USE. STRAIGHT-LINE PRODUCTION SPEEDS OUTPUT.

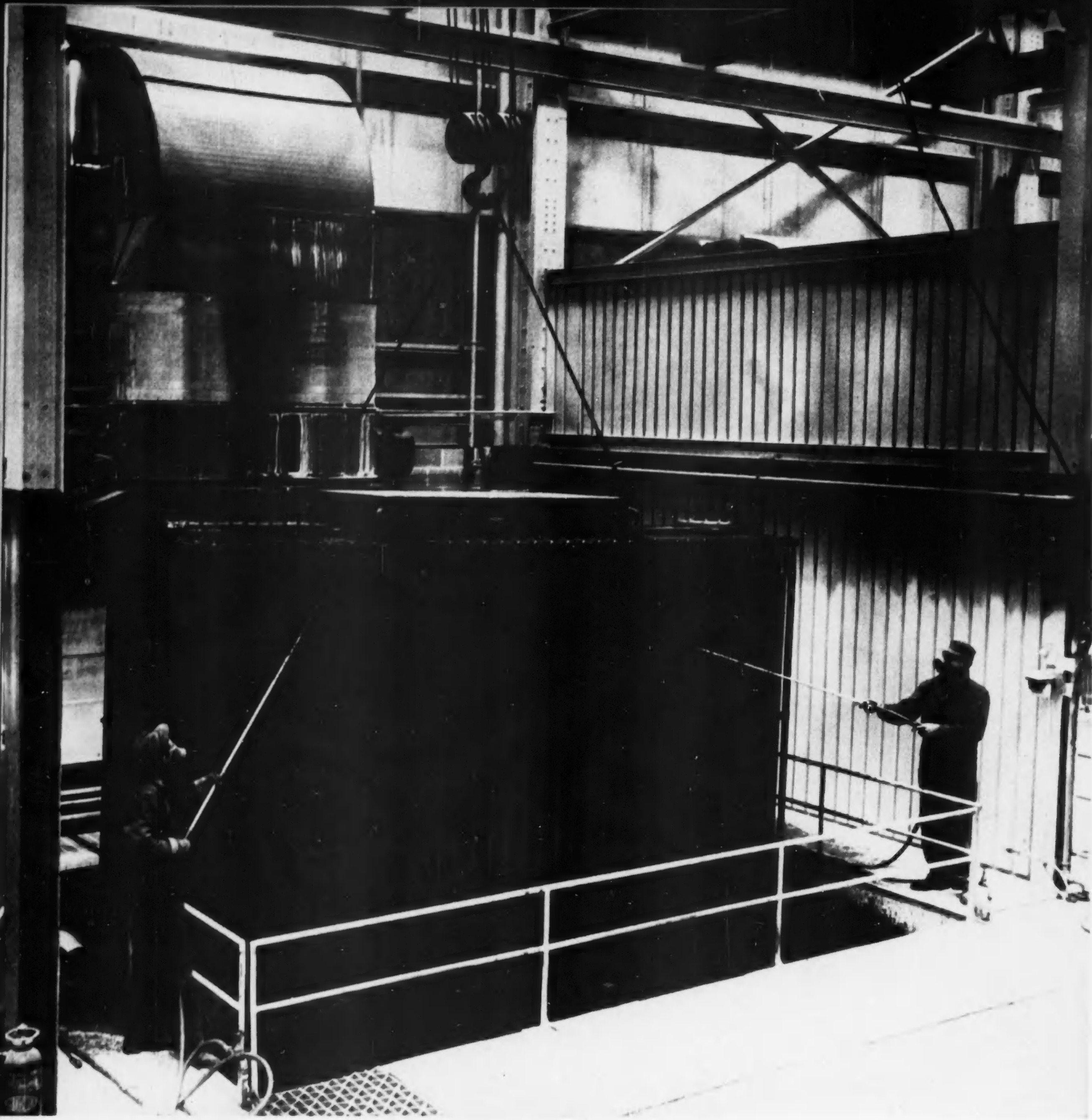
COILS are wound on special machines (*left*) fed by reels nearby. Overhead cranes above winding machines remove completed coils and lower them on elevated conveyor. Still on conveyor, coils are carried to drying oven at end of line where moisture is baked out for 12 hours (*below*). The coils then go to test cells where they receive preliminary electric tests of ratio and turn-to-turn insulation. Placed on carts, the completed coils are sent by drag-chain conveyor to the main production line where the cores and coils are assembled (*next page*). All materials used in coils undergo quality-control sampling and laboratory tests.

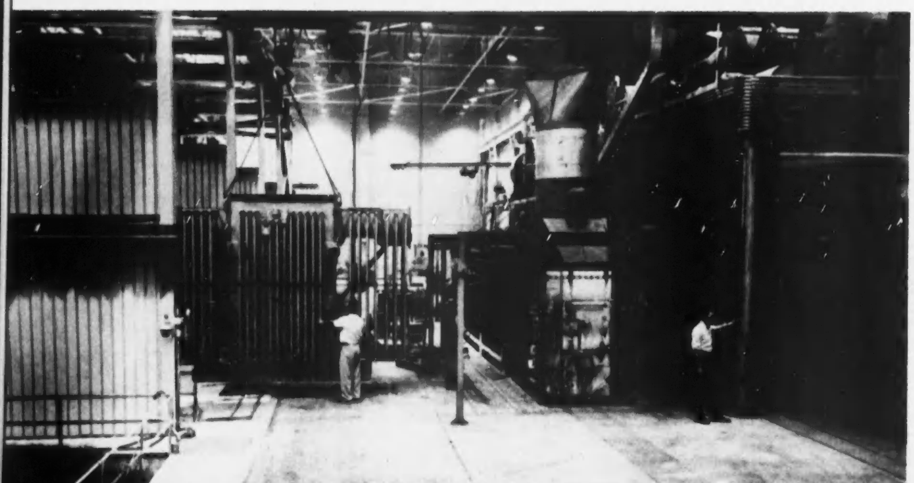




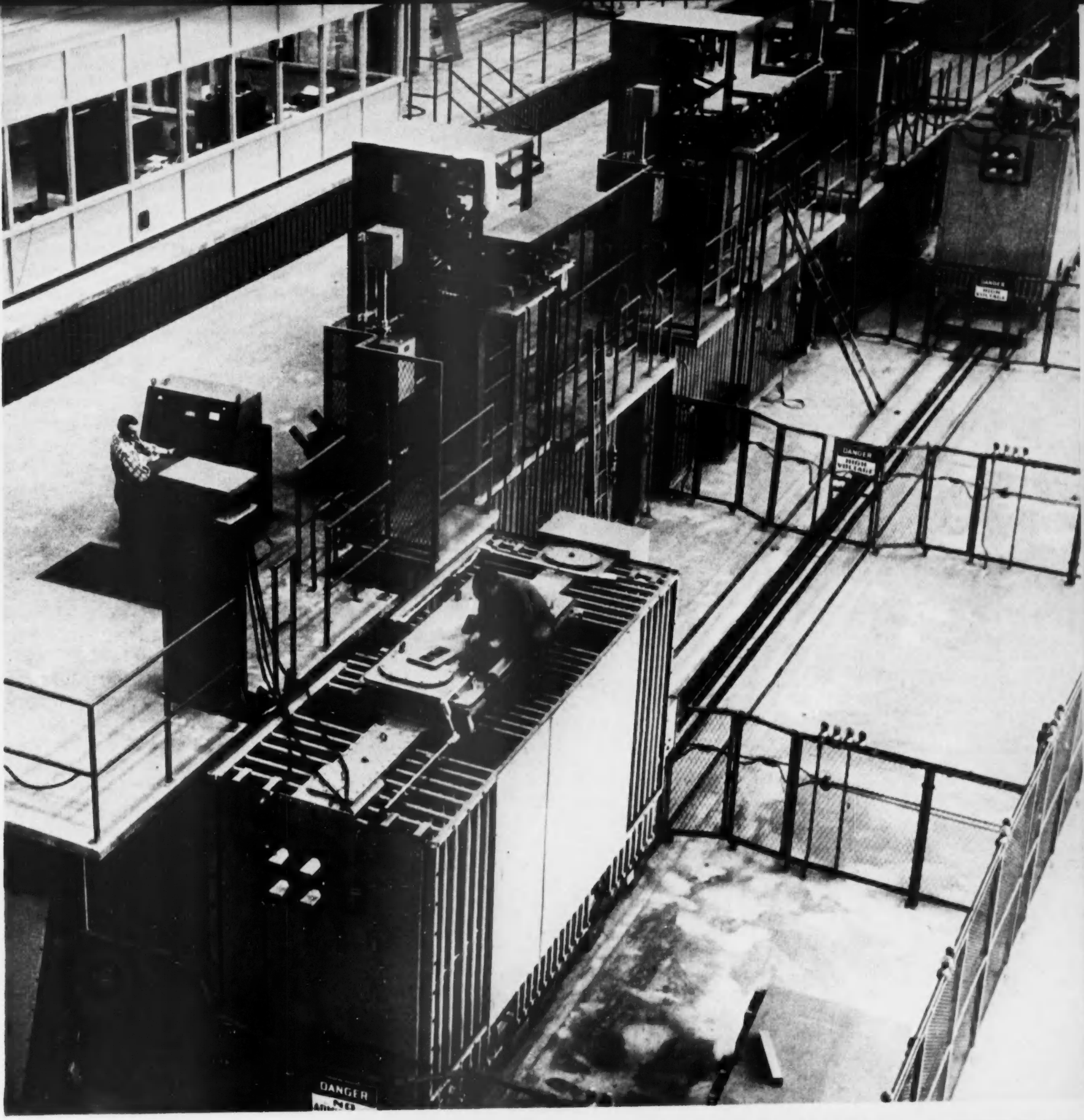
FINAL ASSEMBLY of core and coils takes place on one of three production lines (*above*). On this particular line the assembled core-and-coil unit passes through a continuous drying oven. No doors are used: "curtains" of high-pressure air seal in the heat. On the other production lines, units of higher voltage ratings are dried in vapor-phase tanks. In the Tank Shop (*left*), a new welding process—submerged arc welding—gives consistently stronger welds at major tank joints. Because arc is submerged in flux, operator doesn't need protective mask, can work more comfortably.

WINDMILL fixture holds tubes and headers in position, permits them to be turned end over end for "downhand" welding. Many such mass-production techniques are used in the Metal Parts Shop and the Tank Shop where tanks are fabricated and painted (*next page*).

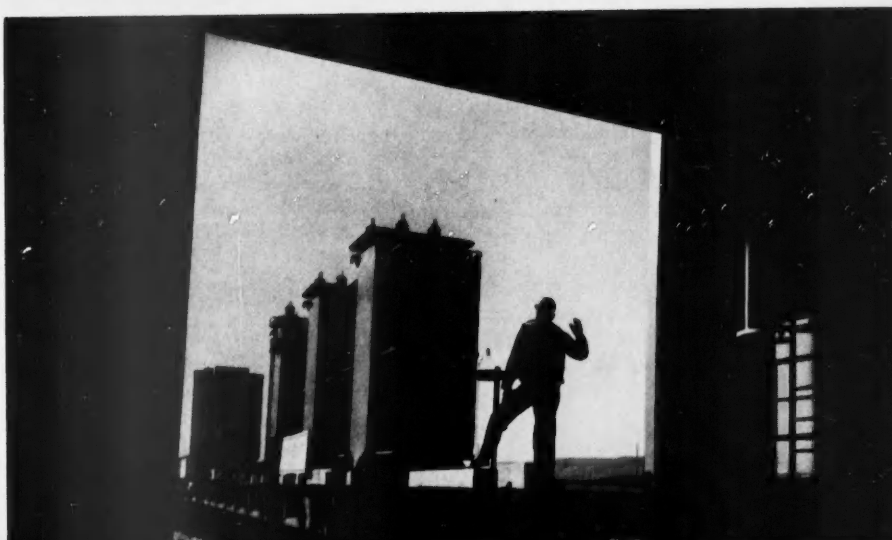




FLOW-PAINTING the tanks in special booths (*above*) is one of the last operations before cores and coils are installed. "Captive" cranes in paint booths make it possible to transfer the tanks to the baking oven (*left*). Tanks move through oven on conveyor.



TESTING is also done on a production-line basis (*above*). Each operator does his own particular test when a unit stops in his berth. After final inspection, transformers are loaded on flatcars at end of production line, sent on their way to final destination. Ω



PHOTOCONDUCTIVE CELL, relay, and transistor make up the high-speed relaying system held by the author. In the foreground are photoconductive crystals of cadmium selenide.

The Photoconductive Cell

By DR. JOHN E. JACOBS

One of the most promising mass-application products of solid-state physics research is the photoconductive cell—truly a device of the future. Resulting from work done during the past 10 years or so, it is a welcome sight to engineers in search of a low-cost radiation-sensitive device that is highly responsive yet electrically stable, mechanically rugged, and compact in size.

Point of Difference

The photoconductive cell differs from the more familiar photoelectric cell in many respects.

The simple photoelectric cell is a high-vacuum electron-emitting device. Light of certain wave lengths focused on its light-sensitive cathode causes electrons to be emitted and collected at the plate, or anode. These few microamperes of current are then amplified and put to practical use. The simple photoelectric cell is relatively insensitive to feeble radiations of light. However, when coupled with an electron-multiplier structure, the resultant photomultiplier tube has a sensitivity that produces amperes of current per lumen of incident light.

Dr. Jacobs—Manager of the X-ray Department's Advanced Development Laboratory, Milwaukee—joined GE in 1940 as a shipping clerk. After serving in World War II and acquiring a college education, he returned to the Company in 1950. Last year he received the Coffin Award for his work on x-ray photoconductors as well as honorable mention by Eta Kappa Nu as one of the year's Outstanding Young Electrical Engineers.

The photoconductive cell is classed as a semiconductor device because its operation depends not on electronic emission in a vacuum but on electronic conduction in a solid. The resistance of a photoconductive cell is a function of the intensity and wave length of radiation falling upon a radiation-sensitive crystal within it. Thus the cell has its highest resistance when no radiation falls upon it and a diminishing resistance as the radiation increases. Its sensitivity is comparable to that of the photomultiplier.

Photoconductive Materials . . .

Of all the materials that exhibit photoconductive properties, cadmium sulfide (CdS) and cadmium selenide (CdSe) appear best suited for general applications.

The advantage possessed by both of these materials is this: there is a great difference between the resistance of an unirradiated crystal, called its dark resistance, and its resistance when it is subjected to radiation. For example, the dark resistance of a CdS crystal is 10,000 to 100,000 times greater than its resistance when irradiated with 100 footcandles of light. The contrast is even greater for a CdSe crystal under the same irradiation conditions; its dark resistance is 1- to 10-million times greater.

With either the CdS or CdSe cells you can cover this wide range of resistances in continuous steps by varying the irradiation from total darkness to 100 footcandles.

Historically, the CdS photoconductive cell was first used commercially as an x-ray detector. X-ray machines using these cells have been in operation many thousands of hours with no evidence of cell failure that can be directly attributed to the cell material itself. In view of this and barring electrically induced thermal overloads, the newer hermetically sealed cells will have a life expectancy that exceeds 10,000 hours.

. . . and Their Mechanism

Without going into too many technical details, we can say for the mechanism of photoconductivity that when incident light falls upon a photoconductor, it creates free electrons or free holes, or both, that are drawn to their proper electrodes—anode and cathode, respectively. Consider a crystal—one large enough to be seen with the naked eye—that consists of N constituents. The outer electrons of each of these constituents can assume different energy values. And as a result, the total energy of the crystal—represented by the sum of the energies of its constituents—can assume a large number of values within an upper and lower limit.

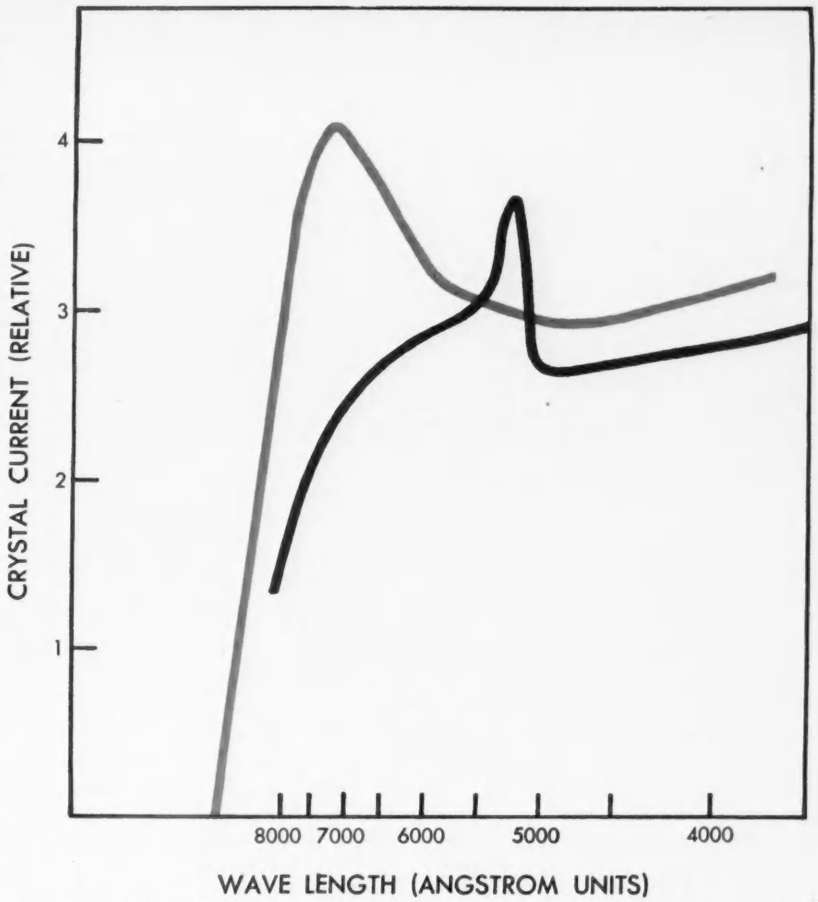
The exact theory shows that N constituents can have $2N$ energy states and that the ensemble of these $2N$ energies represent an energy band. If the electrons of these constituents are restricted to their normal states, no transport of charges within the crystal can take place. But when they are excited by some external source of energy, such as electromagnetic radiation, the ensemble of $2N$ energy states represents a new band in the energy range. If the excited electrons number much less than $2N$, they are free to move across the crystal.

At each instant the number of free electrons in the crystal is determined by the stationary negative space charges of electrons that are held in so-called trapping states. As one electron leaves the crystal at the anode, another enters the crystal at the cathode so that the number of electrons always remains constant. When light or x-ray energy quanta are absorbed in the crystal, certain electrons are "lifted up" into the conduction band. The empty spaces, or holes, they leave behind are then filled by other electrons.

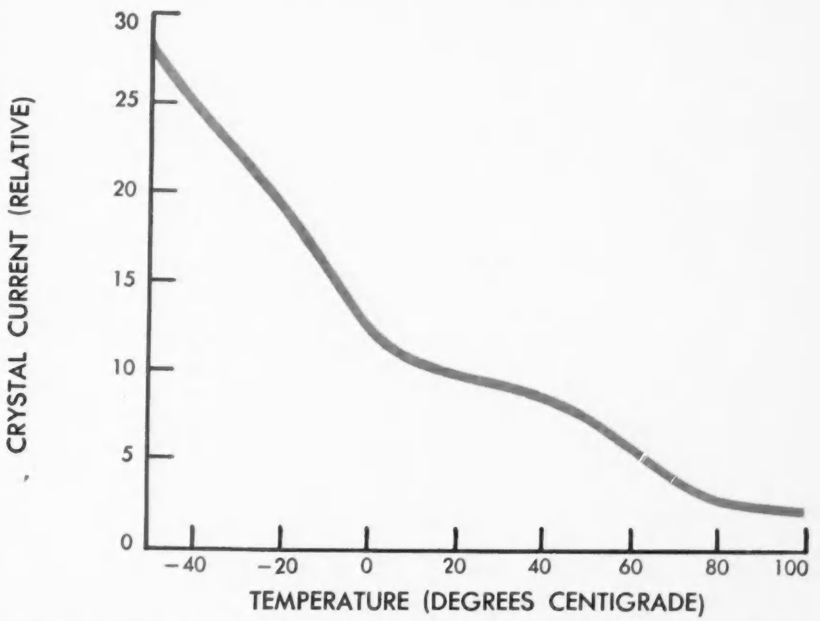
The current through a photoconductive crystal increases approximately with the square root of light intensity at extremely high levels of illumination. But at the lower levels this relationship changes. For both CdS and CdSe cells the photocurrent is essentially a linear function of light intensity, whereas its speed of response is strongly dependent on the illumination level. This behavior results from trapping conditions within the crystal. Their principal effects are to decrease the photosensitivity of the crystal and increase its time constant—that is, the time required for it to change conductivity when irradiated. Trapping conditions also alter the temperature dependence of the photocurrent.

Properties Compared

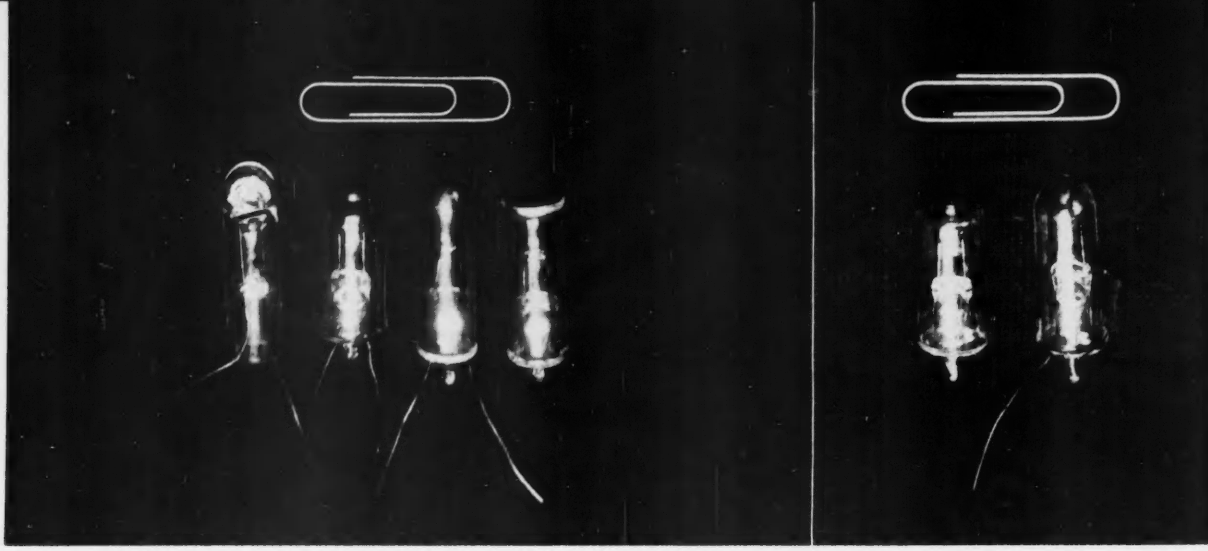
Both cadmium sulfide and cadmium selenide differ greatly in their sensitivities and time constants. For example, under equal irradiation intensities by x-radiation, essentially identical samples of Cds and CdSe will have photocurrents that differ in magnitude by a factor of



SPECTRAL RESPONSE of cadmium-sulfide crystals (*black curve*) and cadmium selenide crystals (*gray curve*) to visible portion of the spectrum runs from about 3800 to 7600 A.



PHOTOCURRENTS in cadmium-selenide crystals are inversely related to the temperature Scientists think this effect results from an increased electron mobility at lower temperatures



PHOTOCONDUCTIVE CELLS of cadmium sulfide (*above*) are fabricated at temperatures exceeding 200 C to exclude harmful moisture; melting point of the glass used for pressing these cells is above 600 C. Cadmium-selenide cells (*right*) are available in only two forms.

100, the CdS crystal having the larger current. Similarly, the time constants of the two crystals will differ by a factor exceeding 100, CdS having the longer time constant.

Under equal irradiation from a white fluorescent source, however, CdS photocurrents will exceed those of CdSe by a magnitude of only 5 to 10. Their time constants will remain essentially the same as when they were irradiated with x-rays. On the other hand, if they are irradiated with light from an incandescent tungsten lamp at 2870 K, the CdSe photocurrent will equal or exceed that of CdS and the time-constant ratio between the two crystals decreases from 100:1 to 50:1. This apparent change in sensitivity comes about because the CdSe cell more effectively utilizes the radiation from the tungsten source than does the CdS cell (illustration, top, page 29). The decrease in the ratio of the cells' time constants, as well as the drop in CdS sensitivity, results from an infrared quenching effect.

Cadmium sulfide's characteristics are remarkably independent of temperature; its photocurrent doesn't vary more than plus or minus 15 percent over a temperature range from −80 C to +60 C. And in most applications this variation is so slight that it can be neglected. Cadmium selenide, however, shows a marked temperature dependence (illustration, lower, page 29).

Fabrication Problems

The CdS and CdSe photoconductive cells (photos) are now available for only certain purposes. You get some idea of their ruggedness when you consider that the glass used in pressing the CdS cell doesn't flow until temperatures exceeding 600 C are reached.

But just as with all other semiconductor devices—transistors, for example—humidity has marked effects on cell life and performance. For this reason all cells are hermetically sealed and maintained at temperatures exceeding 200 C throughout the fabrication period, from mounting to seal-in. Excluding moisture in this manner is one of the major reasons for their long life and stability—a paramount factor in commercial applications.

Cadmium selenide can't usually be pressed in glass, as is done with cadmium sulfide, because of its lower sublimation point—the temperature at which it passes from a solid to a gaseous state. Hence CdSe cells are made available only in the two-bulb forms shown (photo, right). The cell proper is enclosed in a clear silicone-resin sheath that serves to rigidly hold the crystal in position under conditions of extreme vibration.

The sensitivities of CdSe cells measured under tungsten-lamp radiation is in the order of 1.0 amp per lumen with an applied d-c voltage of 100 volts; CdS cells will exceed this amperage by factors as high as 50. Dark resistances of either cell are in excess of 5000 megohms. Accordingly, when illumination levels are on the order of millilumens, the cells possess an extremely good signal-to-noise ratio.

Because of the high radiation absorption of CdSe, it's necessary to increase the working area of the material to achieve the maximum ratio of light to dark current. This is done by making the cell as thin as possible, thus allowing a maximum permissible current of 0.01 ma. The CdS cells, however, handle currents up to 1.0 ma. And when backed up by a copper plate, they can be used at a power dissipation of 250 mw.

Some Applications

In the field of light detection there's a need for a photocell actuator that can operate a relay directly from the 110-volt a-c source without any amplification other than that supplied by the crystal itself. The CdS cell promises to be the answer.

For example, a simple CdS actuator (photo, opposite page) constructed at GE's Research Laboratory, The Knolls at Schenectady, has a sensitivity of 20 amp per lumen. Serving as a simple and reliable device for the control of home lighting, it is actuated by prevailing light levels at dusk and dawn. The CdS cell was used exclusively in this application because of its high intrinsic sensitivity and greater current-carrying capabilities. It has many other potential applications.

The CdSe cell, by way of comparison, finds its greatest use where simplicity of instrumentation, speed of response, and sensitivity are foremost. A specific application is its use in automobile headlamp controllers. But before going into this application in any detail, let's look briefly at the electron-multiplier photocell, or photomultiplier, that has been employed by the automotive industry for this service.

In an electron-multiplier photocell the electrons released from a photosensitive cathode are directed toward electrodes called dynodes that are characterized by high secondary-electron emission. Each of these electrodes is held at successively higher potential than the cathode. Their net effect is to multiply the electron current collected at the anode, multiplication factors greater than a million being theoretically possible.

The electron-multiplier photocell has its practical limitations. For example, the type 931A photomultiplier used by the automotive industry is limited principally because: 1) it requires a high-voltage supply; 2) having little or no red response, it doesn't react to automobile taillights; 3) its sensitivity is extremely dependent on dynode voltage, and thus its voltage supply must be highly regulated; and 4) the complex construction of the electron-multiplier mechanism dictates a high cost for the cell.

HOME LIGHTING can be controlled by photoconductive cell utilizing prevailing light levels at dusk and dawn. Current from highly sensitive cadmium-sulfide crystal needs no amplification.

For use in a head-lamp controller a photocell must meet rather stringent requirements. The over-all unit must be rugged to withstand road shock. It must be simple in operation yet meet exacting requirements in speed of response, sensitivity, and spectral response.

Specifications tentatively formulated by the automotive industry call for a headlight controller actuated by an incident light level of illumination in the range of 0.5 to 3.0 millifootcandles. The unit should preferably operate at this level whether the illumination is produced by the head lamps of an approaching car or the tail lamps of a preceding car. In addition, the sensitivity contours of such a system must be within approximately 3 db—equivalent to a twofold power gain—over plus or minus 6 degrees in the horizontal plane and plus or minus 2 degrees in the vertical plane.

There's an additional feature that must be included in such a controller: once the unit is actuated, switching the lamps to low beam, its sensitivity must be increased at least seven times. (This is required to prevent the head lamps from returning to high beam when the driver of an approaching car depresses his lights.) Finally, and above all, after the approaching car has passed, the head lamps should return to high beam in less than a quarter of a second.

Rugged Service

In applying the CdSe photoconductive cell to a head-lamp controller, one of the principal problems was the optical system. Because cells of this type are essentially point receivers, they can't give wide-angle response with conventional lens systems. The focused spot would "walk off" the crystal.

Fortunately, one of the most efficient optical systems available for the CdSe cell is the parabolic one. So for the head-lamp application, a parabolic lens system is used that has a vertical spread of plus or minus 2 degrees between the 3 db points. It exhibits a measured gain of 600. To achieve the 6-degree horizontal spread, 12-degree spreader glass is used. (The spreader glass reduces measured gain to approximately 300.)

Cadmium-selenide cells with a sensitivity of 24 microamperes per footcandle at an applied potential of 300 volts are used in head-lamp controllers. They deliver approximately 7 microamperes when one millifootcandle of incident light reaches their lens systems. They have a good signal-to-noise ratio, and their sensitivity and optical systems are such that only one tube is needed for each unit.

On actual road test for some time, cadmium-selenide cells are still giving excellent performance. Laboratory tests have been run as long as 1000 hours on the completed units with no sign of failure.

Where the speed of response needn't be below the millisecond range, the CdSe cell has a distinct advantage over photomultiplier systems. It is rugged, has a low cost, does not require voltage regulation, and exhibits marked red response.

But although the head-lamp application is an extremely exacting one, for essentially OFF-ON applications such as punched-card reading, the high speed and sensitivity of the CdSe cell cannot be surpassed. It is in these applications that the cadmium-selenide cell will probably find its widest use.

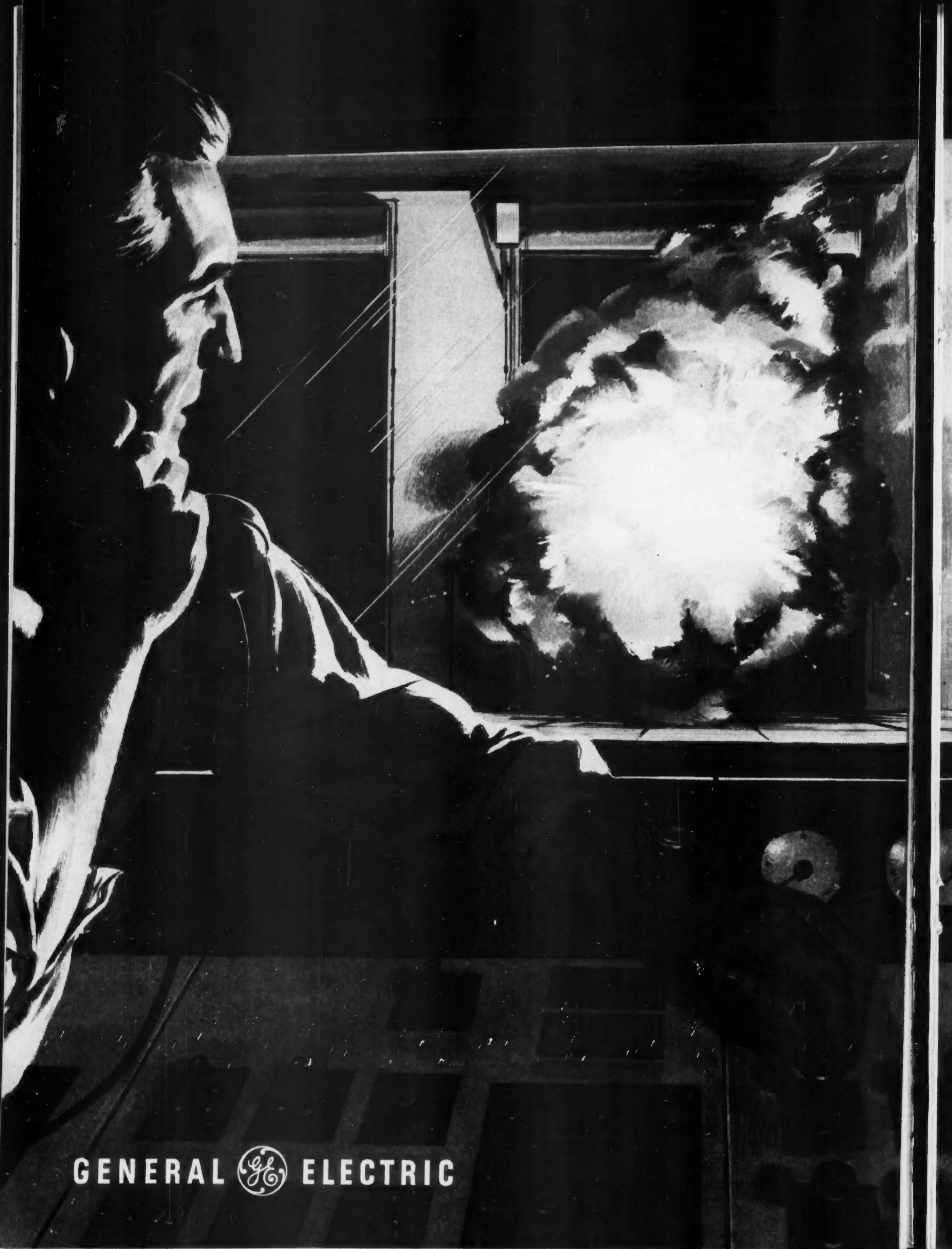
No Vacuum Tubes Needed

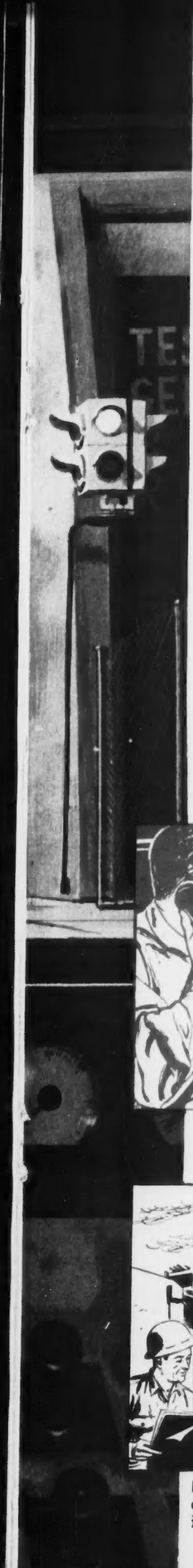
In growing photoconductive crystals and subsequently processing them into cells, you must continually choose between high sensitivity and slow response, or fast response and relatively low sensitivity. Fortunately, the photoconductive cell retains the desirable features of both high-speed response and large current sensitivity when it is coupled to a transistor amplifier.

The transistor amplifier best suited for use with the photoconductive cell is the grounded emitter type. (See pages 50–54 March 1954 REVIEW.) In this arrangement the properties of both the cell and the amplifier are utilized to their fullest.

For example, a presently available photoconductive cell used in conjunction with a single junction-type transistor will operate a conventional d-c relay at a rate exceeding several hundred operations per second—with incident light levels in the order of a few footcandles. This device is extremely simple, consisting of nothing more than the cell, the transistor, and a relay that are connected to a suitable d-c supply. Certainly its potential applications are limitless.

With the photoconductive cell the engineer has in his grasp a radiation detector of well-defined characteristics. And coupled with its ability to effectively utilize the transistor amplifier in a reliable system free of vacuum tubes, it will allow the engineer to more fully exploit automatic control for the benefit of mankind. Ω


GENERAL ELECTRIC



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EARLY FLUORESCENT LAMPS WERE USED AT THE NEW YORK WORLD'S FAIR. IN 1936 AUTHOR WORKED ON LAMPS WITH LUMILINE ENDS.

Fluorescent Lamps—Past, Present, and Future

By G. E. INMAN

More than two years ago the fluorescent lamp caught up with and passed the incandescent lamp bulb as the principal electric source of general lighting in America.

The development of this form of lighting has been phenomenal and brief (Table, opposite page) not only in terms of public acceptance but also in its design, manufacture, and application.

But as in most pioneering achievements, it was not all easy going; and many interesting items and angles of the early days can only now be told. From the beginning I worked with this project, so I'll attempt to relate some of the significant facts and humorous happenings.

Fluorescence Observed Centuries Ago

Even though nameless at the time, fluorescence and its earliest reference date back to 930 AD: A Japanese painter calcined oyster shells to get pigment for some of his paints. And one day he is reported to have painted a picture of an ox that was visible only in the dark after the sun had set. The particular pigment used was phosphorescent, or fluorescent, with an afterglow.

Another incident years later in 1620 is credited to a shoemaker of Bologna, Italy, who is reported to have been an experimenter. Probably while trying to create gold, he pulverized and heated some rocks which we know as heavy spar (barium sulfate) and which were observed to fluoresce an orange red.

The records show that Goethe, the German poet, was also an experimenter. And 150 years after the Italian shoemaker had taken a fling at it, Goethe learned that the blue end of the spectrum was needed to provide light in the orange and red end.

In 1852, about the first time anyone was called a scientist, Stokes—now well known as an able one—worked with fluorescent materials and wrote the law incorporating the principle that bears his name. He also originated the term fluorescence.

•

Mr. Inman began his career with General Electric 35 years ago. He has worked on development of filament and electric discharge lamps, and for six years was in charge of fluorescent-lamp development. He received a Coffin Award, and 26 patents have been issued in his name. In 1950 Mr. Inman was appointed Liaison Engineer, Lamp Development Laboratory, Nela Park, Cleveland.

But it remained for a Frenchman named deBoisbandron to find a key. He reported in 1886 that small quantities of so-called impurities were usually necessary to cause materials to fluoresce. These impurities, now referred to as activators, are essential today in most fluorescent materials (phosphors) applied to fluorescent lamps. So a long history precedes fluorescent materials, and perhaps many people had thought about the possibility of fluorescent lamps.

In 1896, Thomas A. Edison placed some calcium tungstate into what was known as a roentgen tube. The radiation from the target in this tube caused the tungstate to fluoresce, giving a dim light. For this particular tube—a possible forerunner of fluorescent lighting—a patent was issued to Edison in 1902. During the early part of the 20th century, work was also done in America by E. L. Nicholls, D. McFarland Moore, W. S. Andrews, and others, but none of it resulted in a practical light source. And in looking back now, we can realize the reason for some of the disappointments of the early investigators.

TIMETABLE OF FLUORESCENT LAMP PROGRESS

1934	Development work on fluorescent lamps accelerated by General Electric.
JULY, 1935	First showing of G-E fluorescent lamps at a closed meeting of Naval officers. Shortly after tested aboard a ship.
SEPT. 3–6, 1935	First public showing of GE's practical low-voltage fluorescent lamp at Illuminating Engineering Society's national convention, Cincinnati, Ohio.
NOV. 23, 1936	First public application of fluorescent lighting by GE at Hundredth Anniversary Dinner of founding of the U.S. Patent Office.
APRIL 21, 1938	About GE announces development and availability of fluorescent lamps to the public at joint meeting of IES, AIEE, and New York Electrical Society. About 200,000 lamps were sold by the industry in 1938.
SPRING, 1938	First fluorescent lamps from GE used commercially in the preview plans of the New York World's Fair.
1940	Total of 7,000,000 lamps sold.
1950	88,400,000 lamps shipped by GE, Sylvania, Westinghouse, Champion, Durotest, and a few others. In addition, the fluorescent fixture business (ballasts, starters, sockets) was estimated to be close to $180,000,000.
1952	Fluorescent lamp passed the incandescent lamp as major source of general lighting in America.
1953	Fluorescent fixture business estimated at about 70 percent of the total lighting fixture business.

Early Experimentation

Long wave ultraviolet was the basis for many early experiments because that alone was at hand. As knowledge progressed, it turned out that the type of ultraviolet we learned to produce efficiently is in the short wave lengths from low-pressure mercury vapor. The short ultraviolet was present on the inside of the mercury- or other vapor-discharge tubes used in some of the early experiments but not in significant amounts of concentration. Moreover, the fluorescent material was placed on the *outside* of an ordinary glass tube. And the glass simply did not transmit much of the short ultraviolet.

Our modern instruments help us to know a lot that was unknown half a century ago. It often surprises us that the earlier experimenters found out as much as they did. The early contributions of our present century resulted not in developing new discharge sources but in trying to correct color in other types of mercury lamps, such as the Cooper-Hewitt lamp introduced in 1901. Some examples are the use of sulfide phosphors to improve the color of the radiation from certain mercury lamps and the use of red radiating rhodamine to improve sodium lamp color. Further, uranium glass used in certain early developments was sometimes found to increase the green component of light given by mercury-vapor sources. Twenty years before active work of fluorescent-lamp design took place, the scientific background began to build up.

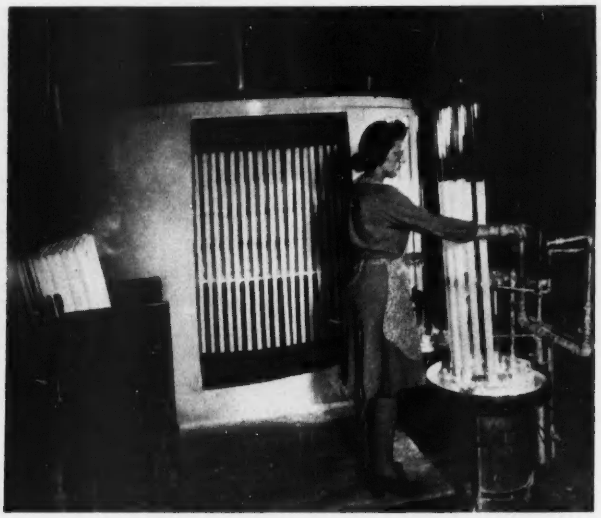
Nothing known or suspected approaches the efficiency that is obtained by using mercury vapor for producing ultraviolet. But the particular kind of ultraviolet that must be produced in an illuminant is not that found in the sun's rays. This natural energy has historically been associated by the public with fluorescent effects. Solar radiation reaching the earth contains middle and long ultraviolet. And in ordinary mercury lamps designed for lighting, only five percent of the input energy is about all that can be converted to this type of ultraviolet radiation. By a totally different mercury-discharge-lamp design using relatively low-current densities and only a few millimeters mercury-vapor pressure, 60 percent or better of the input energy can be concentrated into the resonance radiating line of 2537 Angstrom units.

Many physicists, even up to 20 years ago, generally believed that fluorescent lamps were inherently inefficient and impractical. It took a combination of many bits of information from various sources to produce the evolution of a practical fluorescent lamp in this country.

Phosphors by the Ton

When we first tried producing a lamp, there were no really good fluorescent materials available for changing short ultraviolet to visible. One of our early experiments was with willemite ore from Franklin, NJ. Samples were pulverized, then examined in a dark room under filtered short ultraviolet radiation. The bright particles were picked out with tweezers in a laborious fashion. The lamp made from this selected material was of great interest even though poor in quality, and its examination necessitated drawn shades and turned-off lights. The willemite produced the well-known zinc-silicate green-colored radiation.

Then we examined every available natural material. Scheelite ore, for example, yielded the characteristic blue color of calcium tungstate.



IN THE 30'S LARGE OVENS FIRED PHOSPHORS AND A COATING PROCESS COVERED GLASS TUBES WITH A FLUORESCENT POWDER SUSPENSION.

Today all the phosphors used in lamps are made synthetically and have high purity, except for the activators that are purposely introduced in small quantities. The synthetics are several times as bright as the best that can be obtained from the natural ores—largely a matter of purification, heat-treatment, and activator additions.

In today's handbooks are listed more than 10,000 fluorescent materials that respond to radiations in various parts of the spectrum: x-rays, cathode rays, short ultraviolet, long ultraviolet, and also visible. Emission spectra of phosphors are always of a longer wave length than the exciting radiation and are manifest in the ultraviolet, visible, and even in the infrared spectrum.

No natural ores were found to produce good pink or red phosphors. Thus a determined effort was made to find a phosphor constituent that would produce a red light. One G-E chemist actually examined 60,000 different mineral samples in hope of finding the clue. Although several gave a dim red fluorescence, their strength was so poor that they could not be used in lamps. The red phosphors subsequently developed, as well as many others for different colors, originated in the chemical laboratories. Today the synthetic high-purity phosphors have been so perfected that they effectively utilize 90 percent of the radiation that strikes them, and they are actually made by the ton.

In preparing a room used for examining materials and matching colored light sources, painters sprayed the walls with a white paint. Then electricians smeared up the walls a bit while installing conduits, so our maintenance man touched up the spots with a brush. To him the touch-up job looked fine with the room lighted. But the effect was entirely different when the lights were out and the filtered ultraviolet lamps that had been installed for special tests were turned on. The original sprayed walls appeared white, probably because the pigment in the sprayed paint was a form of fluorescing zinc oxide. But the touched-up spots appeared black, for they were of lead paint and had no fluorescence whatever. We thought it would be amusing to call the painter back and show him his handiwork under the ultraviolet. When jokingly accused of not knowing black from white, his amazement was expressed by a moment of complete silence followed by the comment, "That's an engineer's trick!"

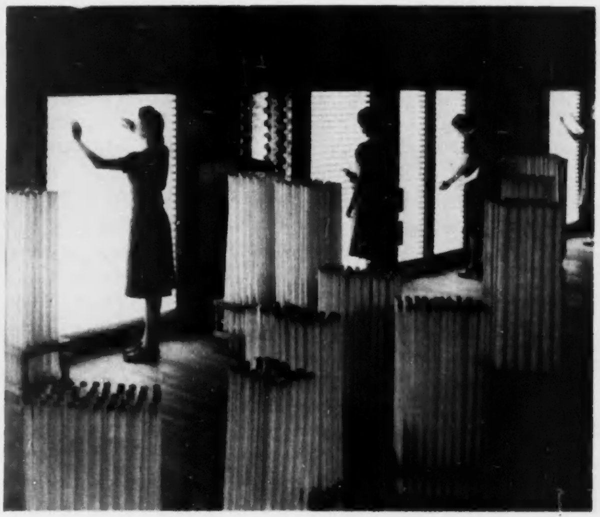
Developing an Efficient Green Lamp...

The development work was carried on in General Electric's Lamp Development Laboratory at Nela Park, Cleveland, Ohio. We made use of all known information and acquired new knowledge from every possible source. Late in 1934 we were stimulated by a letter from Dr. Arthur H. Compton, famous scientist and Nobel Prize winner in 1927, who had been retained by GE as a technical consultant for the Lamp Division. He reported progress by the General Electric Co., Ltd. of England in producing light with fluorescent materials. In 1935, after we had an efficient lamp in the Laboratory, we visited Europe to see what more could be learned about fluorescence and other light sources using electric discharges. The new information did not change our course of development.

By the summer of 1935, an efficiency of 60 lumens per watt for green light had been obtained. This startled many people. Such high efficiencies from a lamp that converted input watts to visible light by a round-about process was unheard of. The lamp we developed was simply an electric discharge between electrodes placed in opposite ends of a tubular glass bulb. Fluorescent materials were coated on the tube wall. A small but exact quantity of metallic mercury and precisely measured argon gas were put in the tube. Controlled current passing between the electrodes excited the small quantity of mercury vapor present so that it produced ultraviolet radiation. The radiation on contact with the fluorescent material was transformed into visible radiation. This two-step process resulted in more efficient production of light than by any previous artificial source that had used either a direct or single-step process.

After the initial development work had been done, a set of rules naturally emerged. These came mainly from the results of our own tests and experiments, but advantage was taken of information obtained by others. A brief list of essentials for efficient fluorescent lamps includes . . .

- Use of mercury vapor at low current density to efficiently produce short wave-length ultraviolet, specifically the 2537 A resonance line. Sixty percent of input watts can be converted to this line, but only 5 percent can be converted into long ultraviolet—the 3654 A line.



LABORATORY EXHAUST EQUIPMENT TESTS EARLY LAMPS. RACKS HOLD LAMPS WHILE THEY BURN FOR AGING PURPOSES.

• Use of phosphors that have their peak of response in the 2537 A region. A few like zinc silicate naturally have optimum response characteristics in this region, but others were "tailored" to more nearly fit the requirements.

• Application of the phosphors to the inside of the tube wall because short ultraviolet does not pass through ordinary glass.

• Use of low temperatures and pressures to provide the optimum short ultraviolet efficiency. A bulb temperature of 105 to 115 F proved best, necessitating the use of a certain number of watts per square inch of bulb surface.

• Use of a gas such as argon at low pressure to provide easy starting and to protect the cathodes during operation.

• A lamp design providing an appreciable length of positive column such as obtained by tubular bulbs. Thus the losses at the electrodes, which are constant because of a fixed voltage drop, may be a small percentage of the total wattage.

• Use of oxide-coated hot cathodes to obtain the best efficiencies.

It soon became apparent, however, that the lamps with the highest efficiencies would not be the most practical. Low currents and low temperatures in lamps of reasonable length meant low wattages and consequently low light values. Compromises had to be made. Sacrifices in efficiencies resulted in greater light from individual lamps of reasonable size, thus reducing the number of lamps needed and thereby lowering costs.

Progress in lamp-making was stimulated by two things: The Laboratory was skilled in making tubular filament lamps; tubular Lumiline (Reg. trade-mark of General Electric Company) filament lamps had been developed there and they had the fabrication know-how. This plus the inefficiency of globular-type fluorescent lamps consequently started them in the Lumiline lamp bulbs. Many of these early experimental fluorescent lamps had chrome iron ends, as did their predecessors.

Another important factor in making progress was the pilot plant with facilities and engineering skill to make the manufacturing changes that would put the new lamps on a production basis. True, the construction features changed, but after the fundamentals were worked out, tube sizes, current ratings, and watts per foot of length of the original lamps remained the same. Other sizes and wattages have been added until now there are 24 standard sizes instead of the original 4 introduced in 1938. These lamps, however, were not all that had to be developed. Their design features had to be matched with those of the lamp holders, ballasts, and starters. These necessary accessories were made economically and efficiently and for the most part outside the Lamp Development Laboratory. They were a big factor in the early success of the lamp.

As far as lumens are concerned, the green fluorescent lamp is still the most efficient: its peak of radiation is near the place in the spectrum where the eye is most sensitive. Because filament lamps are poor in green emission, there was a 200-to-1 difference in efficiency between the two. How natural it was, then, to think that this comparative difference and the higher cost of making fluorescent lamps, plus the necessity of the ballast, would tend to give colored (especially green and blue) lamps a commercial start ahead of everything else. But such was not the case.

. . . and a Satisfactory White Lamp

Early white lamps at lower efficiencies were attractive for general lighting purposes, and they stole the show. Because no single phosphor was giving a good white color, mixtures were needed. The first real application of fluorescent white light was an installation using a combination of one green, two blue, and three pink lamps in a hallway of our Laboratory. Later, mixed phosphors—blue, yellow, green, and pink—gave a good effect from one lamp. The phosphors that have rather broad spectral curves and that have made it possible to get good white lamps commercially were zinc beryllium silicate and later calcium halophosphate. The silicate proved to be a "wolf in sheep's clothing," for it unexpectedly caused lamp-quality and other problems in the lamp factories. It was replaced by the halophosphate as soon as the difficulties were established. The British were slow to put high-efficiency fluorescent lamps into general use, but they had worked on the development of halophosphates before we did.

One of the earliest shades of white was a fair match for a filament lamp (color temperature of about 2850 degrees Kelvin), except for the lack of deep red. The two fluorescent lamps that sold extensively, however, were the 3500 and the 6500 K (daylight) lamps. Later the 4500 K cool white lamps were considered more satisfactory. These lamps were subsequently introduced in both the standard variety, which gives a high lumen output and a reasonable color rendition, and the deluxe variety, which although lower in lumens makes use of a new red phosphor and gives excellent color rendition. Warm white lamps with lower color temperatures were also introduced, and these are not far off in color from the original white introduction. Today there are 7 white lamps in the standard line and 5 in colors. Some of the whites make use of mixtures of phosphors, but the colors always use single phosphors. The gold and the red, however, have color-filter coatings to narrow the spectral range.

Application of Special Phosphors

Although limited in use, several types of lamps require special phosphors. One with bulbous shape did a good job during the war in spite of its low efficiency for converting input watts into usable radiation. Still used on planes for illumination of instrument panels, it produces essentially long ultraviolet instead of visible, which in turn causes the numerals and other dial markings on the instruments to glow. No other light is necessary.

A similar phosphor is now employed in certain long tubular lamps for producing long ultraviolet fluorescence of importance in several industries. A special glass is sometimes used that permits the ultraviolet to come through and yet absorbs the visible, thus making the effects more striking. To produce a phosphor for this work, many hundreds of experiments were made by the Laboratory chemists. Calcium phosphate with cerium as an activator proved to be a fortunate G-E development.

Other phosphors were also developed at Nela Park for ultraviolet emission, and one of special note was calcium phosphate using thallium as an activator. It changed 2537 A radiation into a band near 3200 A, which is in the erythemal range. Consequently, an efficient sun lamp was made possible, but it has not yet come into prominent use.

Coating Development

Coating of bulbs with fluorescent materials is another interesting development. Early experimental types were coated by using glycerine or glycerine with boric acid. The bulbs were covered with a film of the glycerine binder first, the fine powders dusted on, and then the binder removed by heat. Later, a suspension of phosphor in nitrocellulose solution proved to be more satisfactory. Flushing with the suspension, draining, and drying were the natural procedures. Important, too, were elimination of impurities and phosphor aggregates in addition to proper mixtures and drying rates to avoid streaks. The nitrocellulose also had to be burned out, leaving the powder adhering to the glass-tube wall merely by the physical forces of attraction. This heating, or so-called lehring process, is especially critical, and for best lamp quality the temperature, time, and atmosphere must all be under control.

An annoying situation had to do with the coating coming off in small spots, usually near the ends of the tubes. This was an appearance defect and, although it did not materially affect the light output or efficiency, many lamps were rejected in manufacture. Numerous engineering hours went toward correcting this elusive trouble that was ultimately related to factors not usually considered. Glass characteristics were involved, as were fluorescent powder and handling. When glass is heated to a high temperature, as in lamp manufacture, the surface becomes clean and acquires a high coefficient of friction. Although this surface condition does not ordinarily last for many days, during the period of lamp manufacture a slight bump of one tube, or lamp, by another is serious. The bulb does not break, but a sharp friction rub from a slight tap may cause a slight check to appear in one glass surface. This can be seen only under a magnifying glass, but the release of tension when this check occurs causes a shock wave that vibrates the phosphor from the glass in that particular area. The cure was found not only in careful handling but also in glass lubrication.

As longer lamps were made and sold, the light output increased and the efficiencies increased, but so did the difficulties in manufacture. Bulb-coating uniformity was harder to maintain, exhaust times were naturally longer, and it was not so easy to get the parts to a uniform temperature to remove impurities. And that was not all. Eighteen-inch lamps were easy to handle in high-speed production, but "four footers" took experience and special facilities to enable the operators to work with them without considerable breakage. Someone expressed the thought that lamps should never be greater in length than the height of the operators. Today, however, eight footers are common and are manipulated efficiently and safely from elevated platforms by some of the shorter operators, even though it is not always easy to carry the lamps through an ordinary doorway.

The exhaust operation is also one that must be done with great care and precision. After the air is first pumped out, the barium and strontium carbonates on the tungsten coil cathodes must be decomposed and activated. A large amount of carbon dioxide is given off and must be pumped out. Special heating circuits were made to pass current through the electrodes for this decomposition on the high-speed rotating machinery. Exhausting the bigger large-volume lamps required making special equipment not only for pumping out the air and gases but also for heating the tubes uniformly throughout their length.

Improvements to Come

The ultimate in fluorescent lamps would be to eliminate more of the known losses and greatly increase the efficiency of conversion from input watts to visible light. Although we have gone from about 15 lumens per watt in low-wattage filament lamps to 70 or more in white fluorescent lamps, still more progress and higher efficiencies are sure to come.

The lives of fluorescent lamps have always been longer than those of ordinary filament lamps. At their introduction a rating of 1500 hours was given, but this has now been substantially increased, and many lamps live longer than 7500 hours—their rated life. The better maintenance of light throughout life makes 7500 hours economical, while a few years ago it would have been cheaper for the user to buy new lamps more often to keep the lumens at a high level. Fluorescent-lamp improvements will undoubtedly continue to bring about higher efficiencies, smaller ballasts, lower costs, and even greater commercial acceptance.

The new rapid-start principle developed during the past few years has offered fast starting without high voltages, and its use is growing rapidly. The new higher-wattage lamps open new fields, such as street lighting, and make possible less fixture cost per unit of light. The outlook is still rosy, and we should expect greater things to come as fluorescent lamp development progresses. Ω

Illuminating Engineering Society

Prepared by THE HISTORICAL COMMITTEE

Prominent among the vigorous and growing national technical societies stands the Illuminating Engineering Society. In achieving its basic aim of advancing the science and art of illumination and the dissemination of related knowledge, it exhibits an inspiring record of guidance, education, research, and co-ordination. As this Society nears the end of its first half century, the records of its influence on American developments and progress are imbued with the best formative years of our national and individual lives.

An Opportune Birth

The story of the Illuminating Engineering Society is unique in that its history is coincidental with that of the commercial growth and expansion of the electrical business as it directly concerns the citizen. The IES originated at the time when illuminants grew too bright and too large to be usable without shielding and control. In its early days, as now, the Society appraised the evils of gloom while always seeking facts and reasons. Its development progressed as transportation, sports, around-the-clock production, and after-dark living all clamored for artificial lighting. And its expansion—and subsequent contributions—ascended in the exuberant era when light was recognized as an essential ingredient to man's well-being.

This fraternity of lighting specialists grew coincidentally with the growth of electrical services in all fields of radiation. The membership curve (illustration, left, page 41) of the IES could also represent that of the kilowatt-hours of electrical usage for lighting in this nation. One might speculate upon the unawareness that bad vision often resulted from bad lighting, until the preachments of this Society began to take effect. However interpreted, a plurality of influences for good resulted. Even abroad, similar societies—some bearing the same general name—have followed.

After a quarter century of relatively slow growth in the knowledge and applications of artificial illumination (between Edison's lamp of 1879 and 1906), the time was ripe to begin the accumulation of knowledge and to widely disseminate the facts about proper designs and use of lighting devices. It was appropriate to appraise the wisdom of the close relations between people and radiation; the influences of light on efficiency, health, and safety; the best practices and methods of installing and maintaining lighting equipment; and, finally, the beginnings of research into the fundamental reasons for clear and comfortable vision. Natural daylight, as well as artificial lighting, was involved.

A half century ago as much gas as electric lighting existed, and many of the technical subjects thus seemed to lie outside the scope of the existing electrical societies of that period. (This refers chiefly to the AIEE, organized in 1884. But it is interesting to note that the first technical paper inaugurating the beginning of the AIEE was titled "Notes on Phenomena in Incandescent Lamps," by Professor Edwin Houston.) As a consequence of prevailing conditions, a group of prominent New York engineers met at the Hotel Astor on Thursday evening, December 21, 1905, to discuss the needs for a lighting society. Another evening meeting assembled at the same place a few weeks later on January 10, 1906, at which time the Society was officially established and its constitution—largely outlined by W. D. Weaver of the *Electrical World and Engineer*—and bylaws were adopted. On the motion of Mr. O. A. Mygatt, the organization was officially named *The Illuminating Engineering Society*.

Coincidently, in December of 1905, several prominent Chicago gentlemen, including Messrs. George Keech, John Gilchrist, and James Cravath, planned an organization of lighting engineers. This led to a discussion meeting at the auditorium of The Western Society of Engineers early in 1906. As the preliminary steps got under way, it became advisable to unite with the New York group.

This history was prepared by the Historical Committee of the IES through A. D. Hinckley, Executive Secretary of the Society.

Initial Organization

The first officers in the initial organization included: President, Louis B. Marks, a consulting engineer; Vice Presidents, Messrs. A. A. Pope, utility executive, and C. H. Sharp, of the Electrical Testing Laboratories; Secretary, E. L. Elliott; and Treasurer, V. R. Lansingh. Constituting the first board of managers were Messrs. Weaver, Elliott, Kellogg, Brown, Olcott, and Ryan.

Charter Members in the IES numbered 190, representing a broad group of interests that included 34 electric utilities; 23 light-source manufacturers; 13 gas utilities; 17 electrical manufacturers; and about a dozen each of educators, illuminating engineers, consulting engineers, publishers, and others. IES headquarters—with George Guy as salaried Corresponding Secretary—was initially at the same location as The Illuminating Engineering Publishing Company at 25 Broad Street, New York City. Then in 1910 the Society occupied space in the Engineering Societies Building, 29 West 39th Street, New York. Outgrowing the available quarters there, the organization moved to the New York Life Building on lower Madison Avenue and in 1950 to its present address, 1860 Broadway, New York City.

Its Scope and Range

Remembering back to the early 1900's, it is little wonder that many were skeptical about sufficient subject matter to justify a national society. For then, the carbon-arc lamp and the low-efficiency carbon-filament electric lamp, together with the Welsbach gas mantel, represented just about the only light sources of real interest to the average citizen.

Before long, however, the prominent

parts that light could play in human affairs aroused the interest of many more economists, scientists, and humanitarians than were represented in the original list of 190 Charter Members; thus in three years, or by 1909, the membership went beyond 1000. As the deliberations of the Society expanded, the discussions covered efficient redirection of light and its proper shielding; then this activity spread to some of the artistic phases; and, finally, it blossomed out not only into the wide fields of human vision and see-ability but also into the allied problems they encompassed. Representative ones were photochemical usage, growth of flowers and plants, physiological effects on animals, photometry and standardization of measurements, vocabularies and their proper uses, color, shadow, brightness, and all manner of daily and nightly tasks that radiation—wave lengths roughly from 2000 to 20,000 A—could perform!

Branches or Sections

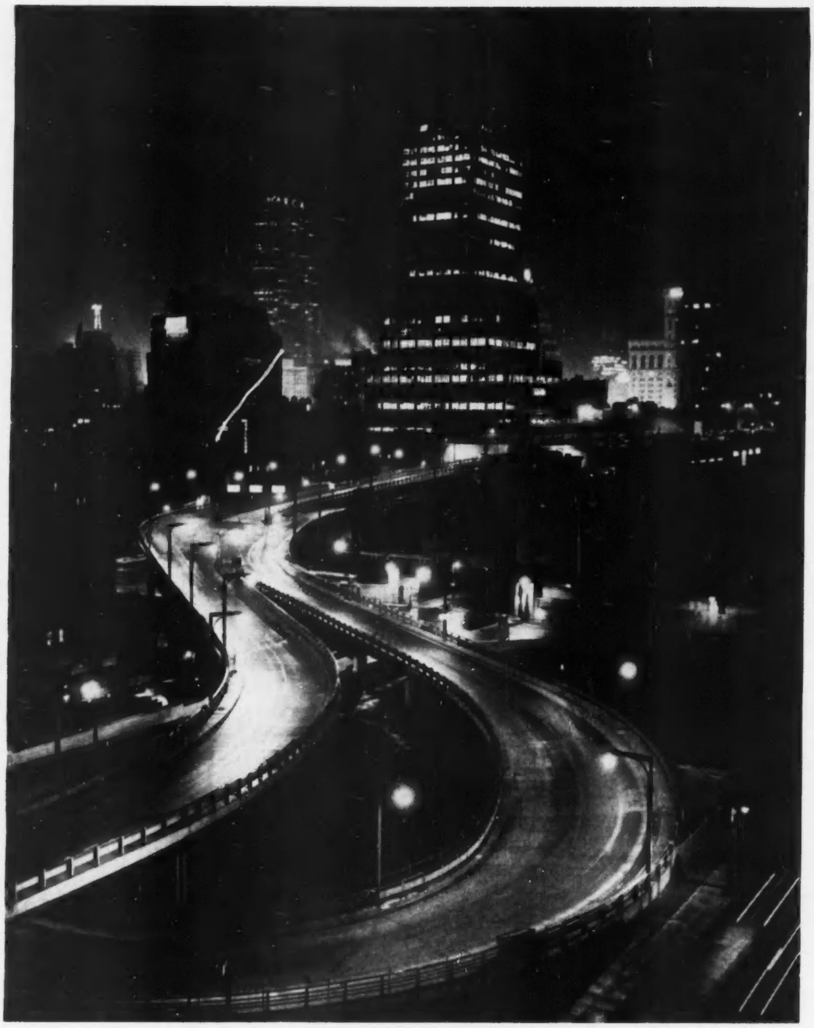
Through the spring and summer of 1906, as membership grew and spread beyond the New York City area, branches or sections were organized in Boston (New England), Chicago, Pittsburgh, and Philadelphia. Some time later, the parent group in New York City also organized officially as a section. This and the Chicago section are considerably the largest in membership.

As the Society continued to grow in membership, the larger cities in the United States, Canada, and Mexico became seats first for Chapters, or inaugural groups, usually of less than 25 members, and later for Sections. At the close of 1953, these local groups numbered 63—53 distributed in the United States, 9 in Canada, and 1 in Mexico City (illustration, right, page 41). Also eight Student Branches have recently been established at technical colleges.

No local groups exist outside of continental North America, although some 200 members are scattered in foreign countries. Each section and chapter usually holds about eight regular monthly meetings annually, including presentation of technical papers plus some social affairs.

Membership Classes and Honors

The official badge, or monogram, of the Society, adopted in 1906, applied to just one class of membership. It was not long until, in addition to regular Members, a classification of Associate Members was established; later one of Honorary Members; then Members Emeritus; and considerably later, Student Members; and the top grade of Fellows.



MODERN LIGHTING PROVIDES HIGH-LEVEL ILLUMINATION FOR CITY ROADWAYS AND BUILDINGS.

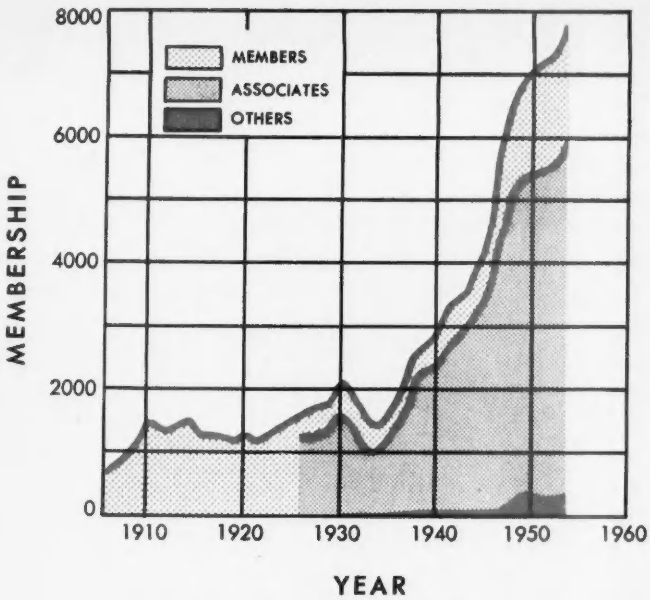
In 1953 the membership totaled nearly 8000—about 1900 full Members and 6000 Associate Members. Within the past few years the Society has added some 75 in the grade of Fellow and a growing number (over 300) of student members (undergraduates).

The class of Sustaining Members was established some 25 years ago. From this source the annual contributions now represent approximately 15 percent of the Society's gross income. At present the regular dues and modest advertising constitute the major income, plus certain special contributions to an expanding program of research.

Certificates of appreciation, scrolls of thanks for leading activities, gold badges for past presidents, and similar records are among the recognitions that increase the satisfaction of combined efforts to advance the cause of light and vision. And the Gold Medal may annually be awarded for especially outstanding services and devotion to the cause of lighting and for work on behalf of humanitarian advancements.

Publications and Pamphlets

The Illuminating Engineering Publishing Company of 12 West 40th Street, New York, under its dynamic editor, E. L. Elliott, printed the early proceedings of the Society. Mr. Elliott was later followed by editors MacBeth and Marshall. The first regular publication of and by the Society was the *Transactions*, issued 10 times each year and continued until 1940. Then the format was changed



RELATED CURVES REVEAL THE RAPID GROWTH OF THE ILLUMINATING ENGINEERING SOCIETY'S MEMBERSHIP AND SECTIONS.

to the *Journal*. More recently it was enlarged to the present 8 x 11-inch monthly journal known as *Illuminating Engineering*.

The greatest sources of output of Society facts and literature reside in some 30 technical committees. It follows, then, that the carefully approved and official reports of these committees are sold in pamphlet form to a wide range of customers; they also have become the bases for American Standard Practices. Characteristically these reports are on such subjects as street and highway lighting, residential and industrial lighting, aviation and transportation lighting, lighting for agriculture, and so on. In addition to the *Lighting Handbook*—the Bible of the lighting fraternity—the Society publishes the majority of the papers read at national and regional conferences, plus related discussions, together with technical data sheets and certain codes for street lighting, school lighting, and others.

Residence lighting is exceptionally well presented in a booklet on that subject. At headquarters the L. B. Marks Library, comprising many volumes on lighting, supplies a valuable reference for consultation.

Management

To accommodate the local interests of a membership totaling more than 8000, the areas within the continental borders of the United States and Canada are divided into 10 regions, each under the jurisdiction of a regional vice president. Every year, with the exception of the national technical conference usually occurring in September, each region holds a two- or three-day regional conference. This facilitates an exchange of local information and makes the latest technical knowledge accessible to the greatest possible number.

The Council, composed of the executive officers, the six directors, and the regional vice presidents, meets bimonthly to transact the Society's business. On alternate months, the Council Executive Committee looks after affairs of moment.

Seven standing committees are concerned with finances, admission to membership, awards, papers, and publications, while 14 general and repetitive committees handle planning, nominations and appointments, laws, national defense, history, public relations, and residence forums. When temporary committees are needed for special services, task committees are chosen by the president.

As an aid to the integration of numerous other societies, especially along lines of mutual understanding and standardization, the Society has representation on some 15 other groups such as American Standards Association, National Research Council, International Commission on Illumination, and others.

A capable headquarters staff—executive secretary, technical director, advertising manager, editor, and some 14 assistants and clerical specialists—complete the management group.

General Aims and Achievements

Because knowledge is fundamental, the Society has ardently sponsored research on lighting and vision. A substantial fund is set aside to carry on approximately a dozen research projects, each endeavoring to disclose the bases for vagaries of vision or the characteristics of strain, fatigue, glare, field brightness, and related matters.

Through the medium of its technical papers, the Society enables its members to keep alert to developments in all light sources and applications. At its annual national and regional conferences, the résumés of progress and the interchange of experiences permit the delegates to proceed toward the second objective—the dissemination of knowledge.

In the first half century of organization, the task of the Illuminating Engineering Society has been to establish the foundations of vocabulary, testing procedures, standards, good practices, fair ethics, agreeable artistry, and widespread education. As each decade sees light usage almost doubled—and then redoubled—it becomes even more logical and vital to enlarge the scope and influence in all phases of visual welfare. This continues to be the Society's chief aim. Ω

1 A single operation insulates and encases a 5000-volt current transformer for indoor applications the modern way. The unit is placed inside a strong steel die that will be subjected to high internal bursting pressure.

2 Open die's mating-half is secured, a steel dome is lowered to form a high vacuum, and butyl rubber—an American-developed synthetic with superior electrical, chemical, and physical properties—is injected into the die under pressure.

Insulating Instrument Transfor

By ROBERT

In 1948 General Electric introduced a revolutionary one-shot process of encasing an instrument transformer with a material that not only electrically insulates its core and coils but also physically supports them (photo sequence). This one operation eliminates a tedious method of hand-wrapping the transformer with layers of asphalt-treated crepe-paper insulation.

Cast or Mold?

For many years the electrical industry had been experimenting with just such an idea. Work was mainly directed along two process lines—casting and molding under pressure. The question was: which is the better process?

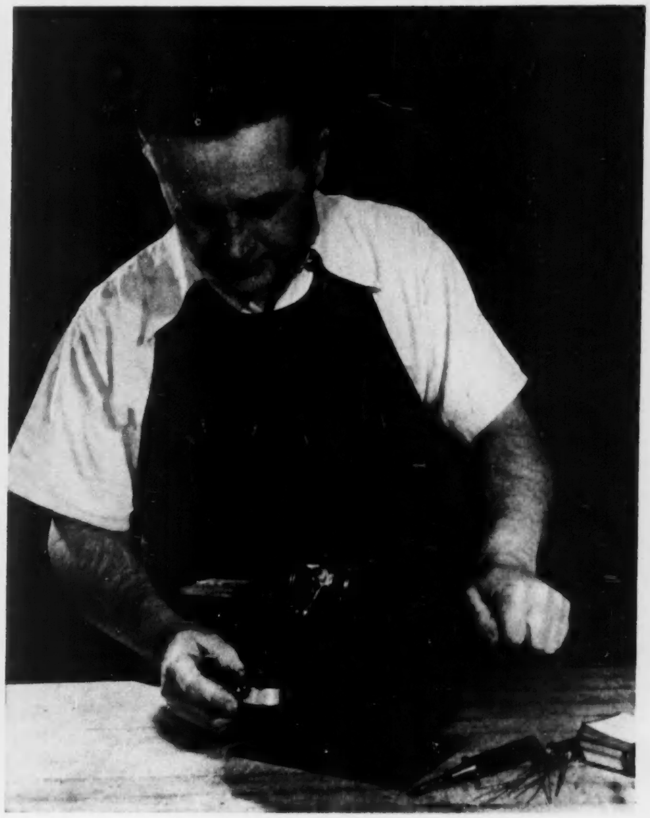
In the casting technique a resin is poured into inexpensive forms that hold the transformer's component parts in a fixed position. After the resin has cured to a solid material, the forms are removed and the insulated transformer is ready for a finishing operation.

At first this process seemed the more desirable: it was straightforward and utilized low-cost forms. But over the years numerous casting materials—even Portland cement—were tried with little success. Early difficulties included voids and bubbles present in the cured resin. These were eventually overcome by vacuum casting, but cracks in the resin caused by shrinkage stresses remained a serious problem.

In the molding process the molding material is injected into the form under pressure. With the materials then available, however, intricate steel forms were needed to withstand the high internal pressure and to properly hold the inserts in place. This same high pressure also tended to distort the inserts—a major drawback of the process. None of the phenolic resins and rubber compounds then available had completely satisfactory physical and processing characteristics. To make matters worse, the cost of the available materials was high.

These two approaches then—casting versus molding—battled down the line to determine which would be the first used for insulating modern instrument

3 After the rubber has had time to cure (harden) under controlled temperature and pressure conditions, the unit is removed. Its core and coils are now encased, supported, and electrically insulated with butyl.



4 Inspection of finished product follows a finishing operation and electrical testing. Butyl is the complete insulation—so elastic it won't crack under stresses caused by chemical or thermal shrinkage. (Photo sequence continued on next page.)

mers—A Continuing Challenge

S. NORMAN

transformers. Although the early emphasis was on the casting process, in later years pressure molding began to pull ahead, culminating in General Electric's announcement of a molded instrument transformer in 1948.

Clear Field . . .

The new transformer molding process used butyl—a synthetic rubber compound formed by the reaction of isobutylene and isoprene at low temperatures.

Although most synthetic rubber compounds were developed in Germany, butyl was strictly an American development. At the time of Pearl Harbor it had just come out of the pilot-plant stage. When our rubber sources in the Far East were cut off by the war, butyl technology had to be rapidly advanced. All available know-how was concentrated on achieving greatly expanded low-cost production.

The particular butyl compound formulated in 1948 for transformer insulation proved highly successful. Readily available, it has just the processing characteristics needed. Its electrical, physical, and chemical properties—resistance to ozone and corona, tearing and abrasion, acids and alkalies, respectively—are completely satisfactory. What's more, it has a high dielectric strength and excellent heat-aging properties. In addition to these desirable technical characteristics, butyl has the basic advantage of being low in cost. Industry acceptance of butyl-molded transformers has soared since the first unit for indoor use was marketed in 1948.

By 1951, butyl-molded transformers had proved superior not only for indoor

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Mr. Norman joined General Electric seven years ago. After completing the Company's Test Course in 1948, he entered the Meter and Instrument Department, West Lynn, Mass. He is now Supervisor of Chemical Development, Measurements Laboratory at West Lynn.

5 Here's the completed 5000-volt instrument transformer alongside its conventionally insulated counterpart. In the former process, the unit was hand-wrapped with an asphalt-treated crepe paper—a laborious and costly process.

6 Butyl rubber gum is compounded with other materials to give it desirable properties. Most of the synthetic rubbers originated in Germany, but butyl is strictly an American development.

but also for outdoor applications. As a result, a 600-volt combination indoor-outdoor current transformer was introduced; marketed two years later was the corrosion-free 5000-volt outdoor current transformer. This unit was a big step forward in design because butyl rubber could both insulate and encase the transformer, eliminating the expensive conventional metal case and porcelain bushings. Today, transformers of similar design in the 15,000-volt range are within sight.

. . . Now Challenged

Since 1948, when molded butyl was first successfully applied to instrument transformers, many new materials have appeared to offer a challenge to butyl. These are being constantly surveyed and evaluated to be sure that no better material is being overlooked. For in selecting an insulation for instrument transformers many things must be considered. Dielectric strength, heat stability, resistance to internal corona, electrical creepage, and mechanical damage are *physically* critical. The cost of both the material and the process, including labor, tools, equipment, investment, and upkeep is *economically* critical.

Recently developed casting resins that are commercially available include epoxides and improved polyesters. Still in the developmental stage are the polyurethane resins, such as castor-oil polyurethane. In the nebulous future are the organoboron polymers.

Among the rubber compounds in commercial production are the silicones, acrylics, and Hypalon. Polyurethane rubbers are available commercially in Europe but not as yet in the United States. Within the next two to five years fluorinated rubbers should appear commercially in this country.

Here's a list of the new materials that vie with butyl rubber for transformer insulation . . .

Polyesters—Solventless resins, they are polymerization products of polybasic acids reacted with polyhydric alcohols. Many types are available. By the addition of other materials, it's possible—within limits—to modify them for specific properties. Work has been carried on for several years to cast transformer insulation of modified polyesters, but it has only been successful for low-voltage applications.

Epoxides—Reaction products of bisphenol and epichlorohydrin, epoxides too are solventless resins that can be modified for specific purposes. Some of the epoxide resins possess electrical characteristics similar to butyl rubber, and an American manufacturer recently introduced a 600-volt instrument transformer cast in an epoxide resin.

European manufacturers have been producing cast-epoxide instrument transformers for several years. (Butyl is not competitive in Europe because it isn't readily available.)

Polyurethanes—These are obtained by reacting diisocyanate with polyhydroxy compounds. In Europe, where they were developed, their use is expanding rapidly in the fields of wire enamels, surface coatings, and adhesives.

Polyurethane casting resins are now under study in the United States, and initial results are promising. Already a castor-oil polyurethane for the military services has been developed by Princeton University's plastics laboratory, though it is not yet available commercially. Good heat stability and chemical inertness are claimed for this material.

Organoboron resins—Laboratories throughout the country are working on these compounds; studies are based on chemical structures of boron-oxygen, boron-nitrogen, and boron-phosphorous. It will probably be many years before they are produced on a commercial basis, however. The goal is to develop resins with superhigh-heat stabilities in the range of 400 to 500 C.

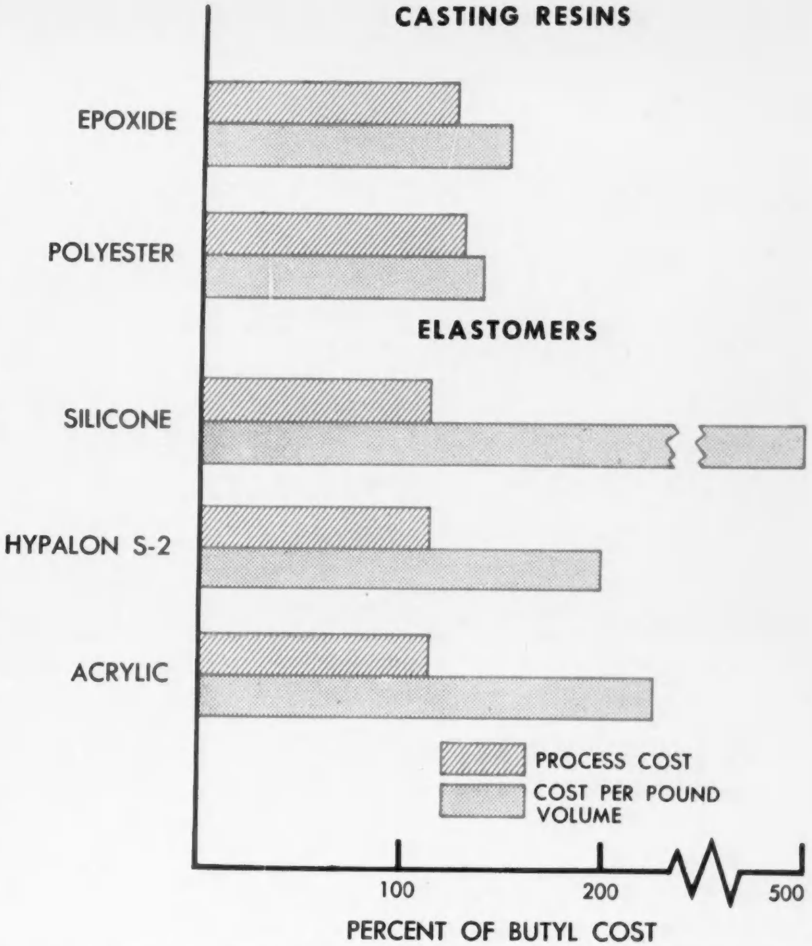
Vulcalon—Another European development, this is a polyurethane rubber prepared from the reaction of adipic acid, ethylene or propylene glycol, diisocyanate, and water. Its resistance to abrasion is said to be greatly superior to any known rubber compound; its resistance to ozone and oxidation is also claimed to be good. At the present time, however, Vulcalon has at least one serious drawback for use as electric insulation—its susceptibility to hydrolysis.

Silicone rubber—More familiar to engineers, silicone rubber is a product of the relatively new field of organosilicon chemistry. It is unusually stable at high temperatures, flexible at low temperatures, chemically inert, and possesses superior corona resistance. Although the original silicone rubbers lacked much in mechanical properties, recent compounding techniques have overcome this.

Hypalon S-2—This chlorosulfonated polyethylene compound is obtained by treating polyethylene resin with chlorine and sulphur dioxide. Along with a high degree of chemical stability, Hypalon S-2 has excellent resistance to ozone, solvents, and chemicals.

Acrylic rubber—Obtained from esters of acrylic acid, this new commercially available rubber includes Acrylon and the Hycar acrylic-based rubbers. According to published statements the latter have exceptional heat and ozone resistance.

The major disadvantage of the last three rubbers mentioned—silicone, Hypalon, and acrylic—is their high material cost (illustration).



BUTYL COST is low compared with new synthetics that challenge it. Excluding the process, butyl also has advantage of lesser density—more volume per pound—over its competitors.

Meeting the Challenge

There's no question but that the old method of insulating dry-type transformers with asphalt-treated paper is on its way out. Pressure-molded butyl rubber is the answer today and will be for some time to come.

At the present time the process of pressure molding with butyl has three major advantages over casting with resins . . .

- Butyl is the complete insulation, and its elasticity is such that despite stresses caused by thermal or polymerization shrinkage, it will never crack.
- Butyl is readily available and its cost is low. Even with a large percentage of inert fillers, all the newer materials are more expensive.
- Larger poundages of the newer materials are required to match equivalent volumes of butyl because of its lower density.
- The molding process involved with butyl is actually less costly than the casting process. The long casting and curing cycle, plus the many molds and additional work necessary to protect the cast insulation from ionization and internal stresses, all add to the basic cost of casting.

Evaluating Developments

Continuing advances in compounding butyl enable it to remain ahead on electrical properties for instrument transformer applications.

Although none of the newer materials are competitive with butyl today, the further development of these and other even newer materials means that a feeling of complacency cannot be enjoyed by the insulation development engineer. For technical alertness and constant evaluation of new materials is the price of good instrument-transformer design. Ω

ELECTROLUMINESCENCE DEMONSTRATED BY AUTHOR MAY PROVE AN EFFICIENT LIGHT SOURCE.

Electroluminescence

By DR. WILLIAM W. PIPER

The conversion of electricity into visible light is a process of major importance today. Considering the millions of dollars that are spent each year to produce light, any means of increasing lamp efficiency is important. If electric energy were converted into white light with 100 percent efficiency, about 220 lumens of light would be produced for each watt of electric energy consumed. The most efficient fluorescent lamps today are capable of delivering about 60 lumens per watt—a significant advance beyond the tungsten lamp efficiency of about 15 lumens per watt. But both of these lamps are limited in ultimate efficiency by the indirect means used to convert the electric energy into light.

A fundamentally attractive method of producing light, which is not inherently limited in efficiency, is the direct conversion of electric energy into luminescence within a semiconducting solid. The excitation of luminescence by the application of an electric potential to a crystalline phosphor or the suspension of such a crystal in a changing electric field is called *electroluminescence* (photo). The present electroluminescent lamps (a few lumens per watt) are considerably less efficient than the tungsten lamp. However, the basic theoretical limitations imposed on the efficiency of incandescence and ultraviolet fluorescence are not applicable to electroluminescence. With proper materials this new means of producing light may prove a more efficient source.

Electroluminescence was first discovered a little over 20 years ago. The earliest observations were made on crystals of silicon carbide that were mounted between two metallic probes. When d-c voltage was applied between the probes, some crystals were observed to emit light in regions near the electrodes. The light emitted at the cathode was later positively identified as solid-state luminescence.

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Dr. Piper is a research associate in the General Physics Department of the Research Laboratory, The Knolls, Schenectady. He joined General Electric in 1950. At present his work is directed toward a better understanding of the crystal structure underlying the physical mechanism of electroluminescence.

A few years after the observation of electroluminescence in silicon carbide, certain zinc sulfide phosphors were discovered to be electroluminescent. This powdered phosphor when suspended in an insulating liquid and placed between two plane parallel electrodes was observed to electroluminesce whenever an a-c potential was applied across the electrodes. The light emitted was the characteristic luminescence of this phosphor.

In the past five years many improvements have been made in electroluminescent cells that utilize powdered phosphors of zinc sulfide and zinc sulfoselenide. A schematic diagram of a typical cell is shown on the top of the opposite page. The microcrystalline grains of the phosphor are imbedded in a sheet of thermoplastics dielectric material a few thousandths of an inch thick.

This mixture is then sprayed on a piece of plate glass that has a transparent conducting surface on the side in contact with the plastics. This plastics layer, backed by a sheet of aluminum foil or a coat of conducting silver paste, becomes rigid after it has set.

Light from the phosphor escapes from the cell through the glass. Because in principle the surface area of this cell is unlimited, broad-area electroluminescent panels are feasible. Rooms illuminated by such broad-area sources of light would possess the comfort associated with the combination of a high level of illumination and a low surface brightness of the lamp.

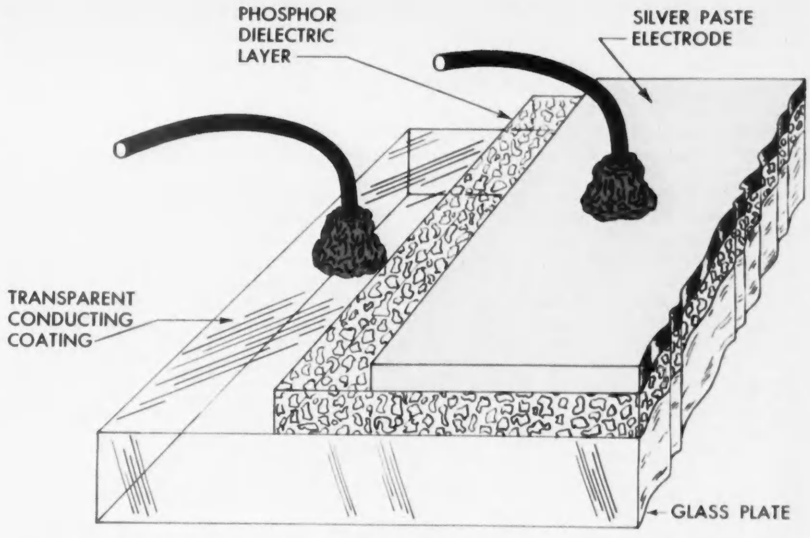
More recently, electroluminescence has been observed in single crystals of copper-activated zinc sulfide and in thin transparent films of manganese-activated zinc sulfide (illustration, lower, opposite page). The single crystals may be grown in an evacuated quartz tube from the vapor phase at 1100 C. The thin films may be chemically deposited on a glass surface heated to 550 C in the presence of vapors of zinc, manganese, and hydrogen sulfide. The electrodes for thin films are similar to those described for the powder cell. Electrodes are placed on both sides of the single crystals. The electrode material may be a thin layer of silver paste or a layer of metal evaporated onto the crystal in a vacuum.

Electroluminescent phenomena in zinc sulfide can be subdivided into two types. In general, when an appropriate voltage is applied to an electroluminescent

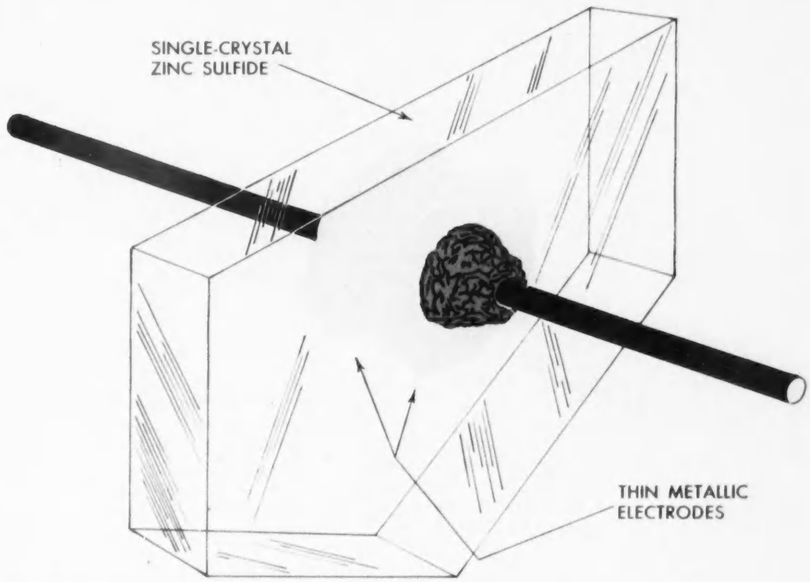
cent system, light is emitted in pulses—usually two per voltage cycle. These pulses are either in or markedly out of phase with the peak-applied voltage. Systems exhibiting in-phase electroluminescence will also emit light when excited by a d-c voltage of comparable magnitude. Single crystals and thin films of zinc sulfide are capable of producing in-phase electroluminescence. Single crystals and powder cells of zinc sulfide emit out-of-phase light. This out-of-phase component appears only above a threshold voltage, increases almost linearly with increasing frequency up to several kilocycles, and varies superlinearly with applied voltage.

A good powder cell today has a surface brightness of about one footlambert when excited by 110 volts, 60 cycles. At 300 volts and 5 kc per second a similar cell designed for the higher voltage has a brightness of about 25 footlamberts. This level of brightness is easily seen in a well-lighted room; it would appear brighter than a piece of white paper illuminated by a 100-watt tungsten lamp two feet away. The brightness for a given applied voltage can also be increased by using a suspending plastics that possesses a high dielectric constant. For example, if a plastics having a dielectric constant of 14 is used to suspend copper-activated zinc sulfoselenide, 5 times as much light is produced as in a similar cell using a plastics with a dielectric constant of 6.

In addition to the problems of a low brightness level and low efficiency, the brightness level of present powder cells under constant conditions of excitation slowly diminishes over an extended period of time.



POWDERED ZINC sulfoselenide electroluminescent cell makes possible broad-area panels that would give a combination of high-level illumination and low surface brightness.



CRYSTAL of zinc sulfide electroluminescent cell may be grown in an evacuated quartz tube from the vapor phase at 1100 C. The thin films may be chemically deposited on glass surface.

Mechanism of Electroluminescence

A large fraction of phosphor materials is composed of inorganic crystalline solids. Electroluminescent phosphors, as well as those used in fluorescent lamps, belong to this class. A crystalline solid consists of a large number of atoms of an element or compound arranged periodically to form a lattice. To make a phosphor, a suitable crystalline solid must be activated. Activation results from a dilute amount of a foreign metallic ion being dispersed atomically throughout the lattice. These impurity ions, or activator atoms, are responsible for the emission of light from a phosphor. The activators can be excited in many ways. Two examples are the absorption of an ultraviolet photon and the transfer of energy from an electron with considerable kinetic energy. When an excited activator returns to the ground state, it may emit a photon of light.

Inorganic crystalline phosphors belong to a broad class of solid materials named semiconductors—germanium is a well-known example. Some semiconductors conduct electric current by electrons that are free to move through the crystal in the conduction band, others by holes in the valence band. In n-type semiconductors the current is carried by electrons that are furnished to the conduction band by donors. Similarly, holes from acceptor centers are the charge carriers in p-type semiconductors.

Two mechanisms for electroluminescence have been proposed, both theoretically sound. One states that the activator centers responsible for the emission of light are ionized by the capture of a hole that has been injected into the crystal. The subsequent capture of

THEORY OF ELECTROLUMINESCENCE

A convenient model often used to represent phosphors and other crystalline solids is the band-theory model. This model arises from quantum mechanical considerations of the interactions of the valence electrons with the periodic electrostatic potential of the crystal lattice. The discrete energy levels that are characteristic of isolated atoms broaden into allowed bands of energy separated by forbidden bands when the atoms are placed in a crystalline array. If the highest band of allowed energies normally occupied is only partly full at absolute zero, the crystal is a metal. If this band is completely full, then the crystal is a semiconductor—the class phosphors belong to.

A composite band-theory model of a phosphor is shown in Fig. 1. The last filled, or valence, band is at the bottom of the diagram. The first empty band of allowed energies—conduction band—is separated from the valence band by a forbidden region.

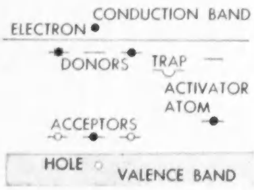


FIG. 1

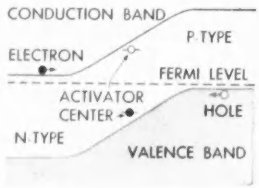


FIG. 2

Energy levels can occur locally in the forbidden region if the lattice is in some way perturbed in that locality. The ground state and the first excited state of an activator center usually occur in the forbidden band as shown. In addition, trapping levels are present in any real crystal. These levels can be introduced by local imperfections of the host lattice. Other added impurities can introduce donor or acceptor levels. Electrons can be introduced into the conduction band by the ionization of donor levels. Electrons in the conduction band are free to move to other regions of the lattice and can be captured by a trapping center or an ionized donor or activator. Free holes (empty states in the valence band) are produced when an acceptor center removes an electron from the valence band. Just as electrons move through the conduction band, holes in the valence band may migrate through the lattice until they are either recaptured by an ionized acceptor center or annihilated by an electron trapped at a localized center above the valence band.

When a phosphor is excited by ultraviolet light, an activator center absorbs a photon of incident energy leaving the activator in an excited, or emitting, state. Neighboring ions then move slightly to a new equilibrium configuration that brings the excited state and the ground state of the activator closer together. For this reason the photon emitted by the activator upon returning to the ground state is less energetic and of longer wave length than the absorbed photon. The difference in energy appears as vibrational energy in the crystal lattice.

In an electroluminescent phosphor the conversion of electric energy into light takes place within the phosphor material. This conversion is not necessarily efficient: nonradiative events may compete with the excitation and emission of light from an activator center. Two theoretically sound mechanisms have been proposed for the electroluminescence phenomenon. One involves the injection of positive holes into the valence band that can ionize the activator atoms by capture. The other requires that electrons be injected into the conduction band and subsequently accelerated to kinetic energies sufficient to excite an activator center by means of an inelastic collision. Some experimental evidence exists that is in agreement with each of those mechanisms.

Holes can be injected into an n-type semiconductor in several ways. The simplest one occurs at a p-n junction (Fig. 2). In the n-type region, current flows predominately by means of the transport of charge by conduction electrons; in the p-type region the charge is transported by holes that travel in the valence band. A barrier exists at the interface between these two regions. When a voltage is applied across the junction whose polarity urges electrons from the n-type region into the p-type region and holes from the p-type side of the interface to the n-type part of the crystal, the barrier contributes very little resistance to the flow of current. However, if the polarity is reversed, the region immediately on either side of the junction is exhausted of its type of current carrier. The ionized donors and acceptors in this region create a space-charge layer, and much less current flows in this direction. When the current is moving in the easy-flow, or forward, direction, conduction electrons that move into the p-type region are shortly annihilated by the high density of positive holes. Holes moving across the junction in the opposite direction also quickly recombine with a conduction electron. If suitable activator atoms are present in or near the barrier, the electron-hole recombination may occur optically at the activator site with the emission of a photon of light characteristic of the activator system. Holes can also be injected into n-type material by positively biased point-contact electrodes as well as by excitation from acceptor centers present in the crystal.

The second theoretically sound means of exciting activators is the result of a conduction electron with a large amount of kinetic energy suffering an inelastic collision with the activator center. Except in electric field strengths approaching those necessary for electronic breakdown of insulators—about a million volts per centimeter—conduction electrons moving through the lattice under the influence of an electric field possess no more kinetic energy on the average than they do when no field is

an electron from the conduction band leaves the activator atom in an excited state so that it can then emit a photon of light. Silicon carbide emits at least part of its light by this mechanism.

That an activator center in an electroluminescent phosphor can also be excited by a conduction electron with sufficient kinetic energy is the basis of the second mechanism. The electron transfers its energy to the activator by means of an inelastic collision. A conduction electron can attain these high energies only in strong electric fields. In weaker fields the electrons lose energy too rapidly to the lattice by phonon emission—a process analogous to a frictional force experienced by the electron.

These high electric fields can be produced close to the crystal surface in zinc-sulfide single crystals because of a space charge that appears in this region when an electric potential is applied across the crystal. According to this theory, when a d-c voltage is applied between metallic electrodes on opposite sides of the crystal, light is emitted above a threshold voltage. If a-c voltage is applied, light appears at lower voltages out of phase with respect to the peak-applied voltage. Two pulses appear per voltage cycle, and the average brightness increases linearly with increasing frequency and superlinearly with increasing voltage in agreement with experiment. (For your information we've included a more detailed discussion of the theory of electroluminescence.)

present. This is true because these electrons are in thermal equilibrium with the rest of the lattice. The energy transferred from the electric field to the electron is shared so quickly with the rest of the crystal that the electron is unable to accumulate kinetic energy. The thermal kinetic energy of an electron at room temperature is about 100 times smaller than the energy needed to excite an activator atom. If an electric field almost as large as the breakdown field exists locally in a crystal containing appropriate activator atoms, the conduction electrons can then successfully gain sufficient kinetic energy to collide inelastically with an activator and excite it. If this high-field region exists close to the surface of the crystal, the electrons may be injected from a negatively biased metallic electrode. The electrons also can be excited into the conduction band by the intense electric field from tightly bound donor levels.

n-type semiconductor, electrons from donor levels flow through the conduction band. Because electrons cannot enter the crystal at the cathode, the donors nearest the cathode remain empty. The positively charged exhaustion layer widens until the entire difference of potential is across this layer. As the voltage is increased, the electric field in the exhaustion layer rises. At a sufficiently high voltage the barrier at the surface is thin enough to permit electrons to tunnel from the electrode into the conduction band. These fields are more than adequate to successfully accelerate electrons to high kinetic energies, thus exciting and ionizing activators by the impact excitation mechanism. With the continuous flow of electrons, light may be emitted near the anode with the proper conditions for hole injection.

When an a-c voltage is applied to these single crystals of zinc sulfide, two distinct pulses of light in phase with the peak-applied

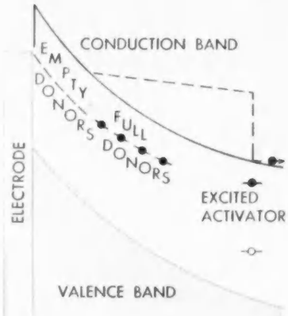


FIG. 3

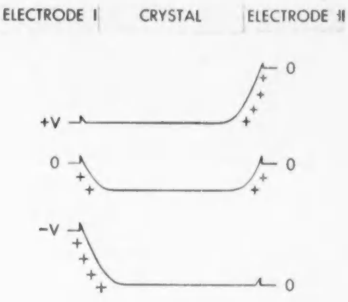


FIG. 4

Silicon carbide can be prepared as either a p-type or an n-type semiconductor. Regions of p- and n-type silicon carbide frequently occur side by side in one crystal. The yellow electroluminescent emission is known to occur at p-n junctions in the crystal that are biased in the direction of easy flow. These crystals electroluminesce by the mechanism of hole injection at the junction.

When a d-c voltage is applied to a copper-activated single crystal of zinc sulfide mounted between metal electrodes, the emission of light and current each increase exponentially with voltage, reversibly to breakdown. The nonohmic behavior of the crystal indicates the presence of a barrier. The current and light depend on the material used at the cathode. For this reason the cathode barrier probably is a Mott-Schottky exhaustion barrier that is effective because of the difference in work functions of the crystal and the metal electrode. Conduction electrons are able to escape easily to the electrode but are unable to return to the conduction band. When a voltage is applied across this

voltage appear above a voltage comparable to the threshold voltage for d-c electroluminescence. Other similarities make it clear that in-phase a-c electroluminescence occurs by the same mechanism as d-c electroluminescence.

The out-of-phase component of the a-c electroluminescence occurs at lower values of applied voltage. Each pulse of light is associated with a particular electrode. The activators next to an electrode are ionized in the exhaustion layer when that electrode is becoming more negative. These activators, excited by the impact excitation mechanism, emit light on the succeeding half cycle when electrons are again available in the conduction band. The electrons are injected into the conduction band from deep donor levels (Fig. 3) that are too deep to be ionized thermally and are emptied by the strong electric field present in the exhaustion layer. An applied a-c voltage alternately depletes and replenishes the exhaustion layers in front of each electrode (Fig. 4). Two pulses of light—one in front of each electrode—are emitted per voltage cycle.

Electroluminescence holds promise of varied applications in lighting and electronics. The present electroluminescent panels are most seriously limited by low levels of light, low efficiency, and depreciation. The gravest theoretical limitation on the efficiency (at present about one tenth the efficiency of tungsten lighting) is the nature of the competing parallel processes within the semiconducting phosphor that absorb energy without subsequently emitting light. These losses occur within the crystal, and a significant fraction appears to be the frictional forces experienced by the conduction electrons as they move through the lattice. The directness of the conversion of electric energy into visible light indicates that much better performance can be attained—provided that proper materials and technology produce phosphors with better-suited properties.

Electroluminescence will probably first appear commercially in low-level lighting applications for use in darkened rooms. Another use under consideration is the visual display of information for military as well as commercial applications. Combined with a crystalline photodetector, a high-speed electroluminescent cell might be used as a storage element for large digital computers. General-purpose lighting by electroluminescent devices will not be feasible until the efficiency is at least equal to that of incandescent lamps. And this does not appear to be attainable in the near future. Ω

SEMAC II—A VERSATILE COMPUTING DEVICE— runs through calculations of complex engineering problems with ease. Author McCracken, checking the circuit of a removable control panel, joined the Company in 1951 at AEC's GE-operated Hanford Atomic Products Operation in Richland, Wash. He is now a Technical Engineer, Components Development Section at General Electric's Aircraft Gas Turbine Division in Evendale, Ohio.

SOLVING PROBLEMS WITH THE SEMAC II

By D. D. McCRACKEN

Initially of interest only to accountants, today punched-card calculators are used by mathematicians, engineers, and scientists everywhere. The May 1952 REVIEW reported some of their engineering applications in an article titled "Let Punched Cards Solve That Problem."

The Card Programmed Calculator (CPC) is a flexible piece of computing equipment that each user adapts to his needs. It recognizes the holes in punched cards, performs mathematical operations with ease and relative speed, and records answers as holes punched in other cards. As a computing device, it is limited largely by the system designer's ingenuity. For its operation is controlled by interchangeable control panels or plug boards. They are an integral part of the CPC, but unlike internal parts, their wiring arrangement can be altered.

Computer Economics

Card Programmed Calculators cost more per hour of operating time than do desk calculators operated by one man. What then makes them so popular? Basically the reason is that they fill the gap between the inexpensive desk calculator operated at tedious manual speeds and the swift but costly giant digital computers.

The larger the calculator the cheaper its operating cost—provided there's enough work to keep it operating most of the time. For example, a recently built large-scale calculator performs nearly one-million arithmetic operations per minute for one two-thousandth of a cent each—or 60-million operations an hour for $300. But to keep it busy requires the services of 20 to 30 mathematicians plus a staff of other workers.

What's in a Name?

The SEMAC II (photo) is a medium-size computing system employed at the Atomic Energy Commission's GE-operated plutonium plant in Richland, Wash. It utilizes punched-card equipment whose removable control panels are so designed that complex calculations arising in engineering and nuclear physics can be effectively handled.

The name itself stands for series evaluated functions, mixed decimal, arithmetic calculator. You get a good idea of its significance by observing how SEMAC II goes about evaluating a problem. The simple illustration and explanations that follow are intended to do just that—point up some of SEMAC II's distinctive features and provide information on CPC's in general.

The Problem

Consider the equation

$$v = v' \left[\left(\frac{1+k}{2 \cos \phi}\right)^2 - k\right]^{1/2}$$

where you want to evaluate v for given values for v', k, and ϕ. To do this you can arbitrarily choose values of the constants v' and k, then find solutions to the equation in terms of ϕ, varying the latter in steps of five degrees from zero to 85 degrees. When the first sequence of operations is finished, you change the values of v' and k, repeating the process until you have sufficient data.

Manually done, this is a long and tedious task. But evaluating the same equation with SEMAC II is speedily accomplished by programming a sequence of simple operations for the machine to carry out, one per instruction card. The following program of 10 operations, translated literally from 10 punched cards, would evaluate the equation for one set of values of v', k, and ϕ. . .

1) Form the sum $(1+k)$ and store it.
2) Evaluate $\cos \phi$.
3) Multiply $\cos \phi$ by 2.

4) Call $(1+k)$ out of storage and divide it by the product of step three.

5) Square the quotient, giving $\left(\frac{1+k}{2\cos\phi}\right)^2$

6) Subtract k from this.

7) Take the square root.

8) Multiply this result by v'. Place the product v in storage so that it can be printed at card 10.

9) Add five degrees to the value of ϕ already used so that steps one through eight can be repeated.

10) Punch the product v into a blank card, along with the corresponding values of v', k, and ϕ.

The 10-card block is operated on in this way until ϕ equals 85 degrees. Then the values of v' and k are changed and the whole process repeated. To give you an idea of the speed with which these operations are carried out, it takes SEMAC II only about seven seconds to run through the 10-card block, or one sequence of 10 operations.

Evaluating the Cosine

Although SEMAC II can "read" the holes in a deck of punched cards, it can't look up the values of trigonometric functions in a table. Of course, you could manually punch the values into the cards and arrange the machine to select the right one—or even interpolate between values. But this isn't economical compared with another method available.

You may remember from your calculus that the cosine of an angle x can be evaluated using the converging series

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots.$$

derived from Taylor's theorem. The ! terms are factorial numbers; for example, 4! = 1 x 2 x 3 x 4 = 24. Depending on the degree of accuracy needed, you can take as many or as few terms as you like.

Suppose that for our example problem the terms through x^6 give sufficient accuracy. The cosine series is then factored into

$$\cos x = 1 - \frac{x^2}{2}\left[1 - \frac{x^2}{12}\left(1 - \frac{x^2}{30}\right)\right]$$

Although considerably more terms are needed in practice, SEMAC II can evaluate a cosine to seven-decimal accuracy in about three seconds by this method. In a similar manner it evaluates hyperbolic, logarithmic, exponential, and other functions. Thus you can see the origin of the phrase "series evaluated functions" in its name.

Logic and the Square Root

The method commonly used to extract the square root is interesting because it illustrates the limited "thinking" ability of computers. First of all, the operator or the machine makes a guess at the square root —which can be any finite number greater than zero—and the computer proceeds to find a more accurate answer by Newton's approximation formula

$$a_{i+1} = \tfrac{1}{2}\left(\frac{N}{a_i} + a_i\right)$$

where a_i is the ith approximation to the square root of the number N, and i equals 1, 2, 3, 4, 5, and so on.

Suppose you didn't know the square root of 121, and you wanted to compute it by Newton's method. Perhaps you would first guess the square root to be about 12—that is, a equals 12. Substituting into the formula, you whittle down your approximations as follows . . .

$$a_1 = a_{1+0} \cong 12$$

$$a_2 = a_{1+1} \cong \tfrac{1}{2}\left(\frac{121}{12} + 12\right) = 11.04167$$

$$a_3 = a_{2+1} \cong \tfrac{1}{2}\left(\frac{121}{11.04167} + 11.04167\right) = 11.00008$$

$$a_4 = a_{3+1} \overset{?}{=} \tfrac{1}{2}\left(\frac{121}{11.00008} + 11.00008\right) = 11.00000$$

$$a_5 = a_{4+1} = \tfrac{1}{2}\left(\frac{121}{11.00000} + 11.00000\right) = 11.00000$$

In practice, the machine is set up to do this process over and over indefinitely. Each approximation is subtracted from the previous one until the difference is zero, indicating two identical approximations. The machine then reasons: "This may or may not be *exactly* the right answer, but it's obviously the best I've been instructed to do. I quit." And the machine stops calculating and calls the last approximation the answer.

Contrary to some popular notions, calculators can make decisions only on the basis of such zero and nonzero tests or plus and minus tests. Still, there are surprisingly many questions in computing work that can be phrased in these terms. This is about the extent of the thinking ability of present-day digital computers—the ability to modify the course of a calculation on the basis of a previously calculated result.

The "Floating Decimal"

Whether you use a slide rule, desk calculator, or automatic calculator, certain problems connected with the decimal point always crop up. When summing the numbers 0.0123 and 1.23, for example, you must line up the decimal points before adding. But conveying this information to a calculator is something else again. Do the digits 1, 2, and 3 stand for 0.0123, 1.23, or 1230? Again, when dividing two numbers—673.23 by 0.004521, for example—most of us have to stop and decide where the decimal point of the quotient will be.

The method commonly used by engineers to keep track of decimal points is to write all quantities as the product of a number less than 10 and some power of 10. That is, 673.23 is written as 6.7323×10^2, and 0.004521 is written as 4.521×10^{-3}. These two numbers divided become

$$\frac{6.7323 \times 10^2}{4.521 \times 10^{-3}} = \frac{6.7323}{4.521} \times 10^5$$

and the decimal point of the quotient is apparent.

In computing language, this is the "floating decimal" method. For CPC work it is modified slightly, however. Each number is written as if it had eight significant digits; base 10, as in 10^5, is omitted, and to avoid negative exponents, 50 is added to each. The exponent plus 50 is then written behind the eight digits of the number like this . . .

$$673.23 = 6.7323 \times 10^2 = 6732300052, \text{ and}$$

$$0.004521 = 4.5210 \times 10^{-3} = 4521000047$$

The first eight digits of a 10-digit floating-decimal number are called the *significant* part; the last two, locating the decimal point, are the *exponent*.

The use of this system takes much detail out of the programmer's hands. Here's the procedure a calculator follows in adding and subtracting two numbers . . .

Call the two numbers to be added *Aa* and *Bb*, where *A* is the significant part and *a*, the exponent part. The calculator first examines *a* and *b*. If they are equal, *A* and *B* are added directly; if they are different, the number with the smaller exponent is shifted to the right the same number of places as the difference in exponents, and the numbers are added. To illustrate,

$$6000000052 + 3200000050 = 6032000052$$

If the significant part of a sum has nine digits instead of eight, it is rounded off by adding five to the ninth digit, the sum shifted one place to the right, and its exponent plus 50 is increased by one. Thus, symbolically

$$7777777750 + 9999999950 = 1777777851$$

or in real numbers

$$7.7777777 + 9.9999999 \cong 17.777778$$

When two nearly equal positive numbers are subtracted, the leading digits of the difference will be zero. The result is then shifted to the left until there's a nonzero digit in the high-order position, and the exponent plus 50 is decreased accordingly. For instance,

$$1111234550 - 1111111150 = 1234000046$$

Despite the apparent detail in floating-decimal addition or subtraction, the operation never takes the calculator more time than that required for one card to run through it—a considerable improvement over earlier CPC floating-decimal systems. SEMAC handles the decimal point in all other operations by similar methods. And the phrase "mixed decimal" derives from SEMAC II's ability to switch from fixed- to floating-decimal notation and back again.

Engineering Application

Here are two fairly typical computing problems readily evaluated by SEMAC II. The emphasis is on methods of solution only because the engineer is primarily interested in the advantages of high-speed computing devices—not in the details of numerical methods themselves. In the following examples, note the . . .

- Reduction in time and effort required to obtain numerical results
- Elimination or reduction of experiment
- Aid in evaluating experimental results.

Problem: A series circuit includes a switch *S*, a battery of constant potential *E*, an inductance *L*, and a nonlinear resistance *R*. Suppose you know that the resistance varies with the current *i* according to the relationship $R = a + bi^n$, where *a*, *b*, and *n* are experimentally determined constants of the circuit element. You are required to find the current *i* as a function of the time *t* after the switch is closed at $t = 0$. The basic equation is

$$L\frac{di}{dt} + Ri = E$$

which, after substitution, becomes

$$L\frac{di}{dt} + ai + bi^{n+1} = E$$

An analytic solution of this equation obviously doesn't exist for arbitrary values of *n*, but you can find a numerical solution. It is a matter of step-by-step integration involving a large number of arithmetic operations that SEMAC II can perform with ease. You can therefore see how it's possible to determine the behavior of a circuit without ever going to the laboratory—assuming of course that you know enough about the components. On the other hand, it might happen in this sort of work that experimental data on the circuit's behavior are available, but you don't fully understand the dependence of the resistance on the current. If so, you could then try different values of *a*, *b*, and *n* or a different expression for *R*, until the combination giving the best correspondence with experimental data is found.

The solution of this differential equation might therefore be aimed at avoiding experimentation or interpreting experimental results. For both, an electronic calculator such as SEMAC II can perform the arithmetic operations much faster and cheaper than a man at a desk calculator.

Problem: Consider a thin wire heated to a high temperature by a known current. The dominant method of heat transfer from the wire is by black-body radiation according to a fourth-power law. If you want to compute the temperature at midpoint of the wire, you must solve this equation for T_m

$$a = \int_{T_o}^{T_m} \frac{dT}{[\,b\,(T^5 - T_m^5) - c\,(T - T_m)\,]^{1/2}}$$

where T_m is the absolute temperature at the wire's midpoint, T_o is the absolute temperature of the surroundings, *T* is the temperature at any point in the wire, and *a*, *b*, and *c* are known constants.

This equation is intractable analytically, but it can be evaluated by a numerical approximation to the integral. Many times, however, it is necessary to try different combinations of values for *a*, *b*, and *c* to get sufficient information about T_m. Imagine numerically integrating this equation 50 times by hand. Yet this is just the sort of thing an automatic computer does so well. You need to set up the basic deck of cards only one time. To study different problems, you change one or two cards at the front and run them through again.

Although the examples here deal with only a differential equation and an integration, other types of problems often arise in engineering and, therefore, in computing work. Among others, these include transcendental equations, systems of linear equations, matrix arithmetic, curve fitting, and statistical analysis.

Versatile Tool

The operations on SEMAC II vary greatly—from simple addition in four-tenths of a second to evaluation of a complex Bessel function in four seconds.

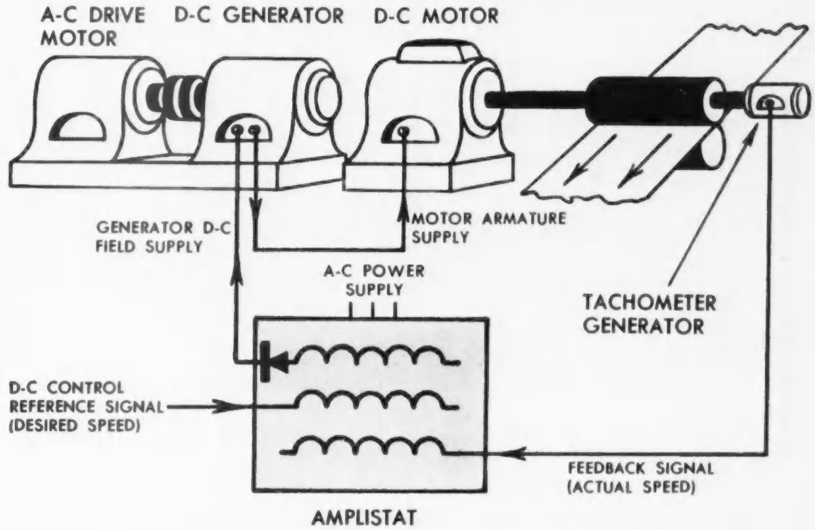
The ability to evaluate Bessel functions makes SEMAC II particularly valuable at the Atomic Energy Commission's GE-operated Hanford Atomic Products Operation in Richland, Wash. This may not be true of other CPC installations, however. (There are many throughout General Electric.) For example, one installation may be called on to evaluate only an occasional sine or cosine. Such a system might be designed to provide two floating-decimal systems on a single card instead of one, as with SEMAC II. Still another installation might want a system that would evaluate sine, cosine, exponential integrals, and the error function on one card.

So you see, flexibility characterizes a Card Programmed Calculator. And ultimately, as with most similar devices, its maximum utilization rests with the system designer. Ω

HOW GOOD IS THE MAGNETIC AMPLIFIER?

By J. J. W. BROWN

MAGNETIC-AMPLIFIER CONTROL SYSTEM



THE MAGNETIC AMPLIFIER, or amplistat, is an electromagnetic device. A d-c signal applied to one or more control windings varies the magnetic permeability—and thus the impedance to the flow of a-c through an output winding—to produce an amplifying action; metallic rectifiers usually convert output to d-c. In this system the regulated quantity (actual speed) is compared with the input quantity (desired speed), and the difference is amplified to maintain an accurate match between the two.

If you had mentioned "magnetic amplifier" to engineers 10 years ago, you would have received a blank stare. Yet this comparatively "new" device (illustration) was developed years before the electronic amplifier. On page 797 of the October 1920 Review you'll find an early description. For a quarter century it lay idle while industry focused its interest and attention on the electronic amplifier and, in later years, on the rotating amplifier, known as the amplidyne.

What brought about this paradoxical state of affairs? When the magnetic amplifier was first developed, a core material with the desired magnetic properties wasn't yet available. Neither did metallic rectifiers then have sufficient reliability and efficiency. And once set aside in favor of its electronic counterpart, the magnetic amplifier was for all practical purposes forgotten until shortly after World War II.

By then technology had advanced to the point where a device more rugged and reliable than the electronic amplifier was needed for certain applications. In the postwar years the magnetic amplifier has rocketed into widespread use.

Conflicting statements about the future of the magnetic amplifier were made during its infancy. Some engineers thought it was the answer to all problems in its field. Others felt the magnetic amplifier was just a flash in the pan, interesting because of its newness. But only now, after nine postwar years of industrial growth have given rise to many diverse applications, are we in a position to accurately appraise its worth or plot its future course.

Cause and Effect

With certain exceptions the magnetic amplifier works similarly to most power amplifiers. A low-power-input current controls a higher-power-output current, the change in output being nearly proportional to the change in input.

Typical steady-state characteristics of a magnetic amplifier, a rotating amplifier and a d-c generator, and an electronic amplifier are shown on page 57.

You can see that the magnetic amplifier's normal operating range is selected so that its output increases almost linearly with input. The drooping upper portion of the curve is used only when the amplifier is overexcited, or forced, for short periods of time to obtain fast response. Although the curve is somewhat similar to the saturation curve of a d-c generator, you'll notice that the magnetic amplifier's output doesn't reverse when its input signal is reversed. In fact, just the opposite happens: large values of reverse (negative) input current tend to increase output current in the forward (positive) direction.

This increase in output is opposite the normally expected results. And sometimes it can be most disconcerting if not considered in the design of a system. As a simple example of this effect, take a hypothetical situation where an operator is reducing the speed of a magnetic-amplifier-controlled d-c motor drive. Were he to decrease the control signal beyond the point where it reversed—changed polarity—the drive would begin to pick up speed again. (However, recent techniques have minimized and practically eliminated this undesirable portion of the magnetic amplifier's characteristic curve.)

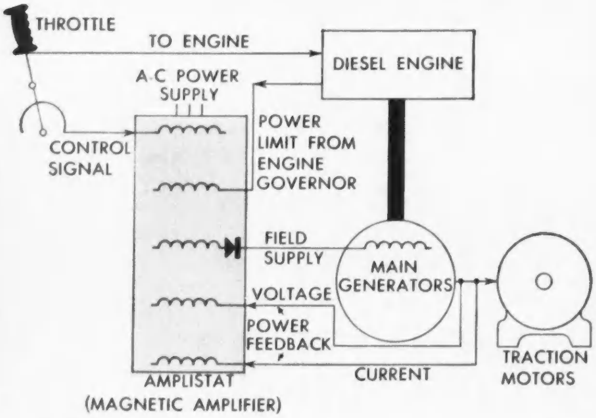
The magnetic amplifier is irreversible because metallic rectifiers are used in its output circuit. Where reversing characteristics are required, two magnetic amplifiers can be used whose outputs are opposed. This is, however, an extremely inefficient method. It is employed for relatively low power outputs where efficiency is of little concern.

•

Mr. Brown joined General Electric's Test Program in 1940. A former application engineer, he is now Manager—Materials Handling and Testing Equipment, Industrial Engineering Section, Apparatus Sales Division, Schenectady.

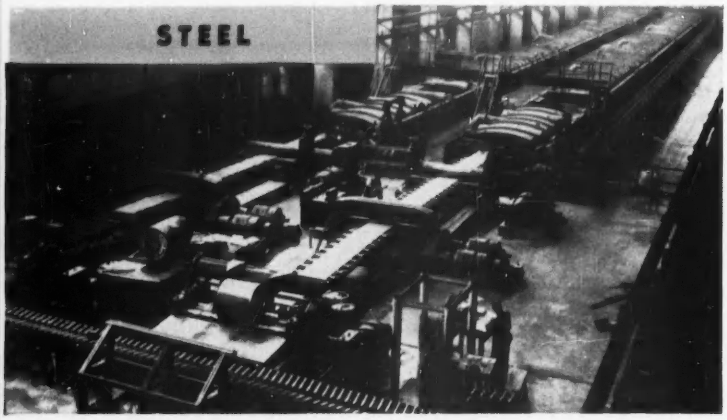
INDUSTRIAL APPLICATIONS OF

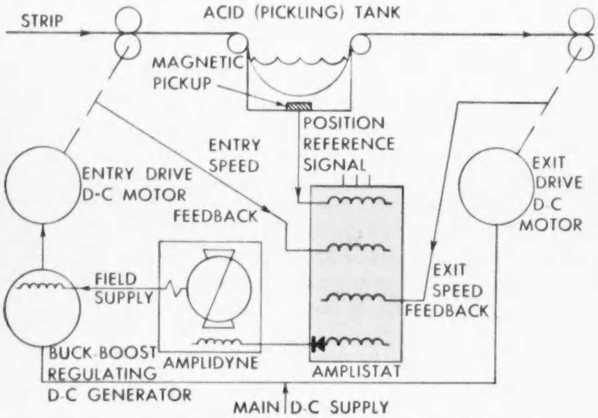
TRANSPORTATION



AMPLISTATS, or magnetic amplifiers, control speed, acceleration, and tractive effort of G-E gas-turbine-electric locomotive (*photo*) and Alco diesel-electric locomotive. In the latter (*diagram*), the amplistat regulates excitation of main generators, controlling speed and acceleration of the traction motors in response to throttle position. The signal from the diesel engine's governor sets up a power limit and reduces wheel speed when more tractive effort is needed, thus preventing the engine from "lugging down."

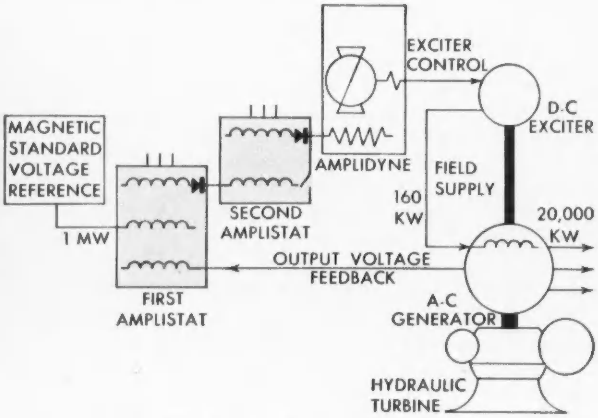
STEEL





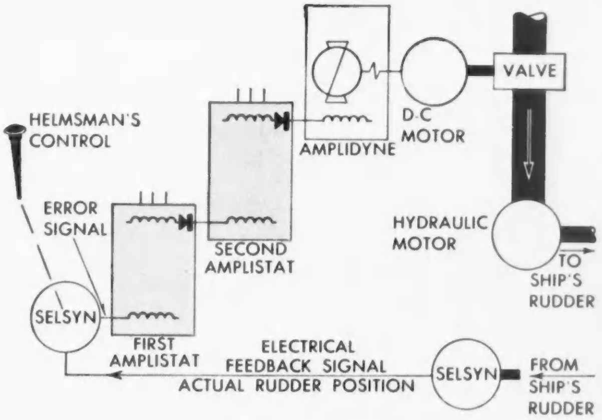
PICKLING AND CLEANING operation that removes scale from steel strip and prepares it for subsequent plating or galvanizing is speeded up through means of a magnetic loop control, employing an amplistat and amplidyne. The acid-resistant pick-up assures maximum footage of steel strip in the pickling tank (*diagram*) without allowing the strip to drag. Output of the pickup, which depends on the proximity of the steel strip, is amplified by the amplistat and amplidyne to regulate entry speed relative to exit speed.

HYDROELECTRIC

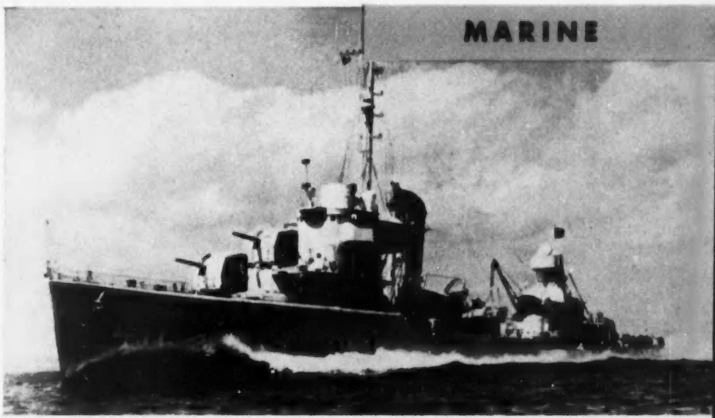


HYDRAULIC turbine-driven generators, similar to this 75,000-kw unit being installed at California's Shasta Dam, utilize the amplistat. Since 1948 their a-c output voltages have been accurately and dependably regulated by an amplistat in combination with an amplidyne. The deviations of output voltage from a magnetic standard reference (*diagram*) are detected and amplified by two stages of amplistats, an amplidyne, and a conventional d-c exciter. Note that only 1 mw controls an output of 20,000 kw.

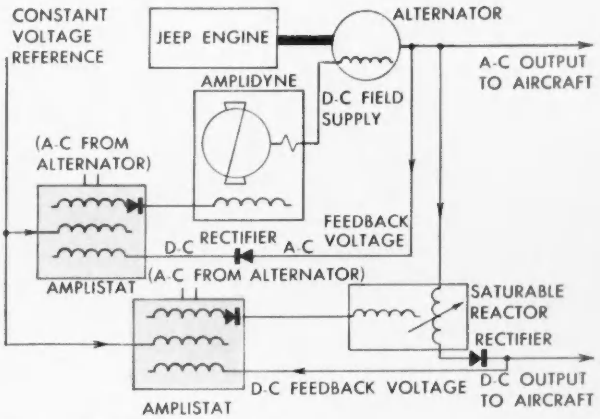
THE MAGNETIC AMPLIFIER



MARINE

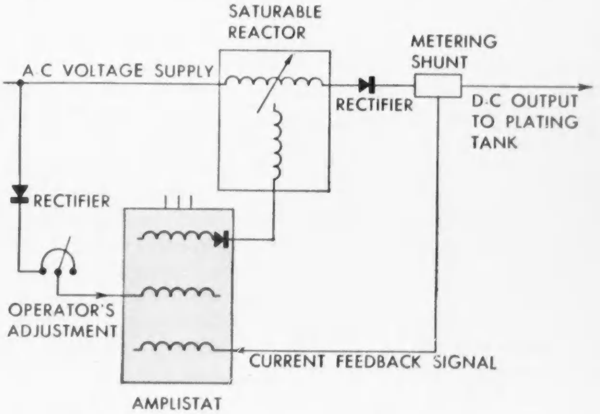


STEERING ENGINE CONTROL systems of destroyers like the USS *Anderson* utilize an amplistat in combination with an amplidyne. Two electrically connected selsyns (*diagram*) compare the position of the helmsman's control lever with that of the rudder. When they are not in correspondence, the error signal generated is amplified by the amplistat to excite the amplidyne. The latter in turn excites a d-c motor that opens or closes a valve controlling the hydraulic motor which actually moves the rudder.

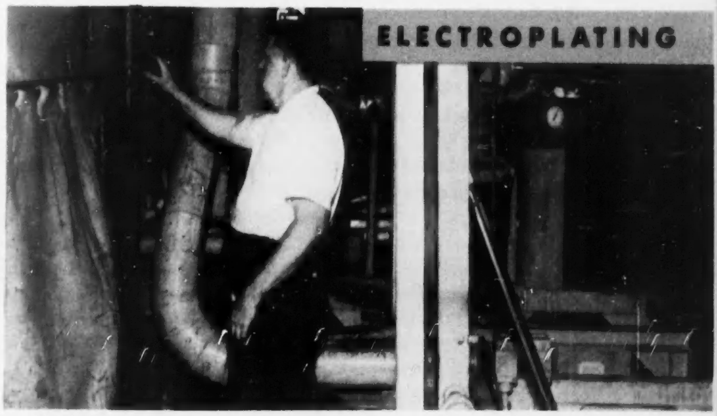


TURBOJETS

MOBILE POWER SUPPLY for jet aircraft—such as the Navy's McDonnel *Banshee*—employs an amplidyne-amplistat system of regulating voltage. The jeep's engine drives an alternator (*diagram*) that furnishes the aircraft with d-c power by means of a rectifier. Holding this d-c output voltage constant is a series saturable reactor. An amplistat controls the impedance of the reactor by comparing output voltage with a constant reference voltage. The amplistat is admirably suited to this application.



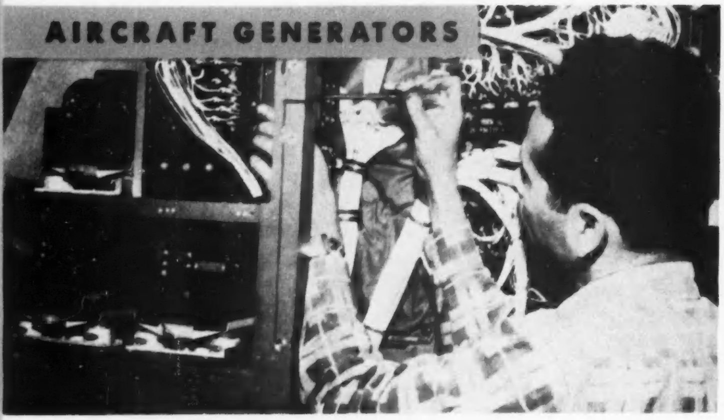
ELECTROPLATING

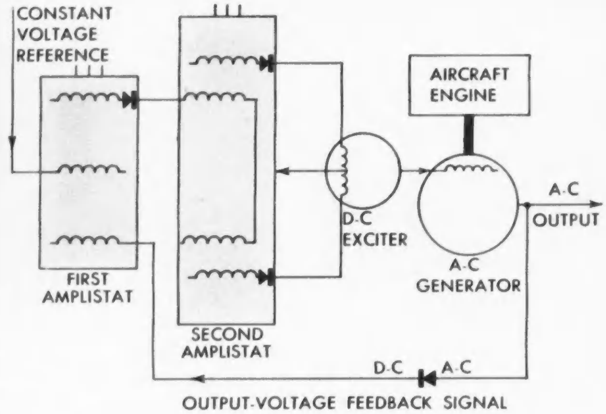


LARGE CURRENTS of an automatic electroplating process—in this instance the silverplating of aluminum conductors—are measured via a d-c metering shunt. The amplistat amplifies the feedback signal from the shunt (*diagram*), compares it with the current magnitude set by the operator, and controls the impedance of the saturable reactor. This is a distinct advantage because electroplating currents are high, and if a dropping resistor were used in place of the shunt, large power losses would result.

INDUSTRIAL APPLICATIONS (CONCLUDED)

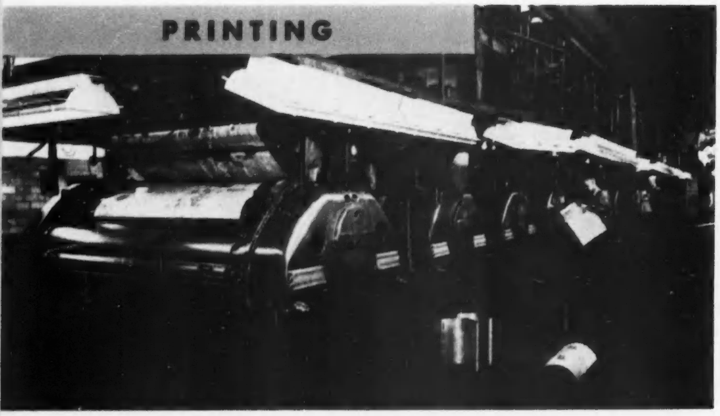
AIRCRAFT GENERATORS

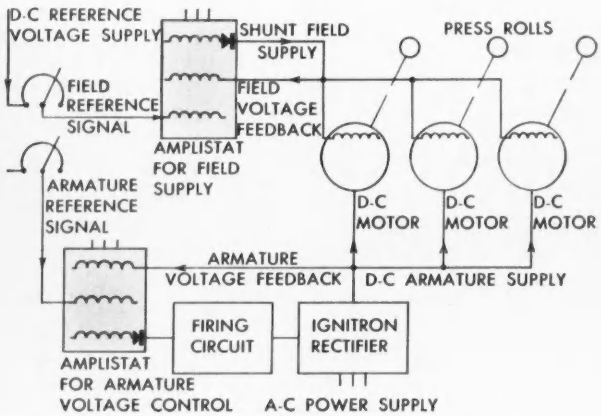




A-C GENERATING EQUIPMENT in the Lockheed *Neptune*, located aft of the pilot's compartment, utilizes an amplistat in combination with a d-c exciter to regulate output of the a-c generator. The first amplistat (*diagram*) amplifies the difference between a reference voltage and a rectified portion of the a-c output. The amplified difference signal controls a second amplistat. And the latter, designed to supply reversing output, energizes the field of a d-c exciter that in turn excites the a-c generator.

PRINTING





NEWSPRINT is rolled out at high speeds—60,000 newspapers per hour—on presses driven by d-c shunt motors. An ignitron rectifier (*diagram*), controlled by an amplistat feeding its firing circuit, supplies power to the drive motors, while a second amplistat furnishes the motors' shunt field supplies. This combination provides the 50 to 1 speed range needed for starting up and running modern printing presses. The amplistat-controlled ignitrons for this service are rated 150 to 300 kw.

As with all inductive circuits there's a time delay between the change in input signal to a magnetic amplifier and the corresponding change in its output. This time delay can be shortened by using a larger input signal, but then you also reduce the amplification. (A series resistance is added to the input winding to decrease input-circuit reactance.)

A magnetic amplifier's output appears as rectified pulses of its a-c input. And if you increase the magnitude of the input power sufficiently, you can approach the theoretical minimum time delay—one-half cycle of the a-c supply frequency. Thus the higher the power-supply frequency the faster the magnetic amplifier can be designed to operate. For this reason power-supply frequencies of 400 cps for power magnetic amplifiers and in the kilocycle per second range for control magnetic amplifiers are quite common.

The characteristics of a magnetic amplifier are changed not only by variations in the a-c supply voltage and its frequency but also by changes in the load itself. Near the maximum output conditions, the predominant factor limiting the load current is the load's impedance. (Maximum load is defined as that load at which there is a maximum output power change for a given input power change.) If the a-c supply voltage increases, the output will increase for a fixed input signal. Likewise, if the a-c supply voltage decreases, the output will decrease for a fixed input signal. For both a fixed a-c supply voltage and input signal, a decrease in the supply frequency will have approximately the same effect as an increase in the supply voltage—and vice versa.

All of these factors must be considered when you use a magnetic amplifier.

In Its Favor

One way to judge the true worth of the magnetic amplifier is to compare its characteristics and features with those of competitive devices—namely, the electronic amplifier and the rotating amplifier.

For reliability the magnetic amplifier is preferable to the electronic amplifier. What it amounts to is a choice between an amplifier with long-lived, stable, and rugged components versus one equipped with vacuum tubes having a long but still unpredictable life.

From the maintenance standpoint the

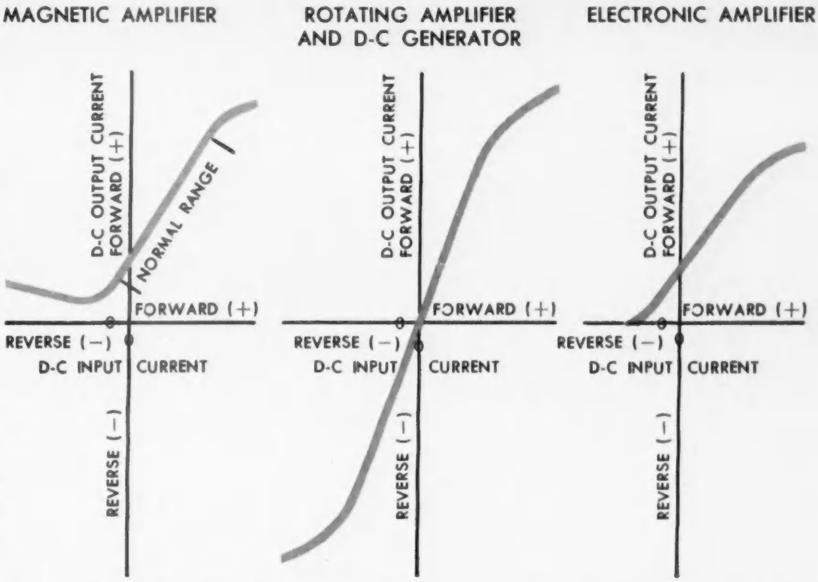
magnetic amplifier is preferable to the rotating amplifier. For it's a completely static device versus one with bearings, brushes, and a commutator.

Judged, therefore, on the basis of reliability, freedom from maintenance, and simplicity of components, the magnetic amplifier has no peers.

In speed of response the magnetic amplifier, in general, can only *equal* the rotating amplifier with difficulty. It can only *approach* the electronic amplifier in speed if it is designed for a high-frequency power supply—say, 1000 cps or higher.

The magnetic amplifier shares with the electronic amplifier the irreversible characteristics of the rectifier, whether metallic or vacuum tube. (For reversing applications the rotating amplifier is supreme.) On the other hand, it shares with the rotating amplifier the distinction of having its various input signals completely isolated. Because of this, magnetic amplifiers can be readily connected in series.

Further, a magnetic amplifier's components can be sealed for protection against adverse environmental conditions. And it can be constructed to withstand shock and vibration better than either rotating or electronic amplifiers.



MAGNETIC AMPLIFIER, like the electronic amplifier but unlike the rotating amplifier, is nonreversing. A reversed input signal increases its output in the forward direction.

How Good?

In many applications a magnetic amplifier is used where its only advantage is the character of its components. In other words, the amplifier's reactors, metallic rectifiers, and resistors can all be mounted in cabinets containing relays, contactors, and meters of the over-all system. Also, because the magnetic amplifier can be completely sealed, high altitude and similar environmental applications can dictate its use.

For applications where only a few watts' output is required, the magnetic amplifier will be smaller than either the electronic or rotating amplifiers. In this instance all its components can be sealed in a single can.

Because magnetic amplifiers are essentially power amplifiers, they are particularly useful for low-voltage high-current applications. Still, they can be designed in the same physical size to accommodate any combination of voltage and current for a given power output. By way of contrast, electronic amplifiers are voltage amplifiers with essentially high-voltage low-current outputs. And for higher-current outputs, you must resort to larger electronic amplifiers because voltage amplification is inherent to them—it's there whether you want it or not.

In the higher power ratings—10-kw and above—a magnetic amplifier becomes quite large and bulky. It needs more room than an equivalent-rated rotating amplifier. And for reversing output its size would be almost prohibitive. In addition, maintenance and the possibility of trouble increases in the higher power ratings. A 10-kw rotating amplifier, on the other hand, needs no more maintenance and is no more likely to fail than a unit rated 1 kw.

As stated before, the input signal to a magnetic amplifier is completely isolated from the output signal—a particularly useful feature when you must employ several input signals to control an output. Again, in this application the magnetic amplifier is most useful in the low power range—500 watts or less—where a rotating amplifier is quite large and bulky in comparison. An isolated input, incidentally, is difficult to obtain with the electronic amplifier.

Magnetic amplifiers can be designed for greater long-term electrical stability than either the rotating or electronic amplifiers. And so they are the logical choice for metering applications or for amplifying the output of millivolt shunts and thermocouples. Their long-term stability suits them particularly to pure amplifier applications where no feedback is used and where variations in characteristics would affect output directly.

You probably concluded from the photos on pages 54–56 that the magnetic amplifier is employed in many diverse applications. That is true. A partial list would include the minute outputs of photocells and ionization chambers, controlling the output of arc welders and the speed of paper-mill drives, and obtaining isolation in metering circuits involving thousands of amperes. Magnetic amplifiers have been applied to systems ranging from compact autopilots for aircraft to the largest high-speed motor drives for steel mills; from the regulation of voltages of miniature aircraft alternators to those of huge steam-turbine-driven utility generators.

The Summing Up

In all its applications the magnetic amplifier has proved to be sturdy, reliable, and effective. But you can determine its true value only after making a thorough analysis of the application itself. For one purpose it may be superior to all other amplifiers; for another, it may be the poorest choice.

All of this means that the magnetic amplifier will not replace the electronic or rotating amplifiers in the immediate future. Instead, it will remain an additional amplifier tool with clear-cut advantages for some applications and equally clear-cut handicaps for others.

Although the magnetic amplifier will no doubt take an equal position with its predecessors, the electronic and rotating amplifiers, you can be sure it won't take a dominant one. Ω

EVERY ONE OF THE 1600 HOMES AND 1000 APARTMENTS IN WESTLAKE, CALIF., HAS A FOOD-WASTE DISPOSER, INDICATING THAT . . .

Garbage Men Are Obsolete

By T. T. WOODSON

Wasted food from kitchens and dinner tables is a unique problem of today's urban American communities. Probably the United States is the only country in the world where reducing diets are used.

This way of life has its penalties. Waste stored in containers soon becomes disagreeable, even dangerous. Depending on cover and security, any number of things can happen: rapid growth of bacteria, fungi, insects, or rodents; creation of odorous decay; and spilling and spreading by prowling animals.

Getting rid of this completely negative material is usually the responsibility of municipal government. From the variety of choices (Table, page 60) all are major headaches. And, except for the last method, the problem worsens as cities expand and collection manpower becomes increasingly scarce and higher priced.

City managements are placing new emphasis on conservation, that is, returning organic matter to the land by such techniques as compost plans. Also, sewage-treatment plants that produce fertilizer can do this easier if both garbage and sewage are collected via the sewers using the last two plans described in the Table.

Attacking the Problem

Back in the early 30's, a group of engineers in the Schenectady laboratories of General Electric interested themselves in the problem of pulverizing household food waste and discharging it from the kitchen sink through the sanitary sewer. With no approval from sanitary authorities, the group worked on the knowledge that sewage solids and food waste are chemical twins. They also had the conviction that this was the right way to solve a nasty problem.

As the word spread, city authorities feared the method because of possible damage to the whole sewage system. They predicted shoaling, or settling, of solids in the lines; overloading, or excessive flow; and disruption of the digestion, or natural rapid biological decay, that takes place in sewage-treatment plants.

The first development devices were large and mechanically complicated to minimize jamming and to provide for the operator's safety. One type slowly and powerfully cut, crushed, and extruded the waste from a tight chamber. Another, and finally successful, design collected the waste in a hopper below the sink drain hole and rapidly tore the

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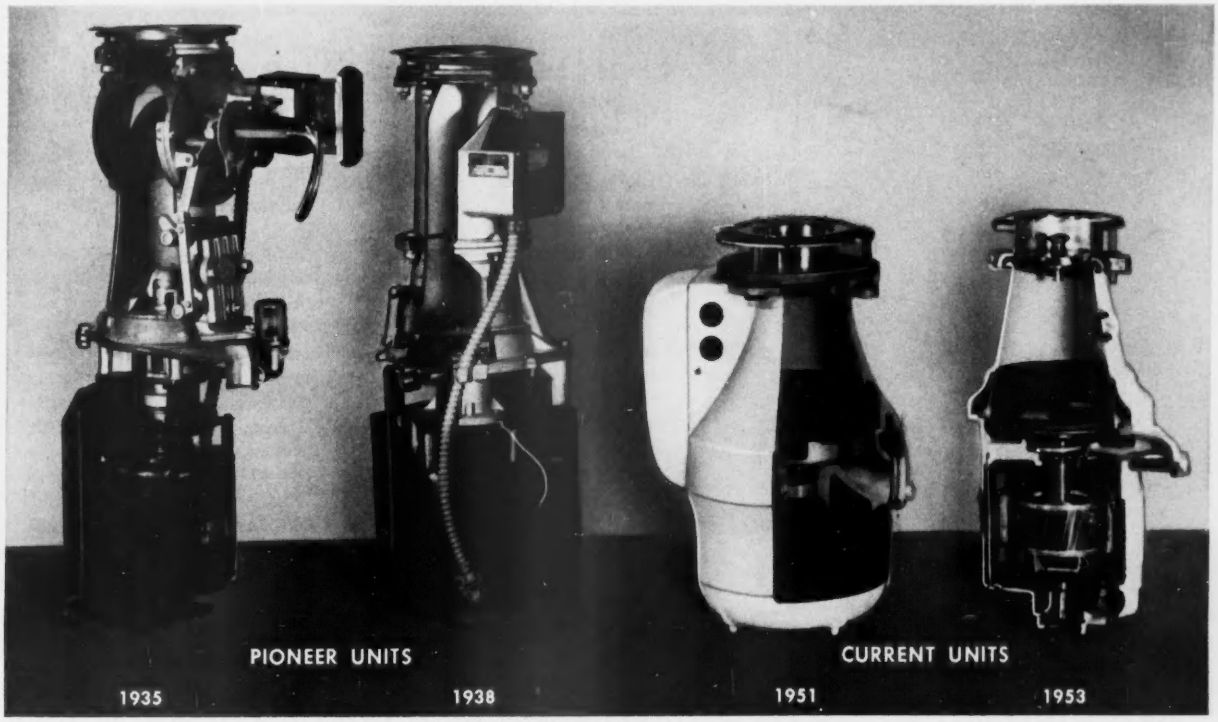
As Manager of Disposall Engineering in GE's Major Appliances Division, Louisville, Ky., Mr. Woodson is in charge of development, design, and production engineering for food-waste disposer units. He came with the Company in 1935 and completed both the Test and Advanced Engineering Training Programs.



NEW INDUSTRY BEGAN WITH PRODUCTION OF LARGE UNITS, ADVANCED TO SHORTER-HOPPER AND LOW-COST CURRENT UNITS *(RIGHT)*.

waste to shreds by shearing it between small rotating and stationary cutter-bars. Both bars were automatically retracted at standstill to avoid stalls that might occur if bone splinters fell between the mating edges. Finally in 1935, it was put into production as the pioneer model of a new industry.

Various cities were voicing formal objections to the installation of the device, and this precipitated detailed studies of the real facts of food-waste disposal into sewage systems. In Schenectady, NY, Morris M. Cohn, then Sanitary Engineer, was retained to experiment on "dual disposal of sewage and food wastes." His report indicated . . .

- Food-waste production amounts to about one-half pound per person per day.
- Food waste is 25 percent solids, 75 percent water.
- Water vehicle through the disposer should be cold to congeal grease, and water consumption should be 1½ to 2½ gpm.
- The increase in average water consumption is only 1 percent, approximately 1½ gallons per person daily.
- Present sewage is 99 percent water, 1 percent maximum solids. If all homes used disposers, solids would increase to 2 percent.
- Any sewer line successful on sewage solids is also successful on food-waste solids.
- The recommended finenesses of grind are 100 percent passage, ½-inch screen; 90 percent passage, ¼-inch screen; and 5 percent maximum passage, No. 4 sieve.
- Shredding hopper should be self-scouring and free of safety hazards.
- The disposer must be permanently connected and installed in compliance with local plumbing codes.

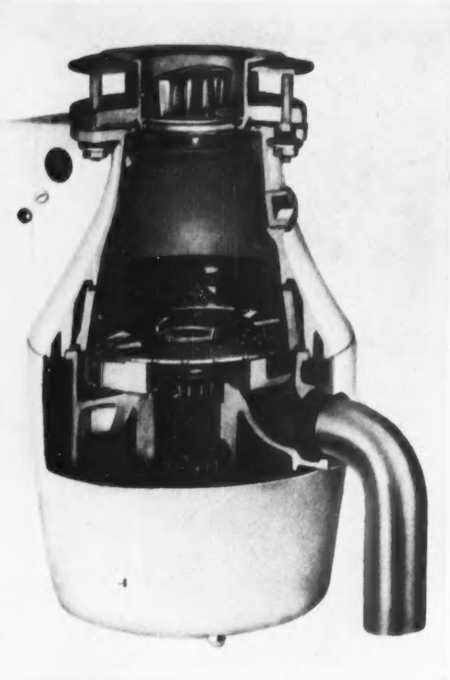
Since Cohn's studies were made, a few extra points have been brought out; among them are . . .

- Operation on septic-tank systems is successful with slightly more frequent cleanouts. It is as if one more person were added to the family.
- Because grease traps don't fulfill their original purpose, they should not be used on disposer drain lines and should be bypassed if already in use in a prospective installation.

More work was also done by other sanitary engineers and consultants, and the findings were reported extensively. Since then, many cities have adopted codes accepting the device in principle and prescribing their particular conditions of installation.

The principle of the G-E Disposall (Reg. trade-mark, General Electric Company) food-waste disposer (photo, above) consists of pinching the food-waste fragment between a shallow raised tooth on the stationary peripheral shredder ring and a small triangulate impeller blade on the rotating floor of the hopper (photo, next page). This action chips off small pieces that must eventually pass the one-thirty-second-inch radial gap or the intermittent one-eighth-inch-deep shredder slots to go down the drain. Shredded only at the periphery of the flywheel, food waste is brought there by the flushing action of the water swirling down the outwardly tapered hopper and finally out the rotating gap.

Although General Electric was the only manufacturer in substantial production before World War II, now more than a dozen others are selling under about 40 trade names. The many varieties of grinding mechanisms can be divided into three classes: stationary or movable shearing shredders, hammer mills, and graters (illustration, page 61). Each has its own degree of success on the various aspects of performance, such as fineness and maintenance of



DISPOSER PINCHES WASTE between stationary shredder ring and rotating impeller. See upper left illustration, opposite page.

CHOICES OF DISPOSAL METHODS

Treatment	Advantages
LAND OR OCEAN DUMPING—Garbage and rubbish	Unsanitary, but relatively cheap if dump is available
SANITARY LAND FILL—18-inch earth cover; garbage and rubbish	Satisfactory, but 10 years are required for decay cycle to restore land
INCINERATOR—High-temperature combustion with added fuel	Sanitary, but high plant and operating cost
CONTRACT HOG FEEDING—Separated garbage hauled to feeding farms	Cheap, but a serious health hazard unless garbage is boiled
AS FEED AND FERTILIZER—Separated garbage cooked, dried, and packaged	Satisfactory, except for high initial cost of plant
CITY SEWER TO TREATMENT PLANT—Either home or central plant food waste grinders, plus regular sewage - treatment plant	Sanitary, low cost, and simple when ground in the home

grind, fiber cutting, antijamming, durability, and noise.

Disposers Today

Manufacturers who are actively promoting the disposer find the greatest response in progressive "modern-emphasis" markets—suburbs of large cities. In these areas where it was first used as a new-house sales aid, the disposer has now become a must.

The industry has grown to a current rate of 350,000 units per year, with the million mark reached in 1952. Of this number about one third are installed in Southern California, the most active disposer region in the world. San Francisco, Cleveland, Houston, Washington, Detroit, and Chicago are the other most active sales areas.

Early installations were made with a low-water-flow limit switch set for 1½-gpm minimum (photo, page 62) in the cold-water line leading to the sink faucet. Called the *flow interlock*, it insured that a proper flow of water was established before the motor started. This flow was necessary not because of grinding inefficiency but because of drain-line errors. Wrong bends, burrs, and temperature conditions are common causes of plugging. This switch served a useful purpose in overcoming plumbing defects, particularly when the operator is continually careless, or as an apartment tenant, has no vested interest in the drain system. However, the installation of more than 200,000 units with no flow interlock showed that householders soon learned the necessity of the right amount of water to operate such a disposer successfully for years. When the plumber comes for the first plugged drain, the home owner learns in a hurry to remember to turn on the water!

Many of the disposers on the market do not cut fibrous waste effectively. Hence, in the Midwest many users pass the word around to keep the corn husks and pea pods out. On the West Coast, dealers and neighbors routinely warn against artichokes. Moreover, some users, fearing that bone grinding will damage their disposer, keep out hard wastes, including fruit pits. Actually, all disposers are designed to handle bones, most of them operating better if such wastes are at least occasionally ground up; the walls are scoured and the movable impellers, if any, are rattled loose and freed of gummy stickiness.

Torture Test

The General Electric unit was given a special torture test by an independent testing laboratory. For one year the unit was fed more than 3 tons of all kinds of food waste. Added to this were 1000 pounds of sand, 500 pounds of glass bottles, 200 pounds of gravel and granite, 1000 pounds of newspapers, 100 pounds of limestone, plus bushels of coal, cinders, ashes, tin cans, nails, screws, and even a few one-half-inch pipe fittings. Examination showed little difference between the waste particles discharged after this test and those discharged prior to the test. Both the lateral drain lines and the city sewer lines were dragged, and substantially no sediment was found. Hot water, however, caused grease to adhere to the pipe walls; and the hotter the water, the farther down the drain line the grease cooled and adhered. Cold water freezes the grease; the impeller and water break it into small globules and aerate it into a suspension that is easily floated away.

Both the field performance of disposers and the report of these tests have encouraged municipal acceptance of this disposal method. One large West

Coast city, for instance, requires only an Underwriters' label to accept a unit for connection to its sewage system. Other cities require such items as certain fineness of grind, a flow interlock, or the use of a locking stopper.

City-wide Disposer Systems

Cities have finally come to look at the disposer as a possible answer to their garbage-collection problems.

In 1947, Jasper, Ind., was faced with an order from the State Stream Pollution Control Board to install a sewage-treatment plant. Mayor Thyen conceived the idea of combining garbage disposal with sewage disposal and initiated studies on the subject by a firm of consulting engineers.

The various methods considered were 1) continuation of their past garbage farm arrangement, 2) sanitary land fill, 3) collection and hauling to central grinder at the sewage-treatment plant, and 4) household grinding and discharge through the sewer system.

As a result of the study, monthly costs per family were reported as . . .

Garbage farm	$ .37
Sanitary fill	1.27
Central grinder	1.04
Home grinder	.65

As any such study must, these reflected all the particular local conditions. A vote of the townspeople showed a majority favored the home grinder. Apparently they liked the tangible and intangible advantages of less effort combined with better sanitary and aesthetic conditions. Steps were then taken to restudy plans of the sewage treatment plant, choose the disposer, obtain the legislative permission, and enter into contracts.

The disposer manufacturers were contacted and samples tested. The 1949 Indiana State Legislature passed an enabling statute, stating in part: "Any town may acquire a garbage-disposal system consisting of grinders in homes, discharging into the sewage system." As a result of these several actions, the city contracted to buy about 900 G-E disposers, although the sales eventually became privately owned individual purchases at the agreed price. Where necessary, the people financed the cost through the local banks. Thus Jasper became the first town to promote city-wide purchase and use of disposers.

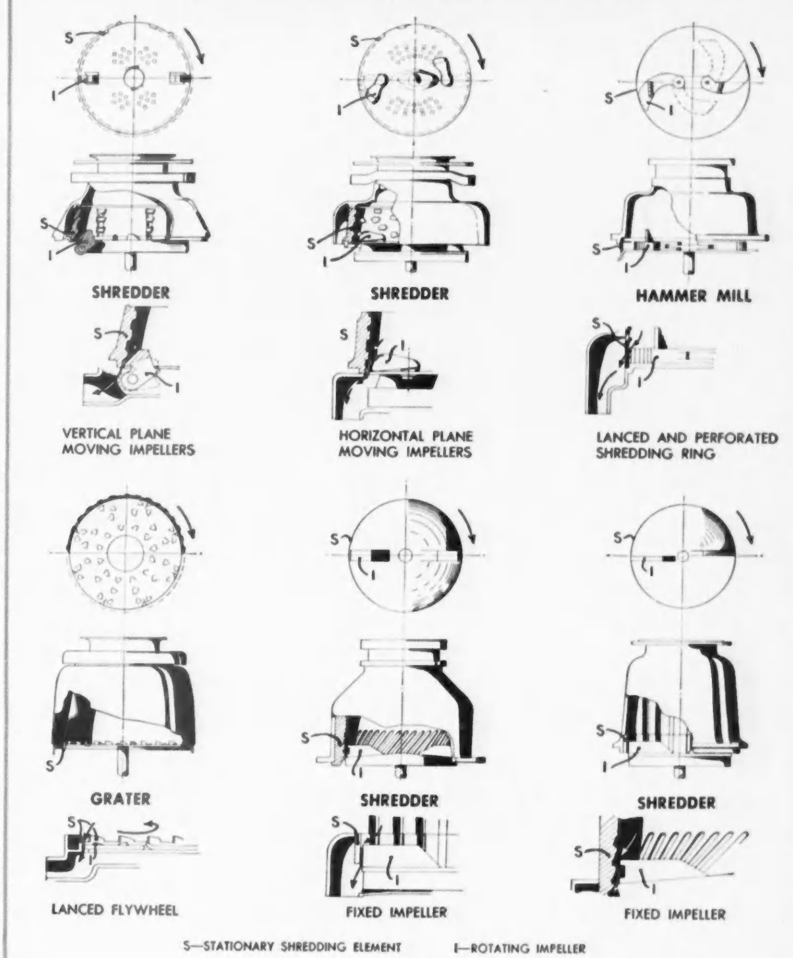
These units have been in operation up to three years now, and with about 80 percent of the homes equipped, the town is reported to be very satisfied with the project. The *Jasper Daily Herald* in July, 1952, stated that a State Board of Health survey revealed an "almost total absence of flies and rats .... Many contagious diseases, especially those known to be carried by flies, have been greatly reduced. It is particularly notable that infantile paralysis, which annually claimed one or more victims, has not recurred in the past two years." Of course no claim is made of the elimination of this or any other disease by the use of food-waste disposers.

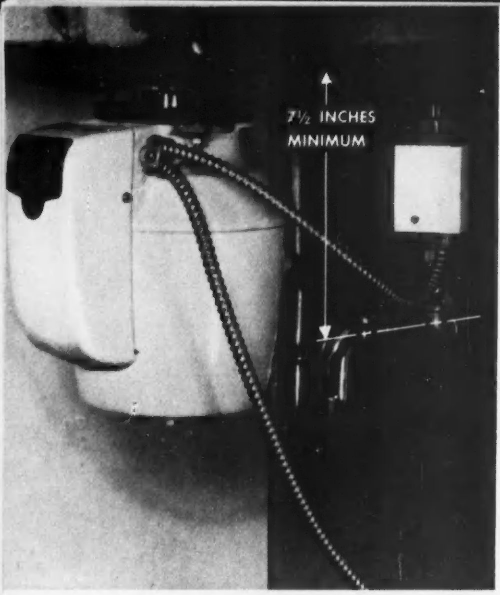
Another municipality did a similar thing. Shorewood Hills is a residential suburb of 475 homes, neighboring Madison, Wis., along the south shore of Lake Mendota. This village, too, was faced with changing its garbage disposal system. Cost of the land, prohibition of unboiled garbage-feeding, and desirability of improvement led the Village Board to a 16-month study of proposals. They finally chose the method of home disposers to be bought, installed, and serviced by the village for every home or institution. The contract was awarded to a plumbing contractor who installed G-E units. The new method cost about $7000 per year—amortizing $70,000 over 10 years—as against $5500 per year when the hog-fed method was used.

L. J. Tooley, Village Engineer and Manager, reported that their particular conditions made this method the best choice. The income level and attitude of the citizens and the conditions of sewers and sewage plan: definitely favored the home units. He reported also that they are satisfied with the job and the performance of the units, some of which have been operating for more than a year.

Other communities too have a high percentage of installations. At Westlake,

THREE CLASSES OF GRINDING MECHANISMS





VERY SHORT HOPPER helps solve plumbing problems. White box is flow interlock.

a promotional subdivision of the Henry Doelger Company, south of San Francisco along the ocean front (photo, page 58), every one of the 1600 homes and 1000 apartments has a disposer installed, put there by the builder.

Present Applications

Even more impressive is the Lakewood tract of 17,000 homes between Los Angeles and Long Beach. Builder Mark Taper calls it the "world's largest garbage-free community."

As a customer, the typical builder wants a unit that will operate reasonably well at a low cost, and he is not too much interested in the life of the unit. The reputable manufacturer, however, wants to stay in the business; so he must build quality into his units. Besides, the manufacturer has both builders and individuals as customers.

With this in mind, General Electric pioneered in the five-year warranty and high-quality product and met the individual customer's demand first. Then a low-cost model was marketed with high basic quality but no extra features. It grinds as well as the deluxe product but is a continuous feed, with a wall switch for operation; it does not have the stopper control feature.

Today many disposers are being installed in rental homes and apartments, usually with the flow interlock, for more dependability in the drain line.

More than a hundred units have been installed in railway dining cars to simplify the problems of collection in the crowded galley. Units put in commercial institutions—such as hotels, tea rooms, hospitals, camps, and clubs—have extreme duty because of the frequent carelessness of the help; crockery and silver often go through if there's no supervision. Some manufacturers are producing special commercial units.

Samples have been made for tests on railway-car toilets. The problem is the pollution of waterways by track-side discharge; the railroads are to come up with an answer on a deadline set by the authorities. The solution, using waste disposers, is the pulverizing and storage of the sanitary wastes for discharge at rail terminals.

The disposer unit's most valuable application is where convenience, sanitation, aesthetic demand, and economics are at a maximum. Of course, any one reason might be controlling in a given instance; but for a single-family modern home, they *all* are important. In a large apartment house, however, the incinerator hopper in the hall takes care of all waste; so with some inconvenience, the factors of economy and outdoor sanitation are met without a disposer. Consequently, apartment disposers are installed as extra margin of convenience and sink sanitation. On the other hand, hospital diet kitchens, churches, and even automobile house trailers are especially well-suited new applications on all four counts.

It is interesting to note here that the disposer, together with its cousin, the electric dishwasher, is an electric appliance that can be more at home in the plumber's showroom than in the appliance or department store. When a store makes a sale, the customer is sometimes left with an uncertain installation cost. But if the plumber sells it, he can visit the customer's home and submit a lump sum installation price. This is particularly significant because of the critical importance of the existing sink plumbing. If the center line of the sink drain pipe going back into the wall (photo) is greater than 7½ inches below the bottom of the sink, practically any disposer will fit. The plumbing cost is usually less than $30, because the job is simply that of taking out the trap and shuffling a few pipe fittings.

If the distance is less than 7½ inches, the job is much more complicated. The plaster has to come off the wall, the wall line cut into, and the drain-line connection lowered to meet the 7½-inch dimension. This complication can make the plumbing cost $40 to $150.

This 7½-inch dimension is sacred only because over the years various members of the industry each assumed that the average customer needs a 1½-quart disposer hopper. A 3½-inch-diameter sink flange became standard; the flywheel was made large enough to cut 6-inch grapefruit halves; and the drain line, coming out just below the flywheel, was thus defined. Certain city codes prevent the sink drain line going into the wall higher than the level of the disposer drain hole. Also, any horizontal drain pipe that runs below the floor leading into the 4-inch stack should for best performance be pitched at the customary practice of one-fourth inch to the foot. At this slope the water carries the solids; at much greater or less slope, the solids may separate out of the stream. When these installation problems are added to those of nearby dishwashers, double sinks, old-fashioned sinks, lead-pipe traps, and specific restrictive city codes, you can see how the installer is the logical salesman.

To avoid the less-than-7½-inch problem, some manufacturers have introduced models with shorter hoppers, but conclusions cannot as yet be drawn.

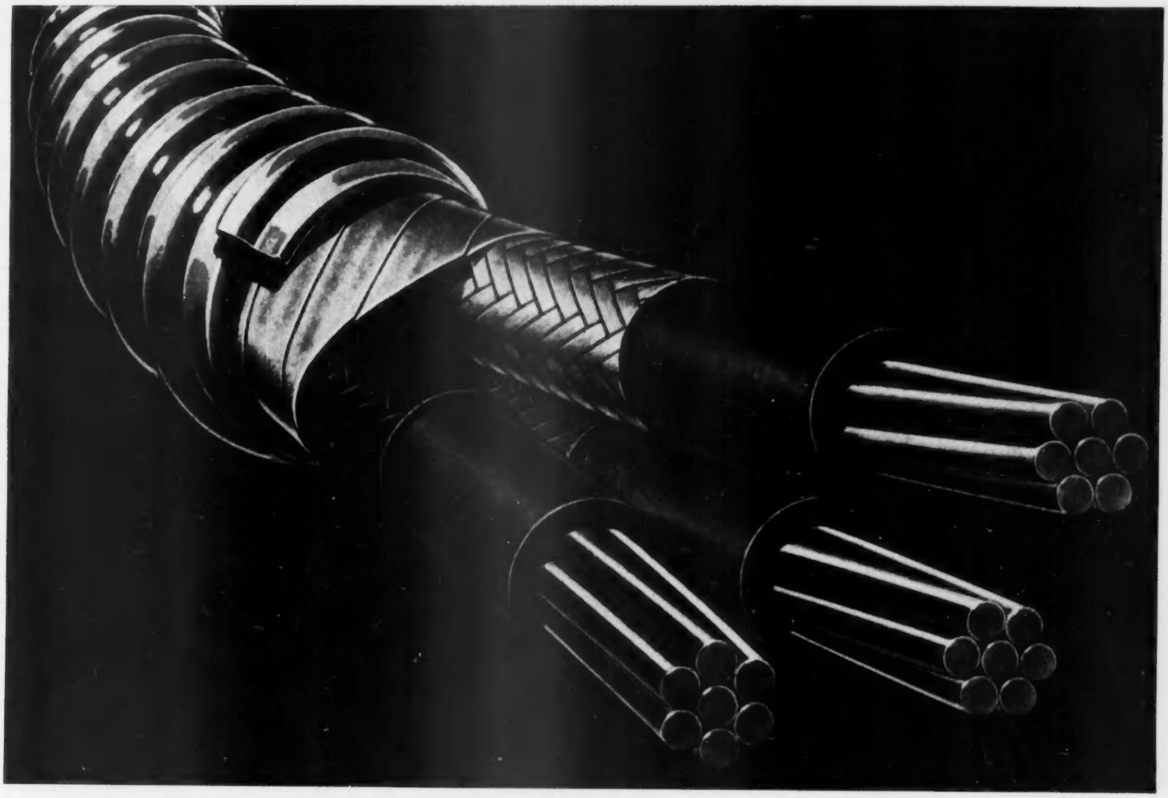
In San Diego the disposer business has been so brisk that one man is specializing as a disposer installer. He employs three men and does nothing but make installations. He has specialized to the point where he can offer a flat installation fee of $27.50 for both plumbing and electrical connections. If the wall tee must be lowered, the charge is $15 more. Another man in San Diego has become a service specialist, acting as authorized representative for several manufacturers. He stocks replacement parts for quick action.

Future Ideas

Basically, the disposer needs to be only a bulge in the drain pipe, designed to reduce solid wastes to suitable condition for drainage. This is the future objective. Safety, convenience, and the limitation of present ideas have brought forth its present shape.

The ideal units meet requirements of noise, life, cost, and performance in common with all electric appliances; reduce all types of food waste to small particles, approximately one-eighth-inch maximum dimension; and withstand extreme abuse due to foreign objects.

Waste disposers of the future will incorporate automaticity in operation and control, reductions in noise, and extra features that will make them perform services even greater than the valuable ones they perform today. Ω



What goes into a G-E Silicone-rubber Cable?

Silicone-rubber insulated cable being subjected to 1400°F flame for 24 hours in laboratory tests. Superior materials and rigid testing go into each G-E cable.

How can G-E silicone-rubber insulated cable keep control circuits in operation—although engulfed in flame? Why can this cable operate at temperatures up to 257° F? What gives it the moisture resistance of the best grades of rubber? In short, what makes it an outstanding cable for vital control circuits, for boiler room installations, and for high-temperature processing operations?

The answers to all these questions are the unique properties of the special silicone-rubber insulation—and each vital property has a history of G-E research, development engineering, and testing. Flame tests at 1400°F proved that this new insulation would remain nonconducting even when completely oxidized. Accelerated-aging tests proved that the cable would dependably withstand continuous ambient or conductor temperatures up to 257° F. Silicone rubber was compounded in many different ways and proportions to produce a cable that would retain its electrical and physical properties through prolonged water-immersion tests—and that could be handled and terminated as easily as an ordinary rubber-insulated cable.

When you specify G-E silicone-rubber insulated cable or any G-E cable you can be sure that the research, knowledge and equipment of the entire General Electric Company have been combined to produce the best possible product. For more information write Section W137-737, Construction Materials Division, General Electric Company, Bridgeport 2, Connecticut.

Progress is our most important product

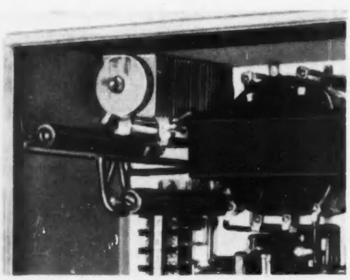
GENERAL ELECTRIC

FASTER STARTING AND STOPPING HELPS THIS AUTOMATIC LATHE TO PRODUCE MORE

General Electric Selenium Rectifiers Help Make This Lathe More Productive

Speeding up starting and stopping operations has increased the productivity of many of today's finest machine tools. In the Sunstrand automatic lathe pictured above, an electric brake and clutch combination starts and stops the machine spindle. Another electric brake provides a fast stop when the tool carriage is advanced to the work, or backed off to the unloading position.

D-C POWER to operate the electric brakes and clutch on this lathe is supplied by General Electric selenium rectifiers shown in the smaller photograph. Their high quality (see C.E. Hamann's article at right) makes G-E selenium rectifiers ideal for almost all machine tool applications.



D-C POWER for the lathe's clutch and brakes comes from this selenium rectifier.

TOP PERFORMANCE of G-E selenium rectifiers is the result of a unique "evaporation" process and careful inspection and testing. Besides providing stacks with exceptionally low forward voltage drop and low reverse leakage, this process assures greater uniformity of these characteristics among different stacks. These qualities last in service. On test in the laboratory, and on-the-job in almost every field of application, G-E selenium rectifiers are demonstrating their extremely slow aging.

OTHER APPLICATIONS for G-E selenium rectifiers include supplying power to operate d-c relays in various control circuits and as components in electronic equipment. A complete range of ratings is available in either open stacks or various types of sealed cases to meet special operating conditions. Contact your nearest G-E Apparatus Sales Office for complete information, or write Section 461-33, General Electric Company, Schenectady 5, New York.

You can put your confidence in—

GENERAL ELECTRIC

METALLIC RECTIFIER FACTS FOR ENGINEERS

Quality

by C. E. Hamann

One of the most overworked terms used in the selenium rectifier industry is "high quality." Every manufacturer claims "high quality" for his product. Every user wants "high quality" in the selenium components he buys because the quality of the end device can be no higher than that of the components assembled into it.

There are many yardsticks for measuring the quality of a selenium stack. Electrical characteristics, for example: low forward drop and low reverse leakage. Often one is sacrificed in favor of the other.

LOW FORWARD DROP

LOW LEAKAGE

UNIFORMITY

STABILITY

RELIABILITY

Which "yardstick" measures quality?

Real quality insures that both the forward and the reverse characteristics are good.

Uniformity of characteristics is another yardstick. If the characteristics vary from stack to stack the performance of the end equipment will be questionable.

Stability is another important standard in determining quality. The initial characteristics must be good, but they must stay good and not deteriorate with time and use.

Reliability is still another measure of quality. No matter how liberal the manufacturers replacement policy, frequent failures in the field are costly to the equipment manufacturer, and annoying to the equipment user.

All of these yardsticks must be considered carefully in determining quality. To really earn the title of "high quality" a selenium stack must measure up to a high standard of performance by every one of these yardsticks.

C. E. Hamann

General Electric Company