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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

The medallions from electric cars—some old, some new—sported on the cover this month symbolize the recent revitalization of the "electric" spirit. For a review of what's new in the technology of electric cars that makes them more feasible now, see the article beginning on page 48.

VOLUME 4 □ NUMBER 4 IEEE spectrum APRIL 1967

Spectral lines

Patent reform. If one reads between the lines in this and the February issues of IEEE SPECTRUM, one can see the beginnings of a great debate on the United States' patent system. On one side, we have a report of the President's Commission on the patent system[1,2] and the "Patent Reform Act of 1967,"[3] with recommendations for patent reform that threaten to shake the system to its very roots; and on the other side, some very serious criticisms of the proposed legislation.[4] As usual, the published articles are careful and studied accounts that veil the strong opinions you sometimes may hear. I dare say much more will appear on this subject in the months to come. I hope we can have an open and frank, but not too vitriolic, discussion of the issues in these pages, because this is a subject of concern to members of the IEEE.

Almost everyone agrees that a patent system is worthwhile. It recognizes property rights to inventions and it promotes publication and utilization. It undoubtedly was an important factor in promoting the phenomenal growth of technology in our age.

Much can be said in defense of the system as it is presently set up. It provides a systematic and orderly method of dealing with exceedingly complex material. Through many years of experience the legal profession has learned to handle almost any eventuality in ways that are generally just. One marvels at the precision with which fine lines of distinction are drawn between inventions in very complex technology. Yet the basic laws governing patents were written in a bygone age, in a very different technical world.

Most engineers will agree, however, that the existing system has its shortcomings. Present operations result in long delays; years elapse between submission of an application and granting of a patent. A large backlog of unprocessed applications continues to grow. Patent litigation is complex, often repetitious, protracted, and certainly expensive. The diversity of practices in different countries leads to duplication and confusion and a great deal of expense. Important innovations call for separate filing in many foreign countries, with quite different procedures.

Many people are annoyed with the mixture of technical and legal jargon one finds in patents. Some are concerned that standards of invention are too low. Sometimes one wishes that patents were a more acceptable and suitable form of technical publication.

Although few people would argue that the patent system of the United States is the best of all possible systems, the problem of reform is monumental. The 30-odd recommendations of the President's Patent Commission, and their interpretations, are controversial, but they are addressed to real problems of long standing.

Three recommendations seem to stand out as being of greatest consequence to the inventor:

1. Patents would be granted to the first to file regardless of date of conception, and would be limited to matter that was not published prior to the patent application.
2. A "preliminary application," with minimal requirements as to form, would be used to protect the inventor for up to one year prior to filing a complete application in final form with detailed claims. However, the preliminary application would include "every feature recited in the claims . . . " of the complete application.
3. Computer programs would not be patentable.

Would the first two recommendations make the patenting process more equitable and more efficient? We recommend that you read the articles cited before forming an opinion. Is it good to leave an important area of innovation (computer programs) without patent protection?

It is claimed that passage of the bill would be a giant step toward international uniformity of patents, and thus toward an international patent system. Surely, this is very much desired, but its realization is still far in the future.

The present recommendations very likely will lead to new legislation. We may or may not approve of what is done—but let it not be because we are not informed, or because we are misinformed. Ours is one profession whose members should know what is going on.

C. C. Cutler

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3. Senate Bill S. 1042, Feb. 21, 1967, introduced by Senator McClellan.

4. Whitmore, H. B., "Should we do something about patents?" *IEEE Spectrum*, vol. 4, pp. 64–69, Apr. 1967.

Authors

Electric cars—hope springs eternal (page 48)

Nilo Lindgren. A biographical sketch of Mr. Lindgren appears on page 196 of the March 1965 issue.

The stormproof power line (page 61)

Henry Greber (SM) received the master of science degree in electrical power engineering from the German Technical University in Brunn, Germany, and another M.S. degree from the Polish Technical University in Lvov, Poland. The wide range of his experience in the area of power engineering includes the operation and design of electrical power plants and transmission and distribution facilities, as well as research. Mr. Greber, who is the author of numerous published papers and articles, holds seven United States patents.

Most of his research efforts have been concentrated on the fields of transmission and distribution and the reliability of electric energy supply systems He is an associate member of the Institution of Engineers, Australia, and a licensed professional engineer in the State of New York.

Should we do something about patents? (page 64)

Harold B. Whitmore (M) received the B.S. degree from Worcester Polytechnic Institute and later was awarded the doctor of law degree from the University of North Carolina. His career with the Patent Office, interrupted in 1925 by a serious illness, was resumed ten years later. He was named superintendent of the Patent Office Examining Corps in 1962, thereby assuming administrative responsibility for technological work in all disciplines of modern science and engineering. Three years later, he was appointed patent advisor to the commissioner, from which position he retired in 1966. The author of several studies of Patent Office problems for the *Journal of the Patent Office Society*, he has served both as president and as chairman of the Legislative Committee for that organization. He received the Department of Commerce Silver Medal in 1957.

Birth of the 'new city': an exciting creation (page 70)

Gordon D. Friedlander. A biographical sketch of Mr. Friedlander appears on page 111 of the Feb. 1965 issue.

Semiconductor-diode light sources (page 87)

M. R. Lorenz, senior research staff member of the IBM Thomas J. Watson Research Center, received the B.S. degree in chemical engineering in 1957 and the Ph.D. degree in physical chemistry in 1960, both from Rensselaer Polytechnic Institute, Troy, N.Y.

Early in his career, he was concerned with research into the nature of high-temperature fused-salt systems. He joined the General Electric Research Center in 1960 and was active in investigations of the chemical, electrical, and optical properties of semiconductors in the II-VI compound family.

In 1963 Dr. Lorenz joined IBM, where he has been studying the properties of III-V compound semiconductors. His special interests include light emission in the visible region of the spectrum from semiconductor diodes.

M. H. Pilkuhn received the master of science degree in 1957 and the doctor of science degree in 1960, both in physics, and both from the Braunschweig Technical University, Germany.

He joined the International Business Machines Corporation in 1961, where his research work has been in the fields of injection lasers, electroluminescence, and surface physics at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y. He was affiliated with the Watson Research Center at the time this article was written.

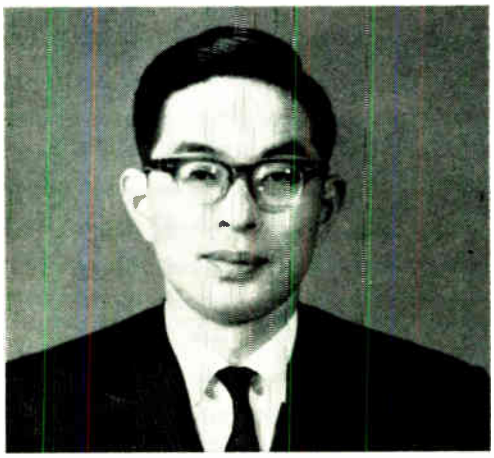
Dr. Pilkuhn returned to the Braunschweig Technical University in 1966. At the present time, he is serving as a member of the staff of the University of Frankfurt, Germany.

Wired broadcasting in Great Britain (page 97)

R. P. Gabriel (M) received the First Class Honours Bachelor of Science degree from London University, England, in 1933 and then joined Rediffusion. In 1945 he was appointed chief engineer of Rediffusion Limited, and he is presently serving in that capacity. In addition, he is now in charge of a number of the companies in the group, including Rediffusion International Limited and Redifon Limited.

Throughout his career, Mr. Gabriel has been closely associated with the development of systems for wired broadcasting, including the multipair cable television and sound relay systems.

Electric power engineering in Japan (page 106)



Teruhiro Umezu (M) is presently serving as supervisor of the Power System Section of the Technical Laboratory, Central Research Institute, Tokyo, Japan. He received the M.Eng. and Dr.Eng. degrees from Tokyo University and, since 1948, has been engaged in research on power system planning and operation, his specific concerns being power system stability, power system automation, economic load dispatching, protective relaying, and system planning.

He is a member of the Institute of Electrical Engineers of Japan and serves as the Japanese representative on Study Committee 4 (Relaying) of CIGRE. In 1961 he received the Award of Thesis for a paper on the study of power system stability. In addition, he served as editing director of the Japanese IEE from 1964 to 1966.

Hiroshi Nakamura is presently serving as supervisor of the Communication and Electronics Section, Technical Laboratory, CRIEPI. He received the M.Eng. and Dr.Eng. degrees from Tokyo University and, from 1948 to 1957, was engaged in research on the high-frequency characteristics of power transmission lines. For the next five years, he was involved in the study of radio noise due to EHV transmission lines. Currently, he is working on the application and development of electronics for the electric power industry. A member of the Japanese IEE, Institute of Electrical Communication Engineers, and Information Processing Society, he received the Award of Thesis in 1960 and, in 1962, the Award of Progress (IEE) for his Shiobara Laboratory design.

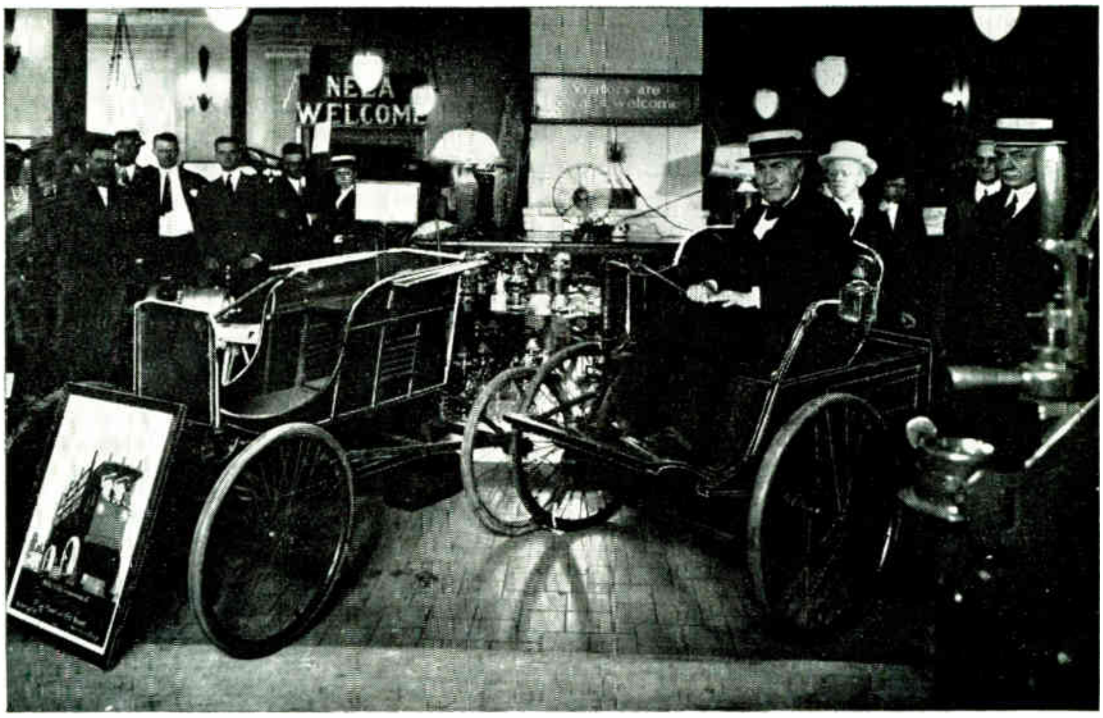


FIGURE 1. Around 1895, Thomas Edison used this three-wheeled vehicle to develop a new type of storage battery. Owned by the Henry Ford Museum.

Ever since the virtual demise of electric cars in the 1920s there have been efforts to bring them back, efforts that previously were defeated by the lack of an adequate energy source for motive power. Today, there is once again much excitement about electric cars, and this time there exists a complex of factors that should bring about the eventual production of a number of types of electric vehicles. Primarily, new energy sources are under development that promise to provide the kind of performance required. Beyond that, the severe problems of air pollution, half of which stems from cars, and the steadily mounting problems of our society's overall transportation system dictate real changes in the vehicles and in the system. This article reviews the engineering and design problems involved in the new power sources for vehicles, projects the potential roles of electric cars in the transportation system, and touches upon the changes that must come about in the attitudes of the driving public and in the auto industry if electric vehicles are to become an important component of the future transportation system.

Around the turn of the century, three types of automobiles were running neck and neck in the United States—the steam car, the electric car, and the gasoline car. For a number of years, the competitors seemed equally matched, but then fairly rapidly, through engineering and other improvements, the gasoline-powered car moved ahead. It was faster, lighter, cheaper, and had greater range; it gained the ascendency and it set the style for an enormous industry and a way of life.

There are some automotive authorities who express regret that the combustion engine got the jump—a "temporary" one, they feel—over the electric car. Otherwise, they say, we would today have an electric-car technology and industry, and we would not have the problems we now must face.

Perhaps the last great try before the electric car went under was that made by the very two men—Henry Ford and Thomas Edison—who have, in the United States, become figureheads of the two industries we shall discuss. Ford had once worked as an engineer for the Edison Illuminating Company in Detroit, and in 1896 when the two met, Edison encouraged Ford in his avocation of building a gasoline-powered car. By 1913, Ford had a growing business, but Edison's Storage Battery Company was in trouble. Battery sales were dropping off because electric cars were fast losing ground to gasoline cars. Edison had long had an interest in electrically powered cars—the three-wheeled electric automobile shown in Fig. 1, in which he posed, is said to have been used by him in 1895 for the development of a new type of storage battery, which he later called the nickel-alkaline battery. So he turned to Ford, and together, in 1913, they proposed to develop an inexpensive battery-powered car. Ford would manufacture the car, Edison the batteries. The project was pushed, two working models were ready by June 1914, and delivery of the first production model was set for July 1915. But the car did not reach pro-

Electric cars — hope springs eternal

When Ford built his monstrous four-cylinder "999" in 1902, with which Barney Oldfield was to break world speed records, he was not only winning races, he was setting the tone for automotive progress—gasoline style. Now it is time to redress the imbalance caused by this Frankenstein's invention and bring back the electric car

Nilo Lindgren *Staff Writer*

duction. It was stopped by the problems that have defeated efforts to revive the electric car ever since—low speeds, limited range, high cost, and great weight. The "electric Model T" never made the American scene.

Those long, hot polluted summers

Is the electric car now making a comeback? Are we now, in 1967, going to have a second chance at the electric car after 40 years of supremacy of the combustion engine? And if so, why? The raft of recent press releases would make it seem so. In the words of Alexander Pope, "Hope springs eternal in the human breast." Witness:

The year	The article
1929	Future of Electric Cabs for Tourists
1931	Electric Trucks Show Gain
1934	Boosting the Electric Vehicle
1936	Why the Electric Vehicle Becomes More Popular
1939	Better Prospects for Electrics
1941	Electric Vehicles Making Headway
1944	Why Not Battery Bus?
1958	Electric Car Bandwagon Gets in Gear
1958	The Electric is Coming Back
1959	Electric's Nearly Over the Hump
1959	The Electric Car: It's Back
1959	Are Electric Autos Coming Back?
1960	The Electric Auto—Stylish Again?
1965	Promise of Electric Cars
1966	Back to Electric Cars?
1966	Electric Car Revived

These titles were picked from a bibliography on electric vehicles that contains more than 1500 items dating from 1928 through 1966.[1] But electric vehicles today are still rare animals. Electrically powered farm machinery, golf carts, mail trucks, milk trucks, etc., can be counted in the thousands, whereas in 1966 the U.S. automotive industry alone sold more than nine million combustion-engine cars. In 1965, the total population of gasoline autos, trucks, and buses in urban areas was reported at 55 million, a number that is projected to grow to 200 million by the year 2000. Fuel consumption of all these internal combustion vehicles is projected to grow from 65 billion to 240 billion gallons (250 billion to 900 billion liters) between 1965 and 2000.

Changing times, changing needs

Some experts say that even with controls on combustion-engine exhausts, the gain in reducing air pollution from internal combustion engines will be more than wiped out by the larger number of vehicles. The auto companies, already defensive about the attacks on them regarding safety of their vehicles, and cognizant of the growing Government interest in finding effective means of combating air pollution, are announcing their interest in electric sources and other means of powering vehicles. Indeed, somewhat tardily, they are publicly acknowledging that they have a moral commitment at least to have an electric vehicle on the design shelf should it be "required."

But the auto makers have not been alone at fault. People do not drive less; they do not refrain from driving into the cities even when mayoral pleas are issued; they have an enormous appetite for more cars. Nonetheless, it is sinking into the great collective public consciousness that attractive alternatives to the private car are required, and that probably it should be willing to accept something different in the vehicles it drives or rides in.

The world's oil reserves are certainly finite. Alternate power sources for vehicles *must* be developed if our technologically oriented society means to continue on its course.

The hunger of the electric utilities for expanded markets, their continued growth of capacity, and the smaller cost of electricity, make the operation and operating costs of electrically powered vehicles extremely attractive. In the process of recharging vehicle batteries at night, during off-peak hours when generators are comparatively idle, the utilities could be selling additional billions of kilowatt-hours while optimizing the use of their facilities. The realization that such a market might now be within reach has been a powerful incentive to the utilities and to the battery companies.

Traffic congestion in the cities not only poisons the atmosphere but wastes energy. Modern cars with 200 horsepower carry people along at 7 mi/h (11 km/h), the worst possible use of such a vehicle.

These are but a few of the aspects of the changed conditions of our time that in turn create pressure for further change. All of our means of transportation—private and public vehicles, mass transit, roads, railways, airways, airplanes (nor is their contribution to air pollution insignificant)—in effect constitute a "system" of transportation that is being seriously strained, a system that, all things considered, is seriously imbalanced. Electric vehicles may seem like one possible solution to one specific problem, but their ultimate "feasibility" must be studied in the perspective of the needs of the entire system. And the "attitudes" of the public, of people as drivers and users of vehicles, are also a highly important ingredient of the system.

Most of the points mentioned might be viewed as social factors, but there have also been important changes in the technological climate. Important technological advances have made electric vehicles at least "thinkable." We shall begin with a discussion of alternate power sources to gasoline—the need for a power source that would even half-way compete with the gasoline engine—since this is regarded by everyone as technologically the number one problem.

Gasoline or—what alternatives?

Among the energy sources proposed for cars are nuclear energy, solar energy, fuel cells, batteries, and ionization methods. All of these energy storage methods and various energy conversion systems have been discussed comparatively by Prof. L. J. Giacoletto of Michigan State University, in a SPECTRUM article[2] last year and in a recent unpublished paper, "Energy for Cars of the Future."[3] Based on fairly exhaustive studies that he and his colleagues made while he was manager of Ford's Electronics Department Scientific Laboratory, these comparisons offer a panorama of possibilities and place in perspective some of the specific problems of developing an electrically powered vehicle. We shall summarize certain of Professor Giacoletto's ideas in what follows.

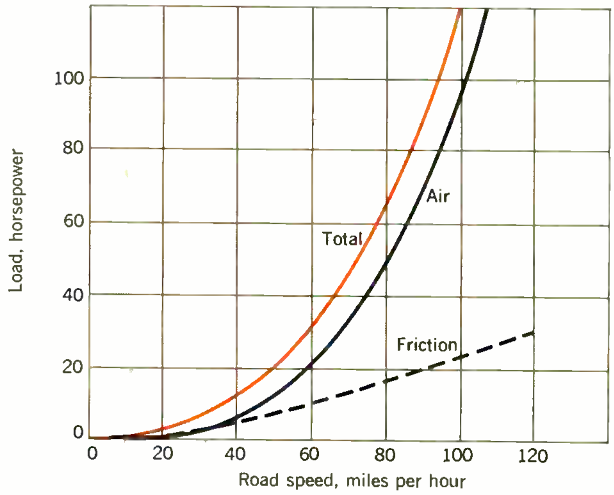
One of the primary distinctions an engineer must make in analyzing the design requirements for a vehicle is that between energy *storage* and energy *conversion*. That is, within an automobile there must be a method for energy storage and a device for converting energy from this stored form into mechanical displacement. In this view, then, the fuel cell is not an energy device per se. It is an energy-conversion device, to be considered in the same category as the gasoline engine, the electric motor, and the steam engine, all of which are energy-conversion devices.

For a moving vehicle, the major problem is one of how to store the energy necessary for a total travel distance of, say, 150 to 200 miles (240–320 km) in a weight and a volume small enough to provide a realistic system. The engineering problems of energy conversion, by no means simple or insignificant, are regarded by all authorities as secondary. In fact, there was relatively little incentive to work on such problems so long as the development of an energy source that was anywhere near gasoline in potential was not in sight.

Thus, almost from the start of the search for new sources, gasoline has served as the yardstick of comparison. A tankful of gasoline, about 20 U.S. gallons (75 liters), weighing 120 lbs (54 kg) occupying about 2.6 ft^3 (0.07 m^3), gives a car averaging 15 miles per U.S. gallon (6.5 km/l) a range of about 300 miles (480 km). Even this relatively small and lightweight energy source is not converted to mechanical motion with much efficiency. In a modern, Detroit type, 4000-lb (1800-kg) vehicle, about 75 percent is lost directly as heat—35 percent in radiator and engine heat losses, 41.6 percent in the exhaust, oil, and miscellaneous rear-end heat losses, 2.5 percent in transmission losses, and somewhat smaller amounts in the generator, fan, power steering, and water pump.[2] Actually, then, as Giacoletto points out, the useful energy delivered to the basic transportation task is rather nominal, say about 20 percent. Figure 2 shows how, for a 4000-lb (1800-kg) vehicle, this power is required to overcome friction (primarily tire flexing) and air resistance. All things considered, the overall efficiency of conversion of gasoline to mechanical motion may be about 10 percent.

Rather similar figures are adduced by Dr. Manfred Altman, Director of the Institute for Direct Energy Conversion at the University of Pennsylvania, in a paper presented at the 1967 IEEE International Convention.[4] Dr. Altman remarks that the "overall efficiency of an internal combustion engine is about 30 percent when it is adjusted properly, and running steadily. With starts and stops and average driving, the efficiency is much less, something more like 8 percent. Also, only about 60 per-

FIGURE 2. Horsepower needed to overcome effects of tire friction and air resistance (typical 4000-pound or 1800-kg vehicle) shows sharply rising speed dependence.



cent of the engine output is transmitted to the wheels as actual tractive work."[4]

The point in discussing these efficiencies is that conversion of battery energy, for instance, to mechanical motion should be much higher. Thus, to anticipate a bit, even though batteries, thus far, offer significantly less energy storage capacity when compared with gasoline, their potentially higher conversion efficiencies compensate in part for this. In other words, you can do more with less.

Of the other possible energy-storage methods mentioned, all present severe problems in terms of automotive applications. Nuclear fusion and fission, which have a million times the energy-storage potential of gasoline, seem unlikely because severe radiation would require heavy shielding in the case of fission; and fusion, provided a nonexplosive method of release were developed, might require elaborate and bulky equipment.

Energy stored by ionization methods might be somewhat better than gasoline, but containment pressures created in a container of ions would be enormous.

Solar energy appears to be a marginal source; however, it might be useful in various kinds of hybrid vehicles.

At their present stage of development, fuel cells,[5] too, present many formidable problems, although most of those people who have been involved in developing and studying them seem to agree that they will eventually perform very important motive functions in later-generation cars.

A feeling of the kinds of engineering difficulties that are involved in the present state of the art of fuel cells can be gotten from technical reports on the "Electrovan," which was built by General Motors as part of their evaluation program on electric vehicles.[6] The fuel-cell-powered van, which was unveiled late in October 1966, uses 32 fuel cell modules developed by the Union Carbide Corporation. The fuel cells use hydrogen and oxygen in liquid form, admittedly a dangerous and explosive system, but one that provides the vehicle with a range of about 150 miles (240 km). However, liquid or gaseous hydrogen and oxygen are not regarded as practical for an automotive power plant. What is needed, GM engineers say, is to develop a fuel cell technology based on a hydrocarbon fuel.

In his discussion of energy sources, Giacoletto also mentions means of supplying power from *outside* the vehicle as through conduction (e.g., trolley cars), by induction (transformer coupling), or by radiation (electromagnetic energy), but, he concludes, all the known methods of continuous energy distribution to a moving vehicle are either prohibitively restrictive to the movements of the vehicle or are prohibitively wasteful of energy.

Thus, we come to batteries, a field in which things have begun to happen, and where wider application in various kinds of vehicles does not seem so far off in the future. Battery power is used already to some extent in highly specialized applications. But lead-acid batteries, which were "aced out" by the combustion engine in the twenties, will not do for general-purpose cars, and for good reason. Though they have admirable characteristics, one of them, in vehicular applications, is not range (i.e., lead-acid batteries, compared with gasoline, are down 100 times in terms of energy per unit mass). One calculation, for instance, shows that for powering a small car like a Volkswagen (assuming a 15-hp electric motor and 150-mile or 240-km range), the lead-acid batteries alone would weigh 700 lbs (315 kg) more than a completely equipped present-model VW; in addition, capital costs and battery replacement costs would be excessive.[7] This is not to say, however, that the lead-acid battery is not and will not continue to be eminently suitable for "workhorse" situations—trucks, buses, farm machinery, fork-lift trucks, railway trains. They can be competitive with gasoline vehicles, too, in such applications under the scheme adopted by the Electric Storage Battery Company, whereby the vehicle user merely rents the batteries and pays only for the power he consumes.

Recently, other newer batteries have been used in automotive experiments. Silver-zinc batteries developed for aerospace applications have been tried in a converted Renault-Dauphine by the Yardney Electric Corporation, and the car does give the visitor a convincing ride, even though it is basically a very simple system. With 250 lbs (112 kg) of Yardney's Silvercel battery, the car achieves a range of 77 miles (123 km) and speeds up to 55 mi/h (88 km/h)—in constrast to a lead-acid battery system where 750 lbs (337 kg) of battery would give a range of only 42 miles (67 km) and a speed of 32 mi/h (51 km/h). General Motors also used silver-zinc batteries in "Electrovair," an experimental battery electric car, which went on display the same time as the fuel cell van. However, silver-zinc batteries are extremely expensive because of their silver content. Even though Yardney argues that the silver in such batteries, in commercial use, could be completely recoverable, and therefore reusable, most people involved in electric car developments flatly proclaim their disbelief that such batteries are really feasible. They point to the problems of relatively low recycle life (two to three hundred recharges), to the limited supplies of silver, to the costs of reclaiming the silver, to the dangers of carrying around $5000 worth of silver. Certainly, silver-zinc is several times better than lead-acid, but in comparison with the storage capabilities of gasoline, it is still marginal.

Theoretically, however, it is possible to get energy storage "in the ball park" with gasoline, provided one uses some exotic and tricky material combinations. And, in fact, investigators are now working on potentially high-energy storage batteries, although all the work is still in fairly early research and development stages. Before looking at a few of these new batteries, however, it will be useful to explain the context in which they have emerged, namely, by looking a bit at the character of the battery business.

The nature of the battery industry

To the outsider—schooled for instance in the solid-state or computer fields—the rate of research and development in the electric battery field appears dreadfully slow. Even though the present standard S-L-I (starting, lighting, and ignition) batteries can deliver 60 percent more output per weight and volume than their predecessors, and though battery life has risen from 20 months (in 1950) to 27 months (1965), the improvements have been evolutionary. Although production has risen enormously (40 million automotive units alone in 1966), and although one would think such a volume of business could have supported a high level of advanced research, the industry has not been noted for its innovation. Not only is battery research itself a peculiar, difficult, time-

Making batteries—a "black art"

Tradeoffs lie at the heart of battery design. There are, as yet, no rational formulas that can crystallize with any certitude the design of a battery. The final judgment depends on the experience and intuition of the battery designer, and he ends up with a "lot of qualitative compromises." That is, the development of new batteries is still, to an extent, something of a "black art." In fact, as one listens to those who specialize in battery research, and reads their papers, one makes the mental leap that perhaps basic battery research is where solid-state science was 18 years ago when the transistor was invented, when playing with semiconductor materials was still an art, before a generation of scientists and engineers built under it and around it a rational foundation.

I. Representative parameters of battery systems*

Type of Battery†	Open-Circuit Voltage	Capacity,‡ Wh/lb	Cycle Life If Secondary
Primary batteries			
Zinc-carbon (Leclanché)	1.5	30	
Alkaline-manganese	1.5	35	
Mercury	1.35	50	
Silver-zinc	1.6	60	
Secondary batteries			
Lead-acid			
SLI	2.2	15	—
Industrial	2.2	12	1000
Nickel-cadmium			
Sealed	1.35	12	1000
Vented	1.35	12	2000
Alkaline-manganese	1.5	30	30
Specialty batteries			
Silver-zinc	1.6	50	50
Silver-cadmium	1.4	30	300
Water activated (P)			
Silver-chloride	1.6	70	
Cuprous-chloride	1.4	30	
Thermal (P)	2.8	—	
Nickel-iron	1.6	12	3000
Lalande (P)	1.1	—	
Air cells (P)	1.3	60	
Batteries under development			
Magnesium (P)	2.0	45	
Lithium nonaqueous (P and S)	~2.5	>100	
Solid state (P)	~0.6		
Metal-air (P and S)	~1.5	~100	
Lithium fused salt (P and S)	~3.0	>100	
Sodium sulfur (S)			

* Values for capacity and cycle life vary widely with conditions of use and to a lesser extent with constructional details. Values quoted are typical only for moderate discharge rates and normal temperatures.

† P refers to primary and S to secondary systems.

‡ Multiply by 2.2 to obtain Wh/kg values.

Source: Arthur D. Little, Inc.

consuming, and even mysterious, art[8] (see box), the business end also has tricky problems. For a variety of reasons, the field has been intensively competitive, and profits have not been easily tapped for research.

Nonetheless, there has been a sudden upswing in battery research, and the upsurge is attributed directly to NASA and the U.S. aerospace programs. In the late fifties, as the U.S. space programs really were getting off the ground, there was a demand for new types of energy sources—smaller, with unusual recycling demands owing to the rapid day–night alternations of satellites spinning around the earth; nonmagnetic, so as not to disturb sensitive scientific experiments; hermetically sealed; and sans the usual one-side-up orientation. In other words, as Dr. Robert C. Osthoff, Manager of GE's Electrochemical Systems Branch, puts it, NASA was posing problems and requirements that the "earthbound battery guys never had to face." As the new demands mounted, it became apparent that much more fundamental research was in order if the requirements were to be met. Industrial companies with varying degrees of involvement in the country's aerospace programs were also stimulated to enter more seriously a potentially lucrative field, so that by about 1960, the year people like Osthoff see as the breakover point, many new investigators had started battery research. (Table I, prepared by Dr. James George under Arthur D. Little's Service to Management Program, lists the types of old batteries and new batteries now under development.[9]) The pace of the research was such that the various satellite programs saw many successful new batteries used in space, covering a whole range of charge capacities from 3 ampere-hours up to 100 ampere-hours.

In all, the NASA battery research programs have been roughly 20 percent in-house, with 80 percent contracted outside. Of this outside research, about 70 percent went to well-known battery companies, with the remaining 30 percent going to companies that had previously done little work on batteries. Thus not only were the going battery concerns encouraged to widen their research and development bases, but new companies and new people were drawn into the work. Another sharp stimulant to battery research came from the recognition of the commercial possibilities—cordless gadgets of all kinds—attracting the R & D energies of heretofore non-battery-oriented organizations.

The zinc-air battery

Of the new battery systems, the zinc-air battery has already reached a reasonably interesting stage. It is, in the words of one expert, the innovation that now makes the electric automobile "thinkable."[10] Under development by the General Atomic Division of General Dynamics since 1960, the battery has since also begun to receive financial sponsorship from the Edison Electric Institute (14 electric utilities are cooperating in this sponsorship). Characteristics offered by zinc-air couples include a high energy storage per pound, and construction of readily available, low-cost materials, which are in addition free of operational hazards to the user.

In a recent report on progress on the battery, T. G. LeClair and D. V. Ragone trace the states of development thus far.[11] Early experiments with small single cells determined air electrode and zinc deposition characteristics for rechargeable operation. These small cells were scaled up in size during 1963 and 1964, and fabricated in cell stack experiments. Further development led in 1966 to tests of a 14-kWh prototype, which is shown in Fig. 3. The development of a full-size prototype, to be tested in a vehicular test bed, is scheduled for early 1968.

A novel feature of the system is that the electrolyte, an aqueous solution of potassium hydroxide, is circulated through the cell during both charge and discharge, making it possible to store the reaction products outside of the cell system, thus eliminating the need for supporting structures in the cell (the grids in lead-acid batteries). In addition, the reaction products do not build up and impede battery reaction. Figure 4 is a schematic of the battery system. During discharge, zinc oxide precipitates as a finely grained solid and is swept out of the reaction chamber, along with waste air and unused nitrogen, where it is separated and stored. During charging, the zinc is disunited from the zinc oxide and replated on the anode substrate as the electrolyte circulates. The battery can be charged in about two hours at two volts per cell. Discharge voltage varies with the power demand as in most battery systems.

For a large-size battery (200 000 cm² of cell area), which might be the size used in a delivery van, it is claimed that energy densities of over 80 Wh/lb (176 Wh/kg) appear to be practical, based on the present studies. As initially conceived, the primary applications for zinc-air batteries appear to be in materials-handling trucks, urban delivery vans, and transit/school buses.

General Atomic engineers state frankly that a great deal of development work remains to be done on their battery before it will have evolved into a reliable system with long life. One of the problems, for instance, is that during replating, the zinc deposition is not uniform so that subsequent discharging is progressively degraded. There is also criticism that dendritic zinc forms at the manifold of the system.

Other firms are tackling such problems with basically different designs. Yardney Electric Corporation, for instance, is reportedly using some form of moving electrode rather than a moving electrolyte. General Electric reports that it is designing zinc-air batteries with no moving parts. Thus far, multicell arrays with 10 to 20 cells have been built. One of the most important problems at this time, mentioned by Dr. R. C. Osthoff of GE, is "how to get the cost out" of these batteries. Other organizations, such as Leesona Moos, are also clearly working on zinc-air battery research.

Although zinc-air is a promising development, it is still too early to determine what effect it will have on the future of the electrically powered vehicle. As Dr. James H. B. George of A. D. Little, Inc., remarks, the fact that the General Atomic battery must employ considerable ancillary power to operate pumps, compressors, and other components dictates that a viable system would need to operate on a large scale as in trucks and buses.

Sodium-sulfur cell

In contrast to the zinc-air battery system, which already exists in an advanced breadboard state, the sodium-sulfur cell, recently publicized by the Ford Motor Company's Scientific Research Staff, is virtually still a "principle," in that it is still in its earliest stage of research.[12] Nonetheless, the cell has excited much interest, for it does represent something of a breakthrough, and eventually it might well serve a number of vehicular applications. Ford engineers say that when the cell is evolved into a fully engineered battery system, its projected current density is superior to that of any other existing commercial system, except perhaps silver-zinc, and the projected energy density is roughly 15 times that of a lead battery and three times that of silver-zinc batteries. Its projected energy density is 150 Wh/lb (330 Wh/kg) (slow discharge five hours), which can be roughly compared to other batteries shown in Table I.

In discussing the development, Dr. Thomas W. DeWitt, Associate Director of Ford's Scientific Laboratory, says that the feeling at Ford is that "the matter of electrically powered vehicles is so important, we can't miss

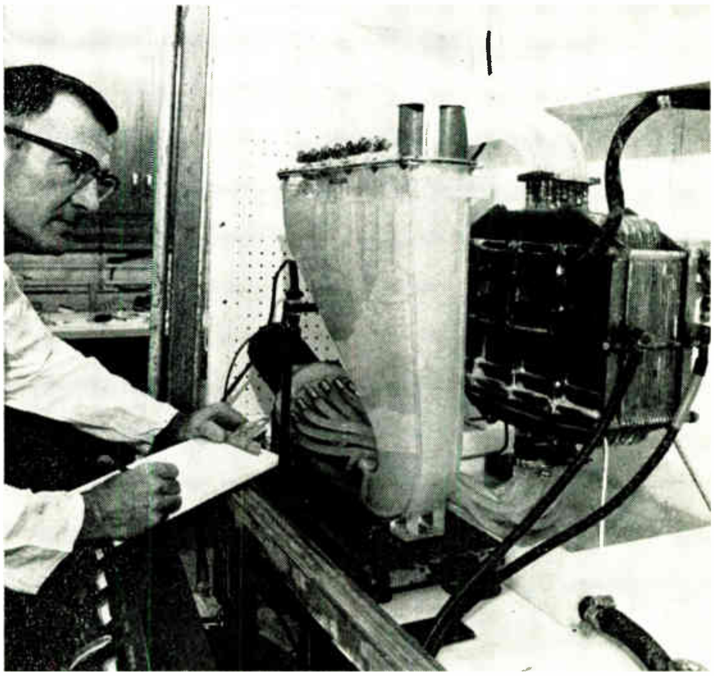
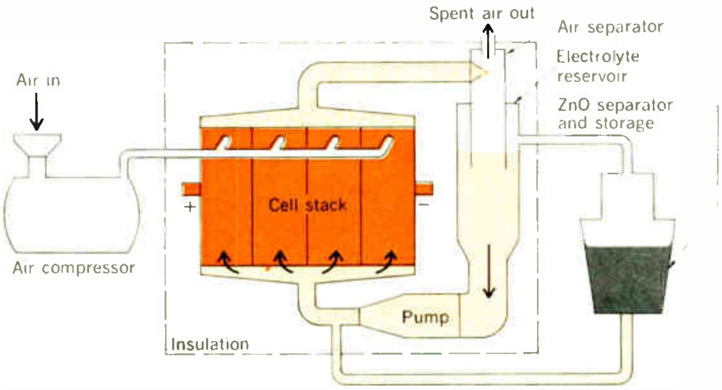


FIGURE 3. Experimental prototype of zinc-air battery during recent test operation.

FIGURE 4. Schematic diagram of the zinc-air battery suggests that we had better reform our conceptions of what constitutes a battery.



any bets," and that in his view the new cell has a "greater practical potential than any other." Some engineers outside of Ford have also expressed a similar view. The cell itself has a number of unusual features. The reactants are liquid—liquid sodium and liquid sulfur—and to obtain battery action, they must be kept liquid at a temperature between 250 and 300°C. The hot liquid reactants are separated by a solid ceramic electrolyte that transports only sodium ions. Figure 5 shows a cross section of the cell and its principle of action.

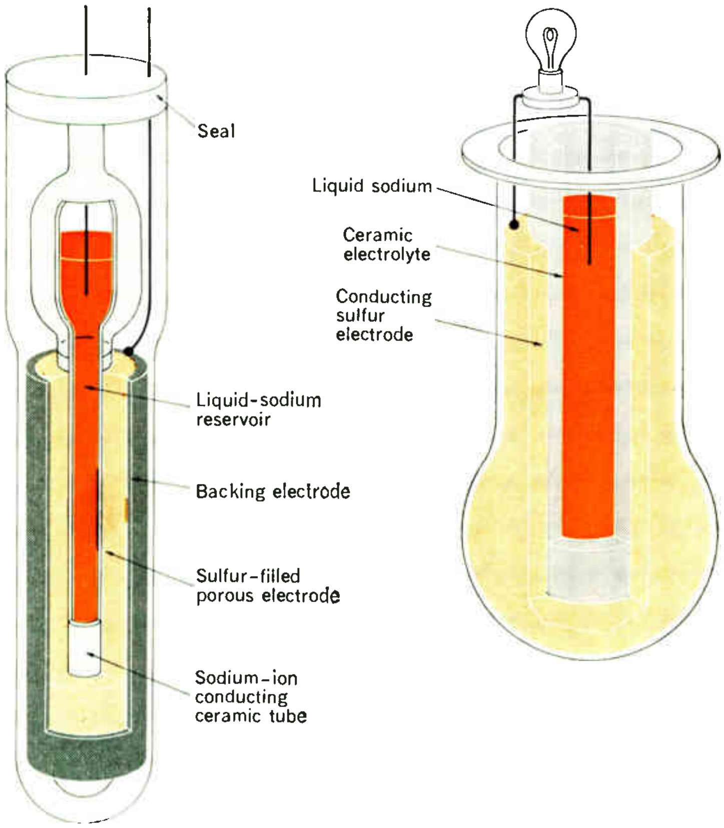
The key to the system is the ceramic electrolyte, which is formed of a material known as beta-alumina and sintered so that it will pass only sodium ions. Its conductivity at 300°C is of the same order of magnitude as that of common electrolytes used in conventional batteries. Beta-alumina is a known material, but its potential for serving as an ionic conductor, according to Dr. DeWitt, was discovered quite by accident a few years ago by Ford scientists while they were doing research unrelated to batteries. More formal studies on the sodium-sulfur cell did not begin until approximately a year and a half ago.

Dr. DeWitt and his colleagues at Ford do not minimize the difficulties ahead in the battery development. Its high temperature of operation and the need to keep it hot all the time, its potentially dangerous liquid contents in the event of a vehicle accident in which the battery would be ruptured, the corrosive qualities of these contents on any containment package, are some of the most obvious difficulties. Also, the research thus far has been concentrated on the qualities of a single "test-tube" cell. Not much is really known yet about the longevity of this cell, how it will behave in recycling, exactly what corrosion problems will occur, or how the cell will take cooling to a solid form and then cycling back to liquid form. The problems of building a multicell system also still lie ahead.

However, Dr. DeWitt expresses confidence that such problems can be solved, and that it will be possible to devise a completely insulated and sealed battery package of sufficient mechanical strength to withstand powerful shocks, so that it can be applied in vehicles. There has been some suggestion that its best applications may be in heavy-use trucks, in which continuing use would eliminate the cooling problems encountered in an automobile that an owner might leave unused for weeks. Electric railway cars, farm tractors, and submarines are a few other possible areas where optimum applicability would be achieved.

This does not mean that special-purpose automobile application is excluded. Ford feels that the battery might meet one of the needs of an efficient, low-cost, subcompact (about 6 feet or 2 meters long), urban–suburban vehicle requiring only overnight charging. A prototype of such a vehicle is being built by Ford in England, to be completed this spring, but it will be powered initially by conventional batteries.

FIGURE 5. The sodium-sulfur cell (left) uses liquid reactants at high temperature and a solid electrolyte. Current is carried by sodium atoms that give up electrons to the external circuit (right). Only sodium ions can pass through the solid electrolyte to react with sulfur.



Some other advanced batteries

At the Electric Automobile Symposium held at San Jose State College, Calif., late in February, R. C. Shair, Vice President of Research and Development at Gulton Industries, discussed the progress that had been made with another high-energy battery using lithium and nonaqueous electrolytes.[13] Mr. Shair remarks that the lithium battery operating at normal ambient temperatures certainly has the power density to provide attractive mileage range for vehicles, but that the present limitation is its power density to provide acceleration peaks. However, he says that a "bipolar" nickel-cadmium battery, which has been developed concurrently with lithium research at Gulton, can, because of its geometry and construction, deliver high power for short periods. "The term bipolar is applied to an electrode configuration that contains the positive material of one cell and the negative material of another cell on two sides of a conducting thin sheet known as a substrate. These plates are stacked together" rather like a sandwich, "so that a battery of single plate cells is formed with the terminals on the ends of the stack. Current flow through the battery is through the total cross section of the plate. By using large cross sections, thin electrodes and thin separators, a high rate battery is constructed. It is capable of 330 W/lb, which expressed as weight/power ratio is 3 lb/kW."[13] Therefore, Shair says, a parallel (or composite) battery combination consisting of the lithium battery with five-hour energy density of 100 Wh/lb (220 Wh/kg) and a small bipolar nickel-cadmium battery with a weight to power ratio of 3 lb/kW (1.3 kg/kW) is an attractive potential power source for electric vehicles.

Continuing efforts at Gulton are being directed at improving the electrolyte and the cathode. The goal, Shair says, is to reduce the effective internal resistance, which is really an electrochemical polarization phenomenon. Another goal is to increase the watthour per pound ratio. The present figure is 100, and they wish to drive this up at least to 150 Wh/lb (330 Wh/kg). Cycle life and temperature effects have not been studied. Support research looks into such questions as surface area, purity of materials, conductivity, and viscosity of electrolyte. Many different materials have been studied for the cathode reactant—among them F_2, Cl_2, CuF_2, NiF_2, and $NiCl_2$. However, the halogen gases are corrosive and difficult to handle, so Gulton has, through its experience with nickel oxides, decided to concentrate on nickel compounds.

The General Motors Corporation, on the other hand, has been experimentally studying lithium/lithium chloride/chlorine cells. Their Allison Division's work on molten salt electrochemical systems dates back to 1958, although specific studies of the lithium chloride system started in 1964.

The cells being explored at GM undoubtedly present some extremely difficult problems. The elements involved entail severe dangers, and even in the experimental stage, extensive precautions must be taken. In any case, working with gases is considered a "pretty wicked thing." Imagine a real-world situation: everyone is familar with the drip of oil from our gasoline cars but the inconvenience and dangers of dripping oil are nothing compared with the dripping of any of these molten components of the advanced systems. Dr. Craig Marks, assistant engineer in charge of GM's Power Development Department, himself expresses reservations about designing around such dangers, and he expresses similar reservations about having high voltages in a vehicle, in which, if something went wrong, a driver or mechanic might be struck down by 400 or 500 volts.

These are just a few of the factors that must be taken into account when the overall feasibility of electric cars is weighed. Furthermore, we should not fail to realize that the most feasible battery applications may lie in "hybrid" systems. For instance, a hybrid vehicle might use two types of batteries, drawing on the better characteristics of lead-acid for acceleration and automatically switching over to zinc-air for the low-drain cruising periods. Hybrid energy systems can theoretically be of all types—battery–battery (lead-acid/zinc-air), battery–fuel cell, battery–gasoline engine, battery–turbine, etc.

Of the possible hybrids, we should stress that the most intriguing from an evolutionary point of view might well be a car employing a dual system of battery-powered electric motor mounted on a common shaft with the IC engine output. The IC engine would give the car the bounce it needs for long-distance superhighway travel while it also recharges the batteries which would be switched on to give quiet, fumeless operation in the short-haul, stop-and-go driving in cities. Thus, this dual system would exploit the very best features of both energy sources. One can imagine the potential complexity such a dual system could foist on engineers and mechanics, but far be it from our civilization to avoid complexity—in fact, for us, it seems to be a one-way street.

Vehicular engineering problems

Dr. Serge Gratch, Manager of the Chemical Processes and Devices Department of Ford Motor Company, states; "As long as there were no breakthroughs in batteries, there was no point in intensifying research on the other problems." Now, however, with new energy sources in sight, interest is picking up in the next two major categories of design problems in electric vehicles—motors and controls.

Not that there has been no work in this area—we are speaking only of the intensity with which solutions are pursued. Here, in the same way that new energy sources must take gasoline as the yardstick, so the electric vehicle will, at least in the beginning, be forced to take the conventional gasoline vehicle as its standard. F. L. Zeisler, in discussing the design of a high-power-density electric motor a couple of years ago, made the point as follows: "In automotive application the main power train components, such as the transmission, are light in weight for the power handled, are quite efficient over most of the wide operating range of speed and power, and are relatively inexpensive. If these parts are to be replaced by 'electric' components with net advantage, the electrical parts must compete successfully on all counts. However, conventional electrical machines simply do not have the economic combination of high power density, high efficiency and low cost."[14]

Those who are looking into automotive functioning for the first time may be prone to think of the various parts only in terms of how they operate in relation to the other parts. Yet, in a vehicle, these parts must also be considered for their weight distribution, for it is in this area that careful design in part gives the driver a "feeling" of its overall performance. Dr. George A. Hoffman, of the University of California, Los Angeles, makes a proposition similar to Zeisler's: "The weight proportions of the main components of the automobile are the result of almost a century of development of cars in response to consumer preferences, and since they reflect consumer acceptance of seating and space provisions, comfort and riding qualities, we should adhere to these proportions as well as we can in designing an electric automobile."[10] Hoffman's emphasis on the "response to consumer preferences" will perhaps surprise some critics who feel that they have had Detroit's big tanklike cars jammed down their throats. But, surprisingly, Hoffman's studies of cars ranging in weight from 1500 lbs or 675 kg (the small European car) to more than 5000 lbs or 2250 kg (the large American car) shows that each major component (body, trim, glass, front suspension, rear suspension, wheels, tires, steering) bears a consistent ratio to the overall weight. These studies of weight proportion are of interest, for future electric cars will have new components (electric motors, energy storage, electric controls, etc.) and they will no longer have, for instance, engines, gas tanks, radiators, and such. Thus, in seeking initially to preserve the feeling performance of gas cars in electric cars, auto engineers will have some nifty juggling problems on their hands. And not enough is known yet about all the variables to put these problems on a computer. Dr. Craig Marks of GM points out that you cannot anticipate all the things that will happen. In this respect, automotive engineering is an art, a point that is perhaps confirmed by the obvious passion with which so many people observe, collect, and even discard cars.

We started out talking about motors and controls. In the old electric cars, there were, of course, electric motors and various types of relay controls. However, the motors suffered from low power density and brush problems; relays provide a "step" type of control, which would probably not be acceptable by today's smooth performance standards (although I would like to say from my own short experience in driving the Yardney electric car, which employs step controls, that the control was not disturbing). Now all the big automotive companies (and organizations such as General Electric and Westinghouse with experience in submarine and aircraft motors which show some suitability for vehicles) have been developing motors aimed at the special problems of vehicular application, and some fairly effective motors have been developed. The higher efficiencies of electric motors are a real advantage. Professor Giacoletto calculates, for example, that a 50-hp electric motor will give about the same performance as a 200-hp gasoline engine. The electric motor developed by Zeisler was in fact begun under Giacoletto's direction at Ford.[3] It is a dc homopolar machine with liquid metal contacts (which avoids brush wear and breakdown), and it is capable of high power density combined with high efficiency. However, Dr. Gratch points out that one problem with this motor is that it is a low-voltage, high-current machine, which makes its applicability limited. Perhaps, he says, when better energy sources become available, this machine might provide the vehicle drive, but some way must be developed for large-current control. In general, Dr. Gratch says that "real new concepts" are needed. Professor Giacoletto, perhaps more optimistic, expresses excitement over the potentialities of the homopolar or unipolar motor in vehicular applications.

The controls problem in an electric vehicle can be put fairly simply. The battery can be considered roughly as a constant-voltage device, but the end job to be done is to provide variable speed at the complete command of the vehicle driver. What is needed is a system whereby continuous or smooth transformations between the constant source and a variable demand can be effected. The answer, which has become available only in recent years, is solid-state devices, namely, silicon controlled rectifiers (SCRs). Costs are still high for the types of SCR that would be required, and they have, so far as is known, not yet been especially designed for vehicle applications. But, the "time is ripe," and these should constitute development, not research, problems. The technology is within reach, and one can safely guess that with the potential volume of the eventual electric car market, the costs of solid-state control devices will naturally slide.

A classy, costly conversion nobody can afford

Probably the most comprehensive and costly conversion of a conventional car body and chassis to an all-electric equivalent is that publicized recently by General Motors. As Dr. Craig Marks puts it, the objective was straightforward: to "design, build and test a smooth, quiet, and reliable Corvair with all of the modern technology available." Although GM has been making preliminary paper studies of electric cars since 1956, Dr. Marks stresses that the big difference was in actually building one. The result, a car that has now gone through two generations of development, called the Electrovair II, is shown in Fig. 6. The Electrovair, as well as the fuel-cell Electrovan mentioned earlier, was built to evaluate new motor and control concepts.[15]

Briefly, the components included in the car were: silver-zinc batteries; an ac induction motor delivering about 100 hp (designed by GM's Delco Products Division, it weighs only 1.3 lb, or 0.58 kg, per horsepower); a high-power switching unit consisting of 18 of the most advanced SCRs available; two blocks of capacitors to turn the power switches off; a trigger box to turn the switches on; a logic system to translate the driver's commands to the system; a conventional battery for the usual accessories, lights, etc.; an oil cooling system for the motor and electronic controls. One sees from this listing that this electric car is far from the popular dream of a simple, silent, easily maintainable, and inexpensive service vehicle. It is a very rich man's toy.

What did GM engineers learn from these experiments? They found that in general high-performance electric cars are technically feasible, but that costs are far too high, and, as usual, that better power sources are needed.[15] Dr. Marks is more specific in his summation of the problems of the project: design of the battery, motors, and controls had to be integrated as a system; paper studies based on single batteries gave overly optimistic estimates of driving range and acceleration; with several hundred battery cells, range was less than 70 miles (112 km); major development problems were hidden in many of the things taken for granted in a gasoline vehicle—e.g., starting and stopping with the simple turn of a key required the development of a completely new electromechanical system, and fail-safe capabilities had to be provided in case the power should lock on, the motor should overspeed, or the control lever were inadvertently thrown from forward to reverse while driving; major problems existed in operating the electronic systems over the temperature range normally encountered in a car, so that two electronic systems were developed, one for winter and one for summer; at least 400 volts and 300 to 400 amperes had to be handled in the electric system, something of a psychological problem to automotive engineers used to thinking in terms of 12 volts. The bugs in the system became major problems: mechanical vibrations, fan, pump, and electrical noises; terrible electronic circuit reliability problems (GM automotive engineers: welcome to the IEEE where you will find many brothers!); transformer hum; and what not. And so it goes on and on, continual problems and engineering solutions, and a more penetrating view of what might conceivably lie ahead for the automotive industry should it one day commit itself with a greater heart to the electric auto.

Perhaps the deepest lesson is that, for a long time, there will be no one-to-one replacement for the general-purpose gasoline car as it has evolved over more than half a century—or that, perhaps, it is a mistake to try to make such a replacement. Perhaps, in the rapidly changing and changed conditions of life in the technologically oriented society, the general-purpose car that has dominated and even created the "system," has itself become just a special component, and the need now is to develop a family of vehicles to suit a wider variety of specialized transportation requirements.

A sampling of engineering responses to the GM Electrovair is various and interesting. One observer laughs ruefully and remarks on the probable cost of the batteries and SCRs alone, somewhere in the neighborhood of $30 000. Competitors at Ford admire it as a "beautiful engineering job," but then they scoff at the

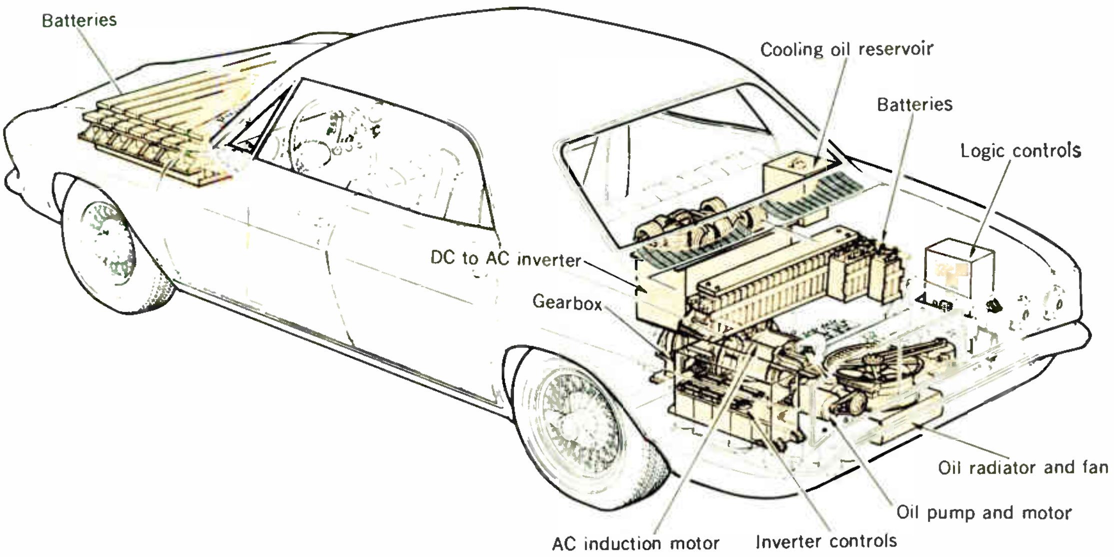


FIGURE 6. Cutaway view of "Electrovair," the most elaborate electrically powered experimental car designed to date.

practical impossibility of silver-zinc batteries, which they "write off" for vehicular uses. One critic states that he regards the development as part of a carefully calculated campaign by GM to prove that practical electric vehicles can't and shouldn't be built. "Why else," he asks, "would they stress the problems so much? They keep saying, 'Look here, look how hard it is.' "

For us, the discussion of this sophisticated conversion based on available technology serves this purpose—it sets off into greater depth the contrast between the theoretical possibilities we discussed earlier and the realities of the engineering and economic worlds.

The pace quickens

Clearly, there are many signs that interest and work in all aspects of electric vehicles is quickening, and that things are happening on a broad international level. On November 23, 1966, a seminar on battery-powered vehicles was held in India, where, it is said, social conditions make present performance of electric cars more attractive than in other countries. In late February of this year, a two-day symposium on electric autos was held at the San Jose State College in California, covering air pollution, batteries, fuel cells, electric motors, and control research. And this month, April 6–8, a symposium on power systems for electric vehicles is being held at Columbia University, covering a wide range of studies going on at U.C.L.A., Stanford Research Institute, Polytechnic Institute of Brooklyn, Gulton Industries, Boston College, NASA, Atomics International, Electrochimica Corporation, Ford Motor Company, General Electric, Union Carbide, General Motors, U.S. Army Engineer R & D Laboratories, Leesona Moos, Yardney, The Electric Storage Battery Company, Gould-National Batteries, and others. It is estimated that 8 to 10 million dollars is now being spent yearly on electric vehicle research and development in the United States, about half of it coming from government agencies and half from private industry.

Federal and State legislators have also become actively interested in electric cars. For instance, on January 17 Senator Magnuson of Washington introduced a bill into the U.S. Congress to authorize a program of R & D on electrically powered vehicles. There are high hopes that the bill will be passed. (See "Focal points," this issue.)

A number of organizations have already introduced electric vehicles for private, commercial, and industrial use. Among them are Exide's "Henney-Kilowatt," Yardney's Renault-Dauphine equipped with silver-zinc batteries, West Penn Power's own design on a VW base, Union Carbide's hydrazine–air fuel-cell motorbike, M.I.T.'s "Commucar," and others.

Abroad, there have been real developments. In Japan, the first battery-powered car has been officially licensed for street driving. Based on a regular Diahatsu Compagno, the small car can run 50 miles (80 km) at speeds up to 44 mi/h (70 km/h). Five Japanese companies formed a group to develop the car. In England, the Electricity Council has done much to push electric vehicle work, sponsoring hearings, studies, and demonstrations. Three small electric vehicles are presently being produced, the "Mini," the "Scamp," and the "Trident."[16]

A further quickening of the industrial pulse is reflected in the announcement on January 30 that the General Atomic Division of General Dynamics had entered into a major program with Joseph Lucas Industries, Ltd., of England, for development of the zinc-air battery for vehicle propulsion. Two days later, on February 1, Ford Motor Company and Yardney Electric announced that they had signed an agreement on a program to develop new energy sources for electric vehicles.

And the general public, ever alert, suggests in a letter to *The New York Times*, February 17, 1967, that the Government offer tax incentives to users of electric cars.

Electric car feasibility study. Several U.S. government agencies are sponsoring potentially influential feasibility studies on electric vehicles. For instance, the Department of Health, Education and Welfare (HEW), Division of Air Pollution, is contracting out two eight-month studies, one to A. D. Little, the other to Battelle Memorial Institute, for a total of $120 000. A. D. Little is to look into the question of the real feasibility in all respects. What this means is not only engineering feasibility, but all of what can be called peripheral factors—how electric cars would be recharged, facilities required in homes and garages and on parking meters, the effects on gas stations, etc. Thus, it appears to be a kind of "systems" study.

The purpose of the study, according to Dr. Bernard J. Steigerwald of HEW, is to survey the field, assess the state of the art of the elements that would be involved in electric vehicles, and to develop criteria for two classes of cars—one, the general-purpose or family car used for all driving missions; the other, special-purpose vehicles for commercial use, or for shopping, city driving, and so forth. The study will attempt to match known systems with these criteria to determine what could be done, what is being done, and the nature of the R & D problems. HEW would then be in a position to outline a broad research program aimed at solving such problems, including an assessment of the resources needed from the Federal Government.

A. D. Little already has a wide background in battery technology, reportedly having done work on all types of known batteries. Heading the feasibility study is Dr. James George, who has just completed a major study of U.S. and European battery industries. His report may prove valuable to those who "need to know."[9]

In addition to paper studies, it is known that A. D. Little is active in the development of high-energy battery systems—as far as is known, on lithium nonaqueous systems similar to those being pursued by Gulton.

The second study contracted by HEW, to Battelle, is to examine nonelectrically propelled low-pollution vehicles.

Another arm of the U. S. sponsoring feasibility studies on electric vehicles is HUD, the Department of Housing and Urban Development. T. H. Floyd, Jr., of HUD, reports that $150 000 has been granted to the National Academy of Sciences for the first phase of a "new bus design."

The outlook

In speaking about events in terms of being ten to fifteen years ahead, what we are really saying is that we do not know how far off these events lie, or even that their coming is certain. Predictions a few years ahead usually means that we are somewhat more certain. It does appear now that electric vehicles will be developed, but when, how, and in what form are matters that will be shaped by very complex and often competitive forces. It will be an evolution worth watching, for no one can easily assess how both the conservative and aggressive nature of engineering development will play itself out.

Nonetheless, most observers who assess the changed environment in which privately owned vehicles must operate distinguish two rather broad categories of function, and thus the possibility of at least two species of vehicle. Loosely speaking, there is the need for expressway, intercity travel with cruising speeds around 70 miles per hour (110 km/h) and for ranges up to 600 miles (960 km) per day. For this function, the now highly refined gasoline-powered car is at its best, is most efficient, creates the least air pollutants, and so on. Hardly anyone sees this function of the IC engine superseded for a long, long time. In this respect, it is almost not wrong to say that the combustion engine is here to stay.

The other situation, estimated to consume the lion's share of automobile mileage, involves short trips in urban and suburban areas as for commuting, shopping, transporting youngsters, and so on. For such purposes, most authorities are agreed that small, limited-purpose or special-purpose battery-powered vehicles would be most suitable. As family "second" cars, they could be simple, cheap to operate, reliable, and long-lived. They could be recharged overnight at home, or at special

Reflections on the automotive industry

One of my major criticisms of the automotive industry is that they have consistently failed to recognize the serious problems engendered by their products. Not only the presently conspicuous problem of air pollution, but the waste of our natural resources such as gasoline, the problems of safety, and so forth.

I make this comparison between the automotive industry and communications, primarily the telephone industry. The two started out pretty much at the same time, but the automotive industry is still much where it was 50 or 60 years ago. If the telephone company was still stringing lines on poles the way they were back at that time, we'd really have a mess. But, I believe, the telephone industry recognized the kind of mess they were creating. They started early putting some real money into research effort and starting utilizing the research results to provide a better communication system. And, certainly today we have a highly effective communication system and a very inexpensive one. I believe that if the automotive industry had had the same kind of recognition of the problems engendered in the building of cars, and had they funded a research program, and followed through on it, we would today be in a much better position to handle the problems that have been created by the cars themselves.

Prof. L. J. Giacoletto
Michigan State University

People criticize our products. But they only see the *outside* of the car. They don't realize all the engineering and improvements that have gradually evolved and gone into the new cars. If you look back ten years, the product now is much different than it was then.

Dr. Craig Marks
General Motors Engineering Staff

FIGURE 7. The so-called staRRcar represents an innovation in transportation. These small electric vehicles would carry people around, on wheels and on guideways, in a combination of private and public transit. A somewhat similar system, in which the vehicles would be owned and maintained by a transit authority, was proposed by Dr. Richard C. Dorf, University of Santa Clara, at an electric automobile symposium, held in February 1967 at San Jose State College, California.

parking meters equipped with electrical outlets in the city. They would have a range of only 30 to 40 miles (48–64 km) and low speeds, not much above 40 mi/h, or 64 km/h. The technology is available to make such cars now, and provided there is a demonstrable market, they could be appearing in quantity in the next few years. The question is, will the public be willing to accept such limited-performance cars?

Next in the time scale, experts foresee rather less limited vehicles becoming available. These would be urban–suburban vehicles with something like 60- to 70-mi/h (95–110 km/h) speed capability, and ranges before recharging of about 100 miles or 160 km. Such vehicles, experts guess, might be ten years away.

Last comes a general-purpose vehicle, rather dimly envisioned in the dark future. It would have a 70- to 80-mi/h (110–130-km/h) capability and a 400-mile (640-km) range. It might well be a "hybrid" vehicle, employing a combustion engine and an electric motor mounted on a common shaft, with the IC motive system being used for expressway driving and the electric motor for city driving. (Hybrids are by no means new—some were built in the 1920s; and in one sense even the modern car is a hybrid, relying on both gas and electric power.) Experts speculate about all forms of hybrid vehicles—combinations of batteries and fuel cells, batteries and batteries, batteries and gas turbines, and what not. Under questioning, automotive engineers say that such systems are being studied now, but they will disclose nothing about how far such studies have gone or how intensively they have been prosecuted.

Clearly, much basic research would be required to solve the problems that would be involved. How willing the automotive industry is to broaden its base of fundamental research is somewhat problematic. If some of its critics are right, who point out that the industry has traditionally put a trivial part of its huge earnings into fundamental research (see boxes), then the pressure to increase research will come predominantly from *outside* the industry.

In any event, however, one can hardly expect such a huge industry, embracing an empire of capital, materials processing, production, distribution, and people, to change its direction readily. Its overall systemic requirements probably "sets" its direction ten years ahead. Traditionally, it designs vehicles several years ahead; the cost of any major changes in this production universe could be staggering, and wounding if they were miscalculated. And we cannot expect its colossal big brother, the oil industry, to fold its tents and steal away in the night.

As one observer says, ". . . it is reasonable to expect that one line of future developments will be along the lines of maintaining the status quo—improving the efficiencies of gasoline engines, using smaller engines, obtaining gasoline from less readily available sources such as shale and coal, and even in using primary sources of energy to synthesize gasoline from air and water."[3]

Nor do we know really what to expect from gasoline emission controls and research in this area. The automotive and oil industries certainly have done research on these problems, and there is evidence that they are now channeling strong efforts toward cleaning up emission. This is not the place to discuss the import of such work, but if you consider that the reactions of automobile emissions in the atmosphere are extremely complex and not well understood, that it might be necessary to remove lead compounds from fuels (if catalytic converters are used), or that the oil companies might be asked to reduce the volatility of their gasolines (to cut down evaporative emissions), and that even car emission checkout equipment involves elaborate and expensive computer setups, you begin to get a suggestion of the magnitude of the technological factors and socioeconomic conflicts that must be faced. Nevertheless, is it totally inconceivable that research might one day discover how to make a fuel and an IC engine that exhausts nothing harmful to life? Or will that eventual engine (converter) be a fuel cell?

In view of the potentially broad research and development problems lying ahead in the field of transportation, it should not be surprising to learn that some thinkers are trying to develop rational programs whereby we can evolve from what is now technologically available (the "given" conditions, so to speak) to that future when we will have those better vehicles. Dr. Manfred Altman is one who at the 1967 IEEE International Convention proposed a ten-year transition to electric autos, which "is desirable and feasible," and he states that emphasis should in the long run be placed on rechargeable fuel cells rather than hydrocarbon fuel cells. Finally, he says, "only massive government expenditures for research and development can remove the incentive for industry to attempt to establish proprietory positions. In a situation which affects the economy and the people as greatly as the electric auto, the secrecy involved in the generation of patents can only be deadly." He further opines that "the cause can best be served if the Government would establish a number of Electric Automotive Research Centers on campuses as well as in Government laboratory installations. These Centers would insure the widest possible dissemination of technical information which will hopefully be used by industry to engineer the products in the time-honored competitive fashion."[4]

In the system. This article is not the place to discuss the overall transportation system except to acknowledge the obviously extensive studies going on at all levels of industry and government—electrified highways, automatic vehicle controls, mass transit, electrically powered trains and buses—involving problems of both private and public transit. But we should not fail to highlight an electric vehicle that possesses the dual character of being both private and public transportation, and which is at once a vehicle *and* a system. Its conception is simple, and yet bold. It is an exciting concept. Furthermore, its designer and promoter, William Alden, the president of his Alden Self-Transit Systems Corporation, has already developed and engineered his staRRcar system (*self-transit rail* and *road car*) to a ripe stage. Figure 7 shows the staRRcar.

This special small car, powered by batteries, goes on regular roads at normal urban speeds and runs on special automatic guideways at high speeds up to 60 mi/h (95 km/h), thus providing its passengers with portal-to-portal trips from home to guideway terminals as a free vehicle, then on guideways to destinations such as city centers, where they once again can embark as free-wheeled vehicles. The construction of the guideways could be lightweight because the vehicles are light, and they could be constructed along existing highways. Alden calculates that the cost of constructing these transportation ways would be considerably less than some of the mass-transit systems now in the works, such as monorails, rapid transit rails, railroads, and highways, and could serve the function of public mass transit while providing the privacy and convenience of the privately owned car.

Alden thinks of the staRRcars as being essentially "horizontal elevators." Users of the system would not own the cars but would pay for them on a per-usage basis, just as we now pay for the use of telephones. A user could leave a staRRcar at a terminal, do his work or errands, and on return to the terminal pick up an identical vehicle. He could take the vehicle home if he wished, paying whatever rental is required, and recharge the vehicle overnight for his next day's usage. It is the kind of bold and elegant innovation that, if it succeeds, can solve many problems. Mr. Alden says that his staRRcar company aims at becoming to transportation what AT&T is to communication. It is a provocative analogy.

Conclusion

This review hardly requires a conclusion. This time around, the evolution of electrically powered vehicles—whether by battery, hybrid, or other exotic systems—is in the cards. The question now is not "Will they be developed?" but "How soon?" The answer, as we have seen, will be determined by very complex and competitive socioeconomic and technological forces. All those who are seared by the deep and real dangers of air pollution can only say "the sooner the better," and do what they can personally to bring about the desired result.

The writer owes thanks to many persons whom he consulted during the preparation of this article: Connel A. Baker, Jr., Lead Industries Association; M. N. Parthasrathi, Indian Lead and Zinc Information Centre; P. L. Daigle, Edison Electric Institute; John D. Turrel, Farm Electrification Council; M. L. Feldman, Tempo General Electric Co.; R. C. Osthoff, General Electric; J. F. Norberg, The Electric Storage Battery Co.; W. E. Sturm, West Penn Power Co.; R. C. Dorf, Univ. of Santa Clara; R. C. Shair, Gulton Industries; J. H. B. George, A. D. Little; M. Altman, Univ. of Pennsylvania; C. Marks, General Motors; W. Alden, Alden Self-Transit Systems Corp.; T. W. DeWitt and S. Gratch, Ford Motor Co.; D. W. Brodie, Committee on Commerce; B. J. Steigerwald and A. H. Sweet, Dept. of Health, Education and Welfare; G. A. Dalin, Yardney Electric Corp.; T. H. Floyd, Jr., Dept. of Housing and Urban Development; L. Henry, Henry Ford Museum; and others. Special thanks are due L. J. Giacoletto for his lengthy consultation.

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The stormproof power line

Streamlining power-line towers and conductors in areas plagued by seasonal storms is an economically feasible way to reduce the millions of dollars' worth of yearly storm damage

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The forces of hurricanes, tornadoes, and typhoons exceed the energy of many thousands of atomic bombs. Only a fraction of this force, however, actually extends down to the earth's surface. A practical upper limit of maximum wind velocity at ground level due to storms is 200 mi/h (320 km/h). Most power lines are built today to withstand less than that. Without increasing the amount of metal in the tower and thus the cost of material, it is possible to make the power line more wind resistant by applying streamlining concepts to the design of the structural elements, including the conductors. There are several approaches to this problem that can be adapted to existing structures. A French patent suggests the use of a hose around an aerial conductor that turns to adjust its airfoil shape correctly to the prevailing wind. This is also adaptable to vertical members in the supporting tower. The proposed use of flaglike tapes or small fringed plastic threads that wrap around a conductor or angle iron to streamline it, regardless of wind direction, is another solution to this problem.

Hurricanes and tornadoes cause millions of dollars worth of damage to transmission lines every year. The normal wind load on a tower is only about 10 to 20 percent of its total stress. But the enormous wind pressure of storms brings giant towers to their knees, twists conductors as if they were cotton threads, and blows away insulators like leaves. Is this situation unavoidable? With all our modern technological advances it would seem naive to assume that nothing can be done. Just how powerful are the forces of storms, and how often do we experience these forces on the ground? How vulnerable are power lines? What simple methods can we devise to cut down their wind resistance?

The forces of storms

Storms are originated by large masses of heated air that move from the equator to the poles. Equally large volumes of cold air move from the poles to the equator. The leading edges of these masses, the fronts, collide at about 1.2 km above the ground, and cause violent storms. The hurricane originates in the Caribbean and moves toward the northwest. Its meteorological equivalent in the Pacific, usually a more violent storm, is called a typhoon. Both are cyclones, and they are essentially air vortexes rotating clockwise in the Southern Hemisphere, counterclockwise in the Northern. Hurricanes last nine days on the average, typhoons slightly longer. The eye of the hurricane, about 22 km in diameter, is caused by the low pressure created by the whirling wind. It is an island of calm amidst a 800- to 1600-km-wide sweep of destruction. The destruction is increased near the coastline. As a hurricane created over the sea approaches the continent, it piles up water and blows it toward the land. At times of high tide their combination with strong winds creates a particularly disastrous storm condition.

Since the tornado lasts only a few hours and covers a much smaller area than a hurricane or typhoon, it generally causes less damage even though it is a more violent storm. The characteristic funnel-like cloud, which also rotates counterclockwise in the Northern Hemisphere, can explode buildings or denude the trees of entire forests by the underpressure created by the whirling wind. Heavy rains usually precede and follow a tornado. Intense lightning strokes illuminate the area. After a few hours the tornado disappears, traveling from southwest to northeast, leaving death and destruction in its wake. Where the tornado funnel touches the ground the destruction is complete. Houses can be entirely blown away, and at times entire towns are wiped out.

There are from 2 to 21 hurricanes a year in the United States, with a mean frequency of seven hurricanes per year. An average of over 40 years shows that there are about 150 tornadoes annually in the United States. These tornadoes cause on the average about 230 deaths and 13 times as many injuries, and property damage of $91 million. No state is free from tornadoes; Florida has some five to six a year, and New York State has about two every three years.[1-3]

To be classified as a hurricane or a tornado in the United States, a storm must have a wind velocity of more than 95 km/h. Most of the so-classified storms do not reach 160 km/h, except for momentary gusts up to 320 km/h. It is of interest to observe that the velocity of the whirl inside a tornado, and high above the ground, may reach 700 to 800 km/h. On the ground, however, the most that can be expected from these storms is 320 km/h. A wind velocity of 320 km/h then can serve as the design maximum for any ground structure.

The lack of data makes it exceedingly difficult to estimate the damage caused by hurricanes and tornadoes in the United States. After considering all available statistical data, press releases, and other reports, the following approximate breakdown of damage caused by a single hurricane or tornado in the United States can be made:

1. Total hurricane damage	$500 million
2. Hurricane damage to electric utilities	$ 2 million
3. Total tornado damage	$ 1 million
4. Tornado damage to electric utilities	$ 0.1 million

Using these figures, combined with the average of hurricanes and tornadoes in the United States, the total damage caused to power lines can be estimated as about $20 million a year. This is only an educated guess, because there are not enough data published to enable a dependable estimate of storm damage to be made.

Storm vulnerability

The public has generally, if tacitly, assumed that it is impossible to build electric lines so that they can withstand any storm. This assumption holds true only for the most powerful gusts of wind and freak storms. In areas where storms are frequent, such as in Florida and Louisiana, utility companies have developed power lines that are sturdier. If it were not for this fact, the damages suffered by these companies would be much greater than they are. For example, in Florida, concrete-reinforced and prestressed poles, provided with crossarms and brackets of the same material, can withstand up to 145 km/h. In Louisiana, some lines are designed to withstand winds of 190 km/h, with gusts up to 290 km/h. Plans are in progress to build strategic towers to withstand 240-km/h storm winds, with the towers for river crossings made to defy the maximum of 320 km/h.[4] Safety factors of 4 to 7½ have been adhered to for critical towers in a power-line system. It is therefore obviously possible to meet the requirements of storm forces on power lines when it is an economic necessity.

More insight into the situation can be gained from a glance at the building industry. In the Midwest, long plagued by tornadoes, stormproof wooden buildings have been built for a long time. All that is necessary to make a wooden building stormproof is to use heavy timber and a large number of nails. The steel-reinforced concrete building has proved to be fully stormproof, except perhaps for its windows. A city like New York withstands many storm assaults with relatively little storm damage. If modern buildings can withstand any storm, why then cannot modern power lines? The answer is that they *can* be built to do so when it is an economic necessity. Of course, to be realistic we must also take into account the fact that the sturdiest of towers might not survive instances of objects being blown against them (a flying tree, for example, buckling a normally strong tower), or the unusual force of a direct encounter with a tornado funnel. No matter how strong the line, an element of risk is always involved. It is not economical, however, to build power lines so that this risk is a minimum.

That this is the case can be seen from the following example. How strong would a power line have to be to withstand 320-km/h winds? A wind of 80 km/h is "normal" and causes a wind load equal to about 15 percent of the total load of the tower. Since the wind load grows with the square of the wind velocity, it can be roughly approximated that at 320-km/h winds, the total load on the tower doubles that of the normal load. Consequently, in a rough approximation it can be assumed that a tower capable of withstanding a catastrophic wind of 320 km/h would have double the amount of metal it normally contains. Although technologically feasible, this is uneconomic since lines would cost twice what they cost today. To prevent a loss of about $20 million per year, it would be necessary to spend hundreds of millions of dollars annually. Are there not solutions to this problem that do not require a considerable increase in the metal requirements of the power line?

Streamlined power lines

The damage to power lines can be restricted by several means. So called "tension limiters" have been proposed and sometimes used to cut down the damage by providing weak links that fail when overstressed. The most promising approach to the problem, and one that is economical at the same time, is to streamline the power lines. Catastrophic wind loads can be reduced to only a small percentage of the load on a power line that is not streamlined. The simplest streamlined shape is the circle. Its most important advantage is that it is also a streamlined

FIGURE 1. French scheme for streamlining conductors.

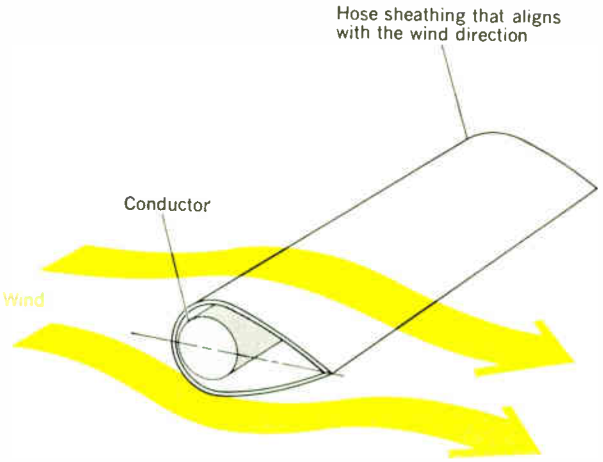
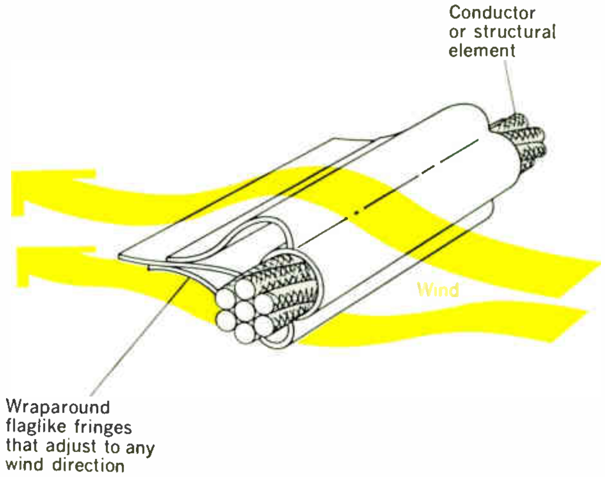


FIGURE 2. Streamlining method devised by the writer.



shape for wind that is coming from any direction. The circular shape can be easily applied to towers by using metallic rods or tubes for the latticework. However, since the wind velocity is smaller at the ground than it is higher up, only the upper part of the tower need be made of rods or tubes. Another possibility is to make the edges of the tower of conventional angles, and to connect them with rods or tubes, bent in a sawtooth shape that is welded to the corner angles.[5]

The coefficient of air friction on a circular rod or tube is about 60 percent of that on a flat surface of the same width. Using rods would therefore reduce the wind pressure on a tower by 40 percent. Of course, a rod capable of withstanding the same tensile stress as an equivalent angle iron has a smaller cross-sectional area than the angle iron has. This would make the decrease in wind pressure on a tower using round structural elements seem more pronounced than would be predicted from a decrease in the air friction coefficient alone. The question is, how much more?

The following estimation will help to evaluate quantitatively the advantage gained by applying round structural elements on towers. A metallic rod having the same cross-sectional area as an equilateral angle has a diameter equal to about half the width of the flange of that angle iron. Rods can replace angle irons of the same cross section when tensional forces are involved, but in order to withstand a corresponding compression force (and avoid buckling), a tube is necessary instead. The diameter of a steel tube with the same cross-sectional area as an equilateral angle iron equals approximately the width of the flange of that angle iron.

For the crude approximation of this example it is sufficient to assume that half of all the angle irons will be replaced with rods, and the other half with tubes. Consequently, the "average" cylindrical elements used to replace an "average" angle iron will have a diameter equal to 0.75 of the width of the flange of the angle iron. As a result the wind pressure on the tower will be reduced to 0.75 times 0.6, or 0.45 of what it was when angle irons were used entirely. This is a significant reduction and it suggests that this approach is in the right direction, although not quite sufficient to produce a practical and economical stormproof power line.

Power lines with airfoil surfaces

The reduction of the wind pressure on a power line by nearly 50 percent does not solve the problem completely. For further reduction of the wind force on a tower, the angle irons must be replaced with structural elements of drop-shaped cross section. The air pressure on an element of drop-shaped cross section is 1/16 the pressure on a circular element of the same cross-sectional area. Replacing the circular tubes with extrusions of drop-shaped cross section would reduce the wind pressure by 1/16 the circular pressure of 45 percent, or down to 2.7 percent of the original pressure exerted on a tower constructed out of angle irons. This certainly would make a tower almost entirely stormproof and enable it to withstand the pressures exerted by storms of 320-km/h winds or more.

Remarkable as this solution seems to be, the question still to be answered is how to achieve it in practice. How can a structural element be made to have an airfoil shape of droplike cross section, and have the longitudinal symmetry axis of this shape automatically adjusted in the wind direction prevailing at any moment? The French firm of Compagnie Electro-Mecanique solved this problem by using a hose sheathing that easily turns with the wind direction, as shown in Fig. 1.[6] Though this idea is meant for horizontal conductors, there is nothing to prevent its application to the vertical structural members of a tower. The hose can be formed of straps, staple-fastened at their edges into the drop-shape cross section; or of two pieces of suitable material fitted together into the correct shape; or suspended on free-turning rings, of an appropriate exterior shape, that align themselves with the wind direction from point to point along the conductor or support. A flexible hose of a weather-resistant glass fabric, perhaps, could be connected at one end, the remainder being free to turn in the wind. An angle iron could be streamlined by using an aluminum foil bent around into the correct drop shape, being supported at the bottom by short rods.

An even simpler method of streamlining the structural elements of power lines has been patented by the writer.[7] If flaglike surfaces were attached to objects requiring streamlining they would arrange themselves in the direction of the wind by wrapping around the structures, and in effect streamline them, as shown in Fig. 2. The same idea can be applied to the conductors of the line, which is the primary concern of the patent. The flags not only decrease the wind pressure on conductors, they also completely prevent them from vibrating. It is possible to fringe the flags, and the fringe may take up the whole width of the flag. In this case, the flag is replaced with a row of threads, fastened to the structural elements by means of dissolved plastic, or to the conductor by interweaving the threads between the strands of copper.

These methods could also be used to streamline poles, substations, or any other structure subjected to catastrophic wind loads.

Conclusions

The practical design figure of 320-km/h wind velocity represents the maximum encountered in all but the most unusual storm conditions on the ground. Until it becomes possible to increase the basic strengths of materials so that the structural members of towers and conductors can withstand any storm force, the most economical solution to the problem of stormproofing power lines seems to be streamlining. Since streamlining markedly reduces the load on a tower, additional savings can be realized because less structural material is then required to achieve the same, or even superior, resistance to the forces of storms. Attaching a fringe of flags or a hose of a weather-resistant glass material to tower structural members and conductors is one inexpensive and practical solution to the problem.

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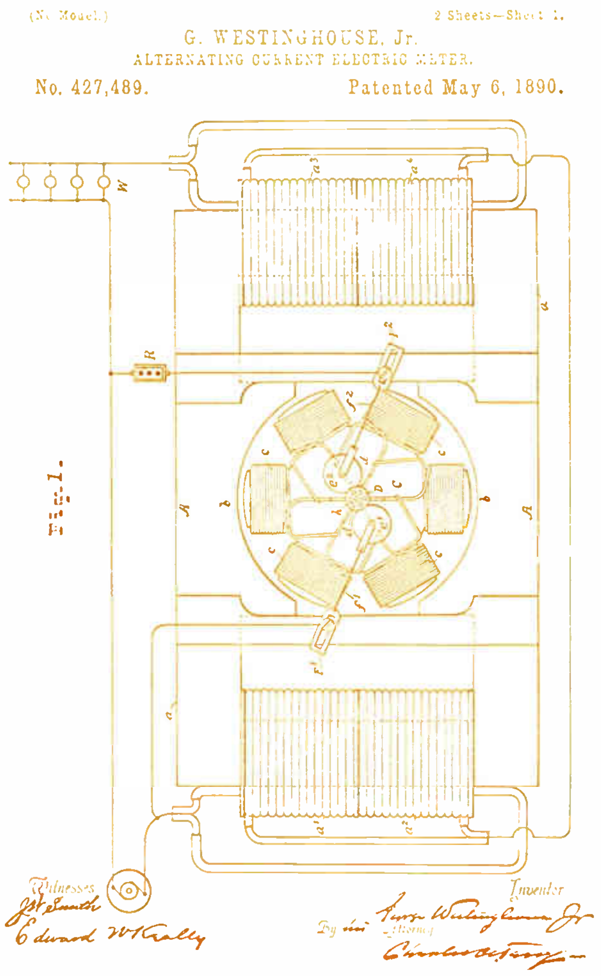
Should we do something about patents?

The U.S. patent system provides many benefits both to the inventor and to the general public. IEEE and its members have a vital stake in perfecting that system's vast potential for promoting progress

Harold B. Whitmore

U.S. Patent Office, Retired



Part of early Westinghouse ac electric meter patent.

In the February 1967 issue of Spectrum, IEEE Secretary B. M. Oliver discussed some of the highlights of a recently released report by the President's Commission on the Patent System. The present article examines the benefits of the patent system to engineers and to the public. It touches high spots in the lifelong bond between electrical engineering and the patent system, from the first organization meetings of the AIEE in 1884 up to 1967. Finally, it blends in with the work of the President's Commission by discussing some of the needs and remedies mentioned in the Report, and the opportunity for engineers to aid in vitally improving the fundamental patent system function of promoting technological progress in the United States.

Opinions on the question posed in the title of this article are fascinatingly divergent.

An electronics research man asks, "What good are patents? If people are going to invent, they'll do it anyway. We don't need a patent system. Junk it."

The loser in a patent suit, forced to pay royalties, may say, "Promote progress? The patent system is a brake on progress!"

An engineer, cloistered in his specialized field, may say, "What interest have I in the patent system?"

Yet our own Secretary, B. M. Oliver, writing in the February 1967 issue of SPECTRUM about the recent vigorous report of the President's Commission on the Patent System, stated: "Quite early in its study, the Commission came to the unanimous agreement that a patent system is a necessary part of our technological society." He also said that "changes in U.S. patent law are of direct concern to IEEE members in the United States and, because such changes may induce changes in the laws of other countries, they should also be of interest to IEEE members generally."

If so diverse and prestigious a body as the President's Commission reached this conclusion unanimously, perhaps the public, and especially engineers, should take a deeper look. Engineers in particular should do so because so much of their work is closely interwoven with the patent system, and because, as IEEE President Shepherd said in an address presented at the National Electronics Conference in Chicago last fall (see December 1966 SPECTRUM, pages 35–38), we engineers have the declared chosen mission of adding to the creativity of the scientist the further duty of *implementing* science and technology *for the use and convenience of man.* In the progress of any concept from personal dream to the final use and convenience of man, the incentives and protection of the patent system often have a crucial role.

What is that role? When opinions diverge, a major cause is often an information gap. Perhaps the following discussion will help to bridge that gap.

Benefits to the inventor

Fundamentally, the patent system is a sort of mutual benefit system. The public benefits from the disclosure and development of new inventive concepts. The inventors, in exchange, receive 17-year exclusive rights to personal benefits from their contributions.

Not all engineers are inventors, and not all inventors are engineers. Yet the American pattern that the one who dreams up a new concept also directs putting that concept into practical working form tends to blend inventor and engineer into one. Benefits to the engineer–inventor side of this exchange may be of many kinds.

In the 19th century, benefits were commonly personal and direct. Companies that still bear the names of Bell and Edison typify those benefits. Modern inventors, such as Land of Polaroid and Carlson of Xerox, also have realized such benefits. Certainly many of our own IEEE members in their lives and bank accounts have solid evidence of a first benefit of satisfaction, profit, and prestige, whether from the direct sale of patents, from profits of their own companies, from royalties, or from bonuses and higher salaries paid by corporations that place a high value on creative minds, as in the case of one blithely contented engineer–inventor who remarked, "My salary? I really don't know. The company puts my checks in the bank and I've never overdrawn my account yet."

The first step of any invention—the concept—is often easy. Congenital inventors will always dream of new concepts, regardless of any patent system. It is in the far harder next step, which involves the added thought, time, work, and money necessary to develop the concept into practical operating form, that the patent system's protection for eventual financial recovery and profit offers the inventor or his assignee the second great benefit.

A third benefit to the inventor–engineer, and equally to the noninventive engineer who merely wants to know all that other people have done in his field, is an extension of that cross-fertilization of ideas so familiar to IEEE members and other engineers in the publications of their specialized groups, namely, the enormous body of knowledge available in the Patent Office.

The refined classification of this worldwide scientific and technical knowledge developed over many years by the Patent Office affords similar cross-fertilization on a far larger scale. In the constant search for improved methods of information retrieval, the U.S. Patent Office has long been a foremost leader. The Office is cooperating to the hilt with industrial organizations, with other agencies of the U.S. Government, with other governments, and with international organizations, such as BIRPI and ICEREPAT, to develop all possible advances in the complex art of information retrieval and to make them available to all who are interested.

The enrichment potential of this storehouse of past and present knowledge is no new discovery. A quarter century ago, one court said, in effect: "The appellant argues for patentability because he spent a million dollars developing the ideas for this product. One wonders why he did not instead spend a few hundred, to find in the public files of the Patent Office these same ideas, all old, well developed, and ready to use." More recently, in the Graham case decided by the U.S. Supreme Court in 1966, Justice Clark commented on the "knowledge stored in the Patent Office" and on the "simple expedient of conducting a patent search,. . . a prudent and nowadays common preliminary to well-organized research."

A seldom realized but highly valuable fourth benefit of the patent system to the inventor–engineer in such complex fields as computer technology, nuclear physics, biomedical electronics, and space sciences is the personal interchange of ideas with the broad-ranging knowledge inevitably acquired by expert patent specialists, both examiners and attorneys, working in these disciplines.

For these specialists, the costly fundamental education in both science or engineering and law is only a starting point. Like invisible warp in the ever-changing tapestry of science, law is vital, and information about the law of patents often helps the inventor in evaluating his contribution. The true scope and value of his invention, however, and of the eventual patent, depend mainly upon how the threads of his own contribution interweave with the total pattern of scientific and engineering advance.

It is here that the top-caliber examiner in the Patent Office is often of great help, in evaluating the invention and in formulating proper protection—but not of help, may I add quickly, in actually testing the device. Although the records of the IEEE do show that once upon a time, in 1884, the Patent Office was munificently provided with a test laboratory, which consisted of ten battery cells, one hand dynamo, and "two small galvanometers, of old pattern," such luxuries have ended.

Today, answers to questions of operativeness and significance, no matter how erudite or how far out on the least known frontiers of science, depend wholly upon the knowledge, experience, skill, and judgment of the examiner. His competence reflects an ever-expanding education and constant technological research matching that of the research engineer, to keep constantly abreast of known theory and practice in the ever new and changing fields where he works. Alert awareness of worldwide knowledge in these obscure pioneer fields is immeasurably valuable in aiding inventors and their representatives to visualize the full significance of their concepts, and to define validly in words of optimum clarity the difficult border line between patentable private contribution and the public domain.

Benefits to the public

However, the constitutional provision makes clear that the intended primary benefit was not for the inventor alone. It was for the public—the *entire* public, not excluding inventors and engineers, of course, but also the entire *noninventing* public, including even those scientists and innovators whose rewards for outstanding contributions to progress do not at this time include the direct benefits of the patent system. How does this larger public, the whole public, profit?

The list of benefits is long. Personal rewards through the incentives and protection offered by the patent system reach far beyond the inventor himself. Because of this protection, inventions win the backing of investors, and new industies are born.

From the wellsprings of new industries, expanding benefits flow out in growing streams. Buildings and equipment must be built or purchased. New jobs appear, for skilled and unskilled workers, managers, engineers, salesmen, executives. To new employment benefits, the local community adds property and other tax benefits. With able management and development costs protected by patent rights, the small corporations of today often become the corporate giants of tomorrow, with growing benefits to their communities of origin and to the entire country. Financed by profits, research evolves new and ever-better products, with a recycling and enlarging of the entire floodstream of benefits.

One benefit to the entire country is the flood of ideas that the financial rewards of our U.S. patent system have brought from inventors of foreign countries: the DDT of Swiss inventor Mueller, the life-saving insulin of Canadians Bunting and Best, the carbide cutting tools of Schroeter of Germany. A method basic to all atomic processes today was fully disclosed to us long ago by the Italian Fermi and others in the U.S. patent they sought and received. The Japanese contributions to the alnico permanent magnet art and the older innovations of the German Wilm on age-hardening aluminum alloys, which changed aluminum from a laboratory curiosity to the industrial giant of today, are typical of the thousands of contributions from abroad that the incentives and rewards of the patent system have brought to the United States.

How does one measure the benefits to health? How many lives have been saved because the protection of the patent system afforded funds for the private research and development that brought us the sulfa drugs, the antibiotics, the birth control drugs, and the numberless others that typify the hope of ultimate answers to problems that have plagued humanity since time began? Is it significant that swift advances in biomedical electronics, in diagnostic, therapeutic, and prosthetic fields, are often financed by funds derived from patent system benefits?

Financially, the benefits flow to endowment funds, educational and eleemosynary institutions, and most of all to governments. Income to the Federal Government directly from royalties and indirectly from incomes and profits derived from the stimulus of the patent system has long since passed into the billions.

Finally, of course, there is the composite benefit to all consumers in the United States, a benefit so vast that its total extent is immeasurable. It permeates our daily lives. Why can farmers grow 50 bushels where they used to grow 25? In large part, certainly, because patent-protected research has brought them new chemicals, new fertilizers, new insecticides, new machines. New helmets of new and tougher plastics make construction workers safer. New aerosol hairsprays keep your daughter's teased hair in place.

And do you remember Grandmother, 50 years ago, straining her failing eyesight by the glimmer of a single kerosene lamp to mend the ceaseless stream of holes that appeared in the toes of the family socks, day after day after day?

That glimmer of light today is a flood that rivals daylight itself, and synthetic fibers are banishing toe-holes in socks to oblivion. What, then, do grandmothers now do with their evenings? They probably watch color TV. The protection of the patent system made possible the investment of hundreds of millions of dollars in color television research, estimated at $130 million for one company alone. Today, we look at a sheet of glass blanketed by four million separate dots, each electronically supplied by systems so complex that they rival nature herself, and we see the whole world, even the universe beyond, an arm's length away.

Private invention and industrial research under the stimulus and protection of the U.S. patent system have had a major share in bringing to the United States the most luxurious civilization the world has ever known.

The electrical engineer and the patent system

It seemed worthwhile to learn what share electrical and electronics engineers have had in the evolution of the patent system and its many benefits. Volume 1 of the TRANSACTIONS OF THE AIEE, one of IEEE's two forebears, seemed a logical place to begin. The first look was a revelation. For entertainment, as well as for solid information, I recommend a perusal of this volume.

The AIEE was organized on May 13, 1884. Elected were 21 Officers and Managers, in a list laced with such still-famous names as A. Graham Bell, Thomas A. Edison, Charles F. Brush, Elisha Gray, Edwin J. Houston, Theodore N. Vail, and Edward Weston, among others.

At that first meeting, besides the election, what other items of business were involved? Just one—the Patent Office! Quite evidently, "C. J. Kintner, Ex'r Class Electricity, U.S. Patent Office" was not a timid soul. A communication from him, regretting that illness in his family prevented his personal attendance, bristled with such language as . . . "burning shame" . . . "are inventors to sit idly by and submit to this while the Patent Office is crowded out of its building" . . ." it is simply absurd that the Congress of this great country does not have the foresight" . . . "Throttling the upward progress of an advanced civilization" . . . "the Examining Corps crowded down into the coal vaults and cellars of the building" . . . "two small rooms . . . so damp and so crowded as to cause much sickness. . . ."

Small wonder that apart from thanks to the host, the only two resolutions passed at that meeting urged that the Institute and its members exert their influence that "the work of the Patent Office may be put on a more efficient footing," and call ". . . the special attention of Congress to the needs of the Patent Office, especially in regard to the class of electricity."

The IRE, our second forebear, with such founders as Dr. A. N. Goldsmith, holder of more than 200 patents, carried the tradition into the 20th century.

In today's "space age," when so many inventor-engineers work with organizations that have large patent departments, personal interest and involvement in patent matters is less common; but the high caliber of the specialists who guide the onmoving patent fabric is an eloquent reminder of the continuing importance of patents. It is no accident that IEEE members have been chosen as presidents and other officers of such organizations as the Patent Office Society and the American Patent Law Association. It is no accident that IEEE Bylaw 105.3, mindful perhaps of the engineer's duty of "implementing science and technology for the use and convenience of man," specifies "patent prosecution or patent law" among the related activities where distinction may qualify IEEE members for higher grades. The importance of a sound patent system is reflected by the Fellow nomination form, where "patents issued" constitute one appropriate gauge to indicate creativity.

The foregoing background suggests how well founded is Dr. Oliver's conviction that the patent system is of concern to every IEEE member. It is important that the story that he so clearly presented in the February SPECTRUM evoke our intensive study and action. His article highlights the *quid pro quo* benefits of the patent system, the stimulus and mutual enrichment of ideas, and the advantages of early public disclosure over the wastefulness of secrecy. It is implicit that patents justify industry in abandoning the risky and socially wasteful reliance upon secrecy *only if the patents are valid.*

The present dangers threatening patent validity include standards of invention that are too low or too wobbly. Examiners in the Office are often trapped between the

Scylla of too great a workload and the Charybdis of too meager time and staffing, between the conscientious desire to issue valid patents and the sinister awareness that many pressures make it always, as Dr. Oliver says, "far easier for the examiner to allow than to reject."

He summarizes objectives of the recommended reforms as to improve the quality, validity, and enforceability of patents; to accelerate the disclosure of technological disclosures, and the issuance of patents; to minimize patent litigation and costs; and to flex U.S. patent procedures and practice to meet the future needs of increasing technological knowledge and more international cooperation.

Tested against those objectives, the Commission scores high. It has had the courage to back meritorious old proposals, and to propose creative new ones.

If the report seems less than wholly satisfying, it is perhaps because lack of time required that it touch too lightly upon two closely related questions that seem fundamental to all the rest. The first deals with validity. The second involves probable future demands upon the Patent Office, and probable future capacity of the Office to meet those demands.

The quest for validity

In order for us to understand the first question fully, a quick look at the nature of validity is necessary. It is not a single mathematical fact. It is rather a whole spectrum of increasing probabilities, intimately bound with economic factors that determine those probabilities.

At the left of the validity spectrum, a patent is issued on the basis of a pure "registration system," as in France. The Patent Office gives no administrative adjudication of patentability. The issued patent amounts to little more than registration of a concept; it is little more than a notice of intent to claim patent rights if some court should subsequently establish that patent rights do in fact exist.

Moving to the right, the probability that the patent expresses a valid patent right increases in a country with an "examination system," which issues a patent only after an administrative determination of just how much protection the patentee is entitled to, as in the United States and a few other countries. The *amount* of the increase depends entirely upon the extent of the facilities for search of prior art, and the thoroughness of the examination.

In the United States, for example, there are three main essentials for which a court looks in any patent suit. Is the *disclosure* adequate to meet the requirements of the law? Is a legally *patentable concept* present, namely, something new, useful, and patentable? And do the claims *define* that concept clearly enough to be enforceable in court?

A thorough examination must consider all three questions. To decide whether the disclosure is adequate is seldom difficult. Whether the claims properly define a patentable concept is often more difficult, as a young examiner learned when his more experienced and imaginative supervisor pointed out that in an application for patent on a clearly patentable space-satellite control device, certain claims he had allowed were fully met by any outboard motor! As to whether the disclosed matter is new, deciding the extent of the search necessary to find out can often become a matter of pure economics. With the amount of money Congress has provided, the examiner asks himself how much time he can afford to spend, as the probability of finding pertinent art in additional fields of search becomes less and less.

Any inadequacies of the examination may be offset in part by any postpublication opposition proceedings and postissuance cancellation proceedings, which move farther to the right the probability that the patent will be found valid by the court.

In court, if the patent is found valid, the probability line on the spectrum moves yet a little farther to the right. Regardless of how thorough the examination and search have been, however, if the court disagrees with the examiner's judgment as to whether the subject matter involves invention or unobviousness over prior art, the patent may still fail. Only when the final decree is issued by the court of last resort is the validation spectrum complete.

Certain of the report's recommendations for legislative changes could at low cost move the probability for validity well to the right of where it now rests. These would include at least Recommendation X, which puts the burden of proving patentability on the applicant; Recommendations XI and XV, which would afford opposition and cancellation proceedings; Recommendation XIII, which provides that the usual Administrative Law principle that administrative decisions, in the absence of clear error, are not reviewable in court, shall apply uniformly to all Patent Office decisions; and Recommendation XIV, which provides an appellate procedure that would eliminate many of the conflicts and confusions that now handicap the work of the Patent Office. Yet the greatest problem of potential weakness, the examination within the Patent Office, seems less than clearly met.

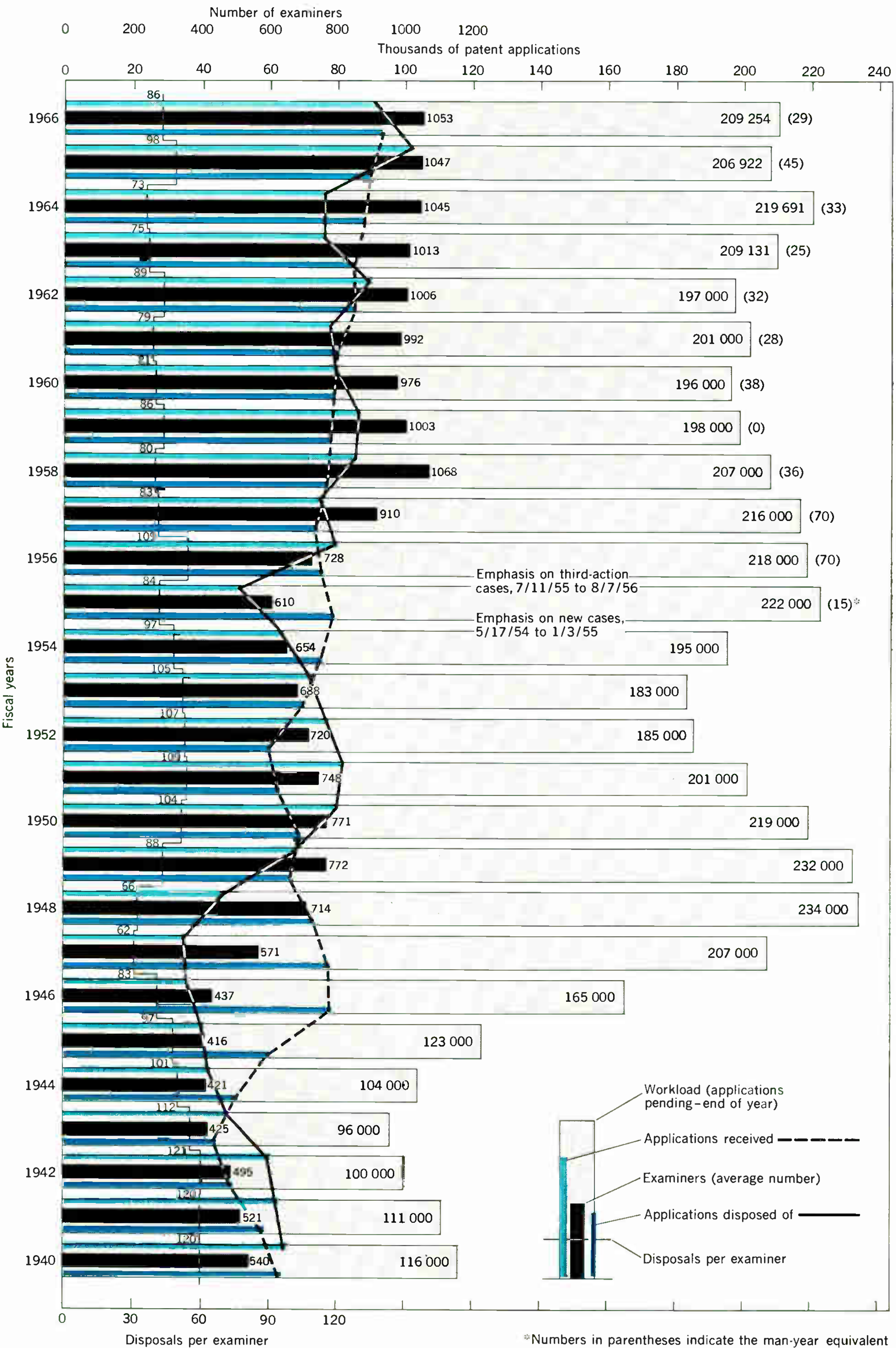
Adequacy of the full examination system

The Commission's split opinion with regard to Recommendation IX, the need for a "deferred examination" system, which is admitted by the entire Commission to be an inferior substitute for the present system, may arise from incomplete information. The points discussed in the next few paragraphs seem to the writer to indicate clearly the adequacy of the present system for many years to come.

There has been a recent tendency, perhaps based on inadequate information, to panic about the future of the patent system. There is talk of the current explosion of scientific and technical knowledge, and an expectable inflooding of patent applications beyond what the Patent Office can handle. The mass of human knowledge is becoming so great that no patent system based upon thorough examination, upon comparison with known existing knowledge, can possibly survive. Cases also are far more complex, more time consuming. The proportion of such complex cases is rising.

The number of items to be searched continues steeply upward. The annual bill for R & D in the United States has risen from the $2 billion of two decades ago to $22 billion today. All over the world, the number of applications is rising. With the number of people in science and technology doubling every 15 years, will not the massive inflooding of their applications soon make the information retrieval tasks in any examination system impossible?

There is talk too that just as we have been unable to



*Numbers in parentheses indicate the man-year equivalent of overtime examination for the years shown.

FIGURE 1. Workload, examiners, and rate of production in U.S. Patent Office, 1940–1966.

wipe out backlog and long delays in the past, the American people, speaking through Congress, will continue unwilling to provide the time, money, and personnel to permit functioning of the old system, however good, in the far more difficult future.

Should we be alarmed by all of this talk? Many a young camper, frightened by noises and shadows in the night, discovers at daylight that the man-eating tigers of his fears have turned into cows. A little light can liquidate a groundless fear. Touch this ballooning talk of an endlessly ballooning backlog with the needle of sound statistical analysis, and it collapses completely.

Temporary staff shortages are nothing new. The Office files contain an official copy of a patent (see title illlustration) issued to one G. Westinghouse, Jr., in 1890. On the back, in the faded ink of some long-forgotten hero, is written: "Claim 1 was inadvertently allowed. It was intended to cite German patent #43487 of '87 as a reference, but in the hurry due to the great pressure of work in the office it escaped the Examiner's mind."

Conceding such temporary troubles, does a *long-term* view show a continuously rising backlog? The chart of Fig. 1 gives the answer.

The high rectangles show the total workload of pending applications at the end of each year. For each year since 1948 when the backlog has risen, there have been *two* years when it was *reduced*. In 18 years, 12 showed backlog reduction and present trends hint that fiscal 1967 and 1968 will add two more years of backlog reduction.

Analysis shows that had appropriations permitted a productivity increase averaging not 10 percent, nor even 5 percent, but a mere 3 percent, we would have *no* "backlog" today. Our workload would be down to a size where we could stay completely current, even with our present work force.

How then will future Patent Office capacity compare with probable future demands? Is a catastrophic rise in applications wholly beyond Office capacity to handle inevitable? A deeper look at those fearsome demands is needed.

Figure 1, which covers the years 1940 through 1966, shows a rise in recent years in "applications received." Office records show a similar upsurge in the late 1920s, with a crest in 1930 of over 92 000 applications, not remotely approached for more than 30 years. So far in fiscal 1967, the trend seems down. Are we perhaps at the crest of a long recurring cycle?

Is the astonishing upsurge in cost of R & D being reflected in the rise in applications? Quite the contrary. Analysis of applications filed in recent years shows that almost the only increase is in foreign applications. Applications from the United States have been almost static, around 67 000, for several years. Perhaps the cause is that most of the huge increase in R & D is not in R, but in D; far less, that is, for invention and research than for costly development, in an insistent engineering quest for those trouble-free practical operating systems required for the far-out uses of today.

And what of the worldwide rise in the number of foreign applications filed in every country? Studies indicate that this rise does not reflect an increase in original thought or in the number of inventions; it appears due rather to the growth in international trade. A company operating in only one country needed only one patent. Today, with many industries operating in many countries, patents in all of those countries are often a necessity. Where formerly one patent for one idea was enough, one idea today may require a dozen patents, in the dozen countries where the idea will be commercially used. What then does this international rise in applications mean? It means not a rise in inventions, but rather, in the long run, a demonstrated need for the economy of international patents.

And from the alleged doubling of scientific and technological personnel every 15 years, what fascinating possibilities we may infer! With the world total population doubling only every 40 years, logic requires that we reach a point soon where we have more scientists than people. Could we possibly be reaching a ceiling? Could it even be that as the scientists among us reach deeper and deeper toward the irreducible minima within the atom, and farther out to the moon and the planets and the faraway stars, the logarithmic curve of our learning might be leveling toward a momentary asymptote?

In all of the evidence that has come to the writer's attention thus far, no realistic basis for any gross upsurge in applications filed can be found. The demands will be moderate.

Conclusions

What then can we say of the Patent Office's capacity to meet these moderate demands? As a starting point, the Patent Office is freshly armed with the results of five years of creating, developing, and applying new modern streamlined procedures, which have already cut hours off the time required to process each case. If, as some contend, so much has been cut away that the thoroughness of examination and probable validity is hurt, current quality control studies will provide the cure. Current operations are already reducing the backlog.

What of the years ahead? The improved procedures are functioning more and more effectively, as demonstrated needed changes are adopted and become effective. Congress has already provided some increase in funds and personnel as part of a long-term program to reduce backlog and improve classification, and hopefully it will continue its support. However slowly, information retrieval processes are being improved. Economies through international exchange of search results and through limited international search offices are being studied. There has probably never been a time when so much thought, effort, and success has enriched and strengthened the effectiveness of the examination system.

Clearly, we need no "deferred examination" system for many years ahead. If the time comes when we do, the cooperative Dutch, already using the deferred system and well on toward learning its long-term effects, will certainly make the lessons of their experience available to us.

We should be grateful to Dr. Oliver and other members of the Commission for their work. By all means, let IEEE members concern themselves with the patent system, and with its improvements. And let us do so carefully, thoughtfully, actively, so that when changes come, they may be all for the better.

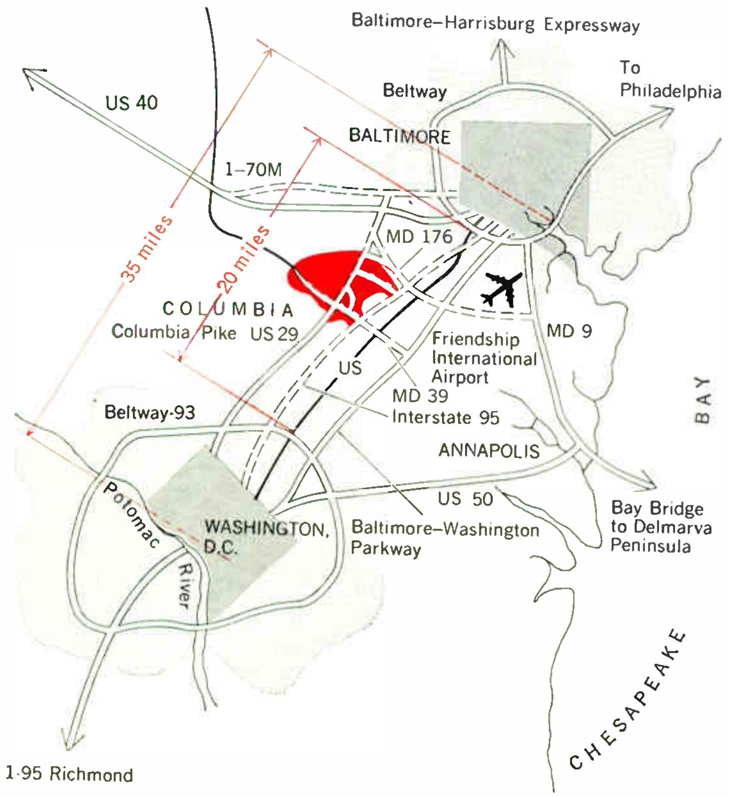
I. Principal 'new cities' in the United States

Name	Locale or Vicinity	Developer	Projected Population
Clear Lake City	Houston, Tex.	Humble Oil	150 000
Columbia	Howard County, Md.	James Rouse	110 000
El Dorado Hills	Sacramento, Calif.	Alan H. Lindsey	75 000
Irvine Ranch	Orange County, Calif.	Irvine Co.	80 000
Janss/Conejo	Ventura County, Calif.	Janss Corp.	87 000
Laguna Niguel	Orange County, Calif.	Laguna Niguel Corp.	40 000
Lake Havasu	Lake Havasu, Calif.	McCullouch Properties	60 000
Litchfield Park	Phoenix, Ariz.	Goodyear Tire & Rubber Co.	75 000
Mission Viejo	Newport Beach, Calif.	Mission Viejo Corp.	80 000
New Orleans East	New Orleans, La.	Clinton Murchison, Jr., et al.	175 000
Reston	Fairfax County, Va.	Robert Simon	75 000
Valencia	Los Angeles County, Calif.	California Land Co.	200 000

ancient Athens. And the Roman forum served the same purpose for urban dwellers of the old city. Thus the concept of many stores in a complex unit is hardly a novelty.

The shopping plaza of post-World War II vintage was planned, allegedly, to ease traffic congestion in urban areas through strategic situation either in the suburbs or on peripheral outskirts of cities. But many of these plazas, with badly planned and inadequate access facilities, have created some monumental traffic bottlenecks even in suburban and rural locales. Also, proper site development was accorded a minimum of thoughtful planning so that many of these centers feature single-field parking areas for 5000 or more cars. And it is not unusual for a prospective customer to be confronted by a 10-minute walk from his vehicle to the store in which he may wish to shop—plus a 20-minute additional ordeal in trying to remember where, in a trackless wilderness of chromium, he parked the family jalopy.

FIGURE 1. Map showing the Columbia site, approximately midway between Baltimore and Washington.



The first step back. In the sequential evolution toward the inevitable concept of the new city, there were bound to be intermediate phases—and even an apparent retreat—toward ultimate progress. Hence, the first step back, in the late 1950s, was a reversal of the decentralization trend, and the shopping center complex, much like the agora of antiquity, was returned to the heart of the city.

Notable multimillion-dollar urban plazas were built in Fort Worth; Rochester, N.Y.; London, Ont.; and Seattle. Huge mid-city centers are being built or planned in White Plains and New Rochelle (N.Y.). All of these projects are literally "cities within cities," and they offer a multiplicity of goods, services, entertainment, and even hospital and medical facilities. Multiple-level parking garages and considerable street reconstruction are necessary to assure proper traffic flow to and from these downtown sites. Naturally, developmental costs are extremely high and few promoters are in a position to make such enormous investments. And the inherent historic urban evils of traffic congestion, inadequacy of public transportation, and soaring tax assessments have militated against the downtown plaza concept.

Pioneering efforts in new city planning

In the early 1960s, many farsighted architects, city planners, and engineers came to realize that the problems of existing metropolitan areas were already so complex that any attempts at large-scale urban renewal would only tend to complicate and exacerbate further these bad situations.

Therefore, they reasoned, why not start fresh—from the ground up—on virgin land that was strategically situated between or near existing major cities? There had been analogous precedents for such planning abroad in cities that had been leveled either by war or natural disasters. Further, there were the established "new towns" of Europe, notably in Finland and England, to serve as prototype planning guides in the adaptation of designs to our native requirements.

To date, some 70 large communities, with at least a resemblance to the new city concept, are either under con-

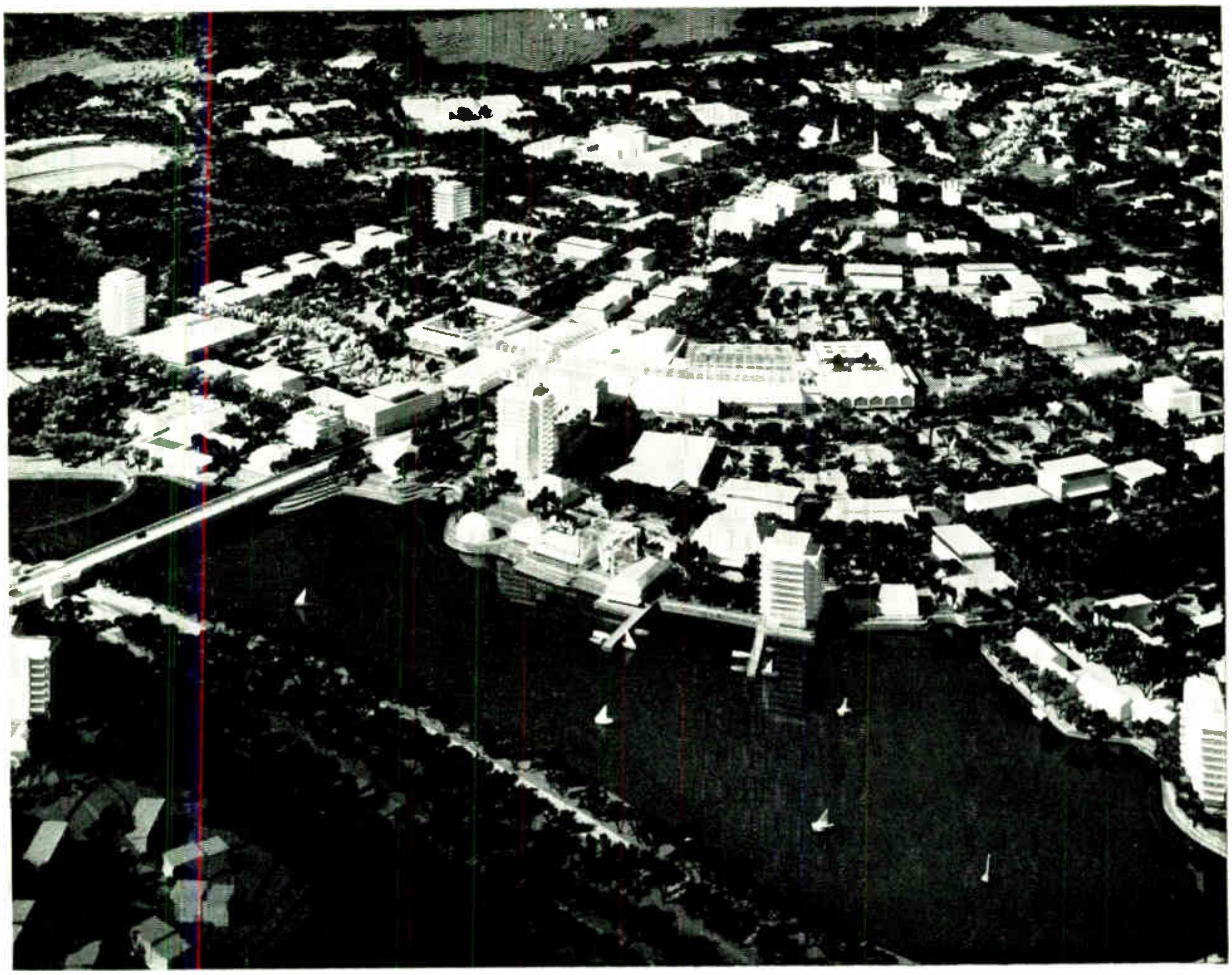


FIGURE 2. Architect's scale model of Columbia town center as it will appear upon ultimate completion in 1980.

struction or in the planning stages throughout the United States. Table I lists 12 of the largest of these ambitious development projects, which, unlike either the legendary Phoenix or Rotterdam, will rise not from the ashes, but rather from virgin woodland or rural pastures.

Spatial limitations in the publication format (not in the architecture), however, will permit a description and critical discussion of only a few of these grand-scale projects.

Columbia—born: 1962. In 1962, the Rouse Company, a site development firm of Baltimore, Md., purchased 24 square miles of rural land in Howard County, approximately midway between Baltimore and Washington (see Fig. 1) to demonstrate the logic of building a truly original and well-conceived new city. The site of Columbia, which will eventually accommodate a population of 100 000, lies directly in the path of an inevitable urban complex that will comprise the Baltimore–Washington metropolitan area.

After four years of intensive study[1] by collaborating teams of architects and engineers, the initial construction phases were begun in 1966. The design criteria encompass not only esthetic and sound architectural and engineering design, but also the results of a comprehensive investigation and projection of human requirements and conveniences in transportation, working conditions, housing, recreation, cultural facilities, and entertainment. Thus the Columbia plan (Fig. 2) includes far more than individual dwelling units and shops; it promises to provide almost 30 000 apartments and houses in the low-income, middle-income, and luxury ranges.

More than 50 elementary and high school sites have been carefully selected to eliminate the need for almost all school buses. A permanent recreational reserve of some 3200 acres of parks, lakes, golf courses, playing fields, and riding trails will guarantee the instinctive human demand for uncluttered open space. The political subdivisions of the city are scaled into the following manageable social units:

1. Eight to ten villages of a fixed area are included.
2. Each village is compartmented into five neighborhoods.
3. A civic center is provided for each neighborhood and village.
4. Permanent open spaces will serve as undeveloped "buffers" between the villages.

The developers are convinced that the community planning concept will provide better local government, education, and intraurban transportation. Primary and secondary education will benefit by adapting the town plan to school requirements. Neighborhood schools in these categories will be built within a half-mile radius of any residence within the school district. To serve the needs for higher education, the town center will eventually support a college or university.

By encouraging residents to participate in local administrative activities, it is anticipated that better community government will result.

Transportation will be simplified by providing convenient bus stops in the town and village centers so that these vehicles can complete their routes within 40 minutes' time.

The town and village centers. The facilities of the town center—the nucleus of the satellite village centers—will include the municipal administration, high-rise office and apartment buildings, a hospital, hotels, and theaters. The center will eventually encompass more than 23 acres of enclosed mall shopping area that will be built in phases to keep pace with an expanding demand for goods and services. Upon its ultimate completion, it is expected to be the first regional project in more than 20 years that will complement rather than compete with the core of a city.

Commercial and industrial expansion. About 1700 acres are reserved for eventual industrial development. The town center office and retail shopping space will utilize approximately 250 acres, and an additional 300 acres will be provided for specialized commercial enterprises. In addition to the 23 acres of town center area, each village center will occupy 30 000 to 50 000 square feet of retail sales areas.

The target data at Columbia for the completion of all the construction phases is 1980. By that time, it is hoped that 29 000 jobs will be available for local residents: 10 000 in office employment, 14 000 in commercial ventures, and 5000 in industry.

Transportation and public utilities. "Minibus" systems, covering 14- to 16-mile routes, will be provided throughout Columbia. The jitneys will operate on a five-minute headway during the daytime. By 1980, about 150 miles of paved-surface roads will be installed. The initial construction phase calls for 20–25 miles of such roads at the end of 18 months.

After considerable study and investigation, negotiations were concluded for the installation of an electrical transmission and distribution system by the Baltimore Gas and Electric Company. The general arrangement and appearance of substations and distribution equipment must harmonize esthetically with the architectural and landscaping decor and all such installations will be subject to the approval of the site developer. Natural gas will also be provided by the same private utility.

Studies were conducted on the practicality of various central heating and cooling systems that utilize oil, gas, or electricity as the prime energy sources. The centralized scheme is feasible in the heavily populated sections of the community and in areas of high industrial load density. Therefore, serious consideration is being given to plans for the eventual construction of such plants within the new city.

The projected ultimate electric requirements for Columbia by 1980 are shown in Table II.

II. Electric power requirements for Columbia in 1980

Installation		Load, MW
Residential (30 000 dwelling units)		
Lighting and miscellaneous		90
Air conditioning		54
Electric heating		120
	Subtotal	264
Town center, commercial		
Lighting and miscellaneous		35
Air conditioning		25
Electric heating		10
Miscellaneous		5
	Subtotal	75
Village commercial (ten villages)		
Lighting and miscellaneous		50
Air conditioning		40
Electric heating		20
Miscellaneous		10
	Subtotal	120
Industrial		100
	Total connected loads	559

Reston, Va.

In 1963, Simon Enterprises Inc., a New York realty firm, began construction on the first of seven projected village centers situated on an 11-square-mile tract of land in Fairfax County, Virginia. The new town, Reston (an acronym based on the site developer's name, Robert E. Simon), is 18 miles west of Washington, D.C., and 6 miles east of Dulles International Airport.

The Reston master plan, scheduled for completion in the early 1980s, includes

1. Seven separate villages of 10 000 to 12 000 people, for an eventual total population of about 75 000.
2. A community center for shopping, cultural, religious, social, and recreational activities in each village complex.
3. A 150-acre town center, planned to serve 150 000 people, that will be the heart of Reston's cultural, commercial, and educational facilities.
4. A 26-acre complex reserved for health and medical services, motel and hotel accommodations, theaters, department stores, and specialty shops.
5. A 1000-acre industrial park for R & D and government installations. (Four firms are already established in Reston, 11 have site options, and the U.S. Geological Survey is planning a $30 million building project for its new headquarters.)
6. Thirty-five sites for houses of worship; sites for 15 elementary schools, three intermediate and three high schools, and one community college.
7. Recreational areas totaling 1500 acres.

The Reston philosophy. According to its developers, Reston is dedicated to the criteria of providing modern housing for people of all income levels and age groups; of fulfilling the concept of religious, educational, cultural, and recreational facilities as an integral part of the community; and of affording employment opportunities for those who wish to work in either commercial or industrial enterprises within the town.

Village residents will occupy clustered town houses, walk-up garden apartment flats, space in high-rise apartment buildings, or individual dwellings that may be built to the owner's specifications on a purchased plot of ground. To give the village a measure of population sta-

FIGURE 3. View of Reston's horseshoe-shaped shopping plaza. Specialty shops occupy street-level space. Professional offices and apartments are located on the second and third floors of the structure.

bility, a resident can move to new quarters within his community as his housing requirements change.

As a unique safety feature, there will be a complete separation of automobile and pedestrian traffic. And to discourage the unnecessary use of cars within a community, all residential units will be within easy walking distance of the village center. Pathways from the residential sections will wind through scenic wooded areas to the schools and shops. Thus a Reston resident may walk, cycle—or ride a horse if he likes—without encountering a single motor vehicle en route.

Reston's streets will shun the traditional grid pattern and follow, instead, large-radius curves that will sweep around the perimeters of the residential areas. Cars are *verboten* in the shopping plazas.

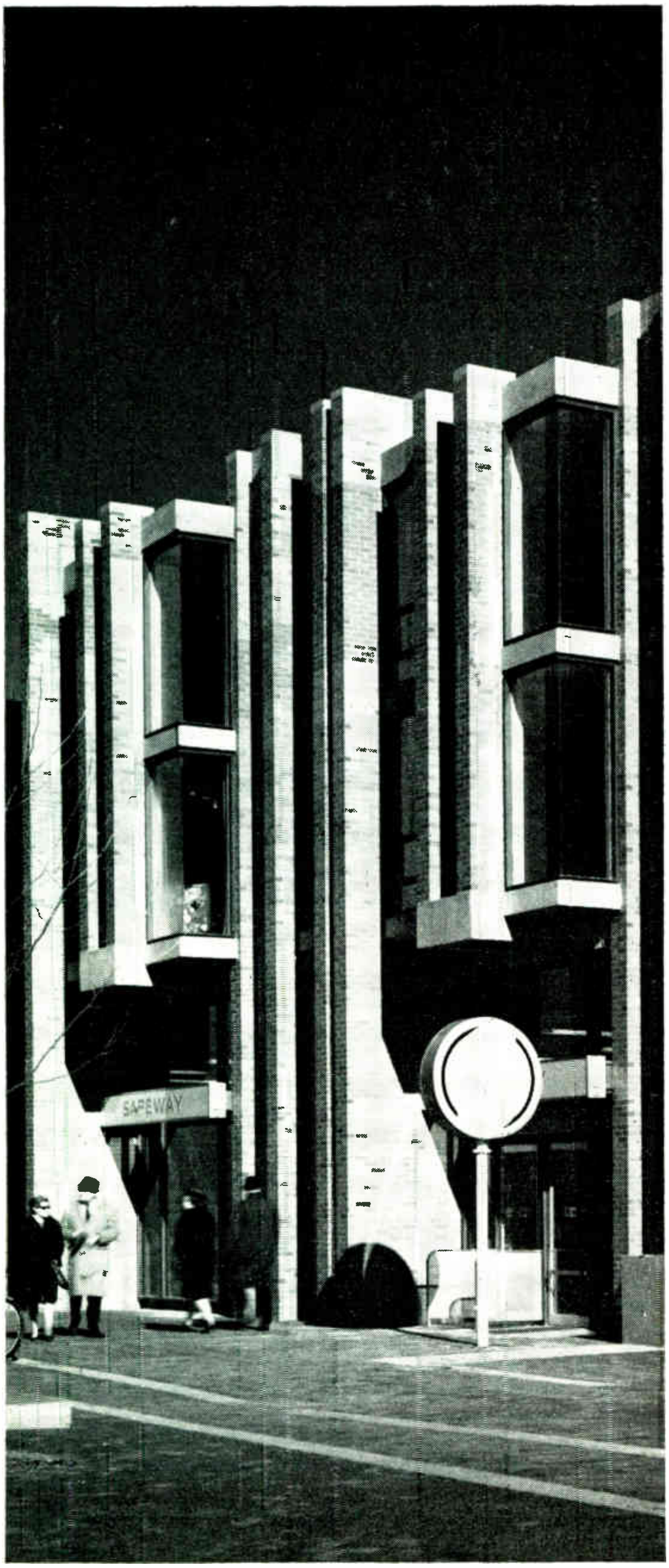
The present status. The first of Reston's villages, Lake Anne, was dedicated on December 4, 1965. Built on the banks of an artificial lake, it is a J-shaped complex of shopping facilities, an auditorium, art gallery, a bank, a nursery, and a club for teen-agers.

A 15-story 61-unit apartment building, Heron House (title illustration), dominates the site and serves as its theme center. Clusters of contemporary-styled modular town houses line the shores of the man-made pond. The U-shaped shopping plaza (Fig. 3) furnishes the central horizontal motif in a dynamic and asymmetric mass balance to the verticality of Heron House diagonally across the lagoon. To the south are the clusters of private dwellings, garden apartments, and row houses (Fig. 4). The present permanent population is about 1500.

A tale of two cities: a comparison and a critique

Although numerous "puff pieces" have been written in fulsome praise of many new city projects, this writer will attempt, in the interest of a balanced presentation, to

FIGURE 4. Row house group, with stores at grade level and apartments on the upper floors.



analyze the functional and esthetic shortcomings in the concept and design of the two East Coast towns, Columbia and Reston.

Town center vs. shopping center. A salient difference in basic planning seems to be that the town center at Columbia is conceived as a regional shopping plaza, with huge adjacent parking fields, and a compartmented plan in which stores are all in one area, office buildings in another, and recreational facilities are in a third grouping. At Reston, however, the cultural and commercial aspects of the town center will be intermingled, and cars will either be tucked away in subgrade parking garages or in parking fields that are remote from the center.

Apparently, there is also a fundamental difference in the philosophical and sociological approaches. For example, at Columbia, the school is the nucleus of each neighborhood; whereas, at Reston, developer Simon's emphasis is on an "adult-oriented community."

Based on the architectural model (Fig. 2), Columbia seems to follow more standardized contemporary architectural motifs; at Reston, architectural diversification is emphasized—perhaps overemphasized.

A 'world's fair' effect? Architecturally, both towns impress the writer as having the transient and artificial appearance of world's fair exposition projects. They lack the solidity, warmth, and permanent feeling that is afforded only by tradition in the application of period architectural styles that are part of the charm of old and established cities. To the writer, the overall esthetic impression of Lake Anne Village—as Frank Lloyd Wright might have put it—is a lack of harmonious blending of the architecture with the existing topography and natural environment of the site. In short, in a rustic area where one expects to see construction in native building materials (timber and ashlar), there is a rather startling incongruity in the cluster of reinforced concrete and brick town houses, and a high-rise structure surrounded and enclosed by virgin forests.

A sociological throwback? The juxtaposition of Heron House and the rows of town houses almost suggests a sociological throwback to the city-state concept of the Italian Renaissance, in which burghers, for self-protection, huddled in row houses as close as possible under the shadow of the sheltering castle of a noble lord. Psychologically, the 20th century version of this security motive may, consciously or subconsciously, evolve into paternalistic, planned, or force-fed cultural patterns that reflect the tastes of the promoters and site developers. As one well-known critic recently put it, in speaking of the new city concept in general: "They are really very nice towns if you are docile and have no plans of your own and do not mind spending your life among others with no plans of their own."

Litchfield Park, Ariz.

Although most town planning experts agree that the bulk of the future population will follow the present pattern of channeling itself into the dwindling open spaces between major cities, there has been some significant reversal of this thinking in the establishment of new cities in sparsely populated regions of the United States, on the logical assumption that existing major industries in these areas will inevitably draw scientists, engineers, technicians, and skilled workers into the local employment pools.

Litchfield Park is one such venture in the series of new cities experiments. It will ultimately provide living and working accommodations for a self-contained community, situated on a 12 000-acre farmland tract 18 miles west of Phoenix, of more than 75 000 people.

A succinct summary. An executive in the development firm recently expressed the general aims and goals of these grand-scale projects and the specific features of Litchfield Park: "The new towns offer a unique opportunity for community planners to introduce all of the improvements that have been developed for balanced, harmonious urban living, while eliminating most . . . of the major mistakes that in the past have contributed to the ugliness, slums, inconvenience and decay characteristics of so many American Communities.

"Schools at Litchfield Park will be built where the people live. Industrial plants . . . will be in special industrial park areas and will not infringe on residential areas. A central core zone will house commercial offices, department stores, and specialty shops.

"By insisting on architectural harmony, by requiring underground installation of power and telephone cables, and by allocating adequate space for recreation, educational, and service facilities for industry and commerce right at the start, we will build not only a beautiful city, but one that will function efficiently while providing a pleasant environment for the people who live in Litchfield Park."

The design criteria. Actually the criteria contained in the Litchfield master plan are quite similar to those of Reston and Columbia; however, two unique salient features include

1. The establishment of a *design and scale relationship that is appropriate to the climate and physical characteristics of the site in order to recapture the color, quality, and enchantment of Arizona's desert lands.*

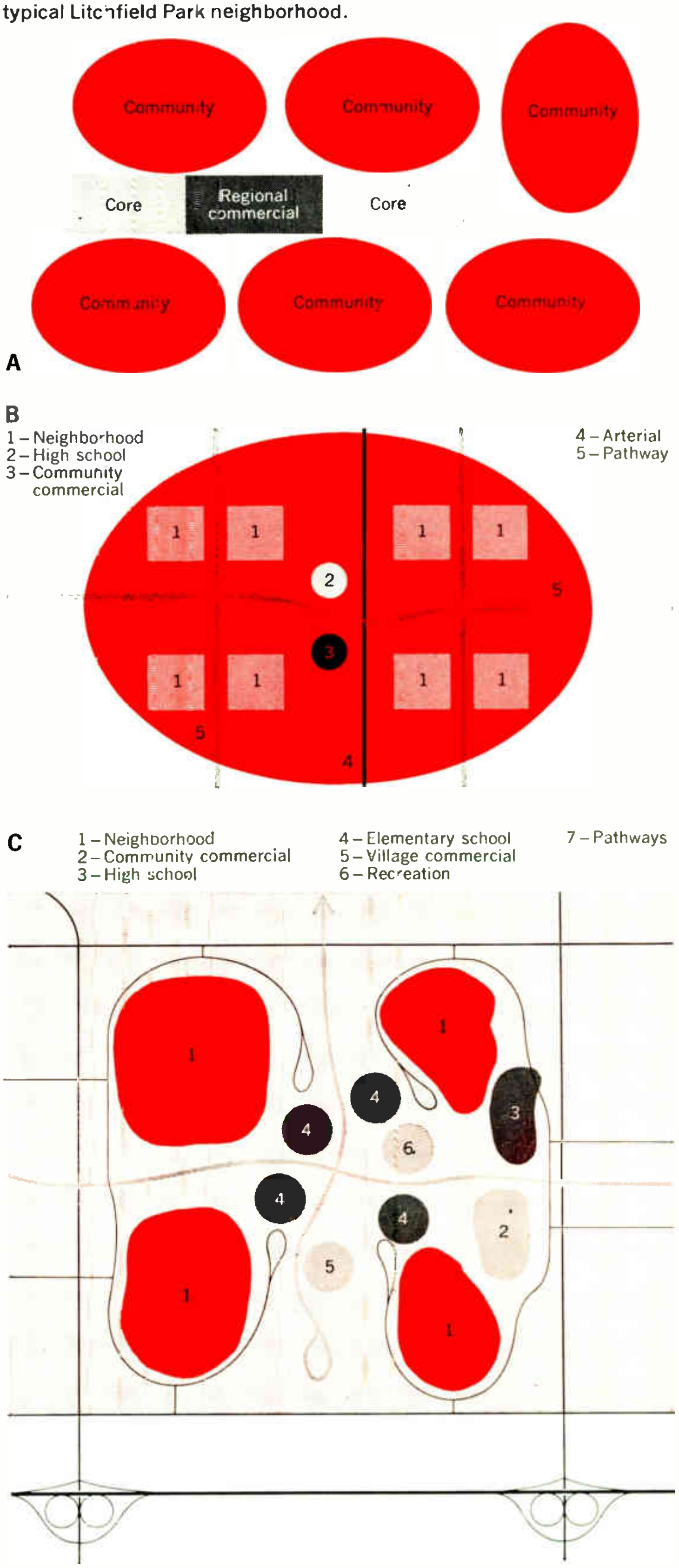
2. Minimization of the extent and cost of automobile travel—and consequent air pollution problems—by providing attractive alternative methods of transportation and by planning the new town to enhance the desirability of such alternatives.

The city and the community. The Fig. 5(A) block diagram shows, in simplified form, the political and sociological scheme of the central city core area and six satellite communities, each with an individual identity that is established by location, site planning configuration, architectural design, specialized recreational facilities, and landscaping treatment. Each community is distinguished by two major elements: a shopping center and a high school. Tied together by a large common plaza, these form an activity center for the 15 000 to 20 000 residents of the typical community.

The community and the village. A typical community, represented by the oval in the Fig. 5(B) diagram, is composed of two villages, each of which is bounded—but not entered—by a major arterial highway. Each community's central complex, consisting of cultural, educational, shopping, and recreational activities, will be located at the intersection of the major arterial and the pathway system that serves its two villages. Provided in this compact center are a general variety of goods and services to meet community needs. Specialized items, however, will be available only in the core of the city.

One village: a cluster of neighborhoods. Four neighborhoods [Fig. 5(C)] of 7500 to 10 000 people comprise a

FIGURE 5. A—Simplified block diagram showing the interrelationship of the city to its satellite communities in the Litchfield Park scheme. B—Diagram of Litchfield Park's primary subdivision—a community composed of two villages. C—Diagram showing the elements comprising a typical Litchfield Park neighborhood.



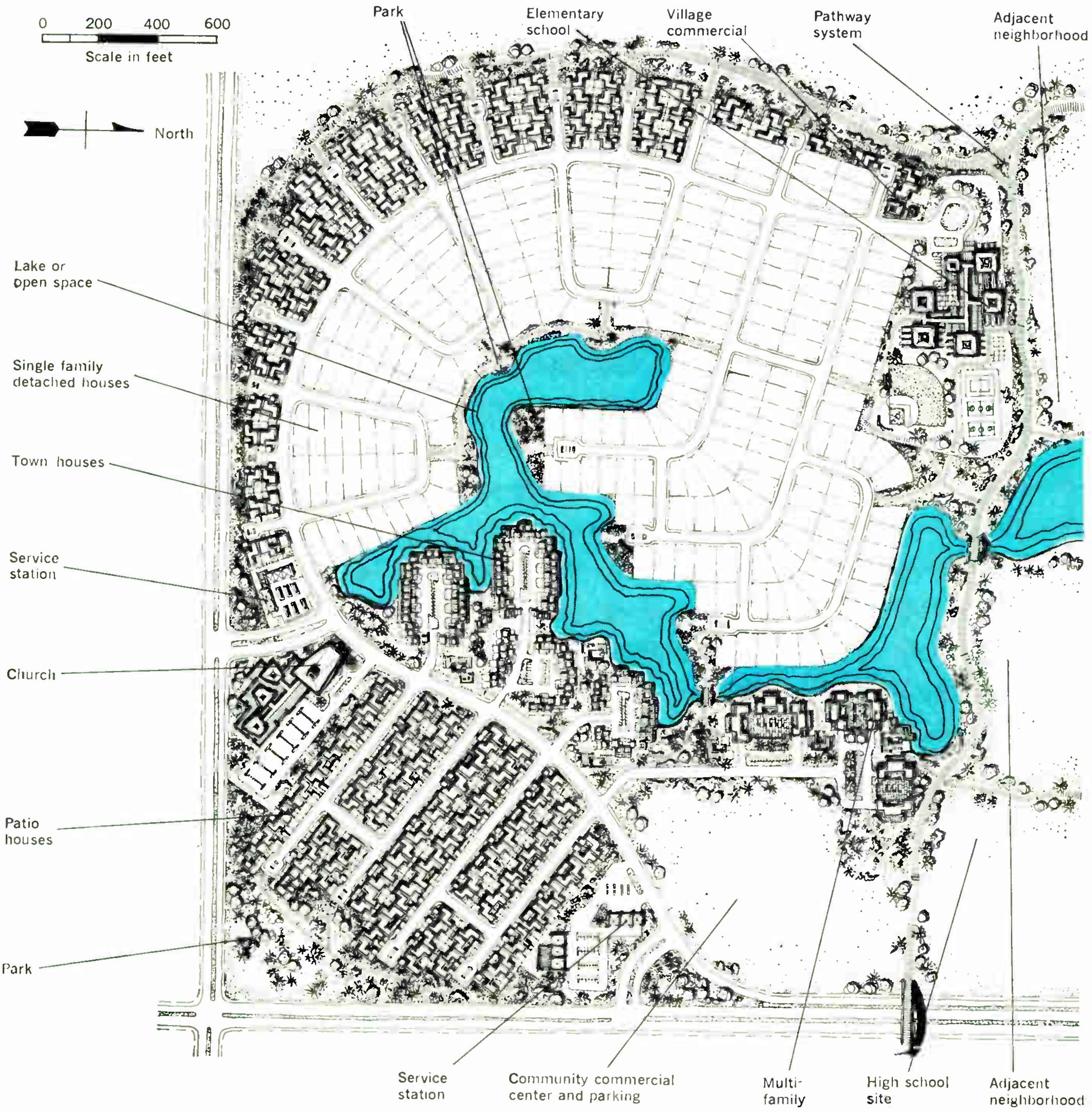
typical village. Pathways and landscaped areas offer convenient access in linking neighborhoods while affording an element of suburban privacy.

The center of the village, at the common junction of the neighborhoods, provides a focal point for social, cultural, and leisure activities. The elementary schools of the neighborhoods will be grouped here to afford optimum flexibility for future changes in school organization, programming, and student loads. The "clustering" of activities also permits the sharing of libraries and recreational installations.

Church sites and automobile service centers will be placed on the perimeters of the village at points where neighborhood streets meet the major arterials that form the village boundary. Although, for esthetic reasons, different types of villages are planned, each would include basic elements such as a lake, golf course, and a park. A wide range of residential accommodations, from individual homes to town houses and rental apartments, would offer a maximum variety of choice to prospective residents.

Figure 6 is a "bombsight" schematic plan of a Litchfield Park lakeside neighborhood. Note the tight grouping of town houses, similar to that of Reston, along the

FIGURE 6. Map showing Litchfield's road and pathway systems that feature traffic separation by means of overpass–underpass construction.



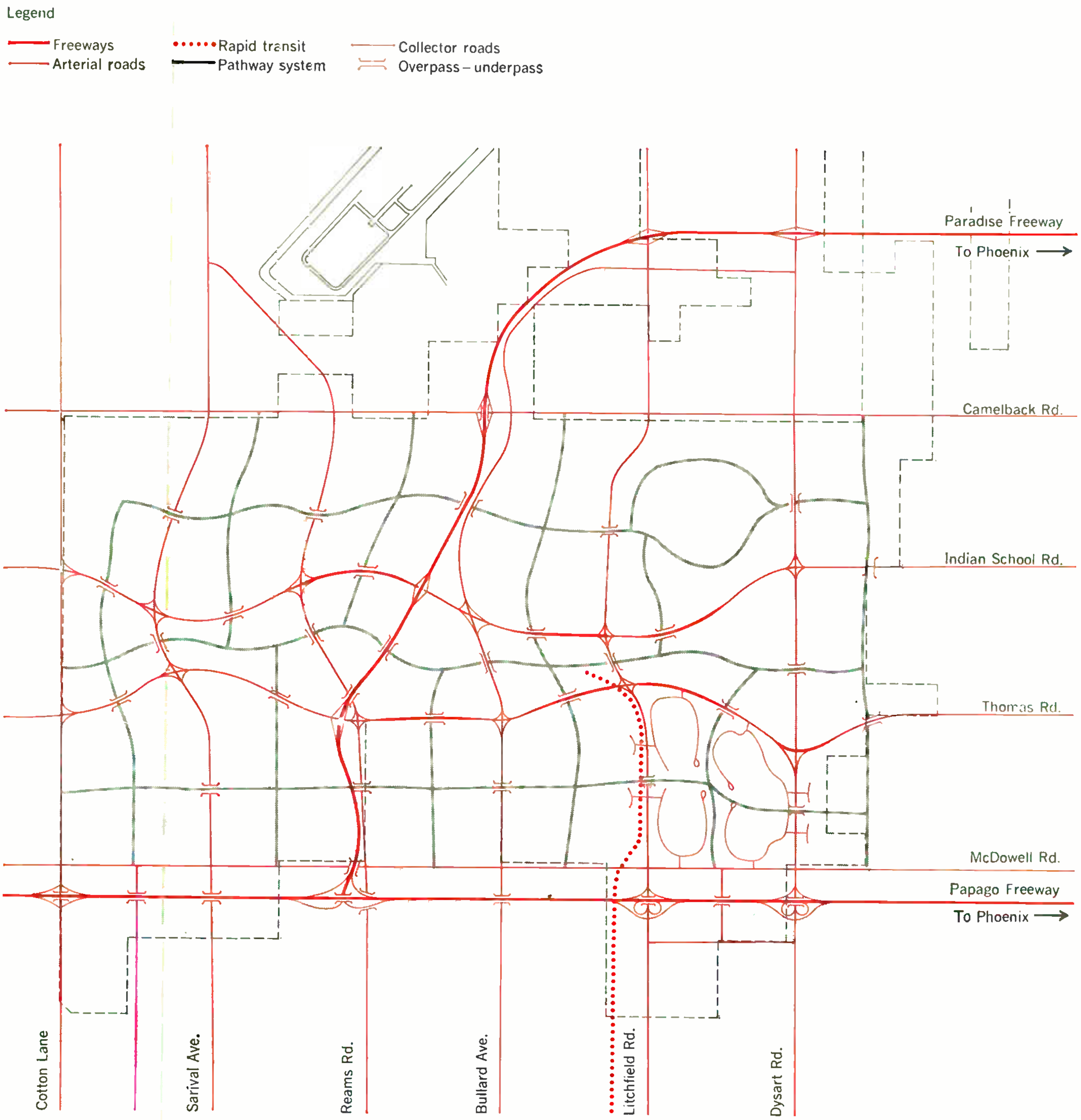
eastern lake shore, and the wide, sweeping arc of the principal circumferential street—terminating in a cul-de-sac—that forms the periphery of the radial plan in which the lake serves as hub.

Transportation: a schematic plan. In the view of its planners, the fulfillment of the concept of primary and secondary transportation (passenger and commercial) is an essential prerequisite for the success of a new city. A free-flowing traffic pattern can be achieved (Fig. 7) by separating automobile and truck traffic from most other means of circulation used by the residents.

Surfaced pathways, avoiding all contact with vehicular traffic on arterial roads by means of the overpass–underpass system, will provide a safe and leisurely way of travel by foot, bicycle, or electric cart to any part of the city. Collector streets, feeding into arterials at one-third- to one-half-mile intervals, are designed to serve only their own local residents. This will discourage and make impractical the use of the collectors as traffic shortcuts through residential areas.

Landscaped arterials provide the primary highway network for the new city. Serving as boundaries for the villages, these will have access onto the two proposed freeways—the Papago and the Paradise—to speed through traffic into Phoenix or to California.

FIGURE 7. A typical pathway, restricted to use by pedestrians, bicycles, and electric carts.



The construction timetable. Work is presently under way on the first of the 12 villages that will form the six communities that will be clustered around the central core area of the city. It is estimated that the ultimate development, including integral industrial areas, will take from 20 to 25 years.

A six-million-gallon-capacity reservoir and a pumping station have just been completed. This landscaped utility will be partially concealed underground. Potable water will be drawn from wells within the town, and, with the planned provision for additional pumps, it is believed that the water system will be adequate for the next ten years.

Valencia, Calif.

Valencia, the largest of the new city concepts, is planned for an ultimate population of more than 200 000 by 1990. Situated 30 miles north of downtown Los Angeles, Valencia will be built on a 44 000-acre ranch site. The first phase, scheduled for completion by 1970, is presently under construction on a 4000-acre portion of the site. It will include a complete range of housing and recreational facilities for 30 000 people, elementary and secondary schools, houses of worship, a 600-acre industrial center, and the nucleus of a high-rise central city that will eventually serve the entire county region. Also under way is a 100-room motel and convention center.

A statement and another philosophy. In the view of a California Land Company executive (the site developers), Valencia "is completely different in concept and form from conventional developments and far more advanced than most of the popularly titled 'planned communities.'" Nevertheless, Valencia is not conceived as an isolated or independent city; rather, it is a city in the southern California metropolis, and, as such, it will depend upon the total metropolitan structure for the full development of its total resources.

The Valencia philosophy, however, embraces a novel feature that seems to go beyond the criteria for the three cities already discussed: it anticipates a computer-controlled public transportation system, and a transit right of way has been incorporated into the master plan for the city.

Heart of the master plan. A dense and compact city center (Fig. 8), consolidating all the major shopping, civic, cultural, and business activities, is the core theme of the master plan.

Encircling the central city will be a series of satellite villages, each with its subcenter for shopping and recreation. As in the other new towns, Valencia's developers also emphasize the easy walking distance from any home to schools, libraries, churches, and shops.

The villages will achieve individual identity in one or more of the following ways:

1. Physical separation by open space in the form of parks, river beds, and landscaped slopes.
2. Introduction of lakes and diverse recreational facilities to alter the physical environment distinctively.
3. Changes in densities of housing facilities (apartments, patio houses, and single-family detached housing).
4. Diversity in architectural style (traditional California Spanish, contemporary, colonial, etc.).
5. Grading and terrain that will range from relatively flat valley bottoms to long, gentle slopes and rolling hills.

Housing geared to the market. In southern California, the predominant preference is the single-family detached house, and it will be a challenge to the developers to avoid monotony in the flat land areas of Valencia. To effect a positive change in environment, the patio house, in various Spanish-style cubistic configurations (Fig. 9) and with multitextured walls, should both insure privacy and afford an interesting, yet orderly, "random pattern" illusion.

To achieve the objective of adequate housing for all income levels, higher-density residential construction will take the form of garden apartments, high-rise apartments, and town houses.

For industry, a strategic site. The planners of Valencia emphasize that their new city is strategically situated in the heavily industrialized northern section of Los Angeles County. As may be seen from the Fig. 10 map, the Lockheed Aircraft Corporation's Rye Canyon Research Center lies just north of Valencia's proposed industrial center sites. The major arterial highway and freeway system that already exists in the north–south direction permits excellent accessibility to the metropolitan area, and the proposed Santa Clara Freeway will eventually provide the needed accessibility in the east–west direction.

Similar to Litchfield Park, Valencia will feature separation of through and local vehicular traffic, and special safe pathways for pedestrian, bicycle, and motor cart traffic.

Valencia has already formed its own water utility to ensure an adequate supply for industrial, commercial, and residential uses.

Private support and financing

A notable aspect of many of the new cities is that they are financed by private sources and not by primary federal assistance (see Table I). For example, in 1964, big business interests began to re-evaluate the Reston venture, with the result that the Gulf Oil Corporation lent developer Simon $14 million; and, in the following year, John Hancock Insurance lent an additional $15 million. Noting the success of the venture, the U.S. Department of the Interior, on May 21, 1966, announced that Reston had been selected as the site for a new $30 million building complex for the U.S. Geological Survey. This governmental agency will relocate some 2000 employees from the District of Columbia area.

Litchfield Park Properties, Inc., a subsidiary of The Goodyear Tire & Rubber Company (the site developers), predict that Litchfield Park will be entirely financed by private capital to the ultimate tune of more than $1 billion when the project is completed 20 years hence. Parenthetically, this is the magic number generally tossed about by the developers as the construction cost of each of the major new cities.

General interest by General Electric. With about 70 large communities throughout the United States staking a passing claim to the new town concept, renewed interest is evolving on the part of large industry. Last year, for instance, George T. Bogard, division general manager of the General Electric Company, told a planners' conference that his firm is considering the creation of "new prototype communities." Further, Bogard observed that GE feels that the new cities will permit industry to introduce exciting new products, building materials, techniques, and new practices. He stated that progress in construction and development was impeded by restrictive and archaic building codes, outdated zoning ordinances,

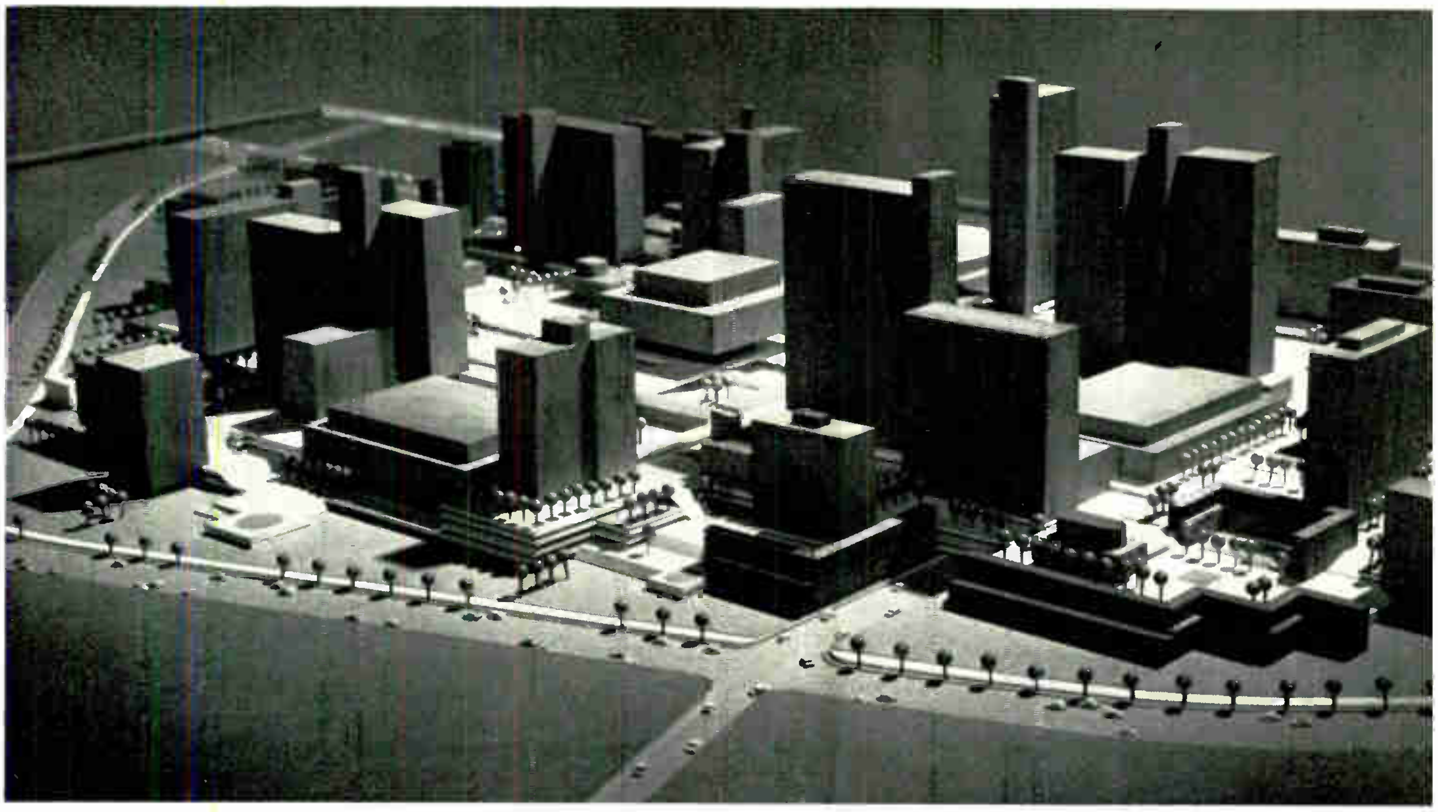
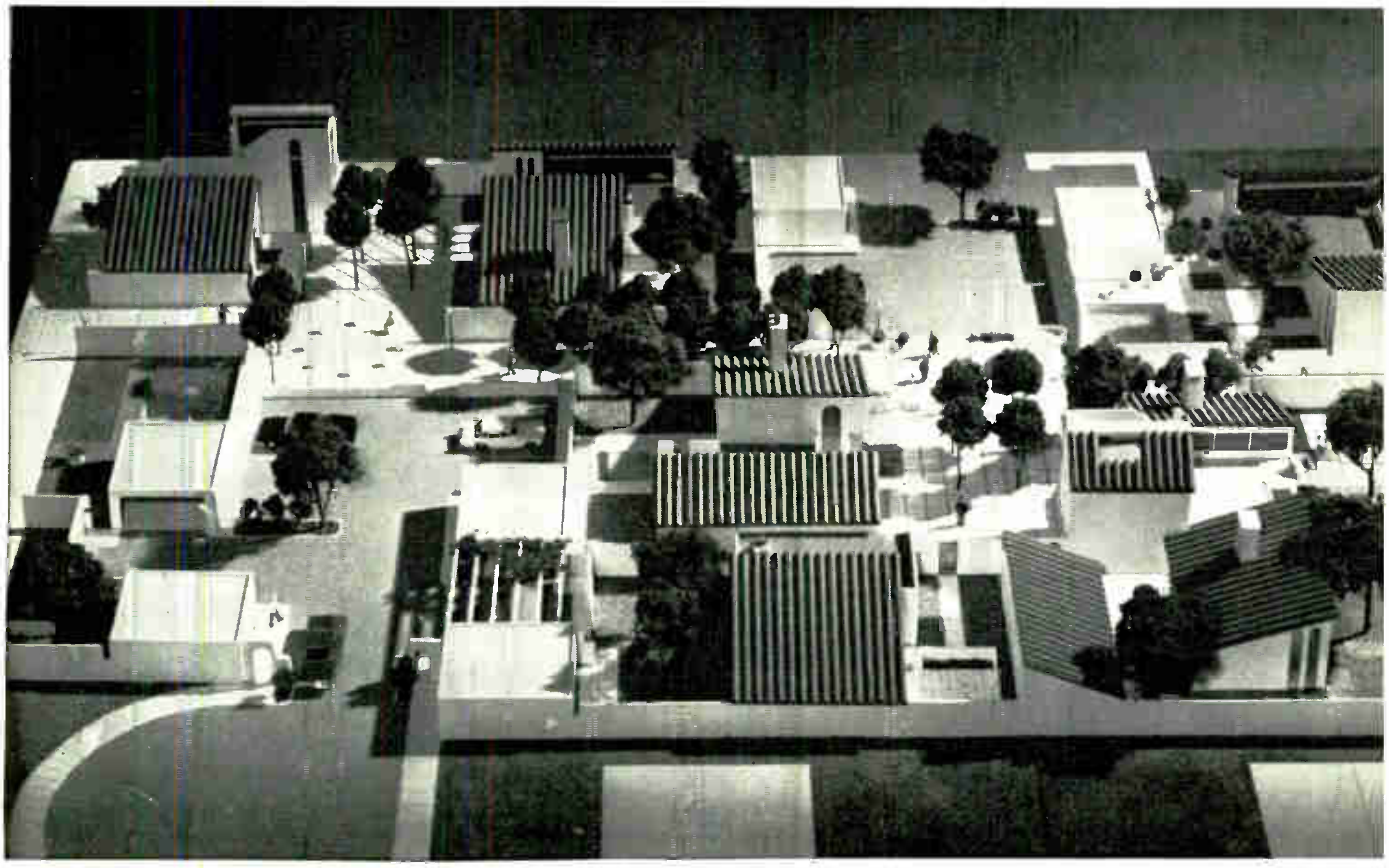


FIGURE 8. Valencia's dense and compact city-center core, in which major shopping, civic, cultural, and business activities will be housed in numerous low- and high-rise structures.

FIGURE 9. Architect's model showing one of Valencia's Spanish-style single-detached patio house developments.



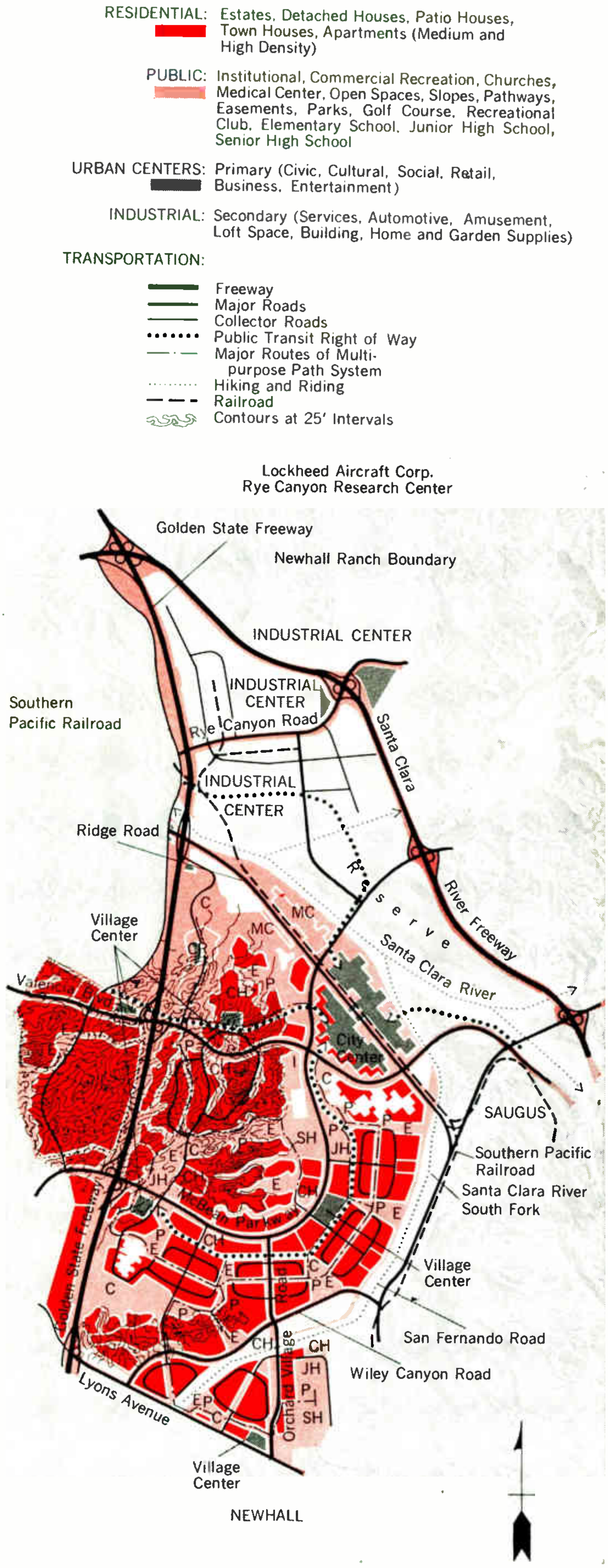


FIGURE 10. Map showing the present development of the Valencia site. Note the large areas allocated for industrial sites and the existing Lockheed Aircraft Rye Canyon Research Center.

union work rules and restraints, and the overcaution of the financial community in providing the necessary funds "to support builders who might want to innovate and experiment. . . in the unconventional."

But despite the approving nod from a segment of industry, considerable political opposition to the new concept—principally from established large cities that fear a drain of industry and workers from local markets—has thus far precluded federal legislation to support new town development. And, without such assistance, there is a question whether the new towns can prosper in the midst of a highly competitive housing market.

Finally, other questions loom large

The general philosophy to justify the dense, vertical construction in major cities has been that of physical space limitations and extremely high property values. But to project such reasoning in the planning of a high-density, high-rise city core area (see Fig. 8) as the nucleus of a new city that will occupy 44 000 acres (almost 70 square miles), in which a horizontal concept appears to be indicated, seems to invite the same problems of congestion and compartmentation that beset our existing metropolises.

Although the promotional pieces stress the availability of low-income, middle-income, and luxury housing facilities, descriptions of the golf course and the marina occupy considerable space in this literature. Thus it is probable that most of the new towns will gravitate toward the needs of middle- and upper-income families. As Robert C. Weaver, Secretary of Housing and Urban Development, recently put it: "The vast majority [of new cities] appear destined to become country club communities for upper-income families."

Another imponderable may be whether the cyclic employment requirements of major industries—particularly aerospace and electronics—in the new town areas will afford sufficient stability to keep long-term residents in these planned communities.

And last, but not least, will the inherent restlessness of a younger population, ever seeking new horizons and new challenges, be satisfied by the prospect of permanent ties to these towns?

The answer to all questions bearing upon the survival of the new cities is simply: Time will tell.

AUTHOR'S NOTE

Since this article deals with that quasi-technical gray area involving art, architecture, new city planning, and site development in the United States, the writer has requested (and received) special dispensation to depart from our standard use of metric units in favor of the English system units that are commonly employed and understood by our architects, city planners, and landscape architects.

REFERENCE

1. Gipe, A. B., "Planning a new city—Columbia," *IEEE Trans, on Industry and General Applications*, vol. IGA-2, pp. 423–430, Sept.–Oct. 1966.

Semiconductor-diode light sources

In the recent past there has been considerable interest in the phenomenon of p-n junction luminescence, which has resulted in many investigations of the properties and potential applications of semiconductor-diode light sources

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Electroluminescence can occur as a result of the application of a direct current at a low voltage to a suitably doped crystal containing a p-n junction. It has become apparent in recent years that in certain materials (such as gallium arsenide) and under certain conditions, the efficiency of conversion of electric energy into light can be remarkably high. Since these semiconductor light sources operate at low voltages and low currents and can be made very small, they appear attractive for use in small optical displays. Because they can be switched very rapidly and have fairly monochromatic emission properties, their applications for data transmission are also promising.

Recombination of charge carriers in semiconductors can occur with the emission of photons in the visible or infrared region. Devices utilizing this effect have gained considerable importance in recent years. If the radiative recombination is caused by the direct introduction of charge carriers, the light emission is referred to as "electroluminescence." One of the most widely used applications is found in the screen of the television set. This type of electroluminescence, better known as cathodoluminescence, is caused by the collision of accelerated electrons with the polycrystalline phosphor that coats the inside of the cathode-ray tube. A similar type results from the application of an alternating current to certain microcrystalline insulating solids embedded in certain dielectric media.[1]

We wish to discuss here a third type of electroluminescence—one that occurs as a result of the application of a direct current at a low voltage to a suitably doped crystal containing a p-n junction. This process is usually referred to as p-n junction luminescence. Light emission from a p-n junction was first observed by Lossev[2] in 1923 in naturally occurring junctions. Detailed studies began more recently—for example, with germanium p-n junctions.[3] Since the efficiency for conversion of electric energy into light was very low, these junctions did not seem to be of much practical importance.

In more recent years, it became apparent that in certain materials (such as GaAs) and under certain conditions, the efficiency was not low at all.[4] The recognition of this fact, particularly the discovery of the p-n junction laser[5–7] in 1962, is the main reason for the revived interest in semiconductor light sources. These sources have a number of rather unusual features that make them quite attractive for certain applications:

1. They can be made very small, and therefore may be considered as being close to point sources of light.
2. They are operated at low voltages (1.5 to 2.5 volts, depending on the material) and also at low currents ($\sim$10 mA) if coherent (i.e., laser) light is not required.
3. Their emission is fairly monochromatic.
4. They can be switched very rapidly.

The first two of these properties make semiconductor light sources interesting for use in small optical displays; the last two properties make them attractive for data transmission. Electroluminescence incorporated into electronic circuits or devices actually constitutes a new field called "optoelectronics." In this article we shall discuss the origin of p-n junction luminescence, as well as its present applications and possible future uses.

For a detailed study of our present knowledge of p-n junction luminescence, the reader is referred to a number of recent review articles. Electroluminescence from p-n junctions in semiconductors and of radiative recombination in III–V compounds are reviewed by Gershenzon[8,9]; stimulated emission from semiconductor p-n junctions are discussed by Burns and Nathan,[10] Stern,[11] Dumke,[12] and Nathan.[13]

The recombination mechanisms

Before we delve into the origin of p-n junction luminescence, let us briefly review the basic concepts of semiconductor theory. The electrons in crystalline solids can have only certain values of energy. These allowed energy states are spaced into bands. In a perfect semiconductor at 0°K, all of the lower energy bands including the valence band would be completely filled and all of the higher-lying bands would be completely empty. The first unoccupied band is referred to as the conduction band. The separation between the top of the valence band and the bottom of the conduction band is called the energy gap. In the ideal semiconductor, electrons cannot exist in this forbidden band. However, there are impurity atoms that can be incorporated into the lattice of semiconductor material, and these produce allowed electronic states in the forbidden gap. If these atoms can introduce electrons in the conduction band, they are called donors; such impurity atoms give rise to n-type conductivity.

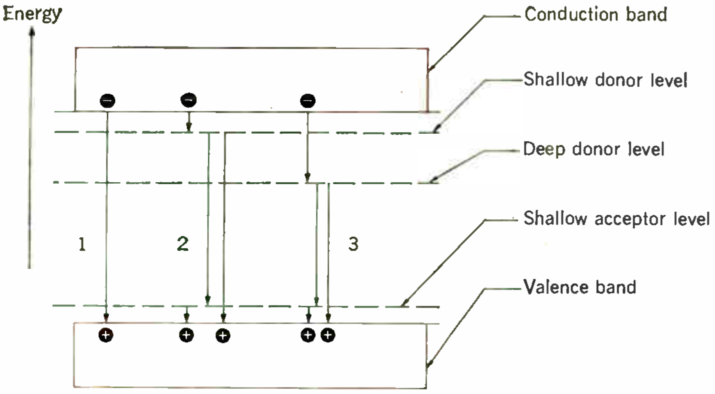
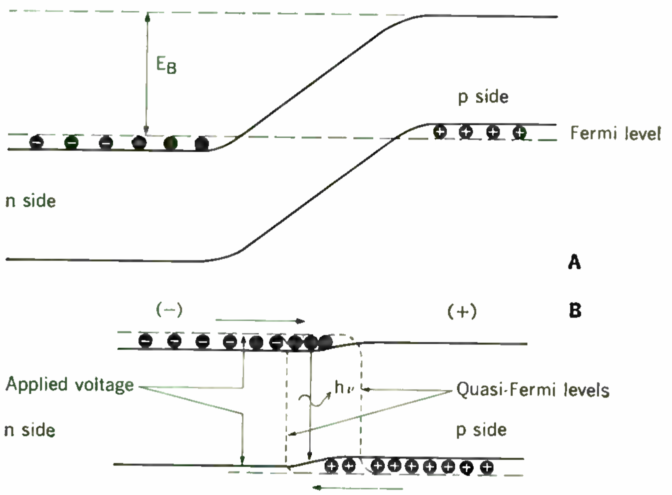


FIGURE 1. Schematic representation of the pertinent energy bands and levels as well as possible recombination paths.

FIGURE 2. Typical p-n junction under (A) equilibrium and (B) forward-bias conditions.



Conduction (by positively charged holes) can also take place in the valence band; impurity atoms that introduce such holes in this band are called acceptors. A schematic representation of the pertinent bands and impurity states is shown in Fig. 1. The simplest recombination possibility (shown as 1 in Fig. 1) is the band-to-band recombination—that is, the direct recombination of a free electron with a free hole. In many practical cases, however, this recombination occurs through intermediate, or "exciton," states. Possibility 2 involves a shallow impurity state. An electron is first trapped by a donor atom and subsequently recombines directly with a hole or with a hole trapped on a shallow acceptor level. The photon energy generated in this recombination process will be a little smaller than that of the band-to-band recombination. Photons with much smaller energies may be generated when deep-lying impurity levels are involved, as illustrated by recombination possibility 3 for the case of a deep donor level.

A common term in the language of semiconductors is the "Fermi level." It describes the distribution of electrons over the energy states of the semiconductor. In an n-type semiconductor (in which electrons are the mobile charge carriers), the Fermi level is situated close to the conduction-band edge; correspondingly, for p-type semiconductors (in which holes are the mobile carriers), it lies close to the valence-band edge. In thermal equilibrium, the Fermi energy is constant throughout the whole semiconductor crystal. A crystal that contains an n-type and a p-type region would have an energy-band diagram as shown in Fig. 2(A). In equilibrium, a potential difference between the n side and the p side of the p-n junction results. It is called the "built-in" voltage (E_B).

If an external voltage is applied so that it partially compensates the built-in voltage (that is, the potential barrier between the n and p sides is lowered), the flow of holes and electrons across the junction is greatly enhanced. A junction in this condition is said to be biased in the forward direction; an example is shown in Fig. 2(B). Since there can be no appreciable buildup of charge in either the n- or p-type regions, the increase in the forward current results in an increased rate of recombination. The current J through a p-n junction is given by the relation

$$J = J_0 \exp\left(\frac{eV}{\beta kT}\right) \qquad (1)$$

where V is the applied voltage, T the temperature, and β a constant whose value depends on the nature of the recombination mechanism. The current–voltage characteristics for a GaP diode are shown in Fig. 3 for various temperatures. The deviation from the exponential behavior in Region B is ascribed to tunneling or leakage, and the deviation at high current is due to the onset of series resistance in the diode.

Selection of materials

The maximum possible energy of the emitted photons is determined approximately by the energy gap of the semiconductor. The band-gap energy therefore provides the first criterion as to the spectral range of the luminescence. Some of the better-known elements and simple compounds are listed in Table I. These have band gaps that lie in the range of the ultraviolet through the visible to the near-infrared region of the spectrum. Also given are some other properties that are important in electroluminescence and which will be discussed later. It should be noted here that the list of eligible compounds is not very extensive. In addition, other factors—such as poor quantum efficiencies or fabrication difficulties—will further limit the possible materials that can be used.

For many applications the most desirable spectral range of the emitted radiation is in the visible part of the spectrum. The sensitivity of the eye to the wavelength of the emission is an important factor here. A typical eye sensitivity curve is shown in Fig. 4. Since the eye is a poor detector outside the wavelength range of about 4000 Å to about 7000 Å, our choice of materials for application in the visible range is quite limited; however, there are other uses, especially in communications, where the longer-wavelength radiation may be suitable.

Fabrication of a p-n junction

A p-n junction is, in principle, produced by a change of dopants (impurities) in a semiconductor crystal. The junction plane is that internal surface at which the crystal changes from n type to p type. The junction can, for instance, be prepared by diffusion of a large number of acceptor atoms part way into an n-type crystal. In order to get p conductivity on the diffused side, the acceptor atoms must, of course, outnumber the donor atoms already present. For example, a common method for the fabrication of a p-n junction in GaAs is the diffusion of Zn (acceptors) part way into a substrate material containing Te (donors). Diffusions are carried out at elevated temperatures typically in the neighborhood of 1000°C. As the diffusion front advances, the junction so formed advances from the surface into the crystal. When the p region has reached the desired thickness, the diffusion is stopped by lowering the system to room temperature.

Another common method of forming a p-n junction involves the epitaxial growth of a suitably doped thin layer on a substrate wafer either from the vapor or from the liquid phase.

Our choice of materials for luminescent p-n junctions is seriously limited by the fact that not all semiconductors can be readily made both n and p type. This limitation applies particularly to compound semiconductors with wider band gaps, for instance, II–VI compounds (ZnO, CdS, ZnSe, ZnTe, etc.), which can only be prepared in one conductivity type. Table I indicates whether a given material can be made highly conducting n type, p type, or both.

Another rather obvious materials limitation is that a poor stability or crystal quality of a material reduces its

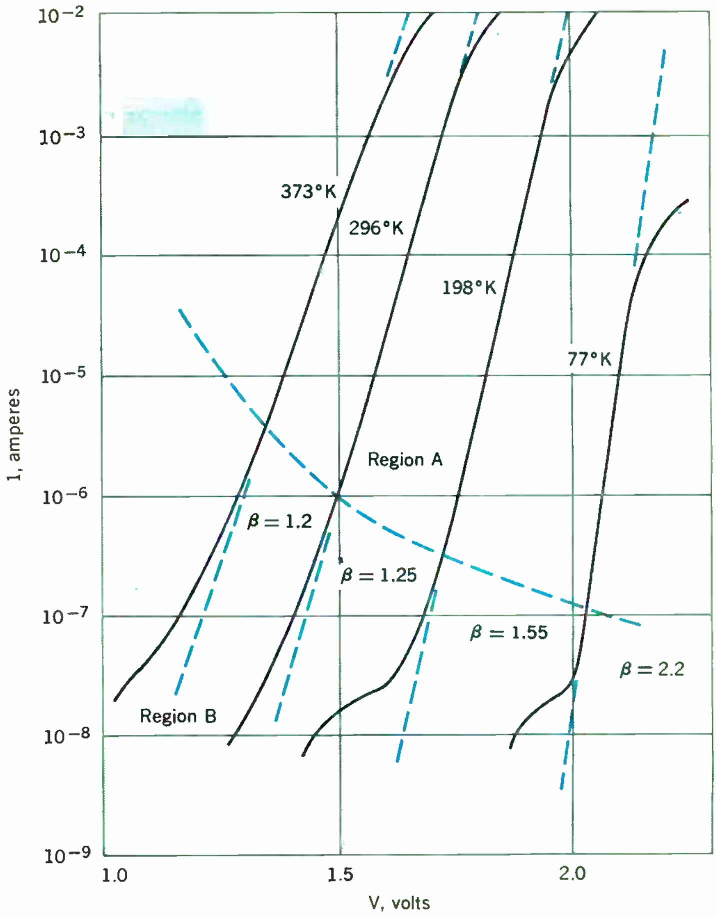


FIGURE 3. Current–voltage characteristics for a GaP diode at various temperatures. Diode area = 3×10^{-3} cm^2; junction gradient at 300°K = 3.8×10^{21} cm^{-4}.

I. Characteristics of well-known semiconductor materials

Material	Band-Gap Energy, eV*	λ, Å*	Transition†	Doping	Laser Effect
Ge	0.66	18 800	i	n, p	no
Si	1.09	11 400	i	n, p	no
SiC	2.2–3.0	5630–4130	i	n, p	?
InSb	0.18	69 000	d	n, p	yes
InAs	0.36	34 500	d	n, p	yes
GaSb	0.7	17 700	d	n, p	yes
InP	1.26	9 850	d	n, p	yes
GaAs	1.43	8 680	d	n, p	yes
AlSb	1.6	7 750	i	n, p	no
GaP	2.24	5 540	i	n, p	no
AlAs	2.3	5 400	—	—	—
AlP	2.4	5 170	—	n, p	—
BP	—		—	n, p	—
CdTe	1.44	8 620	d	n, p	yes
CdSe	1.67	7 430	d	n	yes
ZnTe	2.26	5 490	d	p	no
CdS	2.41	5 150	d	n	yes
ZnSe	2.7	4 600	d	n	no
ZnO	3.3	3 760	d	n	yes
ZnS	3.6	3 450	d		yes

* At 300°K.
† i = indirect, d = direct.

value in the production of electronic devices. For instance, AlP has a desirable energy gap for luminescence in the visible region of the spectrum and can be made both n and p type. It would, therefore, seem to be an ideal candidate. However, this material is ruled out because of its instability under atmospheric conditions.

Junctions have been made and their electroluminescence properties studied at least to some degree in the case of (1) materials exhibiting emission in the infrared region, such as Si, Ge, CdTe, GaAs, GaSb, InP, InSb, PbTe, PbS, and PbSe, and (2) materials that emit in the visible region, such as SiC, GaP, AlP, AlAs, BP, and B_6P. Some studies have also been reported in the mixed alloys of $GaAs_xP_{1-x}$, $In_xGa_{1-x}As$, $ZnTe_xSe_{1-x}$, and $Zn_xCd_{1-x}Te$. Investigations on some of these materials have been very limited. In recent years most work in p-n junction luminescence has been concentrated on GaAs, GaP, and $GaAs_xP_{1-x}$.

Quantum efficiency

The energy released during the recombination process may be partly in the form of light (photons); the remaining energy generally appears as heat (phonons). An important quantity in electroluminescence is the "quantum efficiency," which is the ratio of photons generated to the current flowing through the device. The maximum value for the quantum efficiency is unity.

Obviously, a very low quantum efficiency makes a material uninteresting for any technical application of p-n junction luminescence. Unfortunately, at the present time those materials that are technologically very well controlled, namely Si and Ge, have very low quantum efficiencies, whereas technologically more difficult materials, such as GaAs and GaP, have quite good quantum efficiencies.

The most important quantum efficiency and the one that is directly measurable is the "external" efficiency. The magnitude of this efficiency is determined by two factors: (1) the "internal" efficiency, which is related to the recombination process at the junction, and (2) light losses resulting from subsequent reabsorption. Since the index of refraction of most semiconductors is high, a large fraction of the light is reflected back from the surface into the crystal. Thus the light may traverse the crystal several times before it can escape and thereby suffer a large reabsorption. The reabsorption losses can be minimized by increasing the escape probability of the light at the surface, either by properly shaping the diode or by encapsulation techniques. The external quantum efficiency η_{ext} is related to the internal efficiency η_{int} in the following manner[11]:

$$\eta_{\text{ext}} = \frac{\eta_{\text{int}}}{1 + 4\bar{\alpha}\dfrac{V}{AT_{\text{avg}}}} \qquad (2)$$

where $\bar{\alpha}$ = average absorption coefficient, T_{avg} = average transmission coefficient, V = crystal volume, and A = crystal area. Assumptions include a uniform photon density inside the crystal and small absorption and transmission coefficients.

For practical purposes, the sensitivity of the available detectors at the emitted wavelength is just as important as the external efficiency. A high quantum efficiency of a light source is technically meaningless if only detectors with very poor sensitivities are available. Detectors are in general inefficient at the wavelengths emitted by narrow-energy-gap materials, such as InSb and InAs. The situation is more favorable for light sources that emit at a wavelength shorter than one micrometer, where photomultipliers, Si photodiodes, photographic film, or the human eye can be used as detectors. The sensitivity of the eye is greatly dependent on the wavelength, as shown in Fig. 4. A light source at 5500 Å (green) and one at 7000 Å (red) will appear equivalent in brightness if the latter has a photon emission rate about 100 times greater than the former; therefore, the green emission is the most desirable if the eye is the detector.

Direct and indirect transitions

We will now introduce a distinction between various recombination processes that is based on the energy-band structure of the semiconductor. Charge carriers can move freely in the conduction and valence bands, and the energy they have depends on the direction in which they are moving. The conduction band, for instance, can be quite complicated and may have minima at various directions of motion. A transition taking place between the lowest conduction-band minimum and the highest valence-band maximum is called a "direct transition" when it does not involve a change in the direction of motion of the electron and hole. An example of this case is GaAs, the band structure of which is shown in Fig. 5(A). If the lowest conduction-band minimum and the highest valence-band maximum do not occur for the same direction of motion, the resulting recombination will be an "indirect transition." A typical example of a material exhibiting indirect transition is GaP, whose band structure is illustrated in Fig. 5(B).

One of the basic physical requirements for an electron-hole recombination, namely conservation of momentum, will be easy to fulfill for direct transitions and difficult for indirect transitions. In the first case, a direct recombination of an electron with a hole is possible. The rate of recombination is fast and competitive compared with "other recombination processes." One consequence of this high rate is a high internal quantum efficiency. In the second case, the recombination prefers to go via impurity states (compare Fig. 1) because the impurities can take up the surplus momentum. Recombination rates for indirect transitions are much slower and thus the internal efficiency for indirect material is generally lower.

Luminescence from a direct-gap semiconductor

As an example of electroluminescence from a semiconductor with a "direct energy gap" we shall take GaAs. As shown in Fig. 5(A), it has a direct energy gap of about 1.5 eV. This energy corresponds to a wavelength of approximately 8300 Å, which is in the near-infrared region. An emission spectrum from a GaAs electroluminescent diode is shown in Fig. 6. The emission line due to the band-to-band recombination is the dominant line, as expected for a direct-gap semiconductor. Emission at low energy caused by recombination through deep impurity levels is also present, but it is usually very weak. Only if deep levels are introduced in high concentration will the low-energy emission lines become comparable in intensity with band-to-band recombination.

Recombination involving shallow impurities is hard

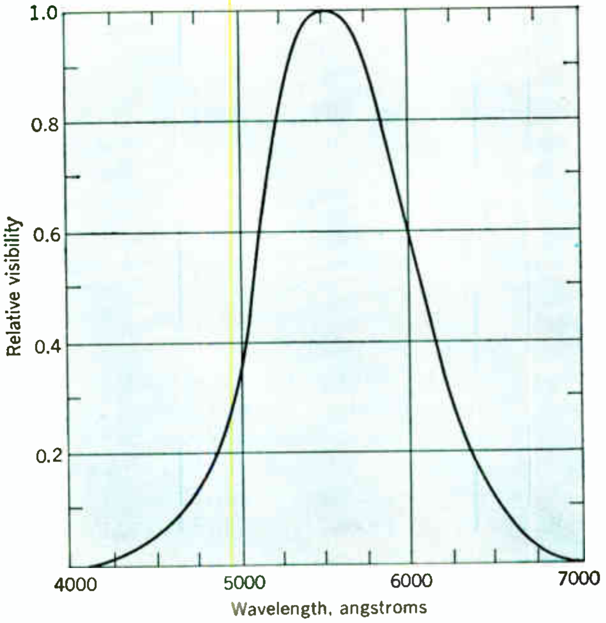


FIGURE 4. Visibility curve for the human eye.

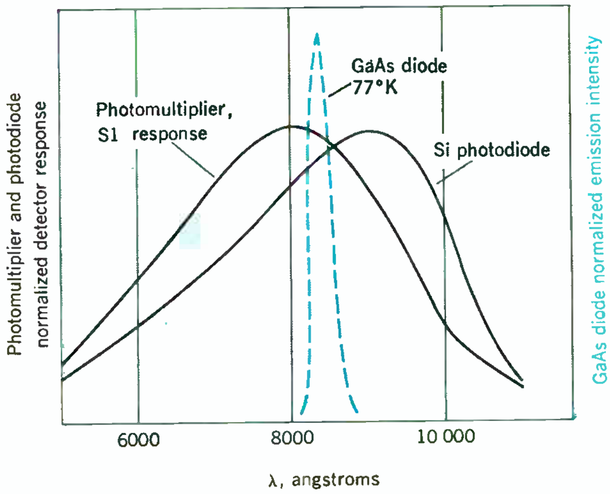
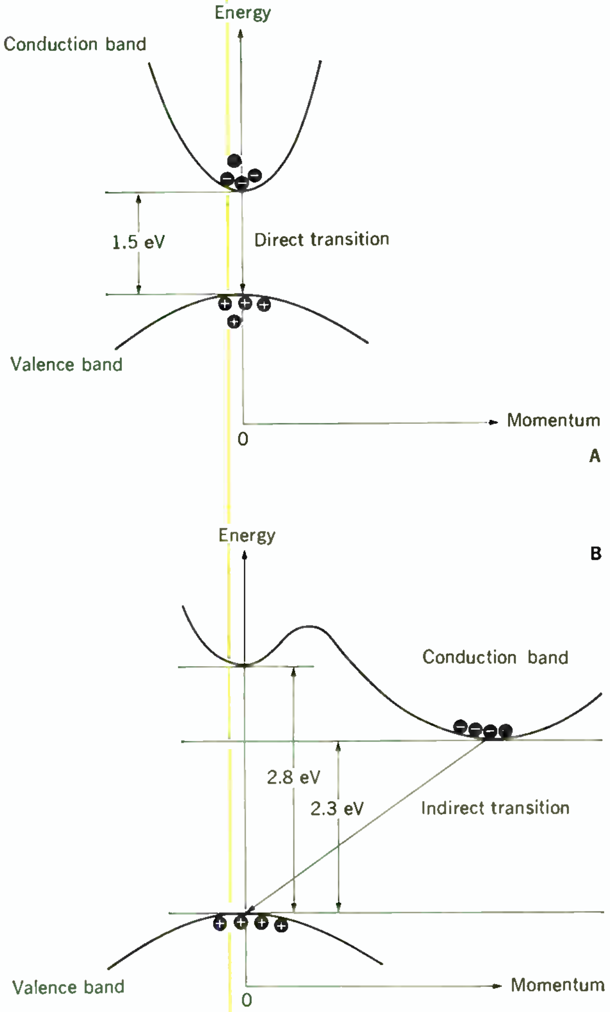


FIGURE 6. Spectral response curves.

FIGURE 5. Energy as a function of momentum for (A) GaAs, direct transition and (B) GaP, indirect transition.



to distinguish from band-to-band transitions. Donor impurities such as Te, Se, and S are so shallow that they overlap with the conduction band even at rather low concentrations. The acceptor levels from Zn or Cd are not quite as shallow. In Zn-diffused GaAs diodes with the concentration of dopants of the order of 10^{18} cm^{-3}, electrons recombine from the conduction band to the Zn level and to the valence band.

It can be seen in Fig. 6 that the main emission line is quite monochromatic compared with incandescent light sources. Its half width is about 150 Å at 77°K. Figure 6 also shows the spectral response of two receivers suitable for the detection of light signals from GaAs electroluminescent diodes: a photomultiplier tube with S1 response and a silicon photodiode. The band-to-band emission coincides very favorably with the response of these two detectors. With increasing temperature the emission line moves to slightly longer wavelength (about 9000 Å at room temperature), reflecting the decrease of the energy gap with temperature.

Spatial origin of electroluminescence

Let us briefly consider where the radiation originates in the electroluminescent p-n junctions. Principally, radiative recombinations take place either in the space-charge region (that is, directly at the junction) or in the adjacent n and p regions. Which case prevails depends on the doping conditions in the n and p regions and the impurity gradient at the junction. Generally one can state that space-charge recombination should prevail if the junction region is fairly wide (that is, the impurity gradient is small). For abrupt junctions, injection into either the n or the p side may dominate. If the energy gap is the same on both sides of an abrupt junction, the number of electrons injected into the p side relative to holes injected into the n side is

$$\frac{j_n}{j_p} = \frac{n_p}{p_n}\left(\frac{D_n\tau_p}{D_p\tau_n}\right)^{1/2} = \frac{n_p}{p_n}\left(\frac{\mu_n\tau_p}{\mu_p\tau_n}\right)^{1/2} \qquad (3)$$

where n_p = electron concentration on the p side; p_n = hole concentration on the *n* side; D_n, D_p = diffusion coefficients; τ_n, τ_p = lifetimes; and μ_n, μ_p = mobilities of electrons and holes.

For most compound semiconductors the electron mobility is much higher than the hole mobility, and one therefore expects electron injection to be predominant. Electron injection is further enhanced because in heavily doped direct-gap materials, such as GaAs, the p side has a slightly smaller energy gap than the n side. In fact, the emission spectra from highly doped GaAs diodes resemble those of the p-type photoluminescence,[15] demonstrating that electron recombination actually takes place on the p side. If the p side is doped very heavily and the n side only lightly, hole injection into the n region can also be obtained.[16]

Stimulated emission

As mentioned before, stimulated emission has been achieved in a number of direct-gap materials. So far, p-n junction lasers with emission in the visible region have been fabricated only from $GaAs_xP_{1-x}$. All other injection lasers emit in the infrared region of the spectrum. By electron beam and optical excitation it has been demonstrated that "wide-gap materials" (such as CdS, CdSe, and ZnSe) may emit laser radiation. However, in these materials it has so far been impossible to form p-n junctions; see Table I.

An injection laser would of course be a most desirable p-n junction electroluminescent light source, particularly because of its high quantum efficiency. Therefore, we shall include a short account of the stimulated emission from p-n junctions, taking GaAs again as a representative material.

One significant feature of stimulated emission is the extraordinarily small width of the laser line ($\Delta\lambda < 10^{-3}$Å). This sharp line emerges from the broad spontaneous emission line above a particular critical current density, the threshold current density. In the most common geometrical laser structure, the Fabry-Perot structure (with two parallel reflecting sides and two roughened sides), the position of the laser line is determined by one of the "modes." These Fabry-Perot modes are caused by interference. That is, an integral number of half waves must fit into the distance L between the reflecting sides; therefore,

$$m \frac{\lambda}{2n(\lambda)} = L \qquad (4)$$

where m is an integer, n is the refractive index, and λ is the wavelength.

In contrast to the spontaneous emission light, which is essentially isotropic, the laser light is emitted perpendicular to the Fabry-Perot mirrors and in the plane of the junction; that is, the light beam is directional. The beam spread is of the order of λ/d, where d is the width of the light-emitting region. The beam spread θ in the plane of the junction is therefore smaller ($\theta_{\parallel} \approx 3°$) than it is perpendicular to the p-n junction ($\theta_{\perp} \approx 20°$). Wider light-emitting regions, as obtained through three-layer structures (p-p_0-n) or (p-n_0-n), lead to smaller vertical beam spreads (as small as 4°).[17]

The external quantum efficiency η_{ext} of Fabry-Perot type of injection lasers is much higher for stimulated than for spontaneous emission. We will consider η as a differential quantity that is the ratio of the change in photons emitted to a corresponding change in current. The quantum efficiency of the spontaneous emission of GaAs diodes has been observed to be as high as 6 percent at room temperature.[18] These diodes, which were produced with an amphoteric dopant, have wide junction regions and do not lase. Other technological criteria must be applied to laser fabrication, such as junction planarity and width, high doping levels, etc. Typically, good laser diodes have external efficiencies of 0.1 percent at room temperature for the spontaneous emission (compare, for instance, Fig. 7). If the temperature is lowered, the efficiency increases significantly.

In the case of stimulated emission, differential external efficiencies up to 70 percent have been observed at liquid-nitrogen temperature and up to 20 percent at room temperature. One obvious reason why these efficiencies are so much higher than in the case of spontaneously emitting diodes is the different angular distribution of the emitted light. The spontaneous emission, being isotropic, passes to a large extent through highly absorbing parts of the diode; also, the average transmission coefficient at the surface T_{avg} in Eq. (2) is small. The stimulated emission, however, propagates in the p-n junction plane, where the absorption losses are small, and leaves the crystal perpendicular to the Fabry-Perot sides. The transmission coefficient T_n is that for normal incidence and is larger than T_{avg}. For stimulated emission, Eq. (2) has the form[19]

$$\eta_{\text{ext}} = \frac{\eta_{\text{int}} \ln (1 - T_n)}{\ln (1 - T_n) - \alpha L} \qquad (5)$$

The relation demonstrates that short laser diodes should be the most efficient ones. The variation of η_{ext} with either the laser length L or the transmission coefficient is a method that can be employed to determine the internal efficiency η_{int} and the absorption losses α. Such measurements give the interesting result that the internal efficiency is practically 100 percent at low temperatures and is still quite high (about 50 percent) at room temperature).[20, 21] The absorption losses of the lasers seem surprisingly low (10 to 20 cm^{-1} at 77°K) if one compares them with the absorption constants of the bulk materials (several hundred cm^{-1} at 77°K). Figure 7 shows the temperature dependence of the internal quantum efficiency and also of the external efficiency for stimulated and spontaneous emission.

For practical application of p-n junction light sources, it is desirable to operate well above the laser threshold. Operation as a laser should lead to very high quantum efficiencies and also should give a well-defined light beam without additional optical focusing devices. Unfortunately, the current densities at which lasing begins are so high at room temperature that continuous operation of the diode is not possible. Many recent studies have been concerned with the temperature dependence of the threshold current density j_t and particularly with its reduction at room temperature.

At very low temperatures (that is, up to about 50°K), the threshold current density is fairly constant and has values of several hundred amperes per square centimeter for good GaAs lasers. At higher temperatures, j_t increases strongly with temperature T and, to a good approximation, a third-power law ($j_t \propto T^3$) holds.[22] At room temperature, the threshold current densities have increased to values of 5000 to 100 000 A/cm². The main physical reason for the increase in j_t is the change of the electron (hole) distribution with temperature, which makes it more and more difficult to establish the population inversion necessary for stimulated emission. The absorption losses α also enter into the threshold relation as follows:

$$R^2 \exp\left[g(j_t)L - \alpha L\right] = 1 \qquad (6)$$

where $g(j_t)$ = optical gain at thresholds and R = reflection coefficient. The losses increase only slightly with temperature and do not cause the steep rise of j_t.[23] The temperature dependence of j_t can be influenced by structural parameters in the p-n junction laser, and the weakest temperature dependence has been obtained for diodes fabricated by a liquid epitaxial process.[24] Still, the best room-temperature values are between 20 000 and 30 000 A/cm², which is too high for continuous operation. At liquid-nitrogen temperature, continuous operation of GaAs lasers is possible and light outputs of several watts have been obtained.

Progress in reducing the threshold current density and in improving the external quantum efficiencies will undoubtedly be slow and will depend on advances made in materials science and technology. So far, however, nothing fundamental precludes the possibility of continuous operation at room temperature at efficiencies of, say, 10 percent or higher.

Gallium arsenide–phosphide

The state of the art of the materials technology for the only existing visible p-n junction laser, $GaAs_xP_{1-x}$, is still far behind that of GaAs. The ternary compound $GaAs_xP_{1-x}$ is a direct-gap material up to approximately $x = 0.6$ (that is, 60 percent GaAs); beyond that composition it has a band structure like GaP, namely, indirect. With increase of the GaP concentration, the band gap widens steadily from that of GaAs (about 1.5 eV) to GaP (about 2.3 eV), and at the direct–indirect transition point it has reached a value slightly below 2 eV. The shortest wavelength where lasing has been obtained at 77°K is 6380 Å—that is, in the orange region.[25] Because of the band-gap shift with temperature, the corresponding value at room temperature would lie near 6800 Å (red). Although the eye is not very sensitive at this wavelength (see Fig. 4), the ternary compound has a high potential on the basis of the good efficiency values observed in GaAs.

Other structures for minority carrier injection

As seen in Table I, there are other direct-gap materials available whose energy gap coincides much better with the maximum sensitivity of the eye. Since p-n junctions cannot be readily produced in these materials, let us briefly consider other electrical methods for creating minority carriers. One simple substitute for a p-n junction is a p-n heterojunction, which is the junction of two different materials of which one is n type, the other p type. These heterojunctions can be grown especially easily when the lattice constants of the two materials are very similar.

Another structure that is, in principle, very similar to a p-n junction is a metal–semiconductor junction. Because of the work function difference, the energy bands of the semiconductor are bent at the interface. Under suitable conditions, the energy bands are bent in such a way that minority carriers are injected under forward bias, as shown in Fig. 8. These minority carriers can then recombine radiatively. This type of structure is called a "Schottky diode." Its efficiency is low, however, since minority-carrier injection constitutes only one part of the total current. Another part of the current results from extraction of majority carriers into the metal, where they recombine nonradiatively. This loss component can be reduced to some extent if a thin "insulating" film is placed between metal and semiconductor

FIGURE 7. Temperature dependence of external quantum efficiency of spontaneous and stimulated emission. Internal efficiency of stimulated emission is also shown.

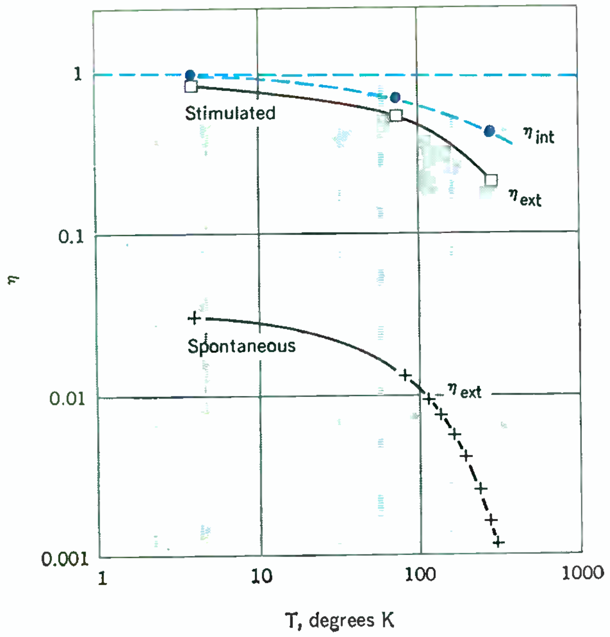
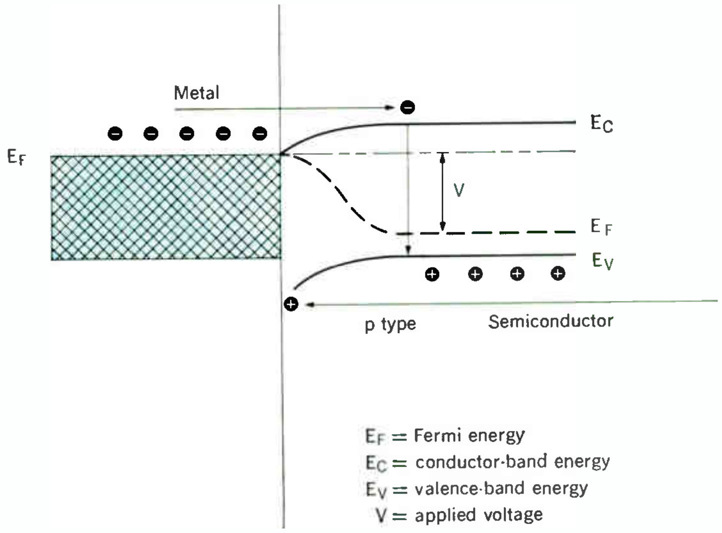


FIGURE 8. Metal-semiconductor junction.



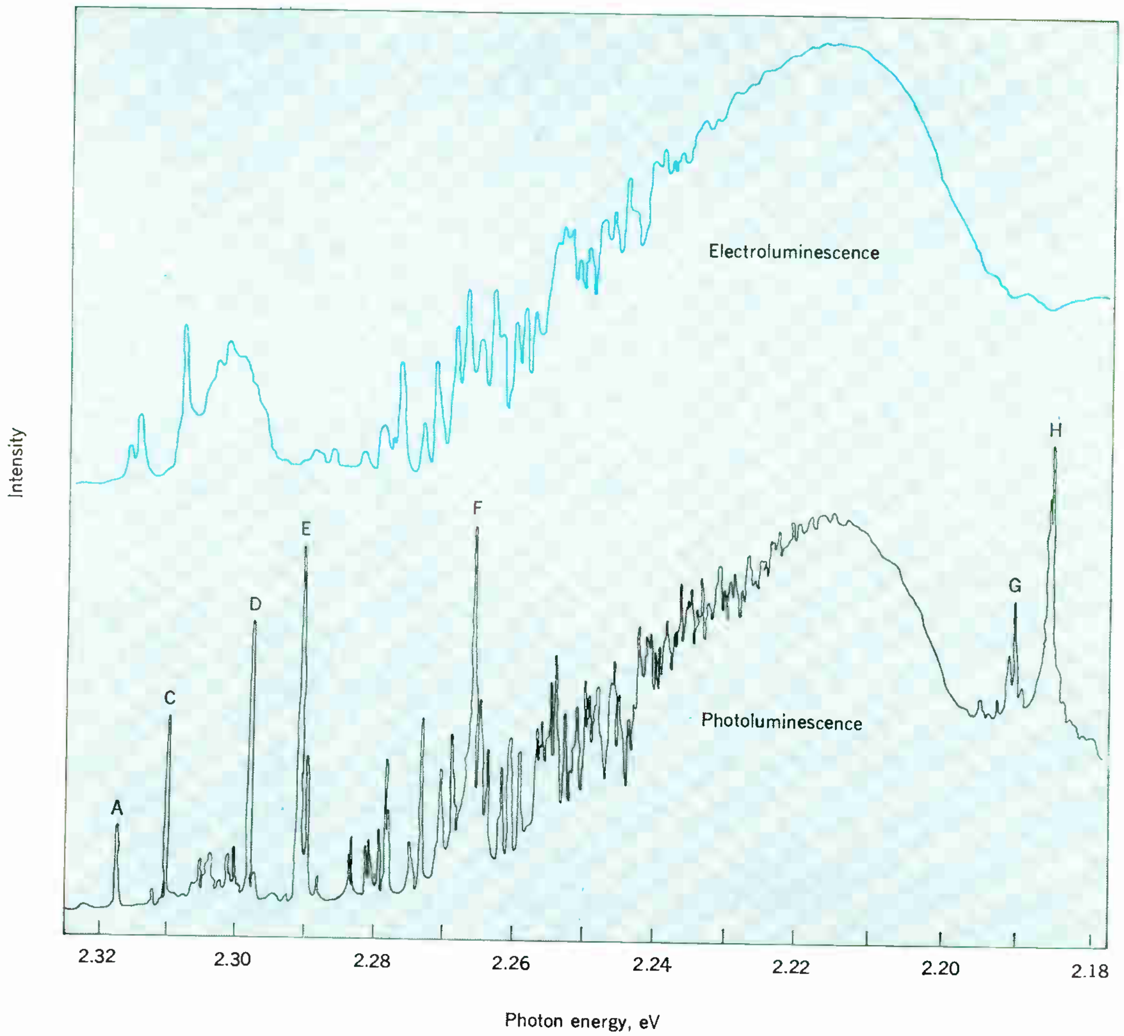


FIGURE 9. Photoluminescence and junction electroluminescence of a GaP diode at 20°K (after Gershenzon et al.[31]) Peaks labeled A to H are bound exciton lines.

through which charge carriers tunnel. By a suitable choice of materials (i.e., their work functions) one can make the tunneling easy for the minority carriers and difficult for the majority carriers, thus improving the quantum efficiency. An obvious disadvantage is the high impedance caused by the "insulating" film. In a few cases these devices have been realized experimentally; however, technological difficulties make them impractical at the present time.

Finally, minority carriers may be created by impact ionization. In a region of high electric fields, as in a reverse-biased p-n junction or simply as in a thin region of high resistivity, charge carriers can gain enough kinetic energy from the field to create electron-hole pairs. The minority carriers may then recombine radiatively. It is easy to see that a reverse-biased p-n junction is not conducive to efficient recombination because the field pulls the minority carriers immediately into a region where they are majority carriers. If the impact ionization takes place in a thin highly resistive layer (for instance, a p-p_0-p or n-n_0-n structure), the minority carriers can recombine radiatively. Efficient electroluminescence has been created this way in GaAs[26] and ZnTe.[27]

Indirect-gap materials

For the following discussion of the emission from p-n junctions in indirect-band-gap materials, GaP has been chosen as a representative material of this group. As mentioned earlier, the recombination mechanism tends to go via impurity levels since this facilitates momentum conservation. Two types of emission lines are observed in GaP: (1) A number of very sharp lines, which have been interpreted as so-called bound excitons (hydrogen-like electron–hole pairs bound to an impurity). This type of emission is described in detail in refs. 8 and 9. (2) The so-called donor–acceptor pair emission, which is the more efficient type of emission at room temperature. In this type of radiative transition the recombination mechanism requires first the trapping of an electron from the conduction band on a donor level. In GaP, even the "shallow" donor levels are discrete and do not overlap with the conduction band. Similarly, a hole is trapped on an acceptor level. The trapped hole and electron then recombine radiatively. The energy of the emitted photon ($h\nu$) corresponds to the energy difference between the donor and acceptor levels, as shown in the energy-band diagram of Fig. 1.

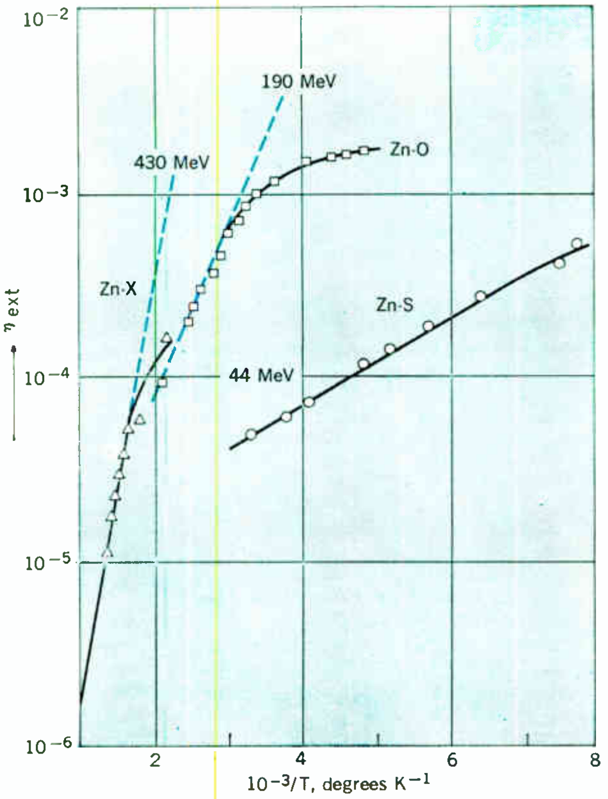


FIGURE 10. Logarithm of the external quantum efficiency as a function of $10^3/T$ for various pair emissions in GaP electroluminescence.

Examples of shallow donors in GaP are Te, S, and Se, whose energy levels lie about 100 MeV below the conduction-band edge. A common shallow acceptor is Zn, with a level E_a at about 40 MeV above the valence-band edge. If we subtract these energies from the energy gap (2.3 eV) and convert the resulting energy into a wavelength, we find that the shallow donor–shallow acceptor pair energy is in the neighborhood of 5600 Å (green). The exact value of the peak wavelength depends, of course, on the exact position of the donor (and acceptor) levels. The green emission band is very suitable for visible electroluminescence, because it nearly coincides with the peak sensitivity of the eye (Fig. 4.).

Another interesting donor–acceptor pair band near 7000 Å (red) is observed in oxygen-doped GaP. It is believed to be due to a transition from a deep donor (caused by oxygen) to a shallow acceptor, such as Zn. Contrary to the bound-exciton lines, these donor–acceptor pair bands are very broad; the deeper the levels involved in the transition, the broader the emission band.

At low temperatures (below about 20°K) the green emission band reveals a remarkable structure. It is found that the band consists of a very large number of sharp lines, particularly on its short-wavelength side; an example may be seen in Fig. 9. Much of the work of identifying these complicated line spectra was done at the Bell Telephone Laboratories.[8,9] The basic ideas underlying the interpretation of the lines are the following: (1) Donors and acceptors are substitutional impurities; that is, they are situated on Ga or P sites. Although the impurities are randomly distributed throughout the crystal, there are only discrete distances between them. These distances can be related to the periodicity of the crystal lattice. (2) Donor and acceptor states are localized, and no impurity-band conduction takes place. (3) A Coulombic interaction energy between donors and acceptors $e^2/\epsilon r$, where ϵ = dielectric constant and r = donor–acceptor pair separation, contributes to the energy of the emitted photon:

$$h\nu = E_g - (E_d + E_a) + \frac{e^2}{\epsilon r} \qquad (7)$$

Since r has only certain discrete values, given by the lattice periodicity, the pair emission occurs at discrete wavelengths corresponding to given pair separations.

The sharp line spectra are seen only at very low temperatures. At higher temperatures they merge into one fairly broad band whose width increases with temperature. At room temperature the red emission band has a half width of 870 Å and the green emission band has a half width of 330 Å.[28]

The quantum efficiency of the donor–acceptor pair bands at very low temperature is quite high (up to 60 percent). It seems likely that the internal quantum efficiency is close to 100 percent, similar to the efficiency of the direct-gap semiconductor GaAs. At room temperature, however, the external efficiencies are low. The best values obtained for the green emission are about 0.01 percent and for the red emission about 1 percent. Because of the variations in eye sensitivity, there is still approximately equal visibility. If we consider Eq. (2), the question arises whether these small efficiencies (particularly that of the green emission) are due to high absorption losses or to a decreased internal efficiency. Experimentally, one can answer this question by measuring the efficiency as a function of the transmission coefficient. It is found that the internal efficiency is about five times larger than the external one (for the green and red emission). We must therefore conclude that a considerable amount of nonradiative recombination takes place at high temperatures. What these nonradiative processes actually are is still open to speculation.

The temperature dependence of the external quantum efficiency for various emission lines is shown in Fig. 10. It can be observed that the efficiencies have a logarithmic dependence on $1/T$ in some temperature ranges. The activation energies derived from the slopes of ln η_{ext} vs. $1/T$ are believed to be related to the depth of one of the impurity levels involved in the transition. The deeper the controlling level of the donor–acceptor pair band, the stronger will be the change of efficiency with temperature. As usual, all the efficiency values are differential efficiencies. How much the values of the room-temperature efficiencies may still be improved is difficult to predict. We have seen that the efficiencies are largely limited by nonradiative processes. As long as we have no exact understanding of these processes, it is difficult to speculate about eliminating them.

Speed

The speed at which light from p-n junction diodes can be modulated is important in some applications. This modulation speed is found to be quite high, particularly for direct-gap semiconductors.

In GaAs diodes, the spontaneous emission can be switched on and off in times of the order of one nanosecond.[29] In most cases the switching of stimulated emission is also very fast. However, Konnerth[30] observed a room-temperature delay effect as high as several hundred nanoseconds near threshold. This seems to be limited to a certain type of injection laser (Zn-diffused GaAs). This effect manifests itself in a delay between the beginning of the light pulse and the current pulse.

Green-emitting GaP diodes (Te-Zn pair band) show time constants of around 50 ns at room temperature. The corresponding time constants of red-emitting diodes (oxygen-Zn pair bands) are near 100 ns. This means that they are slower than direct-gap materials, such as GaAs, but they may still be considered as being very fast in comparison with other conventional light sources.

Lifetime and reliability

The lifetime of electroluminescent diodes has been studied mainly for GaAs. In Zn-diffused diodes a slow degradation effect has been found at room temperature; that is, the external efficiency of an operating diode decreases slowly with time. This degradation apparently does not occur to the same extent in diodes prepared by other techniques. At present, one may expect lifetimes of about 10 000 hours. Diode structures have a decided advantage over incandescent light sources in terms of ruggedness and reliability. They are small and not generally subject to catastrophic failures.

Applications of semiconductor light sources

The high switching speed of semiconductor light sources offers one immediate application in the field of optical data transmission. This application has been much discussed in connection with injection lasers, and various demonstrations of data transmission, such as television programs, voice communication, etc., have been made.

Since the diodes can be made very small, they may be easily incorporated into microelectronic circuits, where various functions of optical data transmission are possible. If the emission is visible, these diodes may at the same time serve as indicator lights. Currents and voltages for diode operation are compatible with those used in the integrated silicon technology.

Another area of application is that of optical displays, including alphanumeric and possibly television-type displays. Through the use of different colors, displays of a color television nature are possible.

Reading of computer cards, technical graphs, and possibly even printed information are some other applications. In this case the light emitters represent only one side of the story. Small and fast light detectors are also required for such applications.

The most promising and immediate application of visible light diodes is as indicators. The light diodes may find use on computer consoles, electronic equipment, in the home, in the car, etc. Their use will undoubtedly grow beyond present expectations if reliable units can be manufactured cheaply and in quantity.

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Wired broadcasting in Great Britain

Systems for the distribution of audio and video programs by wire to large urban populations now challenge conventional broadcasting in Great Britain from the standpoint of both cost and performance

R. P. Gabriel

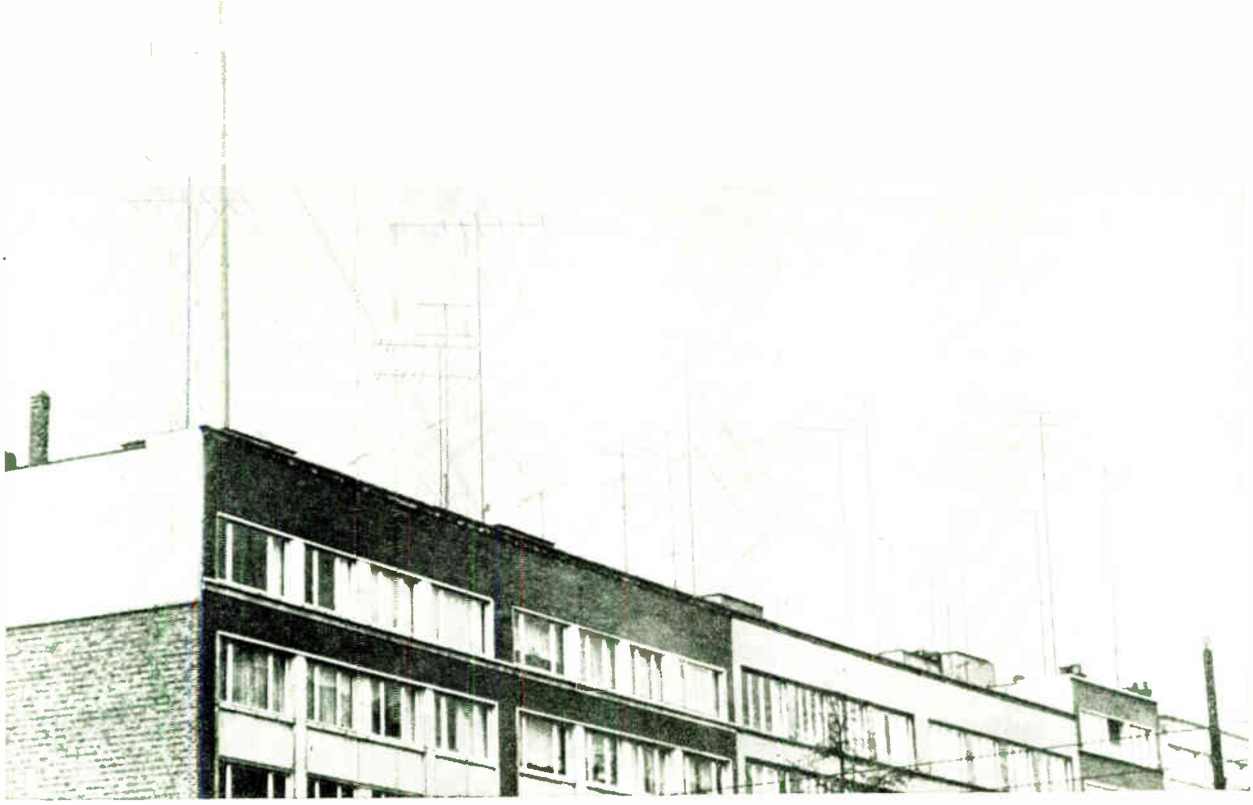
Rediffusion International Limited

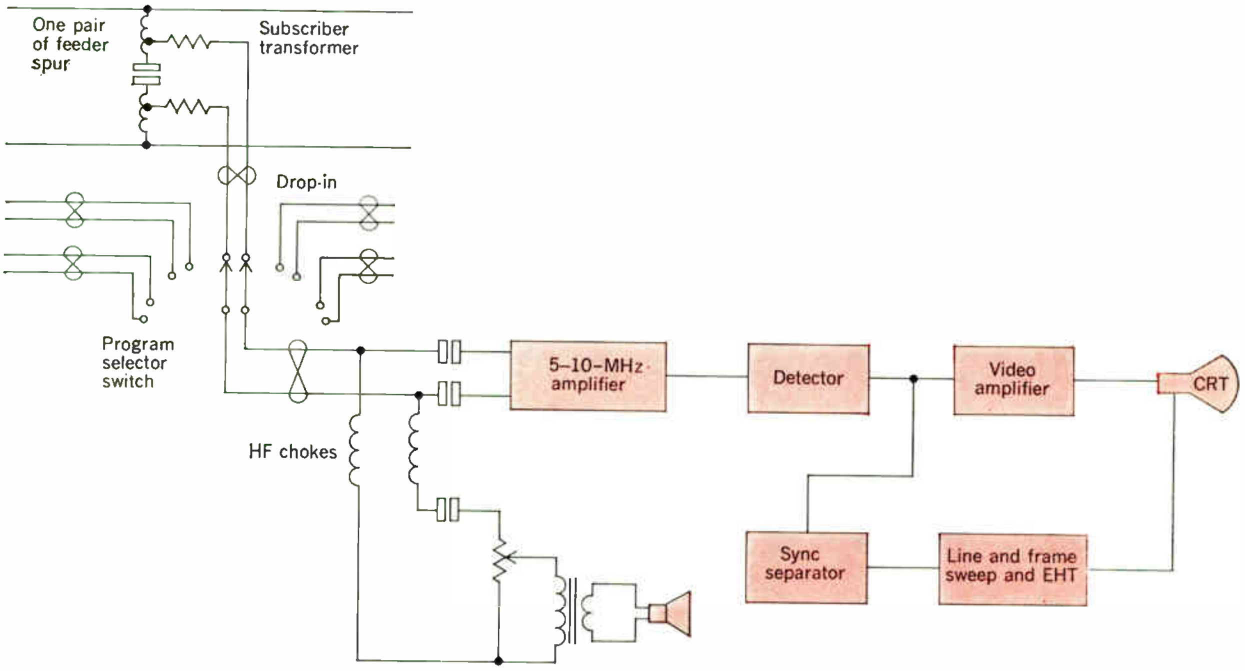
In densely populated areas the number and power of television transmitters in the VHF band are beginning to pose a serious problem of mutual interference. In view of this, and of the need to leave the radio spectrum free for communication circuits for which it is a necessity, it is pertinent at this time to review the possibilities of systems designed for broadcasting by wire. What has been achieved in Great Britain, where wired broadcasting is seriously competing with conventional systems, is described. The requirements, and advantages, of a wired network are examined, and a comparison is made with CATV systems.

In a modern city it can be taken for granted that every home is equipped for the reception of audio and video signals. This service is as much a necessity as running water or electric power—but all is not well with conventional means of providing it, as anyone who has had experience with television reception in a large city knows. Air is not a perfect medium for the transmission of pictures because they are subject to a constantly changing pattern of ghosts and static interference. In any case, direct reception in the home is impossible for many who live in apartment houses, as it must be provided by some form of wired distribution from an aerial shared in common.

In the densely populated areas of Europe the number and power of television transmitters in the VHF bands are reaching the point where mutual interference aggravated by sporadic *E* reflections from the ionosphere is serious, and with further growth and the introduction of color something approaching the existing chaos of the medium-wave band becomes a real possibility. The UHF bands have their own limitations of short range and many blank spots, which lead to the necessity for a great multiplicity of transmitters and again to mutual interference. It is also true that conventional television broadcasting has done

FIGURE 1. Is this the best we can do?





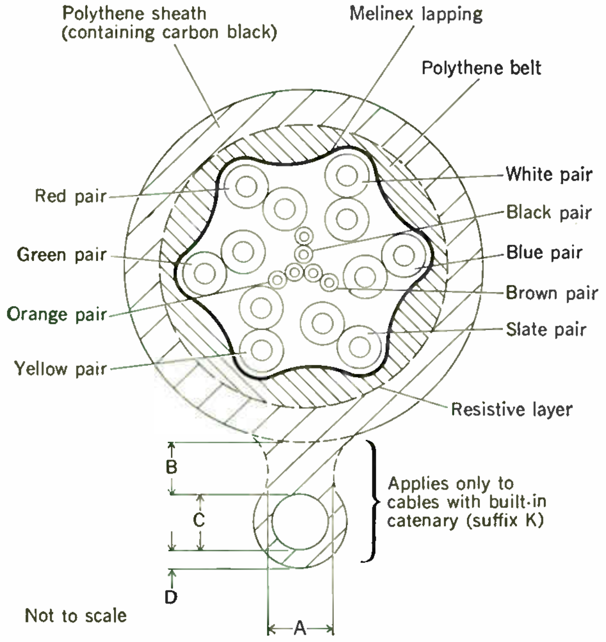


FIGURE 2. Subscriber's installation.

FIGURE 3. Multipair cable with resistive sheath.

much to impair the appearance of our cities (Fig. 1) and the public is entitled to ask if scenes such as that illustrated really represent the best that communications engineers can do.

Finally, and perhaps in the long run most important of all, the precious radio spectrum must be kept free for the ever-increasing needs of those communication circuits for which it is really necessary. The importance of this issue has been emphasized by a recent report[1] that broadcasting in the United States now consumes no less than 82 percent of the nongovernment allocation below 1000 MHz. Although some residual broadcasting by radio will always remain necessary for the entertainment of the traveling public, it is obvious that the transfer of the main broadcast service from air to wire should immensely relieve the crisis.

All these considerations make it of current interest to examine what has already been achieved as well as the future possibilities of systems designed specifically for broadcasting by wire.

System requirements

A distribution system for a densely populated city is built up of tens or hundreds of thousands of units. The essential elements of each unit are (1) a loudspeaker and volume control for the sound, (2) a cathode-ray tube for the picture, (3) a program-selection device, (4) a drop wire about 9 meters long, (5) a tap-off or junction box, and (6) a length of feeder, which will average some 13–14 meters in length.

As long as these elements are provided, the choice of the others should be left to the discretion of the system designer so that he can select the most efficient, and least expensive, method of achieving his objective. In particular, the receiving apparatus in the home will be an integral part of the system and will be radically simpler and cheaper than a receiver designed for reception from an aerial. However, if the system, as will generally be the case, eventually is to displace a well-established radiobroadcasting system, the designer must provide some simple, convenient means of serving, during the transitional period, the conventional television sets that already exist in such large numbers.

In England two companies (Rediffusion Limited and British Relay Wireless Limited) over the period 1930–1950 had built up a substantial business in relaying sound programs by wire to some one million subscribers at home and overseas. It was natural for these companies to

I. Nine-pair cables*

	Screening	Conductor Diameter, cm	Attenuation at 5 MHz, dB/30.5 meters	Overall Diameter, cm
First 15 percent of feeder length	Copper	6 of 0.091 3 of 0.055	0.65	1.40
Remaining 85 percent of feeder length	Resistive sheath	6 of 0.046 3 of 0.041	0.97	0.97
House drop	Unscreened	6 of 0.046 3 of 0.041	1.13	0.76

* See also references 3–5.

approach the design of wired television systems from the standpoint described; both evolved systems that, although differing in detail, are basically similar in that they employ multipair cable and use the relatively low frequency band of 3–10 MHz. These systems have met with great commercial success,[2] as they are able to compete in high-signal-strength areas with ordinary reception from antennas, although without the advantage of being able to offer additional programs that has formed the basis for the growth of CATV in the United States. There are some one million subscribers to wired systems in Great Britain, of which 70 percent are connected to HF multipair systems. This total represents approximately 7 percent of all television homes, which is about twice the corresponding figure for the United States. Being competitive, wired systems have been able to grow in a number of large cities; the HF systems in Lambeth (part of London), Hull, Newcastle, and Nottingham each serves over 30 000 subscribers. The largest system anywhere is in Hong Kong, with 70 000 subscribers and over 1900 km of feeder network. A true wired broadcast operation, it has its own studios and makes no use of transmission through the air.

This rapid growth has been achieved in spite of strict government control of the industry. No relay system may be established without a license from the Post Office, which imposes strict conditions on the programs that may be distributed and prohibits the operator from originating any program of his own. The license runs for a limited period, at the end of which the Post Office has the right to take over the business by purchasing the physical assets at valuation. The present 15-year licenses expire in December 1967 and the industry has recently been informed that new licenses will be granted to expire in 1976. A series of technical conditions are attached to the license, concerned mainly with the prevention of interference by the system with ordinary broadcast reception or with the Post Office telephone network.

The system described here is that of the larger of the two companies, which serves over 500 000 subscribers in Great Britain and Hong Kong.

The method of sound distribution is as simple as possible. Each program is carried at audio frequency on a separate pair of wires with sufficient power to operate the loudspeakers directly. All that is needed in the home are the bare essentials—a loudspeaker, a volume control, and a program selection switch. No tubes, transistors, or tuners are used, and no connection to the electricity supply is required for sound reception. The economics are such that it is less costly to provide sensitive and therefore high-fidelity loudspeakers than to use cheap units that need more copper in the distribution network.

The method of distributing the video signal is very much the same; each program is carried on a separate pair of wires and all programs are transmitted in the same frequency band, 5–10 MHz. The video and audio signal, which together form a program, are combined and connected to each pair of the multipair cable. The arrangement is shown in Fig. 2.

The number of programs distributed can be increased as desired by increasing the number of pairs in the cable. Three television programs (or four in a few areas) are now available in Great Britain. As it is certain that this number will not exceed six for many years to come, a nine-pair cable is normally used with capacity for six television and three sound programs. However, some systems have been installed for special purposes with provision for 12 television and six sound programs. A cross section of the nine-pair cable is shown in Fig. 3 and the main parameters are given in Table I for the three sizes used in a distribution network, as explained later.

Network planning

Figure 4 shows how the network for a typical medium-sized town of 10 000 homes is planned. The signals from the broadcasting stations are received at some point within or outside the town where reception conditions are favorable. The audio signals are demodulated and the video signals frequency-converted to the 5–10-MHz operating band. Both signals are then carried by a primary distribution network or video trunk route (VTR) to the centers of the unit areas or "diamonds" into which the town is divided. The trunk route cables contain a separate pair for each audio signal and a separate coaxial tube for each video signal and they are usually placed in an underground duct. Each diamond will include 800 to 1100 homes or about 12 km of feeder cable fed from the amplifiers housed in a kiosk (Fig. 5) at the distribution point at the center of the area. The kiosk contains a separate amplifier or repeater[6] for each video signal and these may be bridged across the trunk cable or may provide amplification for the ongoing trunks as well. There is also a separate power amplifier for each sound signal and equipment for isolating and testing the cables.

The output level of the video repeaters is about 14 volts, which is allowed to fall to 70 mV at the end of the feeders. Post Office conditions require that the field radiated by the system shall not exceed 10 μV per meter at points distant 9 meters or more from the system with an overriding condition that no interference shall be caused to other parties. To comply with this requirement, the feeder is screened with copper tape for the first section until the voltage has fallen to 5 volts. Thereafter, screening is no longer neces-

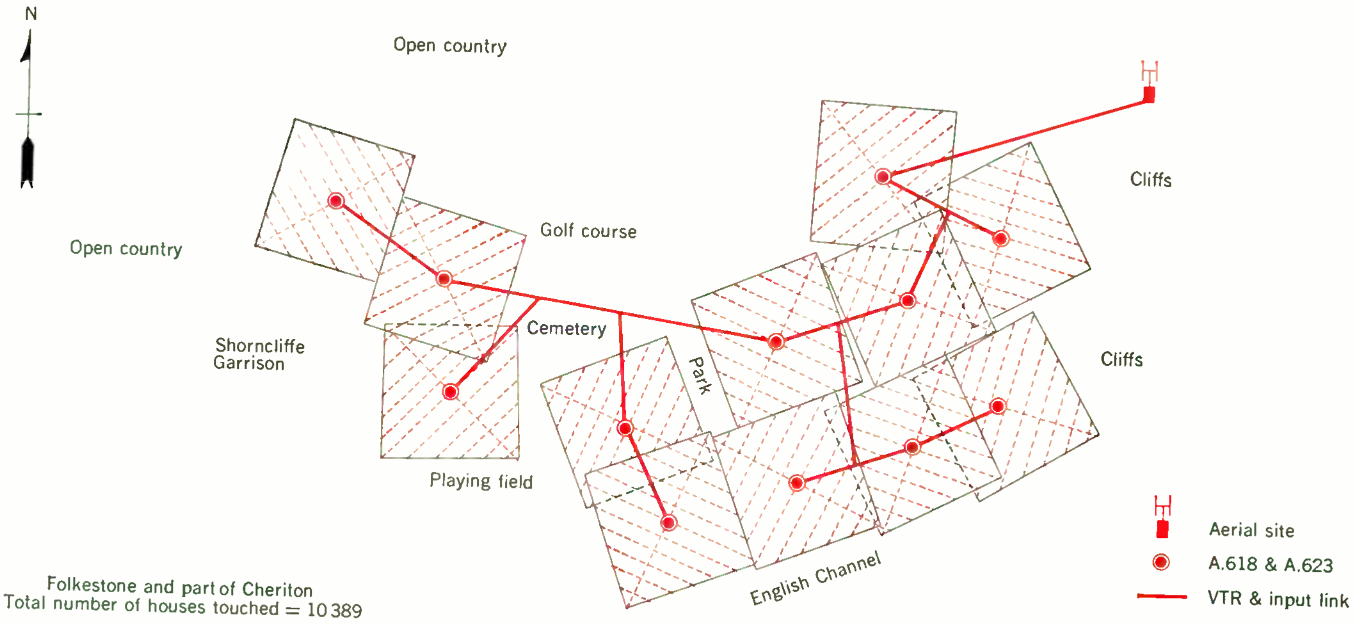


FIGURE 4. Network layout for Folkestone.

FIGURE 5. Kiosk housing repeaters.

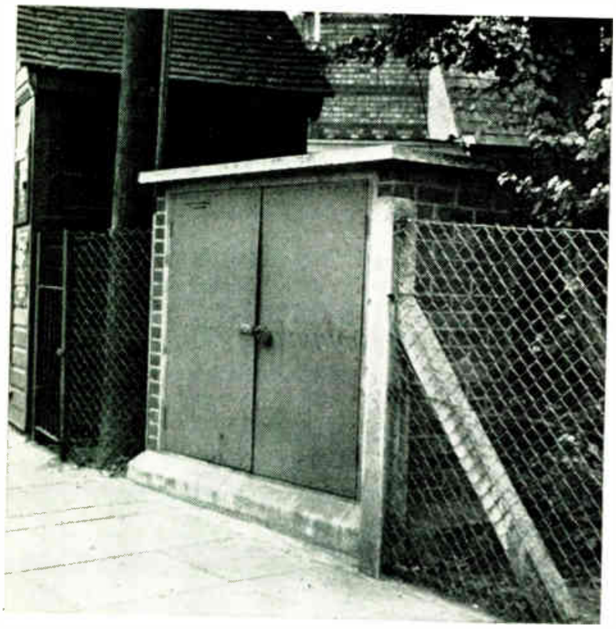
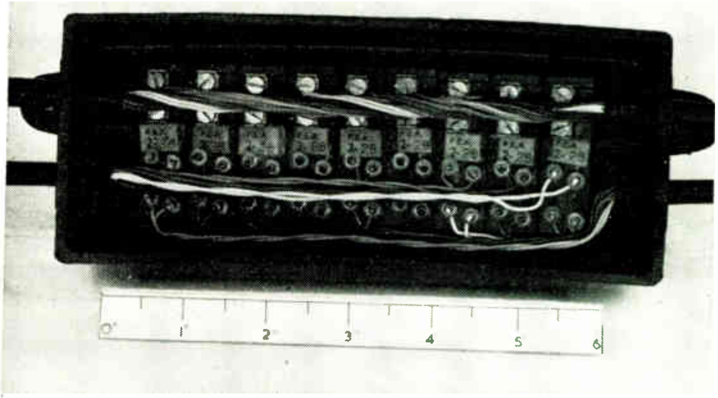


FIGURE 6. Junction box with inserts.



sary to limit radiation but if the cable has no screen at all, attenuation will increase to an unacceptable extent as the outside surface goes from being dry and clean to being wet and dirty. In order to stabilize the attenuation the cable is given a sheath of material having a resistance in the range of approximately 2600–26 000 ohms per meter. This is cheaper than a metallic screen and causes less reduction in the attenuation.

Some variation in the attenuation of cables used for house drops is acceptable since they are short in length; the main consideration here is the likelihood of picking up interference from unwanted transmissions in the 5- to 10-MHz band. A long-term study of prevailing field strengths from sky waves in this band has shown that they rarely exceed 30 mV/m. With a minimum signal level of 15 mV at the foot of the house drop, a well-balanced cable will provide adequate protection against interference from this source. Occasionally an interference problem can arise in the immediate vicinity of a transmitter working in this band (e.g., ham radio), but this can be overcome by providing the house-drop cable with a copper screen and, if necessary, by increasing the signal level above 15 mV.

Junction box. The feeder cable and the house drop are connected by means of the high-frequency transformers shown in Fig. 2. The small capacitor at the center prevents the line from being short-circuited at

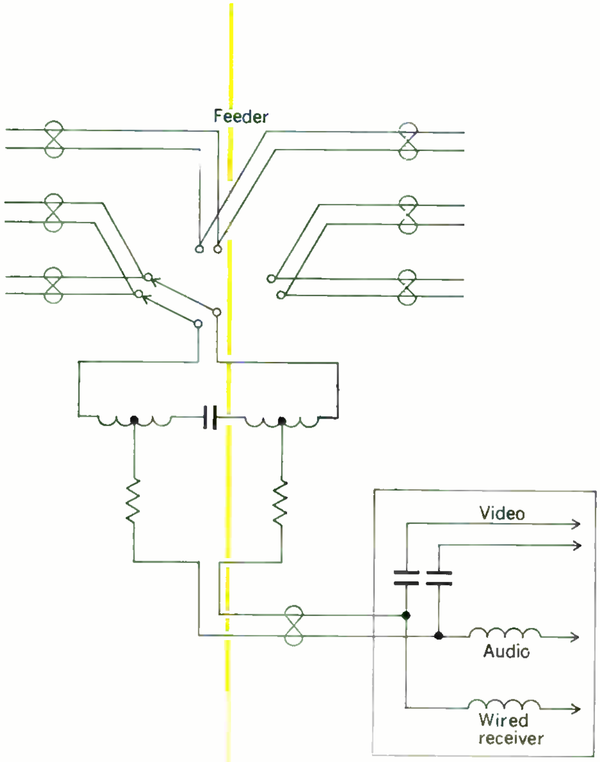


FIGURE 7. Single insert installation.

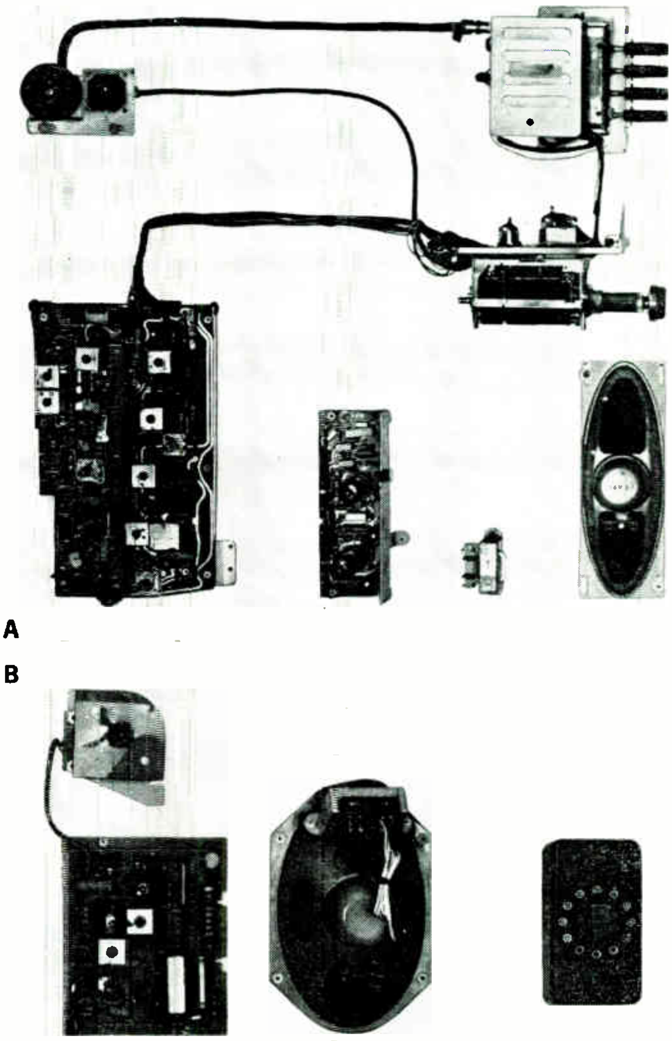


FIGURE 8. Components of a television set. A—Aerial receiver. B—Wired receiver.

audio frequency. The components are contained in an encapsulated block, shown in Fig. 6, which is called an "insert." They are available with various amounts of attenuation, ranging from 9 to 28dB, between the feeder and the house drop and are designed to serve up to four subscribers. The connection to the feeder cable is made without baring or cutting the conductors, and the quick, convenient method of connecting the house drops also avoids the need to strip the insulation.

In some cases—e.g., in wiring a hotel—it may be better to loop the feeder in and out of the subscriber's switch as in Fig. 7, thus enabling a single insert to be used instead of one per program.

Subscriber's installation. The house drop terminates in the program selection switch, which may be combined with a volume control. A cam-operated switch for the power supply may be coupled to the program switch, thus providing complete remote control; this is particularly convenient for hotel rooms, hospitals, and schools.

A block diagram of a wired receiver is shown in Fig. 2 and a comparison with some of the main components of a conventional television set is shown in Figs. 8 (A) and (B). Because of their greater simplicity, the fault rate of wired receivers is less than two thirds that of conventional sets. The power consumption is also sufficiently less to afford the subscriber a saving of approximately nine cents a month.

Conventional television sets are served by means of a small frequency-changing unit containing a single transistor called an "inverter," which may be hung on the back of the set. It follows the program-selection switch and changes the frequency of the video signals to one of the broadcast channels in the VHF band, to which the set is left permanently tuned. This channel can be chosen so as to avoid any possibility of interference due to direct pickup of powerful local transmitters. The sound normally is taken via a volume control and transformer in the inverter directly to the speech coil of the loudspeaker; alternatively, a frequency-modulated audio signal as received from the broadcast transmitter may be distributed in addition with the usual spacing from the video carrier. This is frequency-converted by the inverter and eliminates the need for a special connection to the loudspeaker in the set.

The problem of 'crossview'

The use of multipair cable and the same frequency band on each pair inevitably poses the problem of cochannel interference, or crossview, due to stray couplings between the different program circuits. The difficulty has been overcome partly by careful design to eliminate the stray couplings and partly by a choice of carrier frequencies that reduce the visibility of the interference patterns.

The most important sources of stray couplings are the cables themselves, but the high degree of mechanical ac-

II. Crossview protection required between two television signals transmitted with one complete and one vestigial set of sidebands

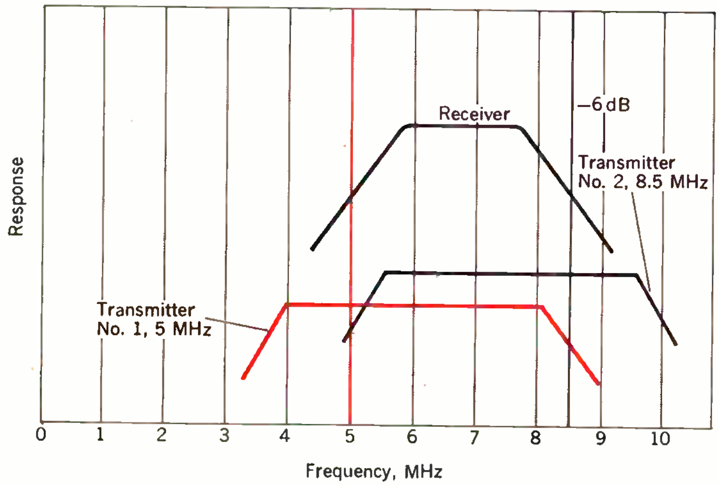
Condition	Protection Required, dB
Synchronized carriers, same standards, carriers in phase	44
Synchronized carriers, same standards, carriers in quadrature	32
Synchronized carriers, one 405- and the other 625-line	34–42*
405 lines, one-third-line precision offset	38†
625 lines, one-third-line precision offset	34†
405 lines, half-line semiprecision offset	42†
625 lines, half-line semiprecision offset	38†
405 lines, *tête-bêche* 3½-MHz separation between carriers	28
Tête-bêche, one 405-line program interfering with one 625-line program with a difference frequency between carriers set to an odd multiple of half line	34–40‡

* Dependent on phase of carriers and difference between frame frequencies.
† Flywheel synchronization required in receiver.
‡ Dependent on difference between frame frequencies.

curacy achieved in recent years in cable construction has greatly advanced their standards of crossview performance. Figures of 50 to 60 dB on a 230-meter length are readily attained, and further improvement appears within reach.

Some examples of the degree of protection required under different conditions are shown in Table II. The *tête-bêche* principle provides an effective and convenient system, particularly if there are no sound carriers to worry about. Figure 9 shows how the fixed tuned receiver can accept either signal and the 3½-MHz separation between the 405-line carriers means that only 28-dB crossview protection is needed.

FIGURE 9. Principle of the tête-bêche system.



Wired systems for color

There is as yet no color television service in Europe but the multipair networks are designed to carry color and systems currently under development show considerable promise of reducing the cost and complexity of the receiver. As with monochrome no tuners or sound receiver are required, but by transmitting a pilot carrier for the chrominance outside the band further simplification may be achieved. For example, the RCA UHF/VHF Model CTC.16 contains 32 controlled cathode streams, 7 vacuum diodes, 13 solid-state diodes, and one crystal. A simplified version of this receiver for the HF system gives noticeably better pictures and contains only 21 controlled cathode streams, 3 vacuum diodes, 12 solid-state diodes, and no crystal.[7]

Remote program selection

Wired television systems are not usually considered for serving relatively isolated houses in the country but if the frequency spectrum is ever to be cleared for more essential needs some answer must be found. Few homes are so remote that the other wired services—telephone and electric power—cannot reach them. The connection of remote homes may not be an economic proposition in itself for any public service; however, if the obligation to serve such customers exists it is perfectly practical to do so and it becomes a question of choosing the best and cheapest method. The HF system offers the possibility of remote selection of programs as shown in Fig. 10. An inexpensive unscreened cable having three conductors combined with simple diode logic circuits and reed relays at the distribution point permits a subscriber at the end of a 2-km "house drop" to select any one of six programs. Simple single-channel line-powered repeaters enable the distance to be extended in successive 1.2-km increments.

Wired systems may also offer a substantial saving in the cost of broadcasting to small pockets of population; for example, in mountainous areas. The capital cost of serving such groups with three television programs from conventional transmitters can be as much as $100 or more per home, and the cost of conventional receivers and antennas will increase this amount to some $300 per home. A typical community of this type with, say, 400 homes in the center, 100 homes in a few outlying groups, and ten isolated farms can all be wired with an HF system at a cost of $100 per home for the system and $140 for the simplified receivers—a total of $240, or a saving of 20 percent.

The same concept of remote program selection may also find application in systems designed to serve big cities with a large choice of programs. Instead of delivering all the programs to all the homes, an automatic program exchange can serve groups of 100 or so subscribers who will dial or push a button to receive a chosen program over a cable containing a single pair for the audio and video signals and possibly a few control wires in addition.

It has been suggested[8,9] that every home in the future will be provided with a very-wide-band communication channel (or electronic grid), offering many entertainment and information services from which one can choose. The alternative concept of a relatively narrow channel combined with remote selection may prove a sounder engineering proposition.

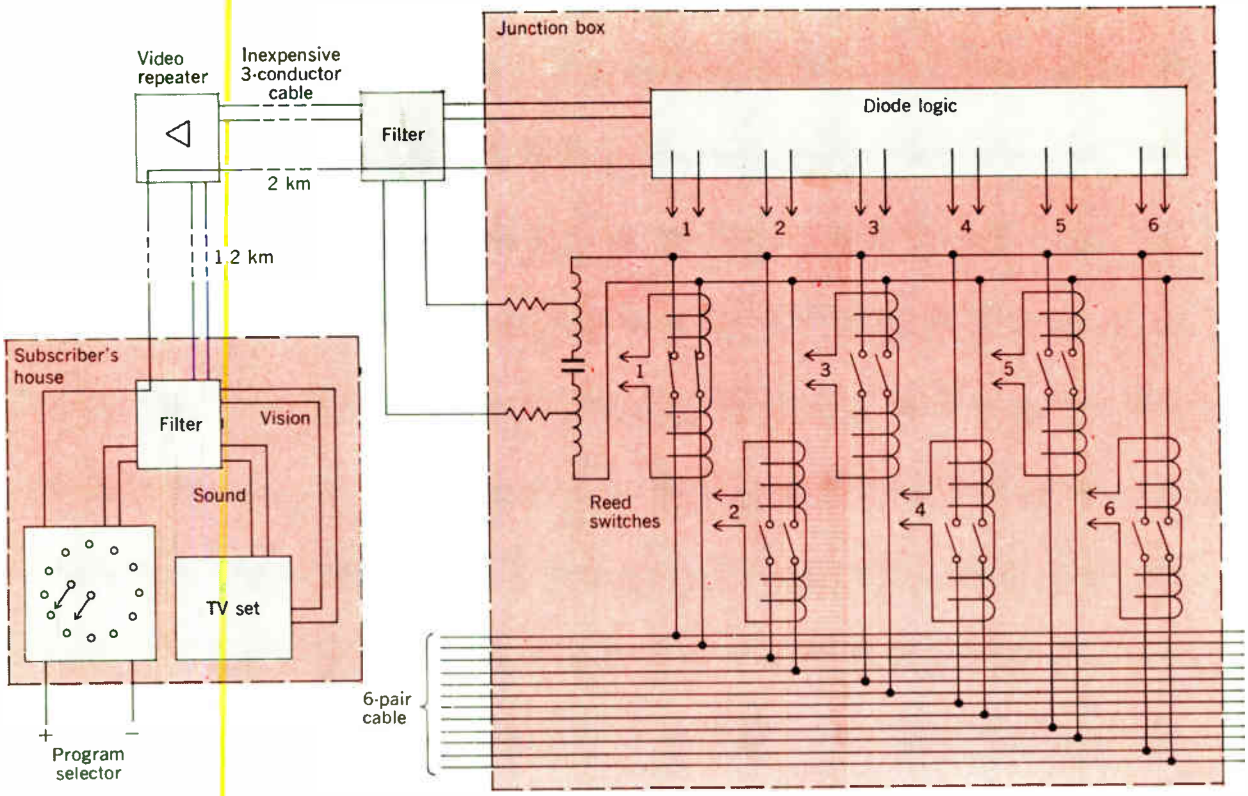


FIGURE 10. Remote program selection.

Broadcasting from satellites

The idea of broadcasting directly to the home from satellites is often advanced as a future possibility but the cost of equipping every home as a satellite receiving station is bound to be greater than the cost of present methods and thus cannot hope to compete with wired broadcasting, which costs less. Satellites could, however, form a very useful primary distribution system for programs that have appeal over very large areas, as is often the case in the United States. The signals could be picked up by fully equipped receiving stations for distribution by wired networks serving each town and city. The power required in the satellites would be no more than that which is now practical.

Pay television

A limited experiment with pay television is presently being carried out on multipair networks in London and Sheffield. Multipair cables are very convenient for the purpose because they enable the necessary control signals to operate directly on the pay-television control unit in the subscriber's home without the intervention of a high-frequency receiver or demodulator. Any pay television system must include these three elements:

1. *Security*. Subscribers must not be able to receive a program without paying for it.

2. *Payment control*. The system operator must be able to vary the program charges.

3. *Accounting provision*. The total amount paid by the subscribers for each program must be known; however, it is not necessary to account for the amounts paid by individual subscribers for a particular program.

One system designed to meet these requirements is the so-called deferred payment system, in which a charge is made at the conclusion of each program and the subscriber must be credited with his payment before he can receive another pay program.

The security on a multipair network is inherently very good as radiation is very low and on a completely non-standard channel. Any radiation present is a jumble of all the programs being carried, and since they are all in the same frequency band, no receiver can sort them out. Additional security is provided by transmitting the sound signal at audio frequency.

Payment is controlled very simply. The pay-television acceptance switch can be closed by the subscriber but it can be opened only by a signal sent over the network. Once a subscriber has accepted a pay program, he has latched himself onto a control circuit from which he is not released until a series of charging impulses has been sent out. Each impulse is priced at, say, five cents, so that, for example, ten pulses would be sent out for a 50-cent program. There are two methods of charging—cash or credit. With credit, the charging pulses are recorded on a simple counter, which is read from time to time like an electricity meter. In the case of cash, the box contains a small dial marked, say, plus $5 to minus $5. When the needle points somewhere in the plus region the subscriber can receive a pay program by pressing the acceptance switch. At the end of the program the charging pulses will be registered as a debit on the dial. If the needle moves into the minus region the subscriber must insert enough coins to bring it back to the plus region before he can receive another pay program. The cash unit is shown in Fig. 11.

The accounting function is performed by a method of Instantaneous Broadcast Audience Counting (IBAC).

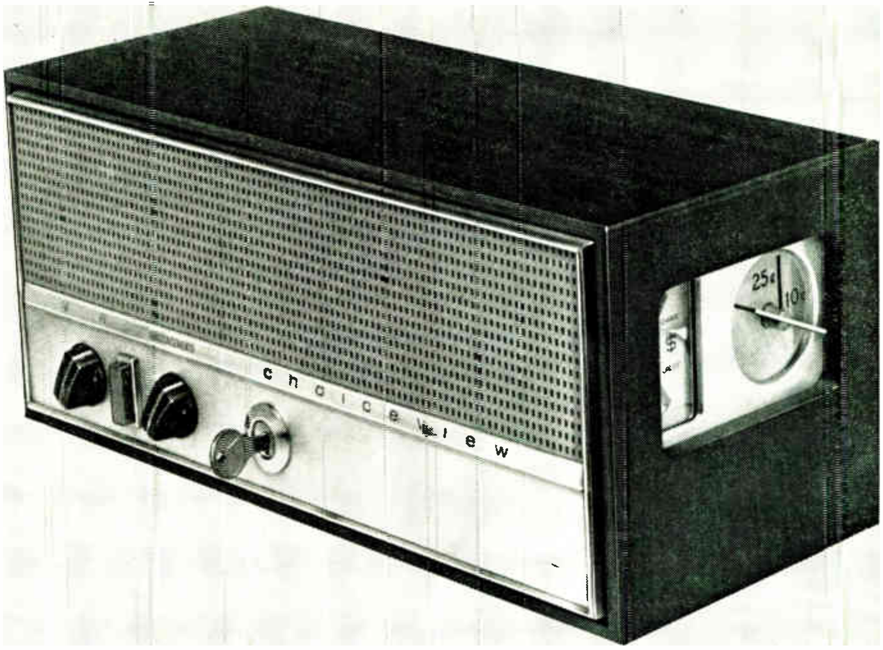


FIGURE 11. Cash unit for subscriber's pay television set.

This is based on the simple idea that each subscriber who accepts a program places a small load, say 1 mA, on the control circuit, so that if the current flowing from the center of the network is 1 ampere, it is known that 1000 subscribers have accepted the program.

Refinements of this idea insure that the current taken is reasonably independent of the voltage regulation of the network and that corrections are automatically made to compensate for the leakage resistance (also see reference 10).

Peak load control. The electricity supply authorities in Great Britain, in order to improve their load factor, offer a special low rate to domestic and other consumers for electricity used during off-peak hours. In most cases this is done by means of time switches, which have the disadvantage of being inflexible and relatively expensive. In other cases, HF signals or "ripple control" may be used, but this again is relatively costly, particularly the injection equipment. The possibility of using television distribution networks to carry the control signals will soon be tried out in practice. As with pay television, multipair networks can transmit enough power to enable the control signals to act directly on a relay, which, in turn, acts directly on the contactor in the off-peak load circuit. The control signals are confined to the subaudio band, 0 to 30 Hz, on one pair of the distribution cable; if more than one type of control is required, other pairs may be used in the same way. The result is a very flexible and inexpensive method of control.

Commercial aspects. Before a network can be set up the agreement of the local authority and the Post Office license must be obtained. The agreement covers two points: (1) permission to install wires across streets, either overhead or underground; and (2) a wayleave to attach cables to local authority property, which generally includes a fair proportion of the homes in the town.

In Great Britain the electric power network is nearly all underground and the telephone network is largely so. As a result there are no utility pole routes that can be used by wired television operators, who must install their own underground ducts for trunk routes and main road crossings; the remainder of the wiring is carried on the outside of the houses, generally at eave level. With private houses the permission of the individual property owners must be obtained in each case. This might be thought a formidable obstacle but is rarely so in practice.

The operator of the system sells or rents the simplified receivers that are used with it but has no monopoly on them. Most television set manufacturers offer a suitable model that their dealers sell or rent in competition with the operator.

Comparison with community antennas. Community antenna systems, which are growing rapidly in the United States, are designed to bring additional programs to conventional television receivers in areas that are inadequately served by transmitters, and they perform this function admirably. However, they do not represent a sound engineering solution to the problem posed in this article. The receivers are designed for one purpose—reception from the air; however, they are used for a different purpose—reception from a network, and the network must be designed to take the place of antennas and not as the most efficient means of distribution. In practice this results in greatly increased costs and various technical difficulties; for example, direct pickup of powerful local signals may be so serious that stringent measures must be

III. Capital costs of audio and video reception, in dollars

	Direct Reception	CATV	HF Multipair
Antenna	15.00		
Network		20.50	21.20
House drop		7.50	11.00
TV receiver	196.00	196.00	137.00
FM receiver	40.00	40.00	
	251.00	264.00	169.20

IV. Total costs of audio and video reception per home per month under bulk contract conditions in Great Britain, in dollars

	Direct Reception	CATV	HF Multipair
Antenna	0.60		
Service rental		0.75	0.80
TV receiver rental	5.86	5.86	4.24
Radio receiver (approx.)	0.50	0.50	
Difference in power consumption	0.09	0.09	
	7.05	7.20	5.04

taken to keep the interference out of the cable system and a special tunable converter unit must be fitted at each outlet to transfer the signals on the cable to some channel that will avoid interference resulting from direct pickup by the receiver itself. Thus each home becomes equipped with two tuners in series whereas with the multipair system none are required.

Network costs

The cost of a network varies, of course, with the number of channels, the distance between the houses, the proportion of underground wiring, and similar factors, but a rough guide to average costs for a multipair six-video and three-audio system would be $4200 per kilometer plus $11 for each house drop. This may be compared with figures for CATV wide-band networks in Great Britain of $3800 per kilometer and $7 per house drop. The greatest saving with regard to HF systems lies in the cost of the receiver, which retails at $137 and reproduces both the television and radio programs, as contrasted with an average figure of $196 for a conventional receiver and an additional $40 for an FM sound receiver. A comparison of the capital costs of audio and video reception is given in Table III.

The capital costs are not of course the whole story since the operating and maintenance costs of the antenna, network, and receivers must be taken into account also. Where HF systems are in competition with direct reception the charge to the subscriber, or service rental, is usually about $2.50 per month with no separate charge for installation. However, there is growing acceptance of the idea that large housing developments should be completely wired under contract with the developer (in Great Britain this is generally a public authority), and the cost of the wired service included as part of the rent for the home. Under these bulk contract conditions the service rental falls to about 80 cents per home per month.

In Britain the renting of television sets is very popular and prices charged include the full cost of maintenance and amortization. The business is highly competitive so that the prices are a true reflection of the costs, which enables a comparison of the total costs of sound and television reception to be made on a basis that is well founded in fact. The figure shown in Table IV for antenna rental is typical for a set of the simplest outdoor antennas for very-high and ultrahigh frequency; the cost of a master antenna for apartment houses would be higher. The figure given in the table for sound receiver rental is nominal and probably understates the market value of the facility provided by the HF system.

Conclusion

It is now demonstrable beyond question that these HF techniques can provide the inhabitants of major cities with a wider choice of programs of much improved technical quality and, at the same time, save them more than 25 percent in their total costs of audio and video reception. Also, the frequency spectrum can be progressively freed for its proper purpose of communicating with men and machines that are inaccessible or mobile. All this can be achieved in not much more than the seven to ten years of a single receiver replacement cycle. There are no engineering difficulties but, alas, there are many others.

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Electric power engineering in Japan

In the growth of the electric power industry in Japan, the latest technologies are being used. High-voltage transmission lines, nuclear power, computers, automation, and electronics are being integrated into present and future power systems

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Since the end of World War II, the installed generated capacity in Japan has increased at an average annual rate of 10.7 percent. In March 1966 it totaled almost 35 000 MW, and by 1975, the total system capacity should reach about 84 000 MW. A 500-kV transmission system and 600-MW turbine generators are to be put into operation in the near future. An MHD plant of 1-MW capacity is to be completed in the 1970s. Automation of dispatching systems and computer application are rapidly increasing. Economic load dispatching, system protection, teletransmission, supervisory control, fault location, and high-voltage insulation design are areas of considerable interest and activity in Japan today.

After World War II, power system designers in Japan were faced with the reconstruction of damaged electric power facilities. They adopted up-to-date technology, as well as operation by system interconnection, in their new designs. The installed generating capacity has increased at an average annual rate of 10.7 percent, and at the end of March 1966, it amounted to 33 287 MW, the fourth largest capacity in the world.

The cost of generation has been reduced considerably by the adoption of large-sized steam plants and the construction of pumped storage hydro plants. Reinforcement of the 275-kV trunk line and systems of lower voltage levels has made it possible to reduce transmission losses to about 8.8 percent. Construction of a 500-kV transmission system is to begin in the near future. In order to attain high reliability and economical operation, extensive efforts have been directed toward the automatization of load dispatch operation and the application of protective electronic relaying systems.

Good planning and efficient operation have made the price of electricity both lower and more stable than prices of other commodities. This article presents some representative examples of recent power engineering technology in a variety of engineering fields. These innovations form the basis for the extraordinary expansion of the electric power industry in Japan.

Present status of electric power generation[1-3]

Up to 1955, the development of the electric power industry in Japan had been promoted primarily by hydroelectric generation. At that time, the dominance of hydroelectric generation yielded to the accelerating development of thermal power plants. At present, thermal generation surpasses hydroelectric generation both in installed capacity and generated energy.

An annual increase of ten percent for average load demand is anticipated. In order to reduce the ratio of capital and maintenance/operating costs to the prime cost of generation, the emphasis is now on the adoption of large subcritical or supercritical pressure units, and the construction of large-scale thermal plants. Turbine generators of 600-MW capacity are to be put into operation in a few years, with reinforced systems.

Most large-scale generating units burn crude petroleum, which is generally imported from other countries. To reduce the transportation cost of petroleum, large-size tankers (of the 300 000-tonne class) are being built.

The adoption of large-scale thermal plants and generating units has reduced the construction cost to less than 30 000 yen (about $80) per kilowatt. Problems of site drainage and air pollution, however, will influence the cost of thermal generation in the future. Methods for

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*CRIEPI, which is operated and maintained by all ten power companies of Japan, carries out a variety of research work in the electric power field.

reducing pollution, such as the desulfurization of heavy oil and exhaust gases, diffusion by a tall exhaust stack, and improvement of combustion control are being studied.

The advent of large-sized thermal plants has been accompanied by low-cost construction of large-capacity pumped storage hydro plants. These plants are required for improvement of load factor and for peak loads, which are increasing daily with the expansion of system capacity. Table I lists the presently installed and future pumped storage hydro plants in Japan. Synchronous starting of the motor-generator in these hydro plants, with attendant reduction in shock to the power system, is being investigated.

I. Pumped storage plants in Japan

Name of Plant	Owner	Output, MW	Year	Manufacturer
Numasawanuma	Tohoku Electric Power Co.	43	1952	Hitachi
Omorigawa	Shikoku Electric Power Co.	11.8	1960	Hitachi
Morotsuka	Kyushu Electric Power Co.	50	1961	Hitachi
Hatanagi 1	Chubu Electric Power Co.	137	1962	Allis-Chalmers, Fuji, Hitachi
Mio	Kansai Electric Power Co.	34	1963	Hitachi
Ananaigawa	Shikoku Electric Power Co.	12.5	1964	Hitachi
Kuromatagawa 2	Electric Power Development Co.	19.5	1964	Fuji
Shiroyama	Kanagawa Prefecture	250	1964	Hitachi, Toshiba
Ikehara 1	Electric Power Development Co.	144	1965	Hitachi
Yagisawa	Tokyo Electric Power Co.	240	1965–66	Allis-Chalmers, Hitachi, Toshiba
Shinnariha	Chugoku Electric Power Co.	152	1968	Hitachi
Eastern area:				
Azumi†	Tokyo Electric	623	1968–71	
Marunuma*	Tokyo Electric	230	1973	
Karasawa*	Tokyo Electric	560	1977–78	
Yamanokami*	Tokyo Electric	320	1975–76	
Central area:				
Takane 1†	Chubu	340	1969	
Takane 2†	Chubu	25.1	1969	
Masegawa*	Chubu	286	1972	
Atashika*	Chubu	198	1973–76	
Samikawa*	Chubu	150		
Kisenyama 1*	Kansai	223	1969	
Kisenyama 2*	Kansai	223	1970	
K*	Kansai	1048	1973–76	
Ikehara 2†	Electric Power	206	1966	
Nagano†	Electric Power	220	1968	
Shintoyone*	Electric Power	1200	1973–76	
Western area:				
Kagedaira†	Shikoku	46.5	1968	
Jizoji*	Shikoku	66.5	1977	
Shintsukahara*	Kyushu	73	1975	
Tanohara*	Electric Power	240	1973	
Hasumi*	Electric Power	200	1976	

* Future project
† Under construction

II. Nuclear power plants in Japan

Owner	Type of Reactor	Manufacturer*	Output, MW	Year	Note
Japan Atomic Energy Research Institute	Boiling-water reactor	GE	15		Japan Power Development Reactor (in operation)
The Japan Atomic Power Co.	Graphite-moderated, gas-cooled reactor	GE	166	1965	Tokai Power Plant
The Japan Atomic Power Co.	Boiling-water reactor	GE	325	1969	Tsuruga Power Plant
Tokyo Electric Power Co.	Boiling-water reactor	GE	460	1970	Fukushima Power Plant
Kansai Electric Power Co.	Pressurized water reactor	W	340	1970	Mihama Power Plant
Chubu Electric Power Co.	Pending	Pending	300	1970	Pending

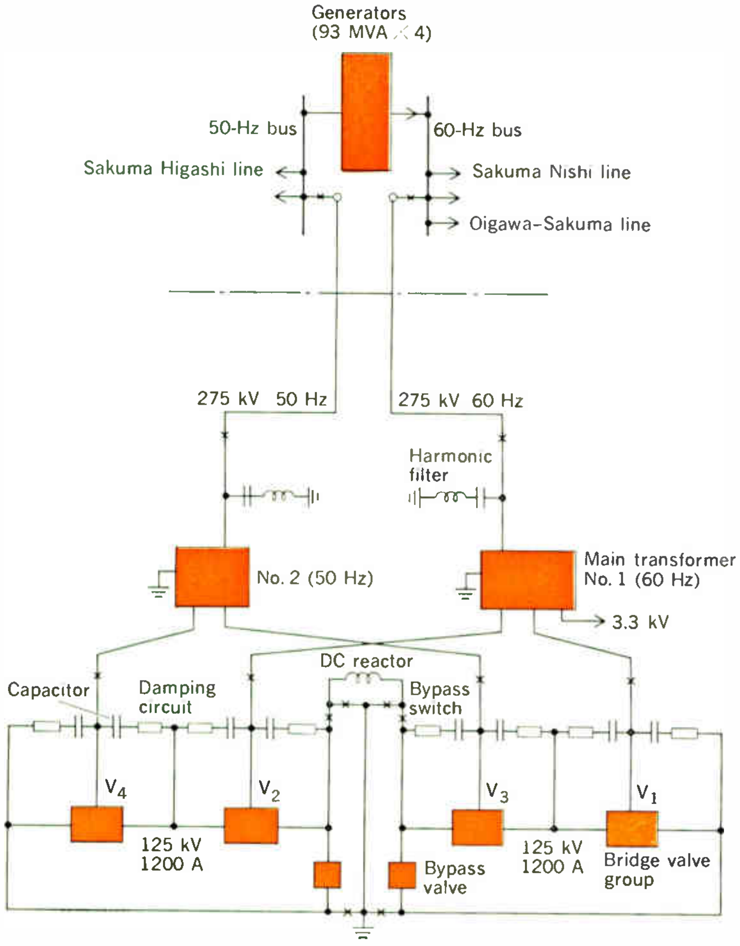
* GE = General Electric Co.; W = Westinghouse Electric Corp.

III. MHD research in Japan

Owner	Duct	Electrode	Fuel	Seed	Generator Capacity
Electrotechnical Laboratory	Magnesia Borides of transition metals*	Graphite	Liquid propane gas or natural gas and oxygen	Potassium	1 MW
Japan Atomic Energy Research Institute	Castable alumina	—	240-kW plasma-jet argon gas	Potassium	—
Toshiba Electric Co.	Magnesia zirconia	Graphite	Insulation oil	Potassium	20 kW
Mitsubishi Electric Co.	Alumina	Graphite	1300-kW plasma-jet	Potassium	20 kW

* Future project

FIGURE 1. Circuit diagram of Sakuma frequency-converter station, which went into operation in October 1965.



Because nuclear power and crude-petroleum-burning thermal plants are considered as the main generating facilities for the future, the economy of peaking load supplied by thermal plants is being explored. The present level of nuclear engineering in Japan is considered underdeveloped in comparison with the United States and European countries. All nuclear power plants for present or future operation will be imported (see Table II). Studies on the development of advanced-type heavy-water reactors and fast breeder reactors are being carried out simultaneously. The improvement of reactor safety and reduction of construction costs are other goals to be met.

Because of air pollution and the high cost of imported petroleum, the use of other fuel sources and the further development of nuclear power generation are strongly anticipated. For example, a magnetohydrodynamic model plant of 1-MW capacity, to be completed in the early 1970s, is currently in progress (see Table III).

High-voltage dc transmission

Electric power systems in Japan are divided into two areas: the Eastern (50-Hz) area and the Western (60-Hz) area. The middle part of Honshu Island is the border line between the two regions. The power systems in these areas are, except in Hokkaido, interconnected by extra-high-voltage (EHV) links. The Sakuma dc frequency converter station, put into commercial operation on October 10, 1965, interconnects the two areas directly (see Fig. 1).[4] The power rating of the converter is 300 MW, and the line-to-line voltage is ±120 kV. Past operating records show that emergency power was supplied to the ac systems five times and that the maximum conversion power was 240 MW. The converter aids in the reduction of system reserve by the supply of trouble-free emergency power, and also provides an economical power interchange between areas. All of the objectives initially established have been realized.

Figure 2 shows the 500-kV ac transmission lines interconnected by the Azumi–Takane dc frequency converter station, to be completed in the late 1970s. Estimated system capacity in 1975 is 31 700 MW in the 50-Hz and 52 200 MW in the 60-Hz region. Presumably, the present installed capacity of 300 MW at the Sakuma station will be insufficient to meet the increase in system capacity. When the Azumi–Takane station is ready to operate in conjunction with the Sakuma installation, power interchange between areas and the reduction of system reserve will become practicable. High-voltage dc transmission facilitates the interconnection of two areas of different frequency and avoids an increase in short-circuit capacity. It is also utilized to advantage for cable transmission, as compared with ac transmission.

For the analysis of ac–dc links, an equivalent circuit theory was developed. Problems such as the operating characteristics of ac–dc links, ac fault current, and stability were analyzed on the digital computer.[5,6] It was found that the dc flashover voltage is almost equal to the rms ac value in cases involving wet or dusty insulators. In addition, a design method for damping circuits to prevent abnormal voltage rise in ac lines has been developed,[7] and a proposal has been made for the control of dc power to improve the transient stability of ac systems.[8]

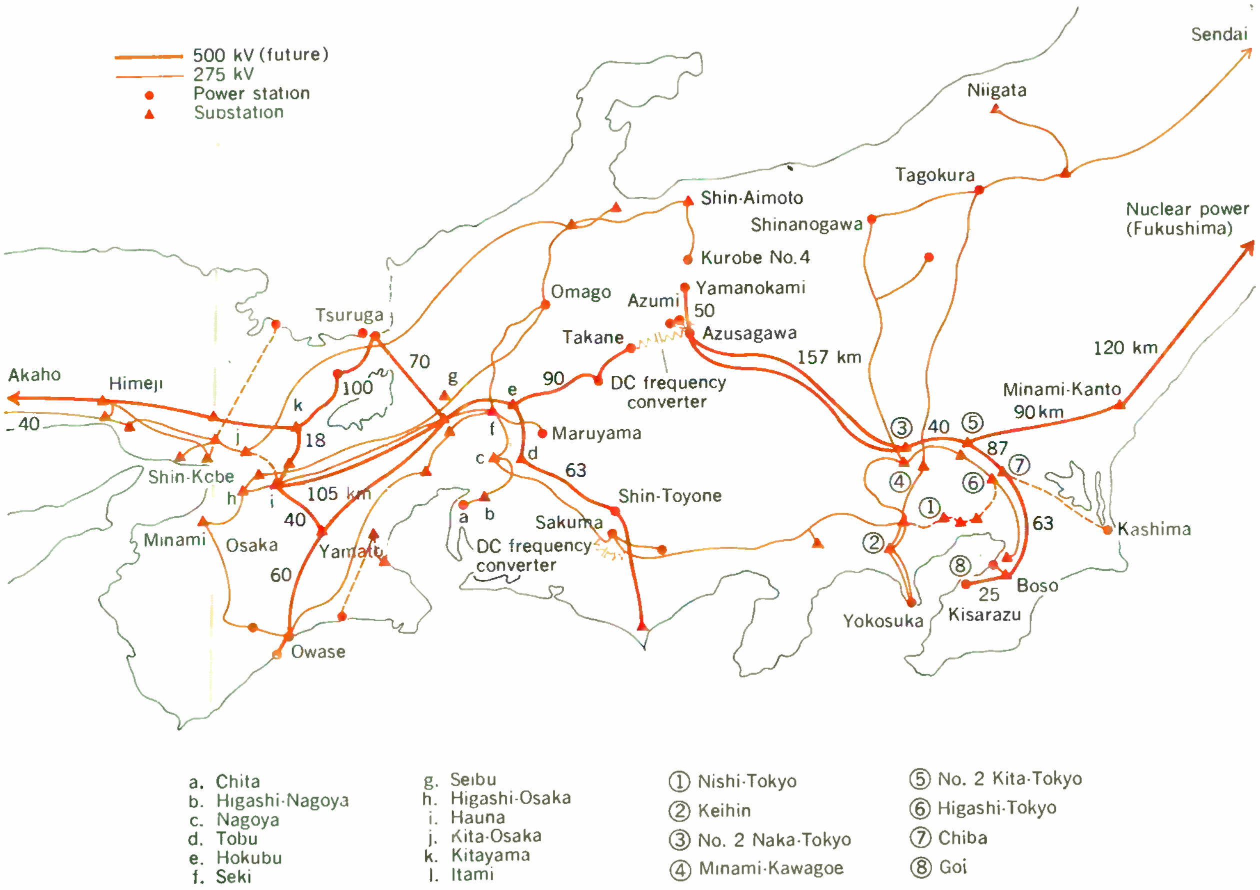
Several methods of control and protection in dc transmission systems are now being investigated. In a method developed at the Electrotechnical Laboratory, Ministry of Industry and Commerce, a universal controller is attached to an inverter. It consists of a wide-range, high-speed phase shifter, a constant-extinction-angle controller, and a commutation-failure-prevention circuit. The control and protective device developed at the Central Research Institute of Electric Power Industry is an AFC tie-line bias control device featuring dc transmission, an automatic tap changer, a protective reclosing device for the dc system, and a constant-extinction-angle controller. A dc transmission simulator is installed at the Electric Power Development Company for further studies.

Mercury-arc rectifiers rated at 100 kV, 200 amperes dc were developed initially at Tokyo Shibaura Electric Company, and are now being further developed at Mitsubishi Manufacturing Company. Development of thyristors for dc transmission is also in progress.

Construction of 500-kV transmission lines

In order to meet the rapid increase in power demand, several large-sized thermal power plants have been constructed in urban areas and EHV transmission lines are therefore needed. As shown in Fig. 2, a new 500-kV line (Boso trunk line) has been constructed for further reinforcement. The Boso line was energized at 275 kV in January 1966 and will operate at 500 kV in 1972. This line will play an important role in transmitting 3000 MW of power to Tokyo. Another 500-kV line, the Azumi trunk line (with a circuit length of 170 km), will be completed in 1968. This line will also carry power from large-

FIGURE 2. Future (10 to 15 years) 500-kV ac system and dc frequency-converter stations.



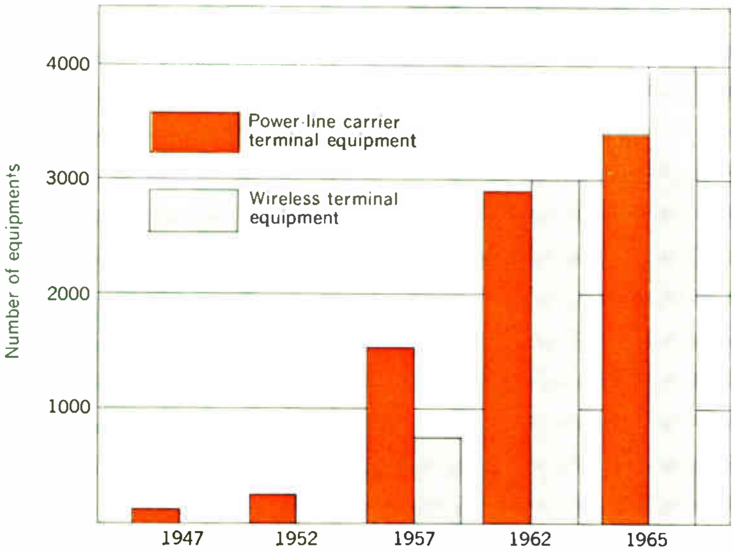
sized pumped storage hydro plants to Tokyo. The transmission voltage is to be stepped up to 500 kV in 1972 and the maximum transmitted hydro power will be 3000 MW. Several other 500-kV lines are also being considered, including one for transmitting nuclear power.

In designing the insulation for these 500-kV transmission lines, a number of tests were performed taking into account geographical conditions, such as salt contamination in coastal areas and lightning in mountainous districts. On the Boso line, salt contamination is prevented by the use of thirty-five 28-cm insulators (which corresponds to forty 25.4-cm insulators). For prevention of corona noise, as well as for the increase of transmission capacity, ACSR bundle conductors (four conductors, 410 mm^2) are used. The maximum allowable switching surge voltage is 2.5 times the line-to-ground voltage. This is permissible because the number of insulators have been increased for salt contamination and the transmission route is at a comparatively low elevation (up to 200 meters above sea level). In one district on the transmission route, the frequency of lightning occurrence is rather high. Unbalance insulation has been adopted to prevent two-circuit faults, caused by the spread of faults from one circuit to another.

Because the Azumi trunk line passes mountainous districts of 500 to 1500 meters in elevation and is susceptible to lightning, various methods of preventing switching and lightning surges were investigated. As a result, a single-circuit, two-route parallel line with a maximum allowable surge voltage of 2.2 times the line-to-ground voltage has been designed. Eleven V-shaped, 56-cm insulators are cascaded in series. Data required for the design were obtained mainly from field tests performed at the Shiobara Testing Laboratory. Switching surges were tested by using 50 percent flashover voltages, and the results were analyzed by comparison with the characteristics of fundamental rod gaps, etc.

In view of the fact that switching surge insulating voltages cannot be determined solely by 50 percent flashover voltages, another test to obtain standard deviation was performed concurrently. Because acquisition of accurate data cannot be expected in the region of low flashover rate when only a single pair of gaps is tested, 20 pairs of gaps were set up to improve the accuracy of the test and to collect required data in a shorter time. The primary advantage this method offers is that, with a single application of voltage, the result is equivalent to 20 applications of voltage. In addition, a number of interesting tests have been made with a surge generator that is the largest in the world.

FIGURE 3. Increase in installed teletransmission equipment from 1947 to 1965.



For salt contamination, a long-term loading test making use of natural humidity conditions has been performed along with the equivalent fog test method developed in Japan. The results of these studies indicate the advanced level of work on insulation design.[9-13]

Automatic dispatching systems and computer applications

The automation of system operation[14] was initiated in 1951. The first experimental and theoretical studies on automatic frequency control (AFC) conducted at Shikoku Electric Power Company led to the installation of an AFC controller at Matsuogawa Power Station in March 1954. At present, all electric power companies in Japan have installed AFC controllers. Flat frequency control (FFC) is used by the Hokkaido, Tokyo, and Kansai companies and tie-line bias control (TBC) by the Tohoku, Chubu, Hokuriku, Chugoku, Kyushu, and Shikoku companies. The controllers are mostly of the analog type.

Because all power systems in Japan are combined hydrothermal systems, the development of economic load dispatching (ELD) has been necessary. In 1957, the first ELD controller, LODIC, was installed in the Kyushu company, followed by similar installations in other plants. The controllers are mostly designed for the determination of optimal daily operation (next-day operation) and a variety of computational methods exist, such as analog, digital, and hybrid types. In 1963, Kyushu adopted the coordinated control of AFC and ELD, the original analog type of which was altered to hybrid in 1965. This controller was the first attempt at digital computer application to system operation in Japan. Similar projects are being set up at other companies.

Introduction of digital computers is being considered by every electric power company to tie in with a centralized digital automatic load dispatching system. This will become a part of a more integrated computing system, which will include business automation. Three companies (Kansai, Chubu, and Shikoku) have already ordered digital computers (HITAC-8000) for the automation of system operation. Studies on digital computer control of system voltage, reactive power, and automatic system switching operation are also in progress.

Protective relaying

In general, main protection is achieved by pilot relaying and backup protection by distance or overcurrent relaying. Various relaying systems, such as directional comparison and phase comparison, are employed for the protective pilot relaying. Power-line carrier, microwave, or pilot-wire signal channels are used.

Most trunk lines are of the two-circuit type, with both circuits mounted on the same tower. Because lightning strokes in summer often result in a simultaneous multiphase fault between two circuits (caused by back flashover), a multiphase reclosing system is currently used on several trunk lines.[15] When two lines (of the six) in different phases are sound, the reclosing system opens the remaining four faulted lines. It then quickly recloses them within approximately 0.4 second. When the fault condition is not as severe, a similar reclosing action also occurs.

Because of difficulties in obtaining sufficient land in urban areas for the construction of new transmission routes, it has become common practice to mount several circuits (four or more) on the same tower. In these multicircuit lines, unbalance in inductance results in circulating zero-sequence currents through a pair of circuits. This is caused either by load currents during steady state or by fault currents in case of short circuits occurring outside of the protected section. The circulating currents may produce misoperation of ground overcurrent relays and/or failure of main ground protection in a directional comparison system. This is the result of apparent outflow current during faults inside the protected section. A new carrier relay system was developed and put into practical use recently that does not involve misoperation or failure even under the operating conditions just mentioned.[16]

Faults occurring in system equipment should be removed by the main or backup protection provided. When failure or delay in relay operation or system instability and frequency drop occur, additional system protection is required. Such protection techniques as system separation relaying, partial generating power interruption, partial load interruption, and automatic restoration are presently in use. System separation relaying is classified into four types, based on

1. Continued heavy faults.
2. Loss of synchronism (out-of-step condition).
3. Abnormal frequency variation.
4. Sudden tie-line load variation.

Most of these separation systems are used at tie points where two electric power companies interconnect. Suitable combinations of these types are installed in other situations.

Partial generating-power interruption by remote tripping of a constant power source, determined by the prefault power, is used for maintaining stability in a long-distance transmission line separated by a fault in the line or busbar. Overloading at tie-line transformer banks and frequency drop are prevented by the partial load shedding system. This is accomplished by the temporary remote tripping of predetermined load.[17]

A low-speed automatic relay system is used as a means of automatic restoration. A series of long-term field tests are currently in progress, leading to the development of a device that will replace all conventional manual restoring operations in case of a total blackout in a substation.

Teletransmission

The teletransmission channels for the electric power industry in Japan are constructed and owned by the electric power companies. Historically, the development of the electric power industry has far surpassed the development and expansion of public communication. Further, private channels are far less expensive than rented ones. Teletransmission channels for the electric power industry comprise radio, power-line carrier, and bare-line carrier channels (see Fig. 3).

Microwave channels. Frequency bands of 2, 7, and 12 GHz are allocated to the microwave channels. Single-sideband FM systems of 60 to 240 channels with a voice-frequency bandwidth of 0.3 to 3 kHz are widely used. For repeaters, nonattended relay stations with supervisory control had been commonly used until 1955, at which time the 2-GHz band began to find popular use. Systems employing passive reflectors are now becoming more and more common since the adoption of the 7-GHz band.

To reduce windage effects, meshed reflectors are used in areas of little snow and ice.[18] De-icing of microwave passive reflectors by nylon threads is used in areas of heavy snow and ice.[19] The microwave channels are so well maintained that the average available rate is over 99.99 percent for each span and over 99.95 percent for the system.

UHF and VHF channels. For the construction and maintenance of power transmission and distribution lines, transistorized mobile radios operating on 60, 150, and 400 MHz are widely used. Output power ranges from 5 to 50 watts for fixed stations, 5 to 25 watts for mobile units, and 0.5 to 1 watt for portable equipment. Multiplex radio stations operating at 400 MHz are commonly used for local channels and promise to become more popular.

Power-line carrier. Since Dr. U. Torigata first conducted experiments on a power-line carrier telephone in 1918, power-line carrier technology has been significant for the electric power industry in Japan. Although it has gradually been replaced by microwave channels since 1955, power-line carrier communication still plays an important role for telemetering, telecontrol, carrier relaying, and telephone for load dispatch.

Frequency bands currently used for power-line carrier are from 50 to 450 kHz, with 200 and 250 kHz used primarily for carrier relaying. Almost all equipment is transistorized and standardized as 1 to 3, 6, 12, etc., channel types.[20] The voice-frequency bandwidth is usually from 0.3 to 2.3 kHz. Single sideband (SSB) is used and the output is restricted to a maximum of 10 watts by the Regulation Law of Broadcasting Enterprise. Costs have been reduced by standardization.

The phase-to-ground coupling method is generally employed for coupling between carrier equipment and power lines. Interphase and intercircuit coupling are used on important channels. Thorough theoretical and experimental investigations on the propagation characteristics of carrier-frequency currents on power transmission lines have been carried out and these serve as the basis for channel design.[21] Since 1950, when the detailed study on the development of aerial coupling, which does not require coupling capacitors, was initiated, aerial coupling has been employed on several occasions for local and temporary channels.[22]

Several other coupling methods also have been developed, some of which have already been put into practical use. These are

1. Core line trap (instead of the conventional coil line trap).
2. Parallel subconductor.[23]
3. Termination of power lines at the substation with a low impedance for carrier current, and coupling performed at a point a quarter wavelength from the substation.

The parallel-subconductor trap (Fig. 4) is quite effective in the high-frequency range, where the conventional line trap does not perform well. To minimize radio interference from ultrahigh-voltage power transmission lines, a parallel-subconductor trap is used (as a high-frequency

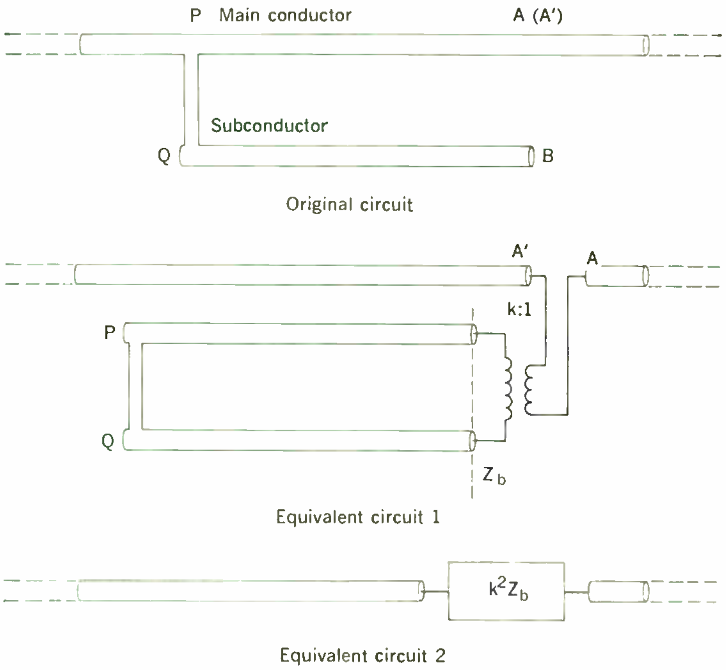


FIGURE 4. Parallel-subconductor line trap (A) and its equivalent circuits (B) and (C).

FIGURE 5. Broadcast by power transmission lines.

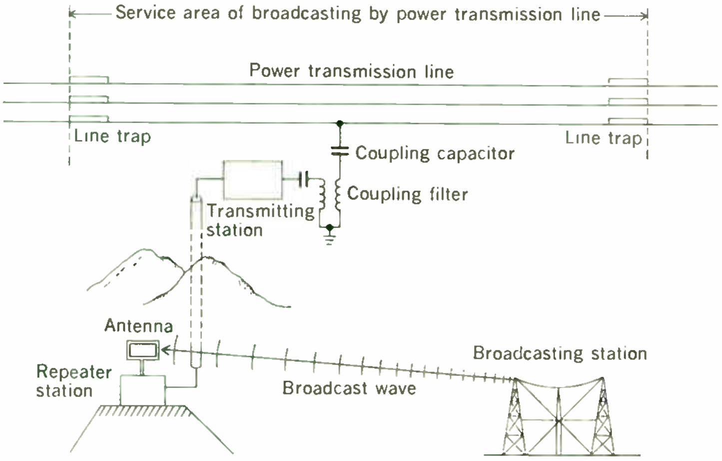
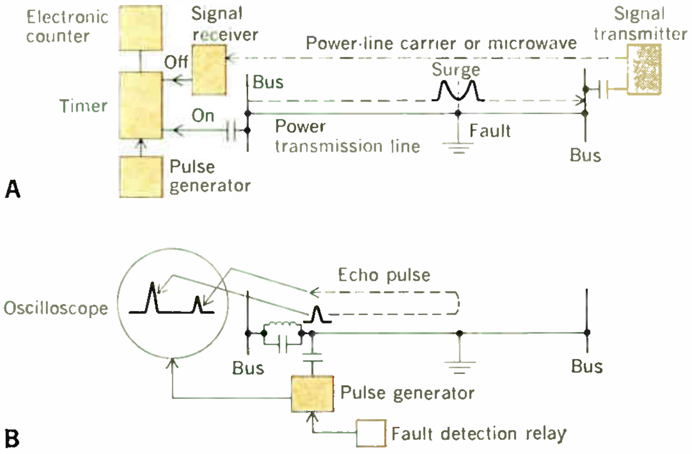


FIGURE 6. (A) Transmission and (B) echo fault locators.



line trap) to prevent radio-wave propagation beyond the service area (Fig. 5).

Teletransmission for protection. Teletransmission for carrier protective relaying is required to be extremely reliable in order to transmit information from the protective relays at a terminal to the relays at the opposite terminal during the time of fault. The period of operation is very short, since it is restricted to the fault time. An extremely high one-shot reliability obviously is required, because the time of occurrence of faults cannot be predicted. Carrier-relay equipment with especially high reliability has been developed. It plays the role of a silent sentinel on the trunk lines of more than 200 systems in Japan.

As for the transmission method, amplitude-modulated on–off systems are popular for power-line carrier channels. When transfer trip action is to be performed, a frequency-shifting system permits constant supervision. A microwave-carrier relay system also has been employed since 1958, which uses SSB-FM tone channels. Both methods have operated satisfactorily and more than 99 percent of line faults are being cleared by these relays.

Telemetering and supervisory control. Since telemetry in the electric power industry necessarily involves long-distance data transmission, the carrier transmission scheme is used exclusively. Eighteen subcarrier channels are assigned to voice frequencies (425 to 3315 Hz), each with a spacing of 170 Hz. One subcarrier is assigned to each measured quantity.

In another system, the voice-frequency band is divided into 24 channels, in accordance with CCITT standards, the channels being spaced 120 Hz apart and each having a bandwidth of 420 to 3180 Hz. FM systems are used in which the subcarrier is shifted by the pulse, whose duration time is proportional to the measured quantity. The requirement of more accurate and faster data transmission will accelerate the development and installation of digital systems.

Supervisory control is essential to the operation of power plants. Control equipment is installed in almost all generating stations, substations, and dispatching offices of every power company. This equipment is playing a major role in the supervision of circuit breakers and nonattended operation of plants. In particular, the supervisory control of hydraulic power stations is becoming increasingly widespread. Successful nonattended operation of large hydro plants, with generating capacities of more than 100 MW, has been achieved.

It is very important that supervisory control equipment be designed to select and operate as much power apparatus as possible with a minimum number of communication channels. Direct visual, synchronizing visual, and code visual systems are used for signal selection. Power-line carrier channels and microwave channels are widely used for communication. In the future, supervisory control will play an even more important role in the automatic dispatching control of power systems.

Fault location

In countries like Japan, where a good portion of the land lies in the temperate zone and lightning occurs frequently, fault points caused by lightning have to be quickly and efficiently located.[24] The Central Research Institute has conducted research on fault location since 1950. Two methods of detection are shown in Fig. 6.

In Fig. 6(A), the master and slave stations are placed at both ends of a transmission line. The slave station transmits a fault signal to the master station over a separate transmission route. The fault point is ascertained from the time difference between the fault surge entering the master station directly and the fault signal transmitted from the slave station.

Referring to Fig. 6(B), a pulse is generated by the pulse generator at the instant of fault. The fault point can be located from the echo of the original pulse, similar to radar operation.

The fault locator must operate upon the occurrence of a fault, and complete its operation before the protective relay clears the fault. As in the case of carrier relays, an extremely high one-shot reliability is required. Accordingly, several methods other than those shown in Fig. 6 have been developed.

Fault locators have been installed on most trunk lines in Japan, and at present total 100 installations. There are approximately 250 channels and 13 000 km of supervised transmission length. The locators are mostly of the simplified echo-type design.

Data transmission and computer applications

In the future, conventional manual system operation will be replaced by automatic dispatching control using digital computers. This practice requires an efficient, integrated data-processing system. Data transmission using presently installed microwave and power-line carrier channels will play an important role. Since 1960, a great number of tests have been performed on data transmission over several main transmission channels throughout the nation. The error rate can be kept well within 10^{-6} for 1200-baud data transmission on microwave channels and for 600-baud data transmission on power-line carrier channels.[25]

The greatest obstacle to data transmission over power-line carrier channels is the operation of line switches at substations. Because of the extremely short time duration of the arc, circuit breakers hardly influence data transmission of less than 600 bauds. Code errors of some 10 to 100 bits occur due to the intensive noise caused by switch arcing.[26]

Further tests have demonstrated that more corona noise is present at the positive peaks of the 50-Hz waveform than at negative peaks, and a very quiet noise period exists. Based on this, a new data transmission system is being developed, which synchronizes the signal with the supply frequency, transmitting it only during the quieter negative half-cycles.[27]

In 1964, Kyushu Electric Power Company successfully installed an integrated data-processing system. Original data generated from more than ten area and regional offices, and from thermal plants in the company's service area, are processed. The original data are teletyped to the computer center with a transmission speed of 100 bauds. In addition, Kansai Electric Power Company in the near future will complete the construction of a new integrated data-processing system. A digital computer will be utilized for both automatic dispatching control and business automation.

Applications of electronics

Robot rain and snow gauges for the forecast of floods have been installed in the basins of many of the main rivers of Japan. The measured data are transmitted to the central dispatching office of each company by 60- or 400-MHz transmitters. Also, meteorological radar systems installed at dispatching offices detect the direction of typhoons and thunderclouds. These techniques greatly enhance the reliability and efficiency of power system operations.

The Central Research Institute has successfully developed a conductor thermometer to measure and directly monitor the temperature of power-line conductors. In its operation, periodic acoustic pulses, whose frequency is proportional to the resistance of the thermistor attached to the conductor, are transmitted to a microphone installed inside the tower. Here, the signals are converted to trains of electric pulses, which are retransmitted to a substation, where they are automatically recorded. The transmitter is attached directly to high-voltage conductors. To ensure high reliability, special attention is given to surges, fault currents, vibration, moisture invasion, etc.

Developments in maser and laser technology have been studied by the Institute of Production Engineering, University of Tokyo, in cooperation with the Tokyo Electric Power Company and the Central Research Institute, with the result that new instrumentation techniques are being introduced into the electric power industry. For example, the current on an EHV line can be measured without touching the conductor. This technique makes use of the property that the polarization of a laser beam varies in proportion to the magnetic field intensity (Faraday rotation). Figure 7 illustrates the operating principle.[28]

Several other applications of electronics are becoming practical, including, for example, the automatic measurement of the salt that adheres to the insulators of transmission lines, and temperature measurements of extra-high-voltage cables.

Radio and television interference

The problems of radio interference resulting from corona discharge of EHV lines are very severe in Japan. Nearly 100 million people occupy a limited area of 370 000 square kilometers and radio and television broadcasting are big enterprises in the country. Consequently, EHV test lines have been constructed in order to investigate corona noise.[29,30] Since 1962, several tests (such as long-term measurement of corona noise characteristics with four-, three-, and two-conductor lines, propagation and radiation characteristics of noise, etc.) have been performed at the Shiobara Testing Laboratory, Central Research Institute, and the Electrotechnical Laboratory, Ministry of Industry and Commerce. Some of the test results have been used in the design of the 500-kV transmission line.[13]

The reflection of television signal waves by EHV power transmission lines sometimes causes ghost images. This problem will become more serious with color television. A 1/40-scale transmission line has been set up, and thorough experimental and theoretical studies of this problem have been carried out.

EHV cable with compressed SF_6-gas insulation

A new type of cable rated at a nominal voltage of 275 kV has been built and tested. The cable is insulated with SF_6 gas at a pressure of 49.6 N/cm² (72 lbf/in²) gauge at normal temperature.[31] No conventional insulating material, such as oil or paper, is used. The diameter of the outer pipe of the cable is approximately 30 cm. The inner conductor is an aluminum or copper pipe with a diameter of 10.1 to 12 cm. Spacers made of porcelain or resin are inserted at 4.55-meter intervals to support the inner conductor.

Compared with conventional cables, this cable has the following superior features:

1. The static capacitance can be made small.
2. The current capacity can be large due to the cooling effect of the pressurized gas.

Various tests made on this cable demonstrate the feasibility of manufacturing a cable having a transmission capacity of 2500 MVA per phase. The transmission loss on such a cable is comparable to that of overhead transmission lines.

Conclusions

Recent trends in power system engineering in Japan have been reviewed in this article. In terms of long-term projects, an increase in installed power plant equipment, substations, and transmission systems is evident because of greater load demand. In addition, system interconnection is also becoming more widespread. Electronics will play a greater role in system operation in the future.

For the preparation of the manuscript, the authors wish to express their indebtedness to T. Udo, K. Ode, T. Nakazima, M. Kawai, S. Tsuzuki, and T. Machida, all of the Central Research Institute.

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FIGURE 7. Block diagram of a laser current transformer.