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Solar power: an energy alternative

RCA Engineer

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Our cover shows Bar Harbor, Maine, at sunset. We think the photograph gives a feeling of our dependence on the sun for warmth and energy, and also portrays the calm feeling we get from "sun power."

Photo credit: Andy Whiting, Missile and Surface Radar, Moorestown, N.J.

•To disseminate to RCA engineers technical information of professional value •To publish in an appropriate manner important technical developments at RCA, and the role of the engineer •To serve as a medium of interchange of technical information between various groups at RCA •To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions •To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field •To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management •To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

RCA and energy

The business of energy is the second largest commercial arena in the United States, larger than either the entire U.S. defense budget or the entire U.S. agricultural enterprise. The $150 billion/year domestic energy business is exceeded only by the $300 billion/year combined social security, welfare, and health care budget.

Because of the political and financial implications of the limited supply of fossil fuels, there is a genuine need for new energy supplies and a more efficient use of existing resources. This new energy environment creates the opportunity for traditionally non-energy-related companies to play a realistic role in the vast energy business. By focusing on non-fossil-fuel energy issues, a substantial fraction of the world's energy bill—$500 billion in 1978—is a business opportunity for a company such as RCA.

RCA is addressing both parts of the energy opportunity with programs exploring new business potential in both energy generation and in conservation techniques. In the energy-conservation area, RCA is active both in controlling its own energy use and developing energy-management techniques for potential commercial application.

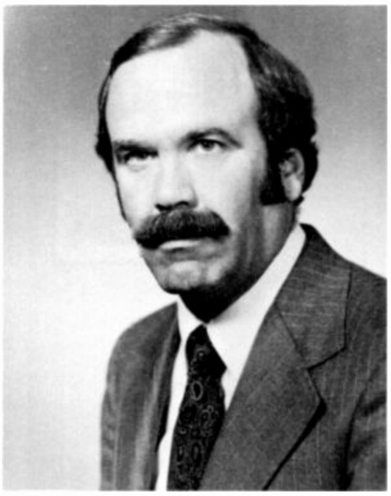
In 1973, RCA instituted a corporate-wide conservation program. After accounting for RCA's increased production, energy use today is 30% less than it would have been using 1973 practices. Because the new energy situation is an escalating one, investments in optimized energy management, whether in building design and management, or industrial processing, have continuing and increasing returns. Last year, RCA Laboratories established the Energy Systems Analysis Group to assist RCA's conservation program with software and hardware capability addressed to specific divisional needs. An article in this issue by Dr. Bernard Hershenov, Head, Energy Systems Analysis, RCA Laboratories, describes these efforts.

For RCA to make a successful business entry in the area of energy generation, we must focus on the areas in which RCA has significant technological qualifications and where business experience can be gained at relatively low cost. Photovoltaic (PV) power supplies, based on solar cells, seem to offer such an opportunity. Our semiconductor materials expertise is an essential ingredient and the existing business, while offering enormous growth potential, is small enough that it may not be terribly expensive to establish a major role in the market. Several articles relating to the PV technologies under evaluation appear in this issue.

Because this potential business is a new one for RCA, the Corporation has established the Solar Electric Business Development (SEBD) group. Headed by R. Weinberg, this group is responsible for developing business plans, establishing relationships with potential customers, both domestic and foreign, and developing the knowledge and skills required to manufacture a solar electric product. RCA's PV technology programs are committed to developing a low-cost power supply that will produce electricity competitive with fossil-fuel-generated electricity. The SEBD organization will provide the business framework for the commercial implementation of this product.

It appears very likely that substantial new business opportunities exist for RCA in the energy area. Further, the uncertainties normally associated with a new business are reduced in this one—the competition, fossil fuels, is going to experience inevitable price increases. Energy generation and control are growth businesses.

Brown Williams
Director
Energy Systems Research
RCA Laboratories
Princeton, N.J.



Energy Highlights

Energy — what's it all about?
Where does solar energy fit in?
Do photovoltaics have a future?

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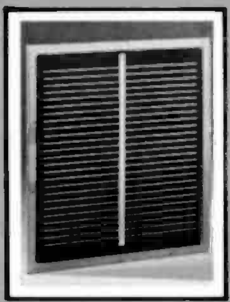

RCA has a key patent for amorphous silicon solar cells.

page 16, 24

Energy management and conservation — it's as important to conserve energy as it is to generate it.

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Fusion energy — still in the research phases... here are some of RCA's contributions.

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Upcoming issues

Microelectronics: lithography, semiconductor manufacturing, data television
Anniversary issue: contributions from many activities
Later: color television, microprocessors, and quality and reliability

RCA Engineer

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The 1979 David Sarnoff Awards for Outstanding Technical Achievement

RCA's highest technical honors have been announced for 1979. Each award consists of a gold medal and bronze replica, a framed citation, and a cash prize.

McGrogan

Ellwood P. McGrogan, Jr.

Government Communications Systems and Advanced Technology Laboratories, Camden, N.J.

For outstanding technical contribution and creativity in the fields of secure communications and switching systems.

The lessons of recent Vietnam and Middle East Wars have demonstrated that the success of tactical engagements can be seriously compromised by lack of communications security. With the advent of large scale integrated solid state technology, a major national program of the highest priority was initiated in 1972 to develop on a systems basis automatic switching centers and terminals, with integrated communications security.

Under the sponsorship of the Joint Tactical Communications Office, the U.S. Government is developing the TRI-TAC Switching System. Associated with the digital side of the system are communications security subsystems.

Mr. McGrogan's outstanding achievements in this national program were manifested in several ways. As a member of the overall communications and security systems team, he made basic and vital contributions to the overall system architecture, the establishment of specifications between the communications and security subsystem elements, and the development of 54 custom CMOS LSI arrays yielding the following benefits:

- Superior Voice Quality
- 25 to 1 Reduction in Volume
- 25 to 1 Reduction in Weight
- 100 to 1 Reduction in Power
- Greater than 5 to 1 Increase in MTBF
- Significant Functional Capability Expansion
- Survivability
- Advanced State of the Art Design

McIntyre

Webb

Robert J. McIntyre | Paul P. Webb

Solid State Division—Ste. Anne de Bellevue, Quebec, Canada

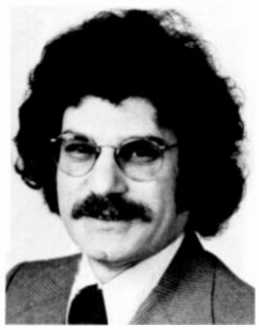
For outstanding team performance in the development of theory and fabrication techniques for superior silicon photodiodes.

During the period 1965 to 1978, this team has been involved in research, development and pilot production on a line of reach-through avalanche photodiodes which, because of their unique and superior design, have not only set a new standard of performance, but are still without serious competition in the industry. These photodetectors are now used throughout the world as detectors for laser rangefinders (including the AN/GVS-5 hand-held laser rangefinder produced by ASD) and have been chosen almost universally as the most suitable detectors for the fiber-optics and other optical communications systems requiring the most sensitive high-speed detectors. During 1978 alone, this team has submitted 6 patent disclosures on new designs or applications of avalanche photodiodes.

These developments have lead to a highly profitable and rapidly expanding business in the manufacture and supply of APD's as well as giving RCA an in-house capability and technological advantage in fiber-optics and other electro-optic fields.


Herzog


Compton


Corsover


Dobbins


Horton

Bertram L. Compton | Stephen L. Corsover
Lawrence W. Dobbins | Donald G. Herzog
Charles R. Horton | Kenneth C. Hudson
Paul B. Pierson | Bohdan W. Siryj

Government Communications Systems and Advanced Technology Laboratories, Camden, N.J.


Hudson


Pierson

For research, development and implementation of laser beam image recording systems.

In 1965, most military surveillance data was recorded by means of a film camera for subsequent analysis. A need to improve the accessibility forced electronic sensors to be developed to allow transmission to ground stations instantaneously or at desired intervals.

Initially the CRT and electronic beam recorders were used as the image generation device. A laser beam recorder could provide better performance if instabilities and poor reliability could be developed out of the recorder. This development represented a major advance in state-of-the-art in image recording technology. The technological problems were solved through a series of maturing innovations:


Siryj

Optics—Performance was vastly improved in such areas as higher resolution, stability, format variability and elimination of cosmetic defects.

Laser and Electro-Optics—Smaller high power lasers were developed with greater output power and alignment stability over thousands of hours. Electro-optic bandwidth was materially expanded with increased stability, both mechanically and thermally. The efficiency of the electro-optic processing was improved tenfold to match the film speed range.

Transport—A new special in-line dry film processor capable of changing its processing characteristics almost instantaneously over a film speed range of 0.5 to 15 feet per minute was developed.

Signal Processing—Electronic signal processing speeds and memory capacity were improved by two to three orders of magnitude. Some very innovative image processing techniques were developed, such as the elimination of the exacting synchronism requirement between the sensor and the recorder, yet absolutely placed resolution elements were produced.

The success of the past 13 years of effort is best demonstrated by the following successful operating Laser Beam Recording Systems:

Operational Laser Beam Recorder (OLBR)—Located at NASA GODDARD for use with all earth resource sensors. A dramatic performance improvement was obtained from all sensors sources. About 6,000 feet of film per week is exposed with one recorder.

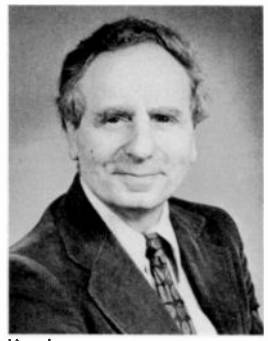
Dry Film Laser Beam Recorder (DFLR)—This was designed to meet NASA's weather satellite sensor requirements for synchronous meteorological satellites. The image resolution of 20,000 elements per scan is outstanding.

Tactical Laser Beam Recorder (TLBR)—The TLBR for the Air Force was shipped from Camden, installed in an Air Force tactical shelter, the entire system air shipped to Germany for war games, then returned to Florida for one year operation. No alignment, repair or replacement has been done after 18 months of operation.


Allen


Bae


Ditrick


Husni


Idell


Mazgy

William F. Allen, Jr. | Myung S. Bae | Norman H. Ditrick | Saleem Y. Husni | Peter P. Idell | James D. Mazgy | Fred J. Reiss | Thomas J. Robe | George L. Schnable

Solid State Division, Solid State Technology Center, RCA Laboratories, Somerville and Princeton, N.J.

For developing a unique family of radiation tolerant, dielectrically isolated integrated circuits.

This team is responsible for establishing circuitry, processing, and manufacturing capability for a complete family of radiation-tolerant linear and digital circuits.

The most salient achievements include:

- The development of a process to fabricate dielectrically-isolated substrates to prevent latch-up and to minimize effects of gamma radiation.
- The development of a process for the fabrication of low-power, Schottky, diode-clamped digital circuits which minimizes the effects of radiation, and which incorporates in the circuits a 1000 ohms/sq resistor, thereby minimizing layout area and circuit capacitance.
- The development of a process for linear integrated circuits which includes the use of vertical PNP transistors, making possible operational amplifiers and FET drivers.
- Beam-lead, trimetal process innovations, such as pulse plating, and the institution of many process controls, all of which assure high-yield metallization.
- The development of a quality and reliability system as an overlay for the entire manufacturing capability.
- The design of a complete family of nine low-power, Schottky, diode-clamped digital circuits and two linear circuits.

In addition to the demanding electrical performance specifications, all circuits perform well during and after subjection to high levels of transient gamma, total gamma dose, and neutron irradiation.


Reiss

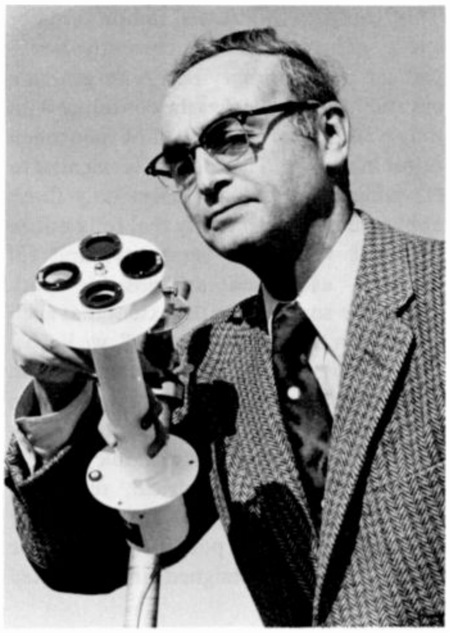

Robe


Schnable

D. Redfield

Solar energy and conservation: hand and glove

All of the reasons given for energy conservation are precisely the same as those given for developing renewable, indigenous energy sources. What are the prospects for these energy sources? Here are some answers.



David Redfield has worked at the David Sarnoff Research Labs in the field of semiconducting materials since 1967. In recent years he has been most active in the field of photovoltaics in which he has also contributed publications and professional committee work.

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RE-24-5-3
Final manuscript received December 15, 1978.

A rare consensus in the realm of energy planning is on the need for wiser and more effective use of energy. The reasons are compelling and clear: Conservation of energy will extend our dwindling energy resources; save substantial amounts of money, thereby decreasing our international trade deficit; reduce our dependence on uncertain foreign supplies; improve the environment; reduce risks to health and security; and lessen the demand that forces up fuel prices that are a special burden on developing countries. Even with strong conservation measures, however, the U.S. will continue to need large amounts of energy while it reduces its present reliance on oil and natural gas. These two fuels now provide more than 75 percent of our energy even though they are becoming our scarcest resources. Among the substantial alternative energy sources, we find that solar energy (SE) offers all the same benefits and motivations for its use as does conservation; in addition, it is widely available and flexible in its application.

Solar energy

The generic title SE is used to include nearly all renewable energy sources: direct sunlight and indirect energy in the winds, falling water (hydropower), the oceans, and "Biomass" (any organic matter of biological origin). The quantities of energy in these sources are prodigious, even on the scale of U.S. energy use. Sunlight alone has about 600 times our total energy consumption; the winds carry not much less, and the heat stored in tropical oceans is still larger. To utilize these resources, a wide variety of technologies has been developed and the engineering feasibility of many is established.

The wide diversity of SE technologies requires careful attention. (There are five that generate electricity.) Though all these are at very different stages of development, technical feasibility has been established for most, and for those, current efforts are directed chiefly at cost reduction, information dissemination, and determination of their best areas of use. Other programs are still in design stages with uncertain prospects.

Altogether, the combination of effective conservation and renewable energy sources offers great promise for our energy future.

Why, then, is SE not in wide use? The answers are plain. There are two major problems with SE: it is diffuse and it is intermittent. These characteristics imply large areas for energy collection, and means for filling the gaps in the supply. (For hydropower and ocean thermal energy this statement does not apply.) The principal impact of these problems is in the cost of complete energy systems. The land-use aspect is seen to be manageable when we note that our rooftops alone receive more heat than our buildings require and all the electricity currently used could be generated from the sun at 10 percent conversion efficiency on an area only 1/10 of that devoted to roads.[1] Thus, costs are the sole deterrent to the broad use of SE, in part because of the artificially low prices of conventional fuels. The challenge to technology and to the nation is to make the costs acceptable.

Because some SE products are just coming into use, the prospects for their success must be judged by developmental programs and projections based on them.

These will now be summarized briefly. Emphasis here is on the links to conservation, but it is obvious that *all* substitutions of SE for fuels are means of conservation of the natural resources.

Thermal technologies

Heat from the sunlight can be used in many ways; it is customary to group these ways according to temperatures required in the various applications. At the low end of the temperature scale are domestic hot water and space heating which account for 23 percent of our total energy use—a very large market. It is estimated that there are now perhaps 40,000 buildings in the U.S. using low-temperature solar heat in some way.

The American Institute of Architects, in a detailed analysis, chose the following definition of energy conservation in buildings: "The reduction of energy demand through the elimination of waste and the substitution, to the degree feasible, of on-site generation and re-generation capacity within an independent decentralized acquisition and conversion system that draws on nature's current income."[2] Here, the inextricable link between conservation and SE becomes explicit. In a follow-up study intended to provide an implementation plan for a national program of energy conservation in buildings, the same group concludes that savings of 60 percent in new buildings could be achieved now with adequate insulation and techniques such as: double glazing; reduced window area and lower aspect ratio; and optimization of pumps, fans, heating, cooling, and lighting. In old buildings, savings of 30 percent are expected.[3]

The role of SE in this area becomes clearer when we note that virtually all estimates show that "active" SE systems (i.e., external collectors) can readily provide more than 50 percent of the energy for single-family residences *at their current rate of use*.[4] The combination, therefore, of sound, existing architectural principles and both passive and active SE could provide essentially all the energy needed by new houses. It should be cautioned, however, that supplemental energy would still be needed for lengthy periods of cloudiness. That need is a source of concern to utility companies that fear becoming suppliers of only back-up energy at low use-factors. This problem of reduced overall demand with concentrated peaks arises in the same way for heat pump-equipped houses or just well-insulated houses,[5] so it must be dealt with. A recent, intensive analysis of this problem, as it pertains to SE, found that the energy storage components of solar heating systems "reduce or possibly eliminate most adverse effects on electric utilities attributable to solar demand patterns."[5]

Costs for solar heating of building space and hot water have been analyzed repeatedly. It is essential when comparing costs with those of conventional sources that life-cycle costing be used and that future costs of conventional energy be estimated. Both of these steps introduce uncertainties but the questions seem to affect only the particular date for economic feasibility of solar heating. The most extensive analysis to date, using four cities that were representative of different parts of the country, concludes that SE will be generally competitive with costs of gas, oil, and electric heat by 1985 with the current investment tax credit and if fuel prices increase moderately.[5] Other studies show that solar heat is cost-competitive with electricity now in many parts of the country. Since half of the houses being built in the U.S. now are equipped with electric heat, this result is of potentially great significance.

Another major area of application for solar heat is in agricultural and industrial processes; these also use very large amounts of energy at temperatures that are often not much above that required for space heating. Among the most energy-intensive industries, paper, chemicals, food processing and textiles use major quantities of such heat. In agriculture, crop drying takes place on large-scale crops such as corn and soybeans, as well as on a wide range of other grains, fruits, and vegetables. This drying has often been done with natural gas in spite of its increasing price and scarcity. Not only could much of it be done with SE, but the nature of these processes reduces the need for heat storage. Thus far, tax disincentives have significantly limited the application of solar energy to industrial process heat. This is one of the more serious institutional problems facing SE.

The technology of low- to medium-temperature SE systems is fairly well developed although not standardized. For domestic hot water and space heating, 60°C is adequate and can be supplied readily by fixed flat-plate collectors. Some improvements are being made in the "black" finishes and heat transfer of these devices. Many demonstration systems of all kinds are in use, and the few that have had lengthy service generally maintain their performance reasonably well.

Temperatures up to ~150°C can be achieved rather simply in light-concentrating systems using low concentration factors in parabolic-trough collectors. Those systems are adequate for space-cooling needs and a variety of industrial steam requirements. A promising application of such systems in the near term is the pumping of agricultural water. The largest current pump of this kind is the privately financed 38-kW unit in Gila Bend, Arizona, that uses a Rankine cycle (no electricity) driven by such collectors.[6] For developing countries this is a particularly important application.

Electrical generation technologies

This category addresses another major energy demand area. We currently use 28 percent of all primary energy to generate electricity which reaches the consumer with only ~30 percent efficiency; and then much is lost in end use. Therefore, it is essential to (1) minimize waste, (2) select only those applications for electricity that fully utilize its great value and versatility, and (3) generate as much as possible with renewable sources. To the extent that such generation takes place "on-site", we have a close analogy to an important conservation technique, cogeneration, which also utilizes an existing, on-site source for electricity. An important example of these principles is the electrical resistance heating of buildings which should be replaced wherever possible with solar heating of better-designed and insulated buildings.

There are four principal SE electric generation technologies, in addition to hydropower, that are feasible but they are at quite different stages of development.

Wind Power

The closest to commercial operation is wind power; both small and large wind-power generators have been demonstrated over extended periods. A 1.25-megawatt generator was used commercially in Vermont for two years and direct mechanical use of windmills reached about six million installations in the U.S. (mostly for water pumping) before cheap rural electricity became available. Because the power available from the wind varies as the cube of its speed, the choice of generation sites is of utmost importance. Nevertheless, over 17 western states, the annual average power in the winds is ~300 W/m^2, or about the same as sunlight on the ground.[8] Moreover, the typical conversion efficiency of wind generators is about 35 percent, quite high for electrical generation systems.

Large wind-generator development is being led by the NASA group at Plum Brook, Ohio, under Department of Energy sponsorship; 200-kW ratings are the current level of attainment in serving the town of Clayton, New Mexico. (Fig. 1) Two-megawatt systems are under construction and may be near the limit of useful size because of the severe mechanical demands on large rotors. Utility links with these large machines are already being undertaken: the Bonneville Power Administration has ordered eight wind generators to supplement its huge hydropower system and many more are planned. Small generators of many types are evaluated chiefly at Rocky Flats, Colorado; these will serve on-site needs, mainly at rural locations. Costs for both classes are expected to reach ~$1,000/kW; the large ones are more efficient, and demands for the small ones are less stringent, making mass production possible. On the other hand, it is still unclear what the average operating capacity factors will be for wind systems, so direct comparison with competing systems is difficult.

The U.S. Bureau of Reclamation has performed an interesting study on utilizing the wind in the western states to increase the capacity factors by linking wind generators with hydrostorage. From "wind farm" sites in the seventeen western states, they conclude that well over 100 gigawatts can be harvested.[8] At that level, the bus bar cost would be 10 mils/kWh, while the total cost, including storage and transmission to the load centers, would be 21 mils/kWh. These costs are fully competitive with present generating costs and the systems avoid many of the present environmental liabilities.

Photovoltaics

Another familiar SE electric technology is photovoltaics (PV). It is now widely recognized that the very high prices (~$200,000/kW peak) and high energy consumption that characterized the space-qualified silicon solar cells are not relevant to terrestrial applications on a large scale. Current prices are ~$10,000/kWp and still lower prices are clearly coming.

Fig. 1
Two hundred kilowatts are being generated by this Clayton, NM, energy converter. Machines up to two megawatts are being built for electric utility links.

The actual prices and projected goals of the federal PV program are shown in Fig. 2. It is clear that the goals are so far being exceeded. Two major questions are how low such prices can fall, and what markets there will be at prices that will still be high in the next ten years or so. Concerning mid-term markets, a great many applications are being discovered in isolated locations for which the high-priced PV systems are being found to be economic. These include communications relay stations, corrosion protection for bridges and pipelines, aids to navigation, agricultural, and military applications. In addition, many developing nations are spending as much on diesel- and gasoline-generated electricity as *current* PV prices would require. These applications point up a facet of such on-site generators that is vital to their successful use: their electricity costs must compete only with the price of alternative power *delivered to the point of use*, not with central station-generated bus bar prices. Thus, most parts of the world without extensive power grids are candidates for such on-site systems in the near term.

Central-station solar electricity from PV seems distant, but feasible if current projections are realized.[5,9] At the $500/kW projected for 1986, these systems will still be expensive compared to familiar base-load power because of the necessarily low capacity factor of PV systems and of other costs besides the arrays. Nevertheless, at that price, wide applications for peaking power become possible and if the utilities acquire load-leveling storage capability that they are now seeking, these arrays will be able to provide intermediate load power with little cost increase. The importance of that prospect is not merely in the enlarged capacity, but also in the ability to cover the entire daily peak demand period. That would match current lifestyles better than the currently-discussed shift to off-peak hours to increase the use of base-load capacity.

Of course, PV arrays will benefit from large-scale mass production regardless of the size of installation in which they are to be used. In addition, a variety of promising, advanced PV technologies are under development. Some are based on thin films of active material such as amorphous silicon ~1μm thick and CdS/Cu_2S 20μm thick which offer prospects of substantial further cost reduction.

Solar Thermal Conversion

The third SE electric technology is solar thermal conversion. To run turbo-generators with good efficiencies, working temperatures of 500°C are desired so very high concentration ratios (~1,000) are required. These are not in current use although the DOE Sandia Laboratories has already begun use of its principal testing facility (Fig. 3) that will soon have a 5 megawatt (thermal) capacity for evaluation of designs of heliostats and the "boilers" which receive the concentrated sunlight. Both Rankine (liquid-to-gas) cycle and Brayton (all gas) cycle systems are under development.[10] The DOE has already begun design of a 10-megawatt (electrical) prototype to be built near Barstow, California, by 1982.

The characteristics of these thermal electric systems make them better suited to large installations than to small ones. They have thus attracted special interest from the utilities, particularly in the western part of the U.S. The geographic influence is the consequence of the generally clearer skies in the West. In turn, the importance of that lies in the fact that only the *direct* sunlight reaches the boiler in high concentration-ratio systems; the diffuse sky light is not usable. In hazy or cloudy climates, therefore, solar thermal electric systems are less effective.

One other attribute of these systems is being studied intensively: the ability to make convenient "total energy" systems close to a load center. These systems are actually cogeneration schemes in which the reject heat as well as electricity is utilized. Such systems would have a double benefit in the water-short West, since the need for cooling water is significantly reduced. It must be said, however, that such systems are still rather far from realization. Thus, although cost projections are in some cases encouraging, a number of uncertainties exist.

Ocean Thermal Energy

Even more uncertainties attend the fourth SE electric technology, ocean thermal energy conversion (OTEC), because intensive work on it is only very recent. OTEC relies on the temperature difference in tropical oceans—a surface temperature of perhaps 25-30°C and a deep-water temperature of ~5°C—to drive a working fluid through a turbogenerator. The entire ocean is the solar "collector" and storage medium, so OTEC has base-load capabilities. The Gulf coast, Florida, Puerto Rico, Hawaii, and perhaps California, are within reach of the needed ocean conditions and there are huge amounts of energy in those waters.

The evident problems, however, are serious. Transporting the energy to load centers is difficult. The small temperature differences available mean very low thermodynamic efficiencies—a maximum of 6-7 percent. Therefore, enormous quantities of water must be pumped, a requirement that will consume ~30 percent of all the power generated.[11] Furthermore, the heat exchangers must have exceptionally good performance in spite of the threats of corrosion and biofouling. The net operating efficiencies are therefore expected to be no more than 2-3 percent. It is also a matter of environmental concern that large numbers of these systems could modify the ocean temperature distribution.

Nevertheless, proponents of this system have responses to all of these objections and they claim cost-effective power is possible. They are proceeding to develop and test the crucial heat exchangers that will be the heart of any OTEC system. A "mini-OTEC" test system is being designed to furnish 50 kW from Hawaiian waters.

Small Hydroelectric Dams

Although few sites remain for further large hydroelectric generating dams, the substantial potential for numerous, small "low-head" dams is just being recognized. One recent report assesses the U.S. potential as 14,000 megawatts. A study by the Army Corps of Engineers has identified 50,000 existing dams that could be retrofitted for this purpose. Because of their small size and simplicity, it has been estimated that 5,000 such generators could be operating by 1990 and 20,000 by the year 2000. Proponents of these systems point to the low environmental impact of small dams compared to large ones.

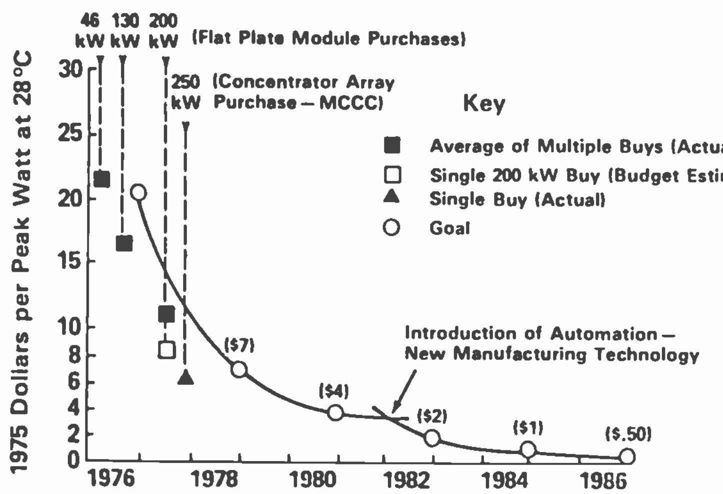

Fig. 2
Photovoltaic module prices under the U.S. program. The curves with open circles show the goals established in 1975. Other symbols represent actual purchases. (From P.D. Maycock, U.S. Dept. of Energy).

Biomass

Conversion of natural organic materials (biomass) to clean fuels and petrochemical substitutes comprises a group of some of the most interesting SE options. Thus, there is the prospect of meeting a significant portion of transportation energy needs with solar-derived fuels. The ranges of biomass sources and methods are already large and new ideas are flowing in rapidly. Estimates of the present magnitude and future potential of available biomass energy vary widely, but there seems to be general agreement that at least 10 percent of our current energy needs could be met if these sources were well exploited.[12] A more optimistic projection has been given by the new Solar Energy Research Institute, according to which a "conservative estimate" of the potential for the year 2000 is[13] 20Q (1Q = 10^{15} Btu or ~10^{18} J), which is more than 1/4 of current total U.S. consumption. For the nearer term, a recent study finds that 100 million tons of just agricultural waste are "immediately available;" this translates to ~200,000 BOE/day (barrel of oil equivalent)[14] or 3-4 percent of our oil imports. The use of agricultural and urban wastes for energy provides additional benefits by reducing waste disposal problems and in some cases permits mineral nutrients to be recycled. For a number of developing nations in the tropics, sun and biomass are the only significant indigenous energy sources, but there the proper technology for their effective use is lacking.

Of the multitude of biomass options, the use of urban waste and corn, wheat, hay, soybean, and sugar cane residues look most promising. But wood has the largest potential and already the forest-products industry obtains 40 percent of its total energy needs (or ~1 Q/yr) by burning its own wastes.[15] In the eastern half of the U.S., the forests contain enough cull wood

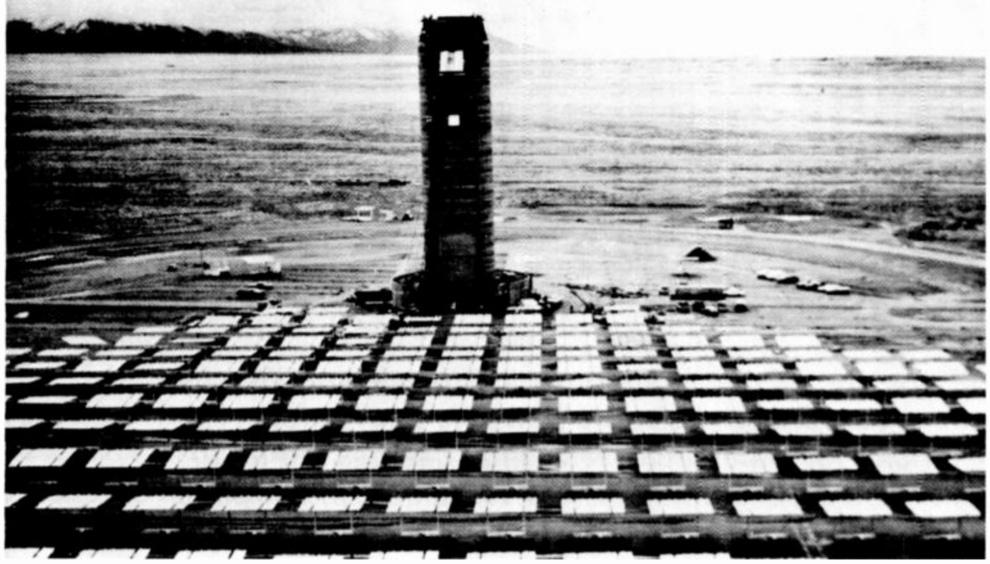

Fig. 3
Solar-powered "boilers" and heliostats are being tested at this solar thermal energy conversion test facility at Sandia Laboratories.

alone to make a significant impact on peak heating demand in that area[12]. There are numerous proposals for special energy crops to be grown, but there are questions about the competition for land and about the depletion of soil nutrients, both of which may limit such enterprises.

The manner in which biomass can be used is equally varied. Simple burning has much to recommend it for a number of appropriate source materials since the pollution potential is low (and in a steady state all CO_2 is recycled in new plants). The newly-developed "densified biomass fuel" looks unusually promising for storage, transportation, and handling.[13] Methane gas can readily be produced from urban wastes, manure, and forest products. One interesting new process is pyrolysis stimulated by solar heat. Methanol ("wood alcohol") follows simply, too, providing a clean liquid fuel that fits well into our automotive fuel. Grain-derived ethanol, now being tried in gasoline as "gasohol" in farm belt states with current crop surpluses, is useful as fuel but appears substantially more expensive than methanol. On the other hand, its manufacture from biomass is cost-competetive with our present petroleum-derived ethanol and could supply the industrial needs with little difficulty.

Institutional factors

It is clear by now that opportunities for the use of SE are numerous. In the low-demand energy future that wise conservation is expected to bring about[16], these SE contributions will be substantial. Thus, one recent independent analysis finds "remarkable progress in solar economics and technology, and rapid improvements are expected to continue. There are good grounds for believing that, with appropriate private and governmental support, solar energy can contribute in a major way in this century to meeting our needs for heat, liquid fuels and electricity."[17]

The necessary support and related policies have been the subjects of numerous studies. In many, it is expected that SE will become price-competitive with alternative sources whose prices will continue to rise while the SE industry acquires the economies of scale and technological improvements that time will bring. For the present, incentives seem needed to encourage the use of SE while it is unfamiliar and first-costs are high. A detailed analysis of solar heating and cooling systems has shown that a 50 percent incentive would be provided by two federal actions: a 5 percent loan for 20 years and a 25 percent direct tax credit.[18] States could supply about 10 percent incentive by property tax abatement on the SE additions. Such measures would be gradually phased out as the industry matures (around 1985) and incentives are no longer needed. For photovoltaics, a number of conceptually similar actions are being adopted to stimulate the various near-term markets mentioned above.

There are ample precedents for incentive programs to guide the nation's energy development. From 1918-1976 federal incentives were granted to other energy systems in the following amounts: $9.7 billion for coal, $15.3 billion for hydroelectric, $16.5 billion for natural gas, $18 billion for nuclear, and $101.3 billion for oil, and $56.6 billion for electricity; for a total of $217 billion (1977 dollars).[19] There are, however, other reasons for SE incentives. Current economic comparisons are being made with conventional fuels whose prices do not reflect the *incremental* cost of added supplies; in the case of natural gas the price of imported LNG, or synthetic gas, is 2-3 times that of the dominant domestic supply. Also, several studies have shown that SE will create more jobs than most other forms of energy.[5, 17] In the case of photovoltaic purchases by the Department of Defense to replace 20 percent of its gasoline-powered generators, it has been calculated that, even at relatively high mid-term prices, a $484 million net discounted benefit would accrue.[20]

The President's Council on Environmental Quality has recently concluded that solar energy could meet one-quarter of the nation's energy needs by the end of the century and "significantly more than one-half" by the year 2020 "if our commitment to that goal and to conservation is strong."[17] Thus, the motivations, the technologies, and the policies for utilization of solar energy are steadily becoming clearer and more compelling.

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B.F. Williams

Do photovoltaics have a future?

While there are several commercial businesses selling photovoltaic power supplies, the applications are all in places where conventional electric power is unavailable. The present interest in solar cell electricity for widespread terrestrial use has led to an intense activity exploring the opportunities for significant cost reduction. In this paper obstacles to cost reduction will be identified and the programs addressing techniques for overcoming those obstacles will be presented.

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Photovoltaic power supplies have proven reliable and effective as sources of electricity in remote applications. There is no question of the economic viability of these power supplies for selected situations. There is major concern, however, as to the economic practicality of widespread terrestrial use because of the high cost of the photovoltaic arrays themselves. Based on their high efficiency, photovoltaic collectors should be one of the cheapest forms of energy generators known.

Fig. 1 compares the relative cost of energy from some familiar forms of solar collectors.[1] In this figure, the cost of energy derived from the various sources shown is plotted against the conversion efficiency of the various options. The entries for biomass and photovoltaic or thermal collectors are shown in their approximate location based on the efficiency of these processes. In the case of meat, cows convert the grain to meat with about 10 percent efficiency. In this case, the energy efficiency is 10^{-5} and the cost is about a dollar/kWh. As the efficiency of the collection increases the costs of the energy reduce in a linear fashion so that for forests, the cost of energy is reduced to $0.01/kWh. The costs of coal and oil are also shown. It is an interesting coincidence that the present day cost of coal is very close to what it would be in its non-fossilized form.

If this interesting trend were to continue for higher conversion efficiencies, the costs of the energy produced would be very low. Present day photovoltaic devices have conversion efficiencies of about 10 percent. According to Fig. 1, the cost of energy produced should be on the order of $0.0001/kWh. The present cost of electricity produced from photovoltaic devices is about four orders of magnitude higher than this.

Because of the diffuseness of the solar energy, the key to low cost collection is low materials costs. In this case of the linear portion of Fig. 1, the materials costs are low; the collector grows out of the ground as a result of the sunshine. The high cost of photovoltaics is due to the high materials costs associated with the construction of the panels themselves.

Present technology

The present panels use single crystal silicon wafers as the photovoltaic material. Fig. 2 is a photograph of a typical such panel (this panel was produced by RCA ATL, Camden, N.J.). The panel shown is four feet square and is designed to produce about 8.5 A at 28 V, or about 150 W. An exploded schematic of this panel is shown in Fig. 3. This figure indicates the materials content of the panel shown. Fig. 4 is a summary of costs of a manufacturing process which will produce such a state-of-the-art photovoltaic panel.[2] We have used present day material costs of $60/kg for the polycrystalline silicon and advanced manufacturing processes which are under development for all the process steps. The figure highlights significant material costs.

The costs in Table I are all expressed in terms of c/peak Watt. In order to compare these costs to those in Fig. 1, we will assume that the average insolation is 20 percent of the peak insolation. The peak solar insolation is about 1 kW/m^2. From Table II we see that if the purchase price of this panel were $2.40/peak Watt, the cost of electricity produced by this panel would be $.20/kWh. In order to have electricity cost

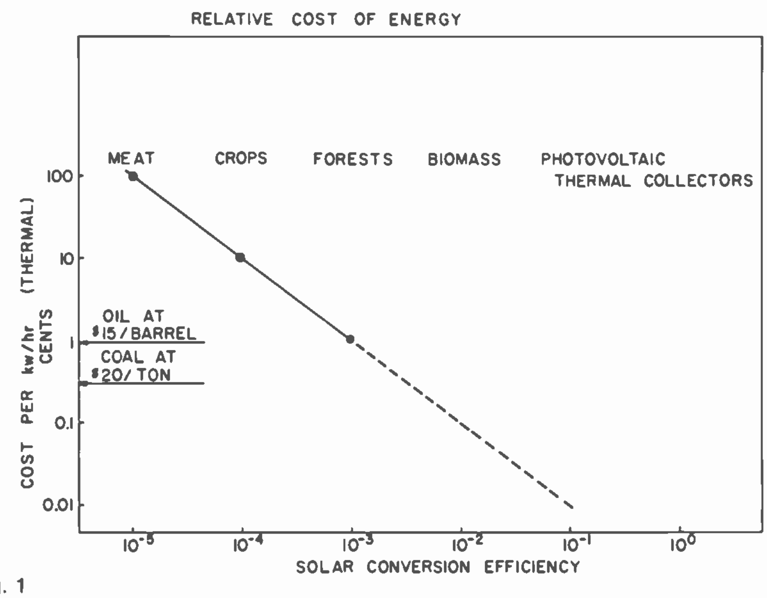

Fig. 1
Relative cost of energy.

Table I
Solar panel costs in cent/peak watt.

	MATERIAL & EXPENSE	LABOR & O. H.	INTEREST & DEPREC.	TOTAL
CRYSTAL GROWING	110.0	18.0	5.0	133.0
WAFER PREPARATION	28.0	26.0	6.0	60.0
JUNCTION FORMATION	4.3	9.0	3.1	16.4
METALLIZATION	9.1	3.0	2.0	14.1
AR COATING	---	0.5	0.5	1.0
INTERCONNECT	---	2.0	0.5	2.5
ENCAPSULATION	21.0	2.5	0.5	24.0
	172.0	61.0	18.0	251.0

less than $0.10/kWh, a selling price for the panels of less than $.50/peak Watt is required.

The costs shown in Table I are the manufacturing cost, however, and not the selling price. If we include an after-tax profit (return on assets) of 15 percent, a cost of sales of 25 percent of the selling price and complete factory level overhead, then a selling price of about $4/W is realized.

How low could the price go if we stay with single crystal silicon Czochralski technology? We have estimated the effect of factory size, single and multiple crystal pulling, changes in polycrystalline silicon cost, and new sawing technology on the manufacturing cost. This is shown in Fig. 4.[2] With presently forecastable technology improvements, a manufacturing cost of about $1.50/peak Watt seems a minimum.

As we see in Table I, if we can eliminate the costs associated with the crystal growth and slicing and the encapsulation costs, the manufacturing cost would drop to about $0.30/peak Watt. The R&D programs in the photovoltaic area are designed to do just this.

Concentrating systems

One alternative for reducing the materials cost of photovoltaic arrays is to concentrate the sunlight with relatively inexpensive concentrators onto a limited area of the more expensive solar cell material. A recent detailed GE study done for EPRI indicated that simple fixed tilt flat plate collectors had the most potential for utility systems.[3] However, high efficiency high

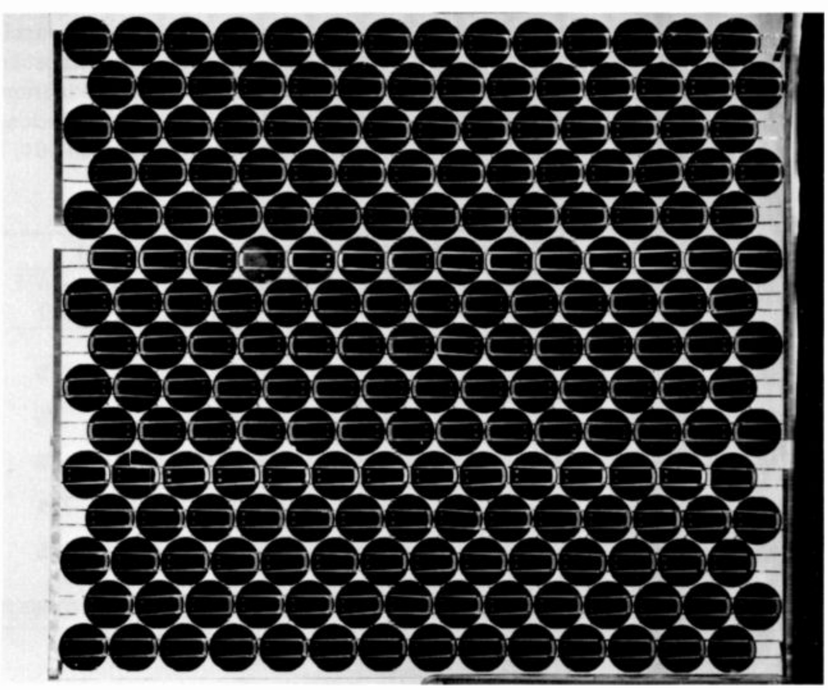

Fig. 2
Typical state-of-the-art panel.

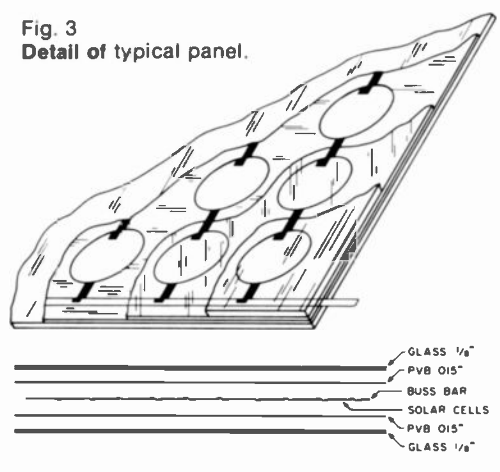

Fig. 3
Detail of typical panel.

Table II
Cost of electricity.

Initial Cost	$2.51/pk Watt	$12,550/average kilowatt
Installation	$50/M^2	$ 2,500/average kilowatt
Lifetime	20 yrs	
Interest Rate	10%	
Annual Cost		$ 1,750/average kilowatt
Annual Output	8760 hrs	8,760 kilowatt/hr
Electricity Cost		20¢ kilowatt/hr

concentration ratio systems also were shown to have "great potential." In Table III we compare the costs of concentrator systems using GaAs and silicon cells for a range of cell costs. The system used here was a passively cooled fresnel lens concentrator developed by RCA.[4] The concentration ratio of the system was optimized in each case based on the cost of the solar cells themselves. The cost of the cells shown in the table was estimated based on the requirement of the high performance shown. In the case of GaAs we have used a range of costs for the cells themselves which reflects manufacturing costs using known technologies. As can be seen from the table, a cost of about $1/W appears feasible. This is less than the projected costs for flat plate collectors using Cz silicon technology by about a factor of two.

Thin film flat plate devices

Crystalline

The Department of Energy is sponsoring research on evaluating the performance of almost every semiconductor material which has a bandgap in the proper range for photovoltaic devices, i.e., from about 1-2eV. There are basically two classes of crystalline materials, high cost high performance materials and low cost low performance materials. The objective of the programs is to reduce the cost of the high performance materials and/or increase the performance of the low cost materials. In general, the cost of the high performance materials, i.e., GaAs or Se, is the cost of the substrate on which the active layer rests. The programs for the most part are attempts to manufacture low cost starting materials on inexpensive substrates or to grow ribbons directly with no substrate at all. Since the materials are crystalline, and large grain sizes are desired, a substrate which lattice matches the growing layer is desirable. This has not proved to be an easy task for inexpensive substrates. A very active and promising program is under way addressing these problems.

Also materials with poorer performance but which may be grown on inexpensive substrates are under study. These are mainly II-VI compounds or thin films of II-VI compounds on top of III-V materials. CdTe p-n junctions or CdS-InP heterojunctions are examples of these devices. By far the most advanced is the Cu_2S-CdS solar cell which has been under investigation for about twenty years. An efficiency of 9 percent has been reported for a laboratory version of this cell.[5]

A principal concern with the CdS-Cu_2S technology has been an instability apparently associated with a reaction of the Cu layer with oxygen. This reaction suggests the active layer must be isolated from air to such an extent that the all glass encapsulation system used in the cost estimate of the single crystal silicon panel (see Table I) may be necessary. Correcting the costs in Table I for the reduced efficiency observed, the manufacturing costs shown in Table IV are developed. The costs in Table IV were estimated assuming no cost at all for the thin film CdS-Cu_2S film itself. The result is a manufacturing cost of ~0.50/W, with a projected selling price somewhat higher.

Table III
Concentrator costs

	SILICON (16%)	GaAs (20%)	
	$17/WATT X190	$1000/WATT X1700	$100/WATT X500
CELLS	10%	34%	16%
HEADER	4%	2%	3%
LENS	7%	3%	4%
STRUCTURE & DRIVE	73%	57%	73%
TRACKING & CONTROL	6%	4%	4%
COMPLETE ARRAY COST	$1.05/WATT	$2.00/WATT	$1.40/WATT

Although the costs of depositing the CdS-Cu_2S layer itself are assumed to be zero, the importance of developing a cell which can exhibit long term reliability without an expensive encapsulation system are emphasized by Table IV.

Amorphous

While there has been much interest in amorphous solar cell developments, actual data on operating cells has been published by only a few organizations.[6-8] The published work is on hydrogenated amorphous silicon.

This is a relatively new semiconductor material, which has optical and electrical properties totally different from crystalline silicon. It is because amorphous silicon has such a high optical absorption and because it is amorphous that it is of interest for solar cells. Its high optical absorption means it will absorb a large fraction of the incident sunlight even though it is deposited in a very thin film. As a result, the deposition times are very short and the consumed material is minimal. That it is an amorphous film means that its properties are insensitive to the substrate on which it is deposited. Inexpensive substrates of glass, plastic, or metal foils have been used with some success.[9]

A major problem with amorphous silicon for photovoltaics is the low conversion efficiency which has been observed, 6 percent. A major plus is the remarkable stability of even unencapsulated solar cells. The cost of a photovoltaic module based on amorphous silicon is shown in Table V. Note that in this case, cost reductions compared to the single crystal panel are due to the reduced cost encapsulation system as well as the elimination of crystalline silicon. At 6 percent efficiency, a manufacturing cost of less than 40¢/W is

Table IV
Solar panel costs in cent/peak watt (nine percent efficient glass encapsulated-10 MW). Active layer formation is assumed to be zero.

	MATERIAL & EXPENSE	LABOR & O.H.	INTEREST & DEPRECIATION	TOTAL
ACTIVE LAYER FORMATION				
METALLIZATION	6.0	4.0	2.7	12.3
AR COATING		.7	.7	1.3
INTERCONNECT		2.7	.7	3.3
ENCAPSULATION	28.0	3.3	.7	32.0
	34.0	10.8	4.7	49.4

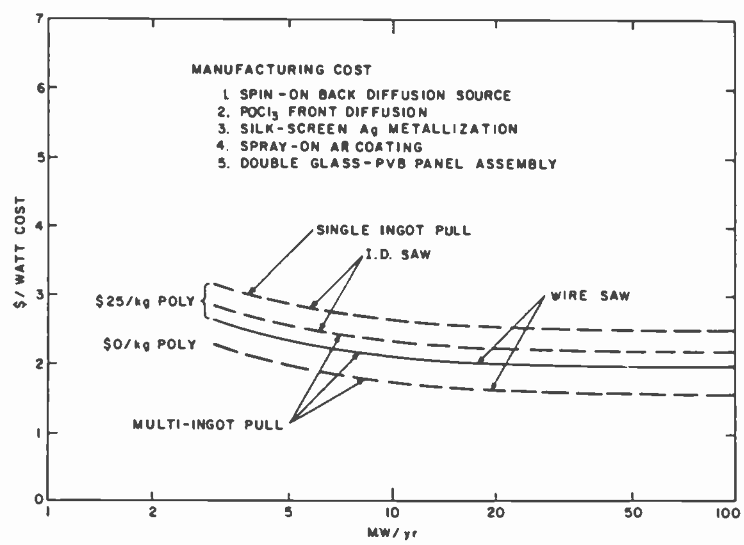

Fig. 4
Cost as a function of manufacturing volume with wafer preparation and polysilicon cost as parameters.

Table V
Solar cell panel costs in cent/watt (amorphous silicon-10 MW).

	MATERIAL & EXPENSE	LABOR & O.H.	INTEREST & DEPRECIATION	TOTAL 6% (12%)
PATTERN SUBSTRATE & DEPOSIT LAYERS	9.3	6.4	6.1	21.8 (17)
METALLIZATION & TEST	.6	3.2	1.6	5.4 (3.5)
INTERCONNECT	.4	2.2	.5	3.1 (2.1)
ENCAPSULATION	4.2	1.7	.7	6.6 (4.4)
	14.5	13.5	8.9	36.9 (27.0)

projected. The widespread concern that the balance of system costs requires a higher efficiency (on the order of 10 percent) is a major stumbling block for this technology. The effect on the cell costs themselves of improving the basic efficiency of the amorphous silicon cells is shown by the column in parentheses in Table V. It is this hoped-for efficiency improvement which is the driving force behind the amorphous silicon programs. The costs do not halve when the efficiency doubles because the factory is not fully loaded at the 10MW output.

Conclusions

Present photovoltaic panels are violating the trend of lower costs with increasing efficiency due to their reliance on expensive materials. While developing solar cells which can produce energy at costs which are consistent with historic trends seems unlikely, a medium technology solution should provide electricity competitive with the existing medium to high technology energy generators such as oil, coal, gas, and nuclear fission thermal plants.

Programs to cost reduce silicon and develop reliable thin film materials both have a realistic chance of producing such cost effective photovoltaic panels.

Acknowledgments

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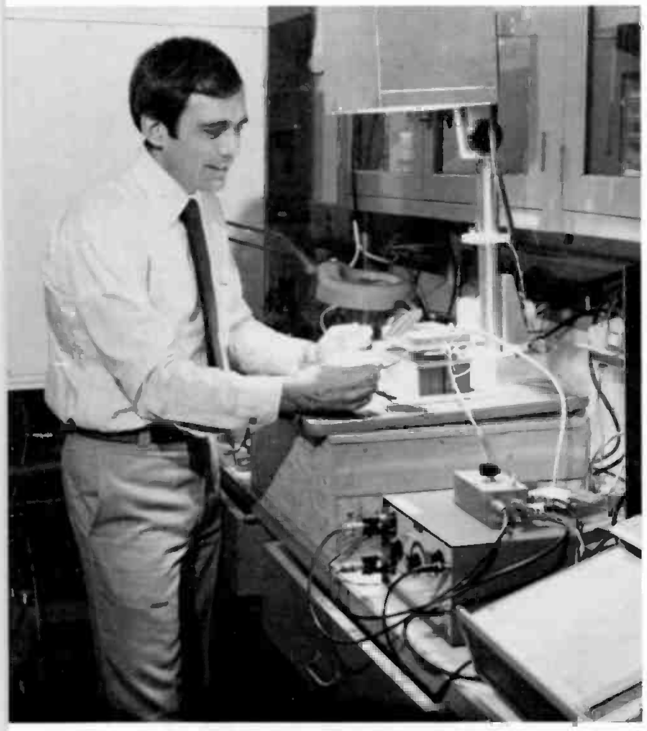
R.V. D'Aiello

RCA progress in flat-plate silicon solar panel technology

Within the next five years flat-plate silicon solar cell arrays could see widespread use as energy sources, emerging as a bright new business opportunity.



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Total electrical energy consumption in the U.S. by 1990 is expected to be about five trillion kilowatt hours per year. The generation of only one percent of this energy by solar panels costing only 50 cents per watt would represent a gross business of almost $700 million for panels alone.

The much talked about 50 cents per watt figure is a Department of Energy (DOE) goal set for 1986, and is based on the economics of competitive energy sources. For example, a solar cell panel costing 50 cents per watt with a useful life of 20 years, assuming no storage and an illumination factor of 0.2 for 300 days/year of sunlight, results in a cost of 1.7 cents per kWh of dc electrical energy delivered by the panel. When the costs of installation, power conditioning, maintenance and storage are added, the 50 cents/watt goal is seen to be reasonable, if solar electricity is to be competitive with other sources for industrial or home use. DOE's interim cost goal is two dollars per watt* for 1982. DOE programs, resulting in increased production and the introduction of lower cost materials and fabrication, recently stimulated a cost reduction from $30 to about $10 per peak watt.

To attain the required technological readiness, RCA Laboratories, in cooperation with SSD-Somerville, and GSD-Camden, has been assessing and developing low-cost methods for large-scale fabrication of flat-plate silicon solar cell panels. Much of the work has been funded by DOE and administered by the Jet Propulsion Laboratory under the "Low Cost Silicon Solar Array Project" with its objective of developing low-cost solar arrays.

*All costs are referenced to 1975 dollars.

Evolution of low-cost technologies

The development of a low-cost flat-plate silicon solar panel technology at RCA has taken an orderly and evolutionary path. First, a method of analyzing the costs for large-scale production of solar cell panels was devised. This analysis was applied to existing production technology to verify the method and to identify cost bottlenecks. Table I shows the process steps of such a manufacturing sequence and a breakdown of the materials, labor, and overhead for each step. The total cost is $1.89/watt exclusive of starting silicon cost, fixed factory overhead, and profit. The cost of the starting silicon wafers is at present considerable, on the order of $3-4/watt, and represents a major obstacle to achieving the cost objective. A variety of approaches to solving this problem are under investigation, starting with ways to reduce the cost of the raw silicon[1] and developing techniques to obtain the silicon directly in sheet form[2,3]. This problem and one RCA approach to its solution will be discussed later.

Returning to the above analysis of production costs, several important conclusions were drawn. First, it is seen that the total cost of materials and expense items consumed is $0.48/watt. Thus, no amount of automation would be effective in reaching a $0.50/watt goal, since the basic cost of the materials and expense items would preclude it. Second, the most costly steps in materials and labor are the metallization, AR coating, and the structural panel assembly. Clearly, alternative, low-cost processes had to be explored to replace these steps. In addition, very high yields were assumed at each step since low yield not only raises the processing costs, but requires additional quantities of expensive input silicon to satisfy a given production volume. This raises the need for simple processing steps requiring a minimum of manual handling. Such processes as screen-printing of the metal contacts, spin-on or spray-on methods for AR coatings, and large-scale reflow soldering are desirable because most of the materials consumed wind up on the solar cell, and these processes are readily automated.

It was also desirable from an economic and environmental standpoint to eliminate, as much as possible, the use of wet chemicals. Such a "dry" process uses, for example, ion-implantation for junction and back contact formation. The rim and oxide etches could be eliminated by the introduction of a planar junction. This would also reduce the possibility of subsequent mechanical damage, thus increasing yield.

This detailed study of cost problem led to the simple conclusion that proposed manufacturing sequences which are to be ultimately successful are those which, (1) minimize the cost of materials consumed; (2) are most amenable to automation; and (3) result in maximum performance of the resulting solar cell arrays.

A process sequence which utilizes these features was then selected and is given in Table II. This sequence produces arrays for a cost of $0.264/peak watt, including $0.046/peak watt of labor and overhead. The increased efficiency assumed in this sequence (15% vs 10%) results in substantial savings in the amount of silicon processed at each step for a given output power requirement. It also reflects an already realized improvement in cell performance, and an optimism that future techniques will result in even higher average efficiency. Processes such as these then have a good chance of achieving the cost/performance goal.

Status of low-cost manufacturing technologies

Having identified a set of low-cost process steps, the manufacturing sequence shown in Fig. 1 was formulated. Three processes are shown for junction formation since our cost analysis showed that they do not differ greatly in cost; thus a selection would be made later, based on actual cost/performance data or compatibility with adjoining processes. The process steps in Fig. 1, which were "state-of-the-art", were exercized immediately to obtain performance and yield data, and those steps requiring significant research and development received greater attention. A summary of the status and progress for each process step is given in Table III.

Significant innovations were made by RCA scientists and engineers in the areas of ion-implanted solar cell processing, synthesis and application of silver-based inks for screen-printed metal contacts, development of a spray-on antireflection (AR) coating, and process development for double glass lamination of panels. A brief description of these follows.

At the onset of our program, ion-implantation appeared to be an attractive junction formation method for the reasons stated earlier; however, it was generally found that cells made with ion-implanted junctions had unacceptably low efficiency on the order of 9-10%. The reasons for this become apparent during our program, and

Table I
Cost analysis: standard processes

Assumptions: 0.500 Watts per Solar Cell and $0.0 for 7.8 cm (3") Diameter Wafer (cell efficiency = 10%)

Step	*Yield (%)*	*Process*	*Mat'l.*	*D.L.*	*Exp.*	*P.OH.*	*Int.*	*Depr.*	*Totals*
1	99.0	System "Z" Wafer Cleaning	0.0	0.020	0.003	0.014	0.001	0.001	0.038
2	95.0	Spin-On Source	0.0	0.024	0.009	0.020	0.002	0.002	0.056
3	99.0	200 Deg. C. Bake	0.0	0.015	0.000	0.012	0.000	0.000	0.028
4	99.0	$POCl_3$ Deposition and Diffusion	0.0	0.014	0.040	0.011	0.006	0.009	0.079
5	99.5	Glass Removal	0.0	0.011	0.033	0.008	0.001	0.002	0.055
6	95.0	Rim Etch	0.0	0.009	0.046	0.015	0.003	0.005	0.078
7	100.0	Post Diffusion Inspection	0.0	0.004	0.000	0.003	0.000	0.000	0.008
8	98.0	TI/AG Metallization-Front	0.025	0.118	0.023	0.104	0.041	0.065	0.375
9	98.0	TI/AG Metallization-Back	0.028	0.116	0.022	0.102	0.040	0.063	0.371
10	99.0	AR Coating: Evaporate	0.0	0.114	0.037	0.124	0.033	0.052	0.359
11	80.0	Test	0.0	0.012	0.001	0.014	0.005	0.008	0.039
12	96.0	Array Fab.: Reflow Solder	0.152	0.070	0.066	0.077	0.012	0.020	0.397
	63.6	Totals	0.206	0.527	0.280	0.502	0.143	0.228	1.885
			% 10.92	27.93	14.83	26.63	7.61		

Table II
Cost analysis: low-cost process sequence

Assumptions: 0.717 Watts per Solar Cell and $0.0 for 7.8 cm (3") Diameter Wafer (cell efficiency = 15%)

Step	*Yield* (%)	*Process*	*Mat'l*	*Exp.*	*Labor + O.H.*	*Int. + Depr.*	*Totals*	*Invest*
1	99.0	System "Z" Wafer Cleaning	0.0	0.001	0.001	0.000	0.003	0.002
2	99.0	Ion Implantation: 2 Sides	0.0	0.005	0.004	0.020	0.029	0.084
3	99.0	Diffusion	0.0	0.002	0.004	0.003	0.009	0.010
4	99.0	Post Diffusion Inspection 10%	0.0	0.000	0.000	0.000	0.001	0.003
5	99.0	Thick AG Metal-Back: Auto	0.021	0.004	0.004	0.008	0.041	0.037
6	99.0	Thick AG Metal-Front: Auto	0.021	0.009	0.010	0.016	0.060	0.069
7	90.0	Test	0.0	0.000	0.004	0.008	0.012	0.035
8	99.0	AR Coatings: Spray-On	0.002	0.002	0.005	0.002	0.011	0.008
9	98.0	Interconnect:Gap Welding	0.002	0.002	0.008	0.005	0.016	0.019
10	100.0	Double Glass Panel Assembly	0.072	0.002	0.003	0.003	0.080	0.014
11	100.0	Array Module Packaging	0.007	0.0	0.001	0.000	0.009	0.000
	82.2	Totals	0.124	0.027	0.046	0.066	0.264	0.282
			% 47.22	10.35	17.12	25.31		

Table III
Status and results of experimental production studies

Process Step	*Beginning of* 1978	*Current*	*Comments*
Etch & Clean	Well established	Operational	
Junction Formation			
A. Ion Implantation	Low cell efficiency 9-11%	Innovative process improvement—14-15% experimental cells	Needs production line verification and higher throughput
B. $POCl_3$ (gas)	Well established	Operational	
C. Spin-on Source	Nonreproducible—unstable	Some success—not operational	Process not compatible with overall sequence
Screen Printed Metallization	Limited experience no well-defined ink available	Feasibility demonstrated suitable silver ink synthesized	Needs further development for process specification, and materials cost reduction
Spray-on coating	Untried	Spray-on solution developed and feasibility demonstrated	Production tests required
Electrical Test	Design	Operational	Needs automatic data acquisition for higher throughput
Cell Interconnect (Solder reflow)	Proven	Operational	Higher throughput required
Panel Assembly (double glass PVB laminate)	Design	Feasibility demonstrated—process parameters determined	Design of specific apparatus required

effective processing methods were developed. Now, ion-implanted cells having conversion efficiencies of 14-15% can be reproducibly fabricated.

Screen-printing of the metallization onto the solar cell is very desirable from a cost standpoint; the metal is applied only where it is needed and screen-printing technology for ceramic substrates and circuit boards is well advanced, with machines available having throughputs of several thousand pieces per hour. The problem in its application to solar cells is finding the proper ink and processing conditions so that the fired contact will have strong adherence to the silicon, together with high lateral electrical conductivity, and low contact resistance on the cell surfaces. This must be accomplished without penetrating the very shallow ($\sim 0.5\ \mu m$) junction layer.

A suitable silver-based ink has been synthesized and a method of firing the printed contacts which utilizes infrared lamps to simultaneously heat both sides of the cells has been developed. This process is easily automated and capable of very high throughputs. A further significant cost reduction could be obtained if a suitable non-noble metal could be found to replace silver.

The use of conventional spin-on applications of solutions for depositing the optical antireflection (AR) coating on solar cells is expensive because of the low rate of throughput. Also, a lack of film uniformity results because the screen-printed metallization is considerably thicker and not as smooth as evaporated metals, thereby interfering with the uniform spreading of the solution. The technical and economic properties of spray-coating techniques were found attractive for this application, since commercial equipment, designed to provide a variety of thin-film coatings on large area substrates offers excellent control with remarkable economy.

However, the requirement was to develop a solution which could be sprayed uniformly on a 3-in.-diameter metallized silicon cell, and to a thickness after drying and baking of 700 Å + 50 Å.

A variety of organometallic component mixtures containing SiO_2 and TiO_2 are well suited to this purpose but were found usable only in conjunction with an optimal solvent system especially designed for spraying. Such solutions were used directly in commercial spraying equipment.[4] A typical reflection spectrum of the resulting film compared to a conventional evaporated AR film (Fig. 2) shows that the optical properties are quite good. The electrical efficiency of typical solar cells (3-in.-diameter, metallized by screen-printing) increased by a factor of 1.4 after spray coating and final bake of the AR film. Fine-tuning of the overall process and cost reductions of the chemical components are now in progress.

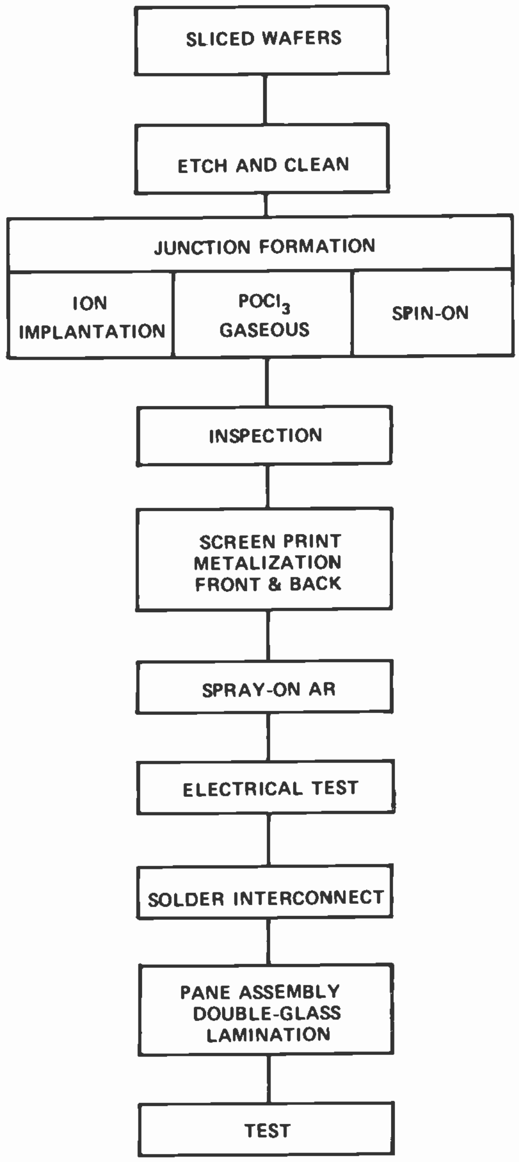


Fig. 1
Major Steps of the Solar Panel Process Sequence.

A preferred panel design and assembly technique was determined on the basis of anticipated electrical requirements and the need for protection from environmental hazards over a 20-year life. This latter requirement is most severe since the effect of moisture penetration is the dominant source of long-term degradation of solar cells. For that reason, a double-glass-structure was selected. The RCA panel consists of a double-glass laminate structure, 4 ft x 4 ft in size, containing 225 cells. The construction makes use of the well-established safety-glass lamination technique. The cross-sectional structure of the panel design shown in Fig. 3, contains two 1/8-in.-thick sheets of untempered float-glass with two 0.015-in.-thick sheets of polyvinyl butyral (PVB) which serve primarily as a filler material and bonding agent for the sandwich. The glass becomes a protective barrier against moisture

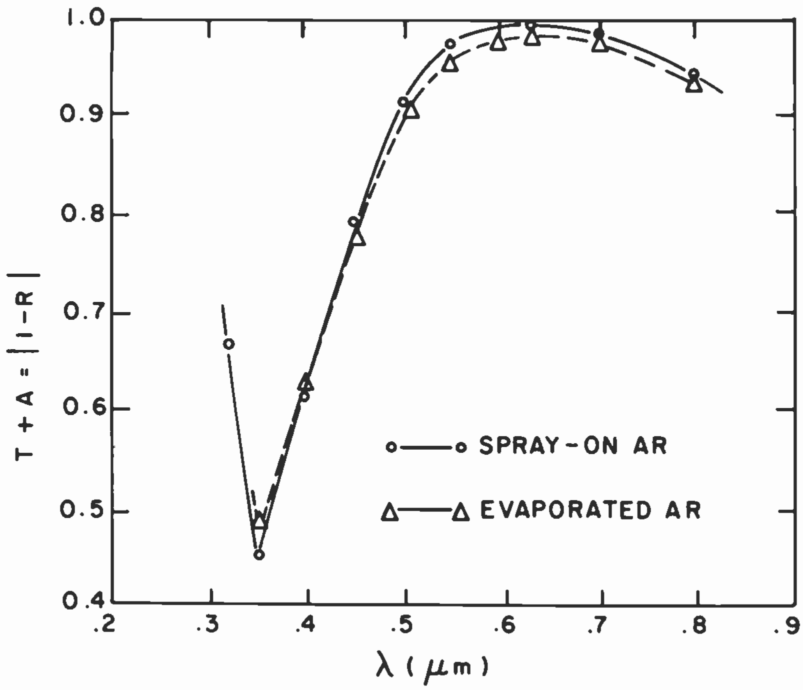
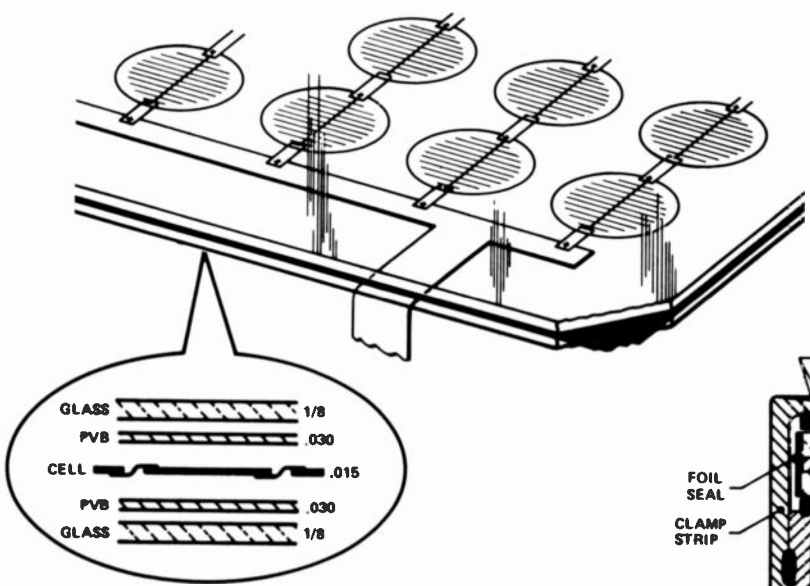


Fig. 2
Comparison of the reflection spectra for the spray-on AR coating and a conventional (Ta_2O_5) evaporated coating.



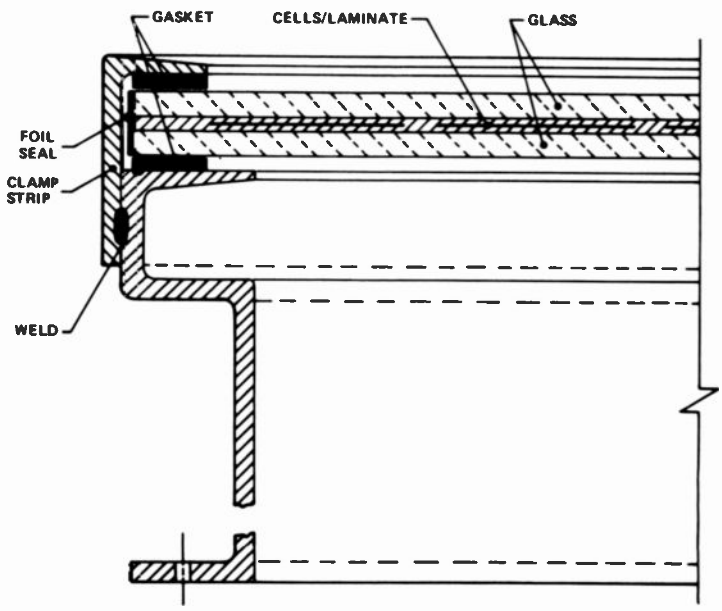


Fig. 3
Features of the RCA Double-Glass Panel Design.

penetration as well as a structural member for wind loading requirements.

Several methods were investigated for modifying the standard flat-glass lamination process in order to accommodate the inclusion of the solar cell array. To make the process work it was found necessary to preheat the structure in vacuum in order to cause the PVB to flow into the spaces between the cells. This, combined with the vacuum, has eliminated previous air-entrapment problems and allows for a successful high pressure lamination. A photograph of a 4 ft x 4 ft panel after lamination is shown in Fig. 4.

This process has been developed using commercial laminating equipment designed to handle a variety of glass sizes under differing laminating conditions. To make the process feasible for solar panel production, specific laminating machines must be designed to ensure high throughput rates consistent with the assumed economy of large-scale production.

Epitaxial Si films— a possible solution to the high cost of silicon

Establishing a manufacturing process for the large-scale production of solar panels at a projected cost of under \$0.50/W is a major step forward; however, to achieve the overall cost objective there still remains the problem of the high cost of the starting silicon. Accordingly, lower cost techniques for the reduction and purification of silicon are under development by several silicon manufacturers[1]. However, these processes often result in polycrystalline forms of silicon containing unwanted impurities and defects. Efficiencies of solar cells made directly into this material have been low, and some of the yet lower cost forms of simply purified metallurgical grade silicon are not suitable for the direct fabrication of solar cells. Regardless of how low the cost of the starting silicon, it is important in most applications from a system-cost viewpoint to obtain as high a cell efficiency as possible, 15% being a desirable target.

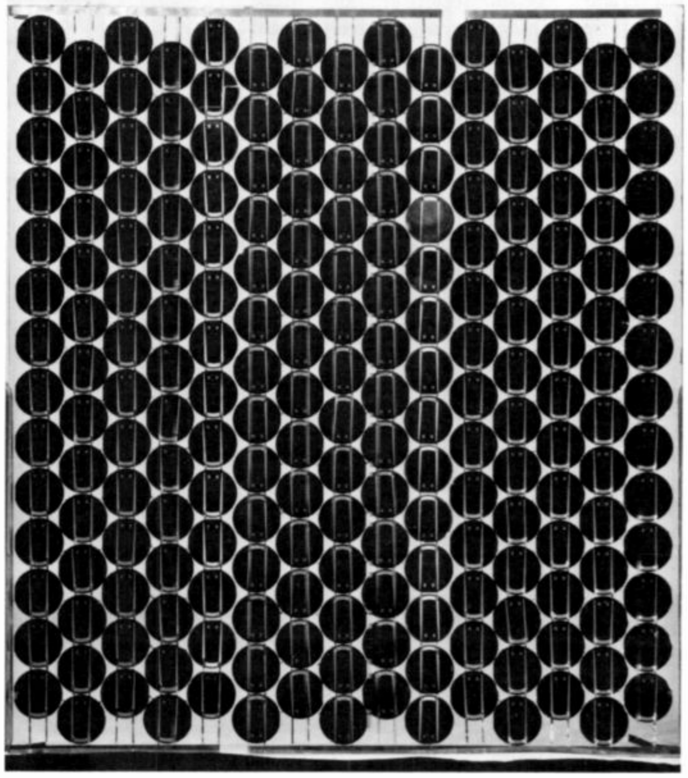


Fig. 4
Photograph of an RCA 4 ft x 4 ft double glass panel after lamination. Panel is now ready for framing and connection of output wiring.

Our approach to this problem is the use of thin epitaxial films grown on low-cost silicon. This approach has a number of already demonstrated technical advantages and utilizes a technology in which RCA is a recognized leader. From a technical standpoint, we have repeatedly demonstrated that epitaxial silicon films can be grown with lower defect density and better electrical characteristics than the substrates on which they are prepared. More importantly, recent work at RCA Laboratories [5,6] has shown that high-efficiency solar cells (e.g., 10-13%) can be fabricated in thin epitaxial films grown on several different low-cost silicon substrates. The solar illuminated output characteristics of such an epitaxial solar cell in comparison with a conventional high efficiency cell are shown in Fig. 5 along with evidence of the improvement in silicon crystal quality obtainable by the epitaxial method. The output current for the epitaxial cell is lower than that for the conventional cell because the active layer in the epi cell is only 15 μm compared to 300 μm in the bulk cell. The epitaxial layer is kept thin, consistant with efficiency requirements, and to achieve economy in its growth; in addition, because the silicon on which the epitaxial layer is grown is potentially less expensive than bulk silicon, an overall economic advantage can be realized with the epitaxial approach. At this time, no other processing technique can yield such high efficiency cells based on substrates of this kind.

The advantages of epitaxy are substantial, even inclusive of cost, since it is a method whereby dopant distributions and the structure of the silicon layer and layer thicknesses can be readily adjusted to obtain a desired objective. However, epitaxy as practiced in the semiconductor industry today is an expensive process because of high labor content, batch processing and inefficient use of electricity and chemicals. Recently, RCA Laboratories has developed a proprietary epitaxial reactor[8,9] which allows a significant increase in the power and chemical efficiency of the process. It is readily amenable to automation, reduces labor costs and greatly increases the capacity of the epitaxial processing equipment.

The main feature of this new reactor concept, known as the RCA Rotary Disc (RD) Reactor in comparison to conventional epitaxial reactors, is shown in Fig. 6. The conventional susceptor on the right is a simple extension of a flat wafer holder in which the substrate wafers lie next to each other. It has a hexagonal cross section and is tapered in order to achieve the proper gas flow dynamics when placed in a bell jar. This geometry limits the practical length of the susceptor, and thus the number of wafers it can hold, to about thirty. In the RD reactor, the susceptors are in the form of discs arranged in a stack-like fashion, with the wafers paired and facing each other. This allows for very efficient packing of the wafers, which in present design results in 50 wafers per 25 cm length of reactor. The gas distribution system consists of a specially designed manifold which injects and distributes the silicon bearing gas in the space between pairs of wafers. Thus, the stack can be quite high and in addition, becuase of this design, increasing the size of the substrate wafers presents no special problems. An assembled version of a prototype RD reactor is shown in Fig. 7.

Because of the above features, the Rotary Disc reactor has the following advantages over conventional reactors:

(1) Higher wafer capacity per given volume of reactor space;

(2) Higher power and chemical efficiency;

(3) Better control of thickness and doping uniformity by eliminating the non-equivalency of wafer positions;

(4) Easy accommodation of large diameter wafers by a relatively small extension of the susceptor disc diamters;

(5) Due to the relatively small volume of gas between the discs, rapid charges in doping type and/or level are possible; this could lead to structures particularly suitable for solar cells; and

(6) The RD reactor is readily amenable to upscaling and automation to a degree which would lower cost of epitaxy to the level acceptable in solar cell manufacturing.

Cost estimates for the large-scale production of solar panels using RD reactors of the current design have been made. The results of such an analysis show that by combining the epitaxial technology with the low-cost processes described earlier a production cost of about $1.30/w is presently attainable. Thus, it appears that this technology in its present form can meet the $2.00/w 1982 goal. Because the RD reactor concept can be easily scaled-up and automated, still lower costs are possible. For example, if the future price of the low-cost silicon substrates can be reduced to $0.20/w, we estimate that a large-scale automated RD reactor capable of processing 1200 wafers/hr. will result in a panel cost of about $0.45/peak watt.

The epitaxial technology described does not require any crucial innovations in order to meet the technical or cost objectives, but rather just scale-up and engineering modifications of already existing technology. Therefore, epitaxial solar cells on low-cost silicon substrates represents a very promising route to the availability of solar power at a competitively low price.

Potential for the future

The elements of the technology for producing flat-plate silicon solar cell panels at costs approaching an acceptable range for commercial applications now exist at RCA. The development of these low-cost processes is remarkable in that they represent significant technical achievement under the constraint of very restrictive cost objectives. However, much remains to be done before a viable product can be manufactured. The successful demonstration of most of the low-cost processes described in this article was accomplished in experimental production lines or in the laboratory. These processes must be

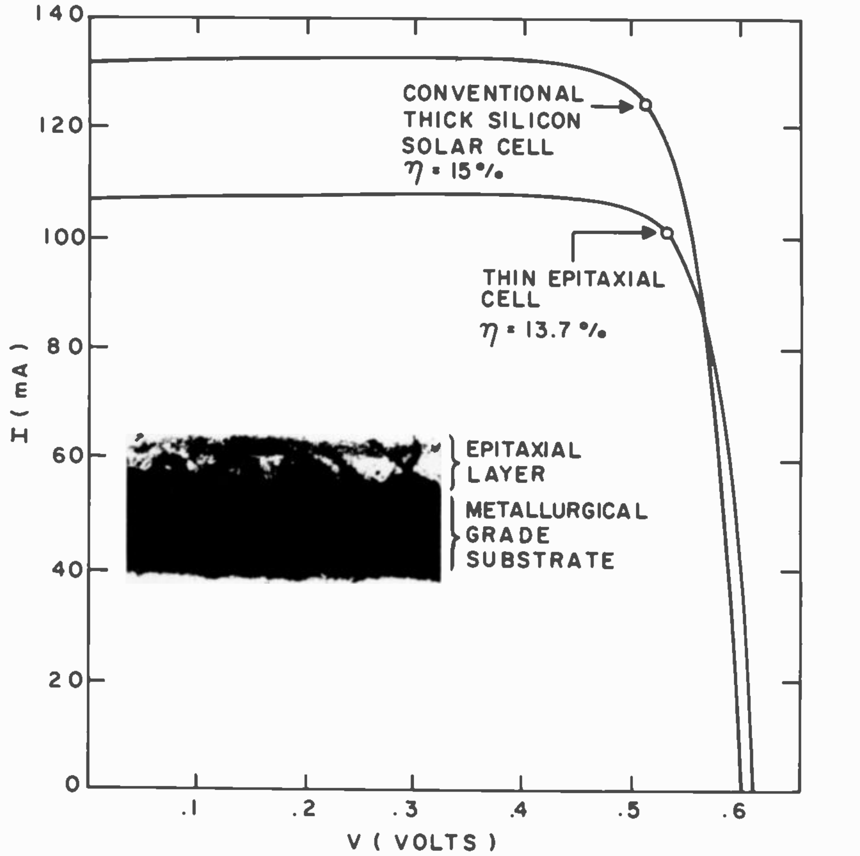


Fig. 5
Electrical output measured in sunlight of a conventional high efficiency solar cell compared to that of a cell made into a 15μm (0.6 mil) thick epitaxial layer which was grown on a low-cost silicon substrate. The improvement in the crystal quality of the epitaxial layer compared to such a substrate is illustrated in the x-ray topograph shown in the inset.

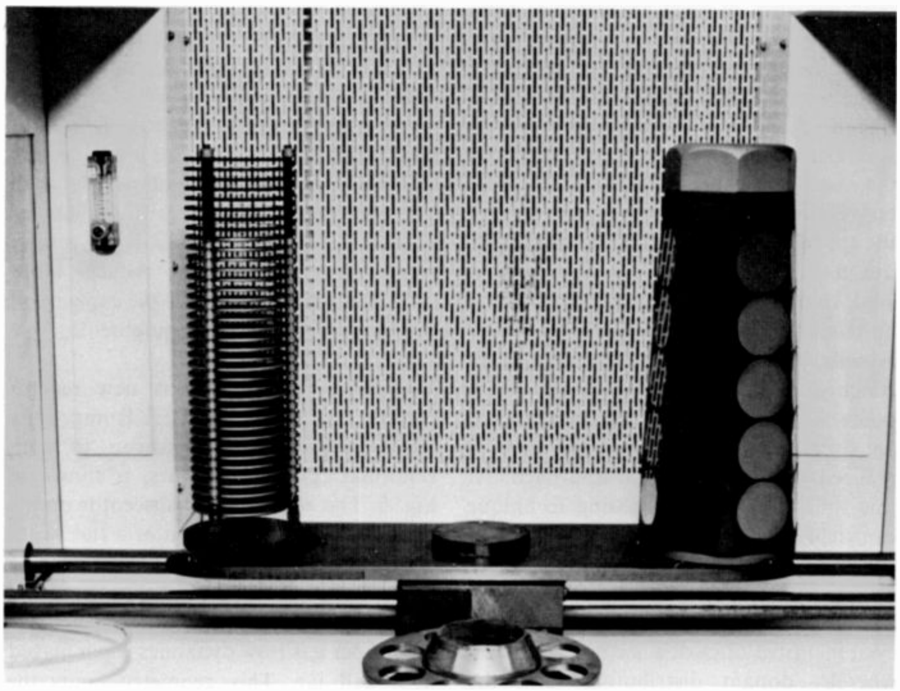


Fig. 6
Comparison of susceptor designs for a conventional barrel reactor (right) and the new RCA Rotary Disc (RD) reactor.

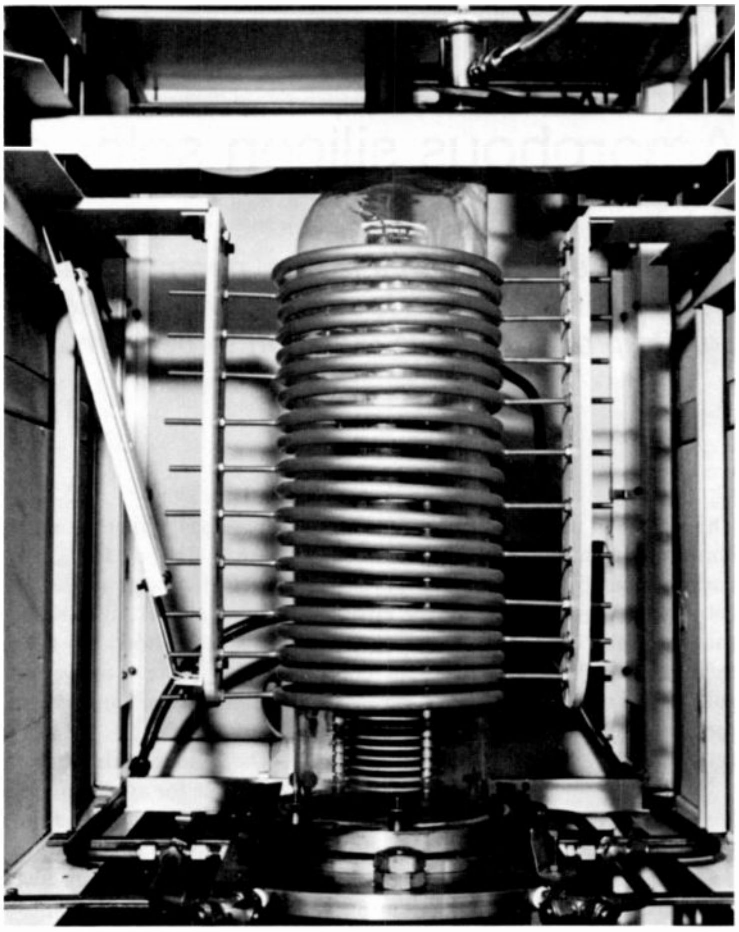


Fig. 7
Operational Rotary Disc reactor.

brought together to form a complete manufacturing sequence and a technical and economic evaluation must be made of the overall cost and performance of such a sequence. High throughput and yield, appropriate methods of automation, and compatibility between the process steps must be achieved in order to reach the cost goals. While striving to accomplish these objectives, much flexibility should be maintained; the field of photovoltaics is ina stage of rapid change with new technologies being introduced which can seriously impact the relative merits of existing approaches. However, the availability of the processes described and the experience obtained in developing them places RCA in a good position to evaluate and utilize new developments.

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D.E. Carlson

Amorphous silicon solar cells

The ideal energy source is free, non-polluting, and inexhaustible. The sun is essentially such a source. We need only trap or convert its radiation to perform useful work.

The science of photovoltaics is one way to convert sunlight into a high grade form of energy, namely, electricity. In the near future the mass production of efficient, thin-film solar cells may reduce the cost of these cells below that of other energy sources for many applications. Moreover, the fabrication and employment of solar cells should be almost free of pollution.

Since solar cells are solid state devices, improvements in design and processing could lead to lifetimes in excess of 20 years. Thus, the conversion of sunlight into electricity via photovoltaics may develop into a large busines within the next decade. (The U.S. Department of Energy photovoltaic program predicts annual sales of $250 million by 1986 assuming a cost of 50 cents per peak watt.)[1]

A promising new type of thin film solar cell was invented at RCA Laboratories in 1974.[2,3] This cell utilizes a relatively new material—hydrogenated amorphous silicon (a-Si:H)[4]—in a thin film (about one micron thick) on low cost substrates such as glass or steel. Preliminary cost estimates indicate that the a-Si:H solar cell could be manufactured at a cost well below one dollar per peak watt. Present single crystal Si solar cells cost ten times that much.

Properties of a-Si:H

The unusual properties of a-Si:H are due mainly to the compensation of dangling bonds by hydrogen. Films of a-Si:H are usually made in a glow discharge in silane (SiH_4), and recent work has shown that these films contain between 10 and 50 at. percent of hydrogen.[5] These a-Si:H films exhibit defect densities several orders of magnitude less than those observed in most amorphous semiconductors.[6] Consequently, the material can be substitutionally doped either n- or p-type by adding either PH_3 or B_2H_6, respectively, to the SiH_4 discharge atmosphere. The ability to dope a-Si:H allows one to form both junctions and low resistance contacts which are necessary for efficient photovoltaic conversion.

The material also has optical properties suitable for application in a thin film solar cell. Fig. 1 compares the optical absorption behavior of a-Si:H with that of crystalline Si. The absorption coefficient of a-Si:H increases with rising substrate temperature due to diminishing hydrogen content; the optical gap of a-Si:H recedes as the hydrogen content decreases.[7] As shown in Fig. 1, the absorption coefficient of a-Si:H may exceed that of crystalline Si by more than an order of magnitude over most of the visible light range. Thus, an appreciable fraction of the solar radiation may be absorbed in an a-Si:H film only one micron thick.

The operation of a solar cell depends on the ability to collect both photogenerated electrons and holes. At present, the efficiency of a-Si:H solar cells is limited to somewhat less than six percent due to poor minority carrier diffusion lengths. The minority carriers (holes) are collected efficiently only in the depletion or space charge region. Thus, the collection region is only

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0.2-0.3 micron thick, and the short-circuit current densities are less than 14.5 mA/cm^2 as compared to about 20-22 mA/cm^2 if the collection region were of the order of 1 μm. Drift mobility measurements in lightly p-type a-Si:H indicate the presence of a hole trap in the vicinity of 0.35 eV above the valence band.[8] This center may be due to residual dangling bonds and may be responsible for the short hole lifetimes (~10 ns) in undoped a-Si:H (which is usually n-type).

Important patent covers new low-cost technology for solar energy

RCA has received an important U.S. patent covering solar cells made of hydrogenated amorphous silicon, a material RCA expects will play a major role in the low-cost conversion of solar energy directly into electricity. Based on laboratory efficiencies of 6% already achieved, amorphous silicon solar cells may produce electricity at costs competitive with many conventional power sources by the mid to late 1980s.

U.S. Patent No. 4,064,521 for a "semiconductor device having a body of amorphous silicon" was granted to Dr. David E. Carlson, Head of Photovoltaic Device Development, Energy Systems Research Laboratory, RCA Laboratories, Princeton, N.J.

Although future amorphous silicon cells may involve different geometrical arrangements, basically the devices will be extensions of those patented by Dr. Carlson rather than new ones. Because of this, RCA considers the patent one of the most important yet granted in the solar energy field. The patent also covers some transistors and diode devices in amorphous silicon.

Initially, amorphous silicon cells could be used for electrification projects in developing nations lacking the extensive electric power distribution networks of America and Europe. Also, many developing nations are in areas that receive a great deal of sunlight and their societies are built around small communities or villages with very modest electricity requirements. Solar cell power supplies seem particularly well suited to this environment. Later on, as the technology is improved, amorphous solar cells could be employed in more developed nations, particularly in applications using large amounts of DC power.

Solar cell structures

A-Si:H solar cells have been fabricated in several structures such as p-n, p-i-n, and Schottky-barrier junctions as well as heterojunctions.[9] The best performance has been obtained with p-i-n and Schottky-barrier structures (see Fig. 2).

The Schottky-barrier cells are usually made by first depositing a thin n^+ layer of a-Si:H (≤ 0.1 μm) on a steel substrate at a substrate temperature of ~300-350°C. The discharge may be either rf- or dc-induced, and the discharge atmosphere typically contains ~0.2% PH_3 to provide the n-type doping. A layer of undoped a-Si:H (~0.3-1.0 μm) is then deposited from a discharge of pure SiH_4 (pressures are usually in the range of 0.01-0.7 Torr). The Schottky barrier is formed by evaporating ~50 Å of Pt onto the undoped a-Si:H, and for small cells a Pt contact pad (~300 Å) is deposited near one edge of the cell. For large cells a current collection grid is deposited on top of the Pt film. Finally, an antireflection coating of ~450 Å of ZrO_2 or TiO_2 is deposited on top of the Pt.

The MIS (metal-insulator-semiconductor) solar cell is a minor variation of the Schottky-barrier cell in that a thin insulating layer (~20-30 Å) is formed on top of the undoped a-Si:H before depositing the Pt. An insulating layer can be formed by oxidizing the a-Si:H in air (15 min at ~320°C), but these devices are sensitive to humidity and must be encapsulated. Generally, MIS devices exhibit larger open-circuit voltages than Schottky-barrier devices.

The p-i-n cells are usually made by first depositing a thin Pt-SiO_2 cermet film (~100 Å) on glass coated with indium-tin-oxide (ITO).[10] The cermet acts as a contacting layer to a thin p^+ layer of a-Si:H (~200Å); a poor contact results if the p^+ layer is deposited directly on the ITO, apparently due to the formation of a thin resistive oxide layer.[9] The p^+ layer is deposited from a discharge containing B_2H_6 ($B_2H_6/SiH_4 \cong 10^{-3}-10^{-4}$). After depositing ~0.3-1.0 μm of undoped a-Si:H, an n^+ layer (≤ 0.1 μm) is deposited from a SiH_4 discharge containing PH_3 ($PH_3/SiH_4 \cong 2x10^{-1}$). Finally, a back electrode such as Nb, Ti, Al, etc. is evaporated or sputtered on top of the n^+ layer.

The p-i-n structure has several advantages over the Schottky-barrier structure. First, the junction between the p^+ layer and the undoped a-Si:H (slightly n-type) is buried so the devices are not affected by humidity or handling. Moreover, since the p-i-n structure is deposited on an insulating substrate, the films can be patterned and connected in series thus producing relatively high output voltages and low currents. This procedure decreases the losses due to shadowing and also decreases the amount of metallization needed for current collection. Finally, the p-i-n structure can be deposited entirely in an rf system using both sputter- and glow-discharge-depositions.

Solar cell characteristics

A solar cell can be easily characterized by measuring the current-voltage response in sunlight. Fig. 3 shows illuminated I-V curves for a series of cells made in a dc glow discharge. In this series, the spacing between a cathodic screen and the substrate was varied from 3.0 cm (curve c) to 0.5 cm (curve a). The resulting change in the discharge kinetics causes a large change in the photovoltaic properties of the material. In general, the properties of a-Si:H depend strongly on the deposition conditions.

The best conversion efficiency achieved to date is 6.0% in a small area device (1.5 mm^2). The conversion efficiency is defined as the percentage of the incident solar power (~100 mW/cm^2 for the sun directly overhead) that is converted into electrical

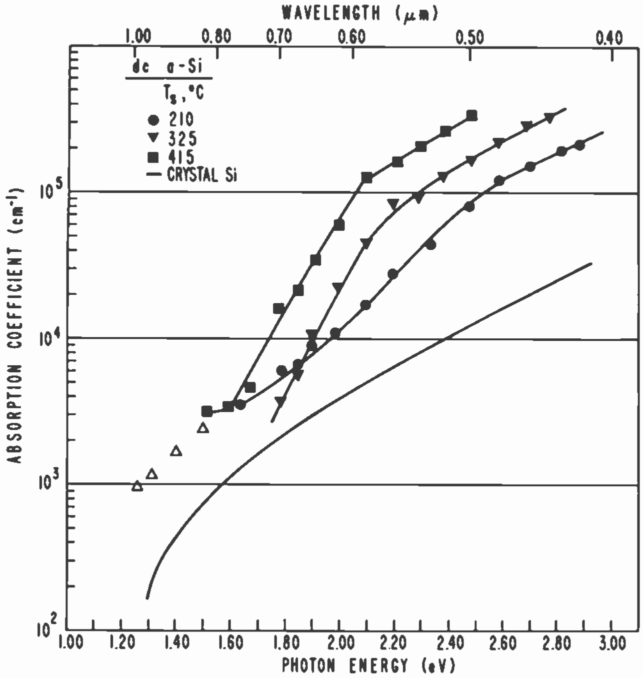

Fig. 1
Absorption coefficient as a function of photon energy for a-Si:H films produced in a dc discharge at different substrate temperatures.

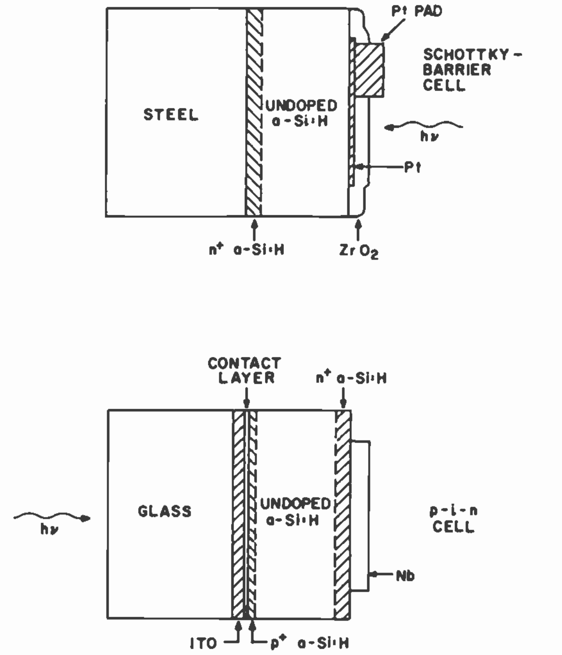

Fig. 2
Schematic drawings of a Schottky-barrier and a p-i-n cell.

power. Open-circuit voltages (V_{oc}) as high as 895 mV and short circuit current densities (J_{sc}) as high as 14.5 mA/cm^2 have been measured in a-Si:H solar cells.

Another parameter used to characterize a solar cell is the fill factor (FF) defined by

$$FF = \frac{J_m V_m}{J_{sc} V_{oc}}$$

where J_m and V_m are the current density and the photovoltage at the maximum power point. Fill Factors as large as 0.69 have been measured in thin a-Si:H cells (FF≅0.87 for an ideal diode). If the best values of V_{oc}, J_{sc} and FF could be obtained in the same cell, then the conversion efficiency would be ~9% ($\eta = (FF) J_{sc} V_{oc} / P_i$ where $P \cong 100$ mW/cm^2 for AM1 sunlight).

One can gain significant insight into the operation of a solar cell by measuring the collection efficiency as a function of the wavelength of incident light. The collection efficiency is defined as the percentage of electron-hole pairs collected by the junction per incident photon. As shown in Fig. 4, the collection efficiency of a Schottky-barrier cell (no antireflection coating) falls off at long wavelengths; the data can be fitted by calculating the percentage of photons that are absorbed in a collection region ~0.3 μm thick. Thus, electron-hole pairs are collected only from the first 0.3 μm of a 1 μm thick a-Si:H cell. Capacitance-voltage measurements indicate that the depletion width is ~0.2 μm so the minority carrier duffusion length is ~0.1 μm.

As an a-Si:H solar cell is forward biased, the depletion region collapses and the photocurrent decreases. This dependence of photocurrent on voltage leads to a reduced fill factor (typically FF ≅ 0.5-0.6) as compared to single crystal Si cells (FF≅0.7-0.8) where the minority carrier diffusion length is much greater than the depletion region. The fill factor can also be reduced if the shunt resistance is too low or the series resistance is too large. In some cells, the resistance of the quasi-neutral region may contribute to the series resistance, but usually the photoconductivity of the a-Si:H is sufficient to keep this resistance below 1 Ω-cm^2.[11]

The dark I-V characteristics are shown in Fig. 5 for several types of a-Si:H cells. Pt Schottky-barrier cells exhibit near-ideal diode behavior with diode quality factors close to unity. The diode quality factor, n, is determined from the diode expression,

$$J = J_o \left[\exp \frac{qV}{nkT} - 1\right],$$

where J_o is the reverse saturation current density. When n = 1, the current is diffusion current injected across the junction. For n ⩽ 2 the current is recombination current through defects in the junction. In general, p-i-n cells exhibit diode quality factors ⩽2 indicating that recombination-generation processes are limiting the junction quality. The presence of phosphorus in the bulk a-Si:H reduces J_o but does not degrade the diode quality factor.

Stability

A-Si:H p-i-n cells have shown no degradation after sitting on the shelf for 3 years. Schottky-barrier and MIS cells are also stable if they are encapsulated or stored in an inert atmosphere. Some Schottky-barrier cells without antireflection or encapsulation coatings have exhibited good stability in air for periods up to 1 year, but many are adversely affected by humidity. The degradation mechanism appears to be the injection of OH^- ions into the a-Si:H in the vicinity of the Schottky barrier. MIS cells that utilize a thermal oxide layer as the insulating layer are also sensitive to humidity, but the degradation can be reversed by heating for a few minutes at 200°C in a vacuum.

P-i-n cells can be heated to 300°C for ~30 min without degrading, but Schottky-barrier cells start to exhibit a decrease in V_{oc} for heat treatments above ~250°C; this decrease in V_{oc} is apparently due to the interdiffusion of Pt and a-Si:H and the formation of silicides. Some life tests have also been performed on Schottky-barrier cells (no protective coatings) heated in air. Cells maintained at ~160°C showed a 48% decrease in efficiency in 1 year while those at ~40°C showed no significant change.

All a-Si:H cells will degrade if heated to temperatures of ~400°C for several minutes. At these temperatures hydrogen out-diffusion becomes significant, and the generation of dangling bonds reduces the minority carrier lifetime. However, since we have determined that the activation energy for hydrogen diffusion is ~1.5 eV, this mechanism will not cause degradation at 100°C until after more than 10^4 years.[12]

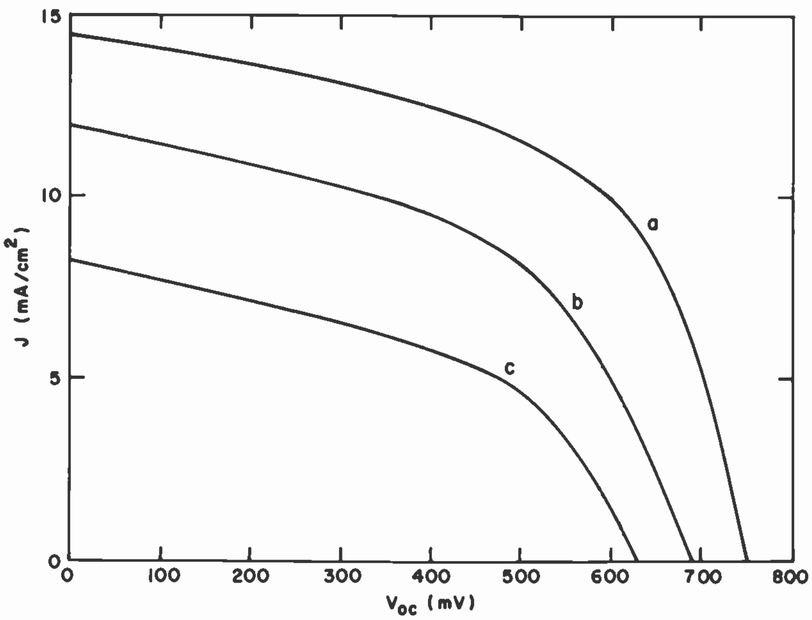

Fig. 3
Illuminated I-V curves for a series of Schottky-barrier cells where the spacing between the cathodic screen and the substrate decreases from 3.0 cm (curve c) to 0.5 cm (curve a).

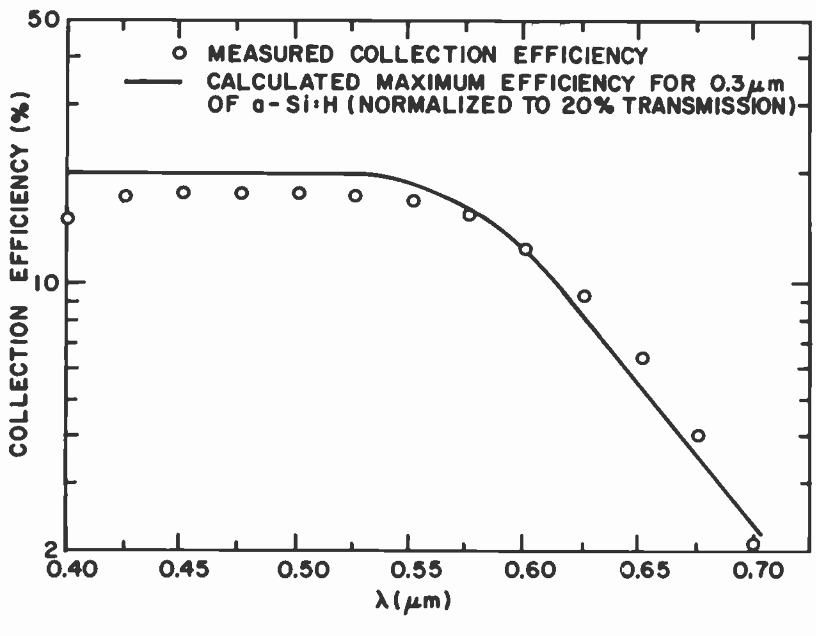

Fig. 4
Collection efficiency as a function of wavelength for a Pt Schottky-barrier cell (no antireflection coating).

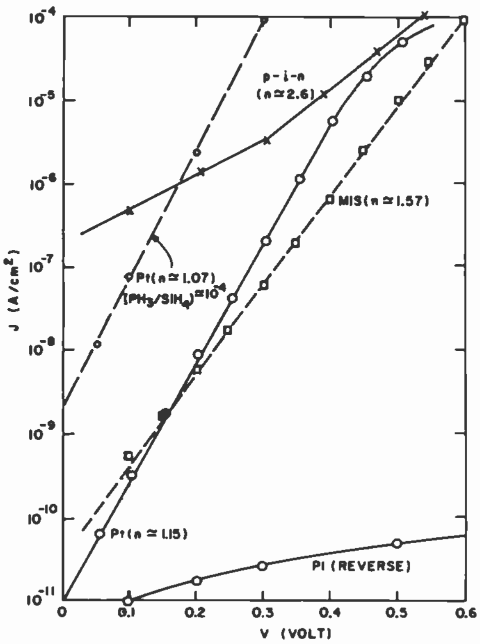

Fig. 5
Dark I-V characteristics of a Pt Schottky-barrier diode, an MIS diode and a p-i-n diode. Also shown is data for a Pt Schottky-barrier cell uniformly doped with phosphorus.

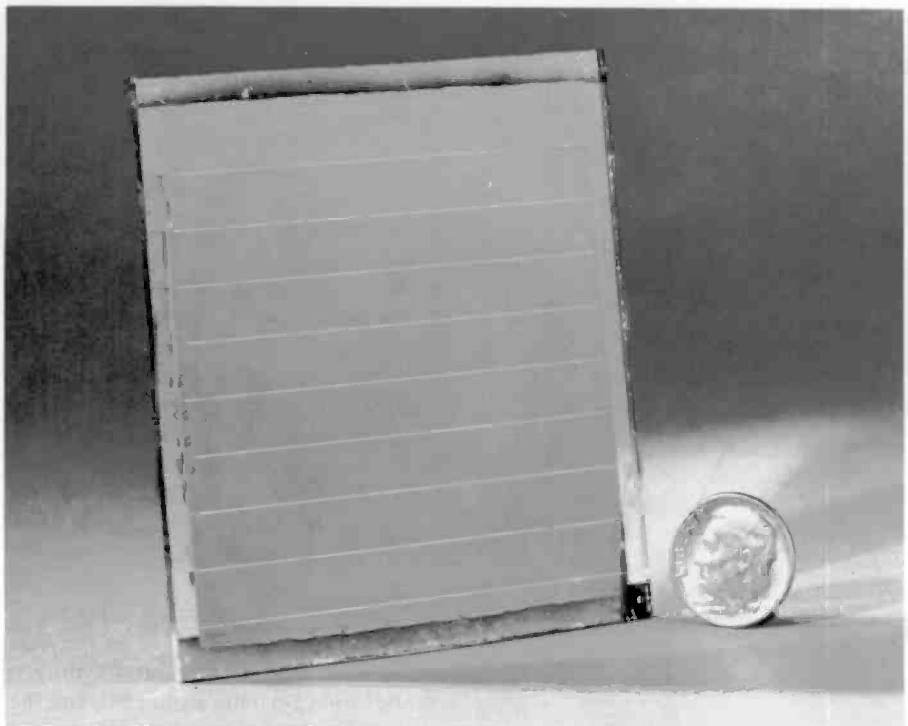

Fig. 6
Photograph of series-connected, a-Si:H solar cells fabricated on a 3x3-in. glass substrate.

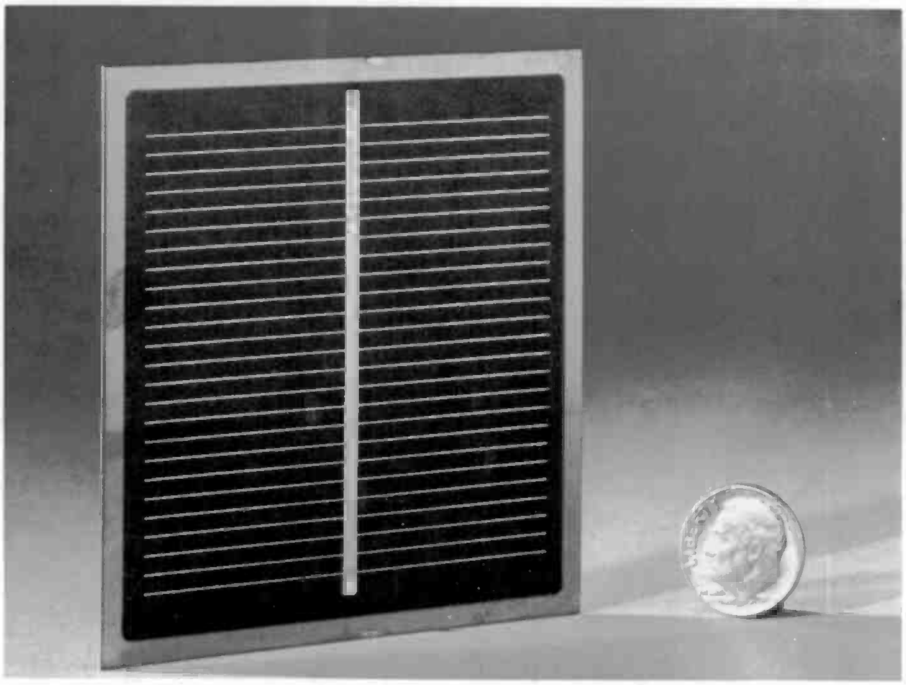

Fig. 7
Photograph of a single a-Si:H solar cell fabricated on a 3x3-in. steel substrate.

Large area cells

Recently, we started to develop the technology to scale a-Si:H solar cells up to large areas. P-i-n cells with active areas of ~40 cm^2 have been fabricated on both steel and ITO-coated glass substrates. J.J. Hanak at RCA Laboratories has recently made series-connected cells on a 3x3-in. glass substrate with conversion efficiencies as high as 2.6%. Fig. 6 shows a photograph of a series-connected, p-i-n structure on a glass substrate. Fig. 7 shows a photograph of a single, large area p-i-n cell on a steel substrate.

Preliminary results indicate that the yields of large area cells are very sensitive to substrate roughness and the concentration of dust particles. Processing in a clean-room environment, or an in-line system, should improve the yields significantly.

Conclusions

The successful development of the a-Si:H solar cell into a commercial product depends on attaining several objectives. First, conversion efficiencies of ~5% or greater must be achieved in large area cells. Also, the technology for fabricating low-cost arrays of a-Si:H panels must be developed. Moreover, these solar cell panels should have lifetimes greater than 20 years.

Future improvements in the conversion efficiency are also necessary for wide market penetration since several studies have shown that efficiencies greater than 10% are needed for widespread application.[13] The theoretical limit for the efficience of the a-Si:H solar cell is not well established, but earlier estimates indicated a limit of ~15%.[3] However, recently R. Williams at RCA Laboratories has demonstrated that open-circuit voltages as large as 1.3 V can be obtained with electrolytic contacts to a-Si:H.[14] The implication is that the efficiency limit may be closer to 20% if the minority carrier diffusion length can be increased to ~1 μm.

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R. Williams

Energy storage by electrochemical reduction of carbon dioxide

How do you match supply and demand in a solar economy? Carbon dioxide may provide the answer.

Petroleum deposits will eventually be exhausted. The energy and raw materials that they provide have become the central ingredients of our civilization, but soon they will have to be obtained from some other source. Petroleum's energy is actually solar energy stored from earlier geologic periods; we must look to the sun again for help. Photovoltaic generators can make an important contribution to our energy needs. They are undergoing intensive development to make them reliable and cost-effective, but, by themselves, are not enough. Sunlight is intermittent and varies in intensity. Solar generators, therefore, will need to be coupled to energy-storage systems to match supply and demand satisfactorily. Not so obvious, perhaps, is the need that will develop for alternatives to petroleum-based raw materials. Some companies, such as RCA's Coronet Industries, depend greatly upon raw materials originally derived from petroleum.

Table I
Energy storage needs vary greatly among energy systems. The amounts of storage shown here are needed for 1 kWh of energy, the equivalent of leaving a 100-watt bulb on overnight.

Energy storage comparison

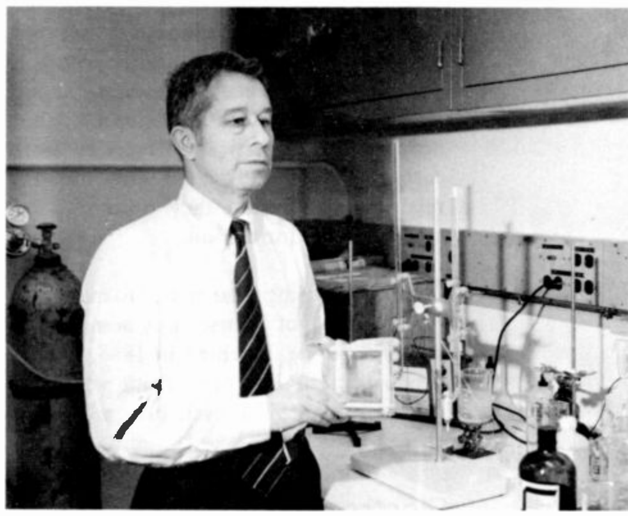
Storage method	*What is needed to store 1 kWh*
Lifting a weight (pumped hydroelectric storage)	Lift 36 tons 10 meters or some equivalent
Heating rocks	100 kg heated 45°C
Lead-acid batteries	55 kg of batteries
Sodium-sulfur batteries	5 kg of batteries
Hydrogen—generated by electrolysis and stored as a liquid	25 gm or 360 cm^3
Malic acid—solid organic fuel	360 gm
Formic acid—liquid organic fuel	600 gm
Octane (gasoline)	83 gm or 110 cm^3

Fortunately, it may be possible to attack the energy-storage problem and the raw-materials problem simultaneously. In petroleum technology the same materials serve both as energy sources and as raw materials. The same is true with solar technology; the electrical energy from photovoltaic generators can be used to synthesize energy-rich organic molecules, which can then be used for fuel or raw materials or as a means for storing hydrogen in high concentrations. This approach, its advantages, and some recent progress are described below.

What it takes to store one kilowatt hour

It is instructive to rank different methods of energy storage according to the amount of material used to store one kilowatt hour (see Table I). Purely physical processes involve enormous quantities of material. It is a sobering thought that, if one inadvertently leaves a hundred-watt light bulb on overnight, the utility company may have to lift many tons of water the height of a three-story building in a hydroelectric storage facility to supply the energy. At the other end of the scale is gasoline, which contains a kilowatt-hour of energy in only 83 grams. (Liquid hydrogen is even better on a weight basis, but worse on a volume basis, because of its very low density.) The high energy density and the convenient means developed for using gasoline and related fuels have led to their widespread use in industry and daily life.

Batteries fall into an intermediate position. They use much less material per kWh than physical storage methods, but orders of magnitude more than chemical fuel storage. It is no accident that, after seventy



Richard Williams has made many contributions in the fields of liquid crystals, semiconductor-electrolyte interfaces, internal photoemission, properties of electrons on the surface of liquid helium, and crystallized suspensions of polystyrene microspheres.

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Final manuscript received September 14, 1978.

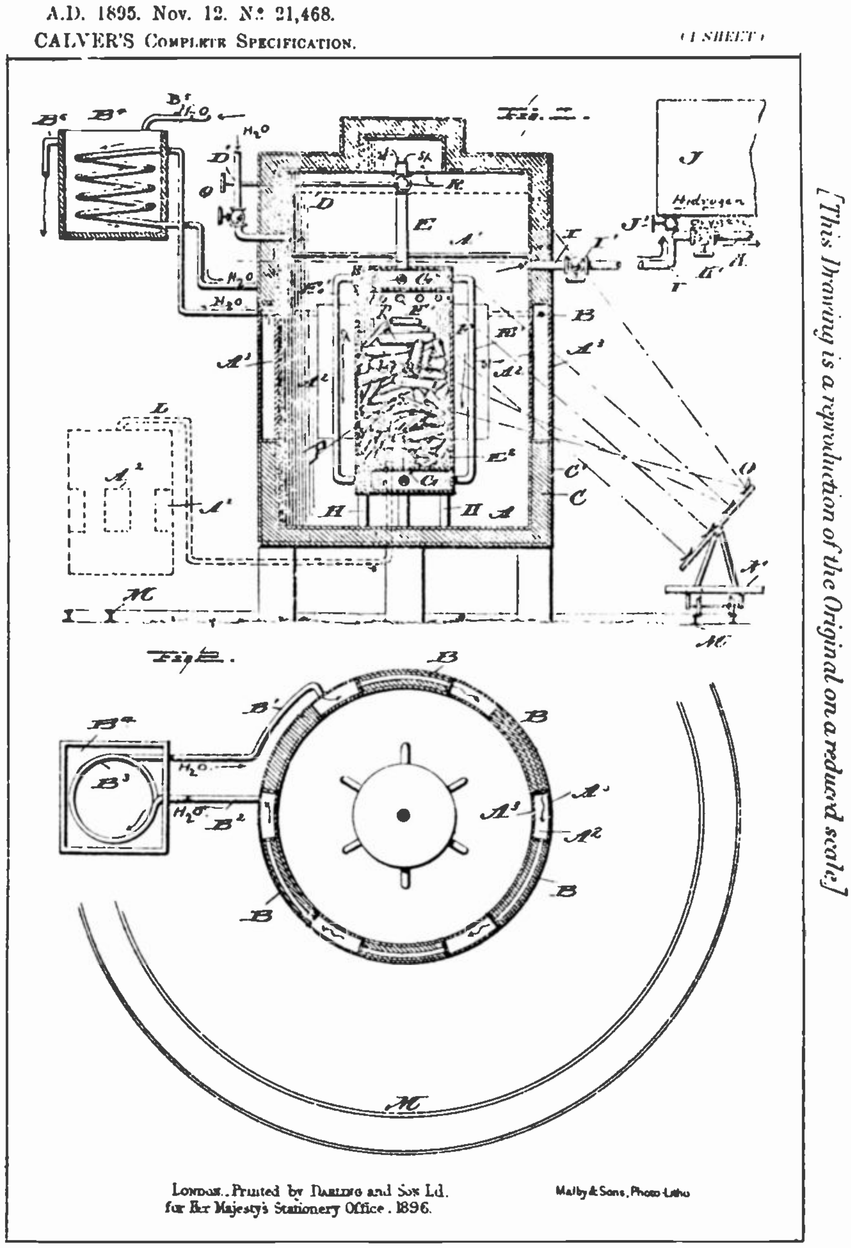

Fig. 1
Apparatus, patented in 1895, for manufacturing hydrogen from water. At temperatures around 90°C, iron reacts with water to form hydrogen and iron oxide. If the oxide is then heated to 1300°C, it decomposes to iron and oxygen. This is a chemical cycle. Water is decomposed to hydrogen and oxygen, the iron is recovered, and the cycle can be repeated. The invention was intended to achieve the required high temperature by focusing the sun's rays and to manipulate the materials through the steps of the cycle.

years of mass production of gasoline-driven cars, a satisfactory battery-driven car is still not available.

What would be the ideal method for storing solar energy? If we could use the energy from a solar collector to manufacture chemical fuels, we could preserve many of the considerable advantages of our existing energy practices. An imaginary version of this is a photovoltaic panel connected to a box that has a faucet on one side; after a suitable period of operation, gasoline can be drawn from the faucet. This is a long way off, but some reasonable approximation to it may be possible in the foreseeable future. The first requirement is a cheap, abundant starting material. The starting materials that produced the fossil fuel deposits were carbon dioxide and water. They are still relatively cheap and they make a good starting point for us now.

(The idea of using solar energy to manufacture fuels is, of course, not new. Fig. 1 shows a device, patented in 1895, for the production of hydrogen from water by means of a chemical cycle driven by solar energy.)

Electrochemical reduction of carbon dioxide

Carbon dioxide can be reduced, electrochemically, in either aqueous or non-aqueous solutions. Any one of several organic materials can be produced, depending on the reaction conditions. The simplest product is formic acid, HCOOH. At the cathode, hydrogen ions from the water combine with CO_2 as follows:

$$CO_2 + 2\,H^+ + 2\,e^- \rightarrow HCOOH \qquad (1)$$

At the anode:

$$H_2O \rightarrow 2\,H^+ + \tfrac{1}{2}\,O_2 + 2\,e^- \qquad (2)$$

Formic acid is a stable liquid compound. It is combustible and could be used as a fuel. Its heat of combustion is 63 kcal/mol, and 600 grams yield 1 kWh of energy, as indicated in Table I. The best way to use this energy would be in a fuel cell, equivalent to an electrolysis cell in which reaction (1) runs backwards. Instead of applying a voltage, as in electrolysis, the cell is connected to an external load. Voltage and current are developed in the load, and formic acid is consumed. This cycle of generation and use is very similar to the operation of a storage battery. The formic acid could also be used as a raw material for synthesizing other organic materials, just as methane is used as the starting material for a variety of petrochemicals. Another application, as a means for hydrogen storage, will be described below.

Under different conditions, especially in non-aqueous solvents, the product of electrochemical reduction is malic acid:

$$4\,CO_2 + 12\,H^+ + 12\,e^- \rightarrow \begin{array}{c} COOH \\ | \\ CHOH \\ | \\ CH_2 \\ | \\ COOH \end{array} + 3H_2O \qquad (3)$$

This material is a stable white solid. It could be used as a fuel or as a starting material for organic syntheses.

Sources of carbon dioxide

How cheap and abundant is carbon dioxide? Table II shows the possible sources and prices.

Table II
Carbon dioxide has a variety of sources.

Sources of carbon dioxide	
Chemical processes:	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$
Combustion:	$C + O_2 \rightarrow CO_2$
Fermentation:	$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
Gas wells	
Carbonate rocks	
Current prices	
CO_2:	\$0.05 per lb
It takes 1 kWh of electric power to make 1 lb of formic acid:	current industrial rate is \$0.03 per kWh.
Current commercial price of formic acid:	\$0.22 per lb.

Most of the commercial carbon dioxide used today is extracted from chemical process or combustion-stack gases. As long as we have industrial combustion this will be available. Fermentation produces a molecule of CO_2 for each molecule of alcohol, but the gas is usually wasted. The production volume from this source is small in the United States, but could become quite significant in countries such as Brazil, where fuel is being produced on a large scale by fermentation of sugar cane. At several places in the American west, wells, similar to natural-gas wells, hold CO_2 in underground deposits. By far the largest potential source is in carbonate rocks, which are present in enormous quantities in many parts of the world. Carbon dioxide is an abundant and widely distributed material.

Experimental considerations

Extensive experiments have been done by the author, together with R.S. Crandall, to determine the optimum conditions for producing formic acid and measure its efficiency as an energy-storage method. The essential elements of the electrochemical cell used in these experiments are shown in Fig. 2. The cathode is a nickel plate covered with a thin layer of mercury. Carbon dioxide bubbles over the surface, dissolving in the water. Usually sodium bicarbonate is used to maintain good conductivity in the solution and to stabilize the pH at the optimum value. The anode is a sheet of platinum for laboratory investigations but, in application, would probably be replaced by nickel. An important part of the system is the ion-selective membrane that separates the cathode compartment from the anode compartment. Made of an ion-exchange resin that freely transmits positive ions but blocks the passage of negative ions, it prevents the ionized molecules of formic acid from reaching the anode and being destroyed. The membrane is thus essential for getting high product concentrations.

After passage of a known current for a known time, the yield of formic acid is determined by chemical analysis. The Faradaic yield, Y_F, is the fraction of current that goes into reaction (1), producing formic acid, as opposed to possible byproducts. Under proper conditions, Y_F is in the range of 90-100%. Formic acid concentrations up to 2 mol/liter have been made by electrolysis.

For energy storage, it is important to assess the energy efficiency of a storage cycle. The maximum thermodynamic free energy yield of a chemical compound in a fuel cell is represented, in electron volts, by $E°$. To generate the compound at a finite rate in an electrochemical cell, as done in this work, requires a higher voltage, $E° + \eta$, that includes the overvoltage, η. The maximum possible efficiency in a storage cycle is then:

$$\text{Efficiency} = Y_F E° / (E° + \eta)$$

Our experiments show that an efficiency of about 60% is possible. This is comparable with the efficiency of a process, based on the electrolysis of water and tank storage of the resulting hydrogen, that has been the subject of considerable development in other laboratories.

Hydrogen storage

Considerable attention has been given to the possible use of hydrogen as a future substitute for natural gas. Some envision a "hydrogen economy," in which the hydrogen would probably be produced by electrolysis of water, using solar, nuclear, or hydroelectric power. A storage problem again arises, similar to that discussed above in connection with solar cells. The optimum time for generating the gas will not always coincide with the optimum time for using it. Liquefaction is technologically

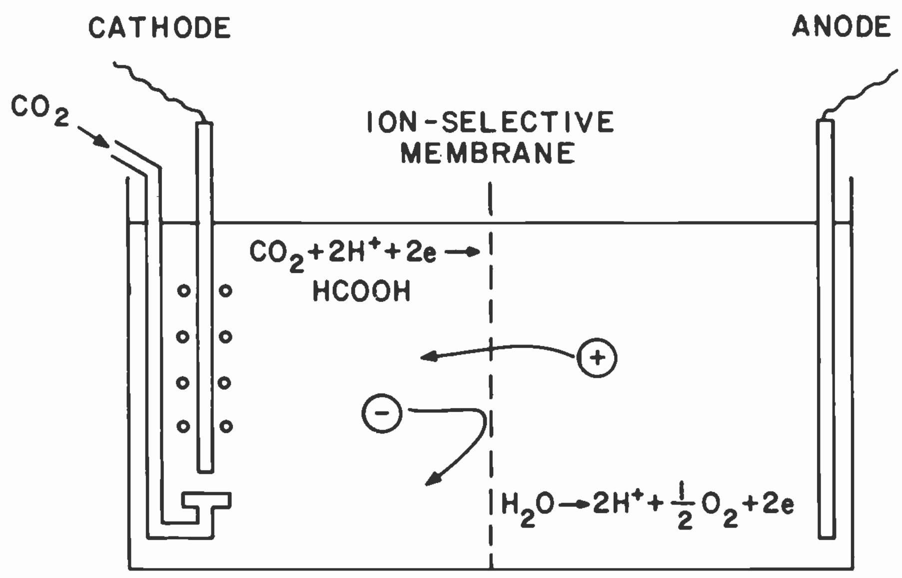

Fig. 2
Electrochemical cell used for the reduction of CO_2. The cathode is a nickel plate, covered with a thin layer of mercury, and the anode may be platinum or nickel. CO_2 bubbles over the cathode. The aqueous electrolyte contains sodium bicarbonate and other components. An ion-selective membrane separates cathode and anode compartments, thus preventing formic acid, generated at the cathode, from being subsequently destroyed at the anode.

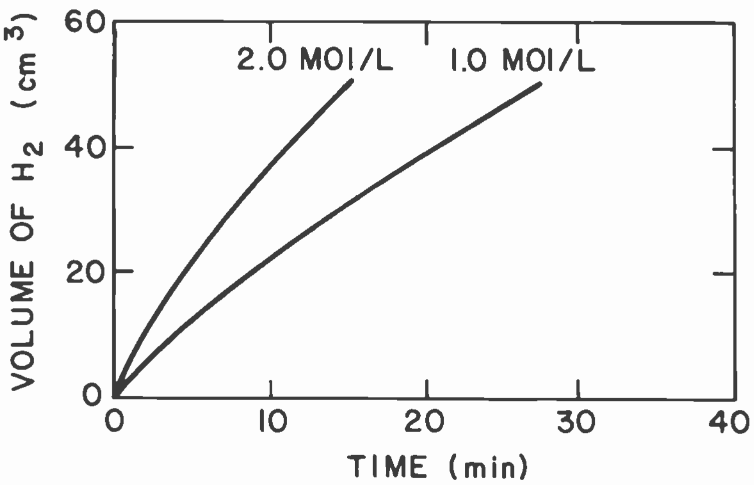

Fig. 3
Generation of hydrogen by catalytic decomposition of formic acid, according to Eq. 4. The curves show the volume of hydrogen generated as a function of time in formic acid solutions of two different concentrations: 1.0 and 2.0 mol/liter. One gram of catalyst was used per 50 ml of solution.

difficult, involves some hazard, and a round-trip liquefaction-evaporation cycle uses energy equal to about one-third of the fuel value of the gas.

Formic acid may someday be useful in solving this problem. Examination of its formula, HCOOH, shows that it consists of CO_2 and two hydrogen atoms bound in a single molecule. In the presence of a proper catalyst, in fact, the formic-acid molecule comes apart, giving a molecule of CO_2 and a molecule of H_2:

$$HCOOH \xrightarrow{\text{catalyst}} CO_2 + H_2 \quad (4)$$

This reaction has been known for many years, but has previously been studied only for formic acid vapor at elevated temperatures. In our work we have found a catalyst that causes the reaction to go rapidly in an aqueous solution of the acid at room temperature. In the absence of a catalyst, though, formic acid is stable for years. Some data for the rate of hydrogen evolution in the presence of a suitable catalyst are shown in Fig. 3. The catalyst consists of palladium supported on fine carbon particles. Chemical analysis of the evolved gases shows that the reaction goes according to Eq. 4.

How might this be used? Assume the existence of a system for the generation of hydrogen by electrolysis and its use at a later time. Some method of hydrogen storage will be needed. The present methods are tank storage of gas, liquefaction, and formation of metal hydrides. Instead of generating hydrogen, though, one could make formic acid and store it in the original solution. The hydrogen could then be generated when needed by adding the catalyst. When compared with the competing storage methods, this method may offer such significant advantages as high energy density and relatively simple equipment.

Summary

When photovoltaic systems begin to deliver abundant electrical energy, we will have a valuable new resource, but the kind of power available and its generation schedule are not the same as what we get from our present power sources. To take full advantage of solar power, we will need new technology for energy storage and use. Electrochemical reduction of CO_2 can be a versatile tool for this purpose.

The future may hold an unusual incentive for using the CO_2 generated by the industrial combustion of fossil fuels. Meteorologists and others are seriously concerned that the rising concentration of CO_2 in the atmosphere may have possible effects on world climate. The origin of this potential temperature increase and its detailed consequences are still uncertain, but significant long-term changes in world climates are a distinct possibility. If this happens, there will be strong incentives to reduce CO_2 emissions. Converting the CO_2 to fuel and useful raw materials could transform a necessity into a profitable operation.

editorial input

RCA's technical symposia—are they helping you?

Exciting new technologies and new applications of technologies are being implemented throughout RCA. They are allowing us to execute difficult tasks much better, and many have bearings to the problems of other groups. RCA's technical symposia attempt to highlight such technologies—be they pioneered by RCA or adapted from others for RCA's use—they help experts keep up to date and in touch with each other so as to allow best use to be made of occurring advances.

Only a few of RCA's very large technical staff have the opportunity to personally attend the symposia. How can the others, who may also be interested in the topics, profit from such meetings? Here are several paths to the information:

- You can contact one or several symposia attendees from your location to discuss your interests. Your chief engineer's office will know who attended.
- It has been recommended to the local technical excellence committees that they arrange for a local briefing soon after the symposium. This is an opportunity for you to get briefed.
- Documentation varies, but is usually available in some form. For example, 1978 technical symposia were documented as follows:

  —*Finite Element Computational Methods*
  March 1978. Chairman: R. Enstrom, DSRC.
  General paper in *RCA Engineer* 24/3, Oct/Nov 78, pages 26-33. Five papers in *RCA Review* 39/4, Dec 78, pages 619-717.

  —*Microprocessor Applications*
  March 1978. Chairman: W. Anderson, GSD-Staff.
  Copies of visual aides reproduced and distributed to attendees and RCA libraries.

  —*MEPS* (Manufacturing Engrg. Productivity Symposium)
  December 1978. Chairman: J. Miller, DSRC. Symposium videotaped. Can be requested on loan from Mary Goodenough, Cherry Hill, 222-5020.

Keep an eye on *TREND* and the *RCA Engineer*. They will report on what symposia have been held, including agendas with topic and speaker.

1979 symposia topics include: software, microwave, LSI, automated test equipment, microprocessors, manufacturing engineering, reliability, and mechanical engineering.

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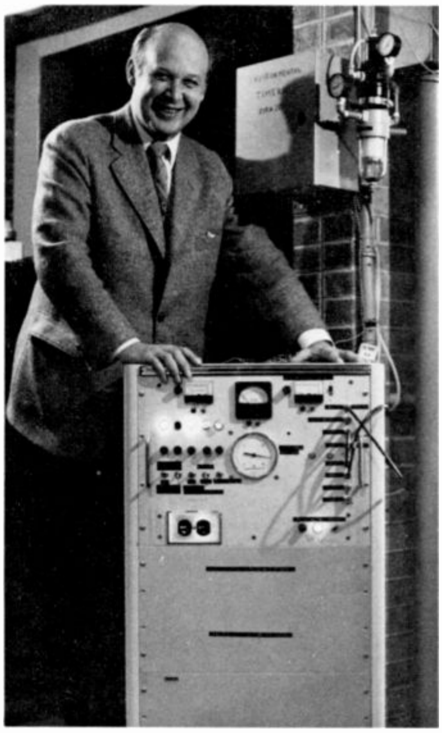
222-4251

B. Hershenov

Energy management

"Good housekeeping" practices can cut energy costs 10-30% easily, but larger savings require capital investment and careful economic and energy analysis.



Bernie Hershenov with a remote data-gathering panel installed in Building 203 at RCA's Cherry Hill, N.J., offices. The unit shown here is for developmental purposes only; it has no CPU installed, and is being used to collect data for eventual software development. The connections go to existing pneumatic and electric sensors, which act as a "fail-safe" backup system.

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"... if we had one British Thermal Unit (Btu) for every speech given since the Arab oil crisis on the importance of energy conservation, our problems would be over. Washington alone could power everything east of the Rockies."[1]

"One Btu represents about the amount of heat produced by burning a kitchen match to ashes."[2]

Evangelical appeals to patriotism and calls to battle in the "moral equivalent of war" serve no purpose when confronted simultaneously by conflicting statements from the government, energy companies, and private research organizations regarding our energy resources and alternatives. Contradictory federal and state legislation weakens the government's case for the energy crisis; credibility and active public support disappear and the nation's economic health is threatened because business is forced to plan around unnecessary uncertainties.

The administration's realistic recognition that energy must be priced at marginal replacement cost is distorted by the politics of pricing, price controls, tax incentives and penalties, tariffs, etc. We are confronted with an upward market-price pressure and a downward political-price pressure, with the latter discouraging the development of domestic oil and gas resources and alternative fuels. In many instances environmental policy conflicts with energy policy.

The National Energy Plan[3] (NEP) for coal highlights some of these problems. The Plan envisions increased coal use by utilities and industry, with a doubling of coal production by 1985. Such a huge production increase in this short time span places a heavy burden on the financial, managerial, and logistics planning and actual management of the program in view of the requirements for additional railroad cars, locomotives, barges, oil slurry pipes, boilers, extraction equipment, and rights of way; new coal-mining boom towns will create societal problems, and environmental controls of air and water must be established.

At the same time, the government has tightened air-pollution standards on sulfur emissions. This by itself is not bad, since costly scrubbers of uncertain reliability can be avoided by using low-sulfur Western coal. But, to encourage development of deep-mine Eastern coal (which requires ten times as many man-days per ton to mine as Western surface mines), coal scrubbers were mandated even if low-sulfur fuel was burned, and strip mining regulations were tightened.[4] The coal strike, increased labor costs, higher haulage charges, and continually changing environmental policies have encouraged inactivity in this complicated arena.

Nuclear power suffers from similar problems. The time from initial decision to operation of a nuclear facility is approaching 13 years and cost estimates for post-1985 plants approach \$1500/kW capacity (vs. current \$700/kW) with one-half the cost representing inflation and interest during construction; both costs are increased by delays.[4] Present licensing procedure is a 3-way adversary process before the Atomic Safety and Licensing Board; a utility, the Nuclear Regulatory Commission (NRC), and intervenors, and any party can appeal any aspect of a decision.[4] Recently, an appeals court decision held that NRC procedures for review of the nuclear waste disposal issue are inadequate to meet the requirements of The National Environmental Protection Act, and it is questionable if "NRC can license new nuclear power plants until this issue has undergone a complete generic review."[4] The government has yet to seriously address the waste problem. Legal delays by intervenors, Federal/State conflicts and "expenditures in excess of $100 million for engineering design, environmental studies, and component fabrication for long-lead items (pressure vessels, steam generators, containment steel, etc.) before a construction permit is issued"[4] plus penalty charges for cancellation for any reason make nuclear power nonviable for many utilities. Small wonder that Energy Secretary Schlesinger himself stated that the nuclear option is "barely alive."

Alternative energy-source developments have also faced uncertainties. A high investment in areas such as liquified coal, shale oil, and coal gasification involves too great a risk; investment in this area is like placing a bet and then having the house change the rules.

Environmental and safety rules are continuously altered while the price of the product being substituted for is kept below market levels by shifting amounts. The government response has not been risk-reduction, but subsidization. For the time being this is all right, providing a balance between short-, medium-, and long-term goals is maintained and a realistic weighting of probability of success is included.

The goal to reduce oil imports to 6-7 million bbls/d by 1985 is not likely to be met, and more than likely, imports will be 12-15 million bbls/d.[5] The utilities' 1974 plans for coal and nuclear capacity by 1984 are higher than their current plans; reductions over 1974 are equivalent to 2 million bbls/d more oil (or gas) in utility boilers.[6]

While the private and public sectors differ in detail about our energy resources, they generally agree that the oil-importing nations will move from the current world oil surplus toward a scarcity in the '80s. The shortage will arise for one of two reasons:

1) Physical scarcity; oil-exporting nations will be at or near capacity, and demand at prevailing prices will not be met.

2) Variety of political, economic, and/or technological considerations; producers elect to produce below capacity and demands are not met.

Either situation leads to price increases. The current oil surplus and absence of imminent crisis can delay the difficult decisions necessary for the development of energy alternatives and rigorous conservation measures. These are necessary decisions if we wish to buy time or delay the demand/supply oil situation, which can severely restrict economic growth and affect our quality of life significantly.

Energy management guidelines

Despite this pessimistic overview, significant progress has taken place, especially in industrial energy management.

Energy management is concerned with the efficient and judicious use of available energy. Following the 1973 oil embargo and the sharp increase in oil prices, many companies instituted "good housekeeping" practices by establishing energy policies and then setting up directives and procedures to implement them. Typically, working hours were reorganized, lighting levels were reduced in certain areas, and nonessential energy-using devices eliminated. Little if any money was required. In addition, industries modified their normal operation and maintenance (from normal operating funds) to include improved testing, adjusting, balancing, and preventive maintenance of energy-consuming systems; replacement of parts with ones having more efficient or lower energy requirements; and additional or improved instrumentation to monitor usage more effectively. Energy savings of 10-30% were realized with minimum investment.

Significantly larger savings can be realized by capital investments for modifying existing equipment or installing new equipment to a building's systems.

However, large capital investments do require a more careful scrutiny of the economics as well as the energy savings. Continued escalation of energy costs (now anticipated as 2-10% per year above inflation), coupled with winter fuel scarcities, provided many companies with the impetus to move from "housekeeping" approaches to more complete and sophisticated methods of dealing with energy usage; energy management has become a permanent part of many companies' activities and an integral part of regular operations. Consideration of capital investments, alternative manufacturing methods, and the development of new technologies and control schemes to ensure efficient energy utilization are now part of management planning.

Effective energy management requires a systems approach, in contrast to that of end-use restriction applications. End-use restrictions such as adjusting thermostats and removing lights have no bearing on a system's efficiency; an inefficient system wastes energy whenever it is used and ignores the interrelationship of the many elements of the total system. A total systems approach requires an understanding of how a building consumes energy, how the user's needs are met, how the external environment affects operation, and the interrelationship of the various system elements. This knowledge then provides a variety of options for reduced energy consumption, including that of end-use restrictions, which themselves are elements of the system. Heating and cooling of a building illustrates this point. If we think in terms of compensating for the heat loss or gain of the building, rather than adding or removing heat from the inside air to realize a given temperature, we become aware of the various factors contributing to the gain and loss.

Although we cannot control the climatic conditions such as temperature, humidity, wind, and solar radiation responsible for this gain and loss, we can modify their impact. Aside from the heating and cooling systems themselves, we can change such factors as infiltration, transmission, ventilation, lighting, solar heat, power

Effective energy management requires a systems approach.

equipment, and number of occupants to influence a building's heat gain and loss. A variety of options, not necessarily mutually exclusive, immediately suggest themselves; they range from simple caulking or weatherstripping of windows, doors, and outside joints, to significant capital investments for the installation of economizer or enthalpy controls and heat exchangers. Lists of modifications as well as the necessary equations, tables, and charts for calculating both energy savings and cost effectiveness can be found in a number of references.[7, 8, 9, 10, 11]

Establishing an energy-management program is a major undertaking.

For an energy-management program to be effective, there must be a firm commitment by top management, reasonable targets and timetables, adequate technical and financial resources, and a well-reasoned plan of action. Programs differ among companies because of differences in organization, operation, products, and processes, but the following general guidelines are usually applicable.

1) *Top-management commitment*: Implementation strongly depends upon complete and continuing top-management commitment. Line supervisors should be informed that it is their responsibility to implement energy-savings actions.

2) *Clearly designated program responsibility*: A coordinator should be appointed by and report to management with program responsibility clearly defined. A committee, headed by a coordinator, should consist of the plant manager and all operating groups including purchasing, production, and maintenance. (In larger companies with several divisions and/or operating facilities, the committee should consist of representatives from each division and sub-committees formed within each division or operation.)

3) *Defined realistic goals*: The committee should provide guidelines of expectations. Specifically, it should:

- plan and participate in energy audits;
- develop uniform record-keeping, reporting, and energy accounting;
- research and develop energy-savings ideas;
- set up tough but achievable goals for energy savings;
- enlist and encourage continuing employee support and interest in the program; and
- develop means for measuring and evaluating program effectiveness.

The material presented up to this point has been largely introductory. Before treating specifics in terms of RCA and the Energy Systems Analysis Group (ESAG) at RCA Laboratories, it is necessary to address two specific areas—energy audits and energy controls. These two areas are key ingredients in an energy-management program and are tightly related to ESAG's role.

Energy audits

The energy audit is a crucial and critical aspect of energy systems analysis—it studies a specific building and how it is used.

This "specific audit" is preceeded by a simple walk-through audit to get a feeling for the amount of energy used, and where, when, and how it is used. The walk-through audit identifies various items for further investigation. Generally, buildings are inadequately instrumented for energy usage and the specific audit will include the necessary instrumentation for proper technical evaluation. It is important to review beforehand the architectural, mechanical, and electrical drawings and specifications to insure familiarity with the building configuration and design, electrical and mechanical systems, and equipment layout as well as the operation and control.

Utility-rate structure should also be known; while the average costs of electricity, steam, etc., are fine for ballpark estimates, the true savings will be the incremental energy costs, which can be significantly lower or higher than the average costs. Any energy-savings opportunities requiring an initial capital outlay must be amortized by energy savings over their expected lifetimes. True economic costs include forgone investment opportunities as well as consideration of such factors as risk, cash flow, taxation schedules, operating and maintenance costs, rising cost of energy, etc. For the first crack, screening can be applied by considering payback period and return on investment, but ultimately a more refined analysis that reflects the time value of money in the form of a discount factor is required.

In making a walk-through audit to identify specific potential energy-savings items, we are trying to ask ourselves the following questions:

1) How is the building used?

2)Is this what the user wants?

3) Was the building intended to be used in this manner?

4) Is the operation correct in terms of the user's needs?

Full-load efficiency is not as important as it seems.

Often items such as heating and cooling were designed with excess capacity, or the designer originally intended that interior

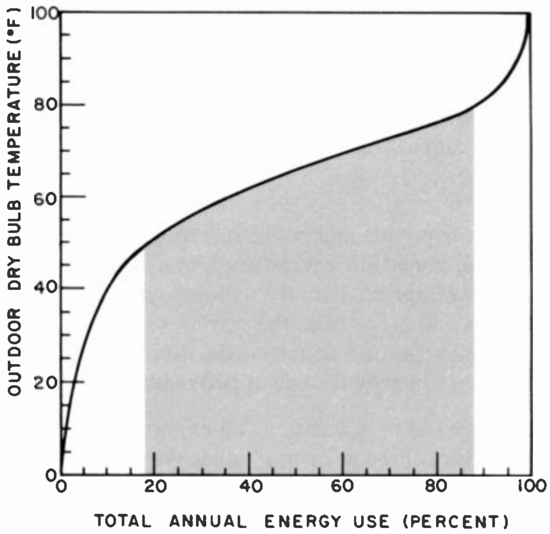

Fig. 1
Most energy use takes place when outside temperatures are between 50° and 80°F (gray area). Boilers and chillers must therefore be designed for efficient operation at partial loads, rather than 0° or 100°F extremes. (Plot is for heating, ventilating, and air-conditioning energy use for a building in Ohio; Ref. 12.)

air be circulated, but now zones are operating with 100% outside air. In considering the building's energy usage, we are concerned with operation at outdoor temperatures representative of normal usage. In the past, designers were concerned with efficiency of boilers and chillers at 0° and 100°F outside (full-load conditions). For our energy audit, we are concerned with partial-load conditions, i.e., the building's operation during the bulk of the time. Fig. 1 is a plot[12] of HVAC (heating, ventilating, and air conditioning) energy use as a function of outside temperature for a building in Ohio.

Between 0 and 20°F outside temperature, the building uses less than 5% of its annual energy, while in the 20° range from 80° to 100°F, it uses only 12%. Between 50° and 80°F, 70% of the annual energy is consumed. Our interest is the system's efficiency at light loads corresponding to 30°, 40°, 50°, 60°, and 70°F rather than 0° or 100°F. It is also important in our evaluation to discriminate in terms of high load factor (those items used for large amounts of time). Furthermore, since we are concerned with the efficient and judicious use of energy, we must bear in mind that the efficiency of equipment at full load is not necessarily the best criterion. For example, small local areas in a building that are occupied after hours may be cooled more efficiently and cheaply with a less-efficient small air conditioner in those areas than with the efficient central air conditioner that cools the entire building.

With any audit, it is advisable to make a 2:00 a.m. check—it is often surprising to see how much energy a building is using unoccupied. With these caveats, and others based on common sense, a walkthrough tour can then provide the basis for identifying items requiring a more detailed audit. References 8,10, and 11 provide some guidance about items for which to be on the lookout; familiarity with these items sharpens one's mind for other innovative possibilities. A sample of a few items to both consider and be on the watch for are itemized below:

1) *Space heating*: Better building, duct, and equipment insulation; reduction of infiltration, waste-heat recovery with heat wheels, heat pipes, static heat exchangers and light heat recovery; consider more efficient equipment; modifications of humidity and air-change requirements: use of low-conductivity window frames, insulated glass, double windows, drapes; improved operation procedures via thermostat set-back and better controls.

2) *Process steam*: Boiler inefficiencies, poor insulation; leaking pipes, valves and steamtraps; recover waste heat, return condensate, preheat air or makeup water if possible by heat recovery from boiler or incinerator stacks.

3) *Electric drives*: Avoid partial loading of equipment, overcapacity of drives, or operating equipment not being used.

4) *Electric lighting*: Best light sources (lumens/watt), relamping schedule, task-level lighting standards, sector lamp switching, increased use of natural light.

5) *Water heating*: Stack and waste process heat recovery; lowered temperature settings, insulation, solar energy.

6) *Air conditioning*: Use outside air when possible (enthalpy control); raise set points on humidistats and thermostats; reduce infiltration; better insulation of building structure and ducts; solar shades and reflective glass coatings; appropriate building envelope color and texture.

The above represents a small sample of items for consideration or examination. Each subject involves a large number of items and options for energy savings. For example, boiler efficiency is affected by air-fuel ratio, atomization of fuel, temperature of air, fuel viscosity and temperature, degree of mixing due to gas turbulence and velocities, deposits on boiler water side (water treatment), operation of automatic controls regulating fuel/air ratio, heat loss in stack, the ash, trace-metal, and sulfur content of fuel (potential slag and deposit problem and corrosion problems), and the rate combustion gas passes through the furnace (affected by draft, air ducts, air heaters, burners and baffles). Any single item on the previous list, such as boiler inefficiency, will thus generate a large number of items subject to examination and control.

Another example is lighting.

For incandescent, high-pressure mercury and sodium, and metal-halide lamps, the higher-wattage lamps are more efficient, while for fluorescent lighting, longer lamps are more efficient. General-service lamps are more efficient than extended-service lamps and are recommended unless maintenance labor costs are high or the lamps are inaccessible. Luminaires should be efficient (an indirect luminaire may require 10 W/ft^2 of floor area to produce a 50-foot-candle level, while a direct fluorescent troffer may only require 2.5 W/ft^2). Table 1 compares properties for various lamps.[1, 11] High-efficiency lamps will

Table I
Lighting efficiencies vary greatly for different lamp types. Output/watt and life ratings for incandescent types are quite low in comparison with others.

Lamp type	*Watts*	*Lamp effic. (Lumens/W)*	*Ballast power (Watts)*	*Ballast + Lamp effic.*	*Average life (hr)*
Incandescent	100	15	-	-	1,000
Fluorescent	40	80	13.5	60	22,000
	65	85	11	73	
High-pressure mercury vapor	80	44	8.5	39	24,000
	250	54	18.5	50	
	400	57	26	53.5	
High-pressure metal-halide	400	85	26	75	
	1000	90	43	86	16,000
	2000	100	68	97	
High-pressure sodium	250	100	33	-	20,000
	400	120	39	108	

What's involved in an audit?

Example 1

At RCA Cherry Hill, ventilating fans were cycled so that they were off 5 minutes out of every 30 minutes (1/6 of time), effecting a 16-⅔% electrical energy savings (as well as reduced volume of air to either heat or cool).

Calculate electrical savings if fan speed is reduced (no cycling) to provide equivalent ventilation.

The airflow from a centrifugal fan varies directly as its rotational speed; the horsepower, however, varies as the cube of the fan speed. (The drop in efficiency between 100% and 50% load for a good motor is small, so it can be neglected in the calculations.)

$$\frac{\text{New hp}}{\text{Initial hp}} = \left(\frac{\text{New air flow}}{\text{Initial airflow}}\right)^3$$

Fig. 2 is a plot of reduced air flow vs. percentage decrease in horsepower. For 5/6 of the original airflow (16-⅔% reduction) the horsepower decreased 42.1%, or a savings in electrical energy of about 2.5 times that of cycling at the same volume of air. Reducing fan speed eliminates timing clocks and keeps air always circulating. The reduced speed must be adequate to overcome resistance losses of ducts, filters, etc. Speed reduction for belt-driven centrifugal fans is readily accomplished by appropriate change-out of pulleys.

Example 2

A recent study of boilers[15] indicated that 3-5% improvements are not uncommon when tune-ups are performed on gas-fired boilers at varying loads. Major efficiency losses arose from excess air use with no apparent visual indication. Stack-temperature and fuel-composition measurements revealed the extent of this problem immediately.

Calculate the annual dollar loss at RCA Laboratories assuming a 3% drop in boiler efficiency; determine cost per 1000 pounds of steam.

RCA data: RCA generates its low-pressure steam (~13 psig) with a 500-hp or 700-hp boiler (and when necessary, with both boilers). In summer, the 500-hp boiler is operated at very low loads and high excess air.

Total 1977 fuel costs (gas and #6 oil)	$228,645
Fuel energy equivalent	29.254 x 10^6 kWh

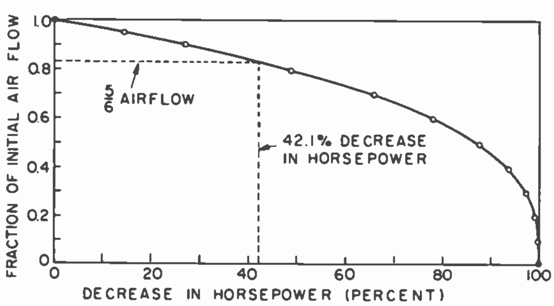

Fig. 2
The same airflow can be had with a significant drop in horsepower because of the operating characteristics of fans. Results = energy savings without on/off cycling timers.

Missing information: Boiler efficiency at varying loads, operation time at given loads, pounds of steam generated, makeup-water temperature, and air temperature.

Assumptions: Estimate magnitude of cost of 3% boiler efficiency drop by assuming a smoothed-out annual operation at 75% efficiency and 1000 Btu/lb steam generated (or 10^6 Btu/1000 lb steam).

Fuel Btu value	=	29.254 x 10^6 kWh x 3413 Btu/kWh
	=	9.9844 x 10^{10} Btu
Fuel cost/10^6 Btu	=	$228,645/9.9844 x 10^{10} Btu
	=	$2.29/$10^6$ Btu
Cost/1000 lb steam	=	$2.29/$10^6$ Btu)/0.75
	=	$3.05/M Btu
	=	$3.05/1000 lb steam
Annual Btu's to convert water to steam @ 75% efficiency	=	9.9844 x 10^{10} x 0.75
	=	74,883 x 10^6 Btu
Btu fuel value required for 3% drop in efficiency	=	7.4883 x 10^{10}/0.72
	=	10.4004 x 10^{10} Btu
Increased annual cost for 3% drop in efficiency	=	(104,004-99,844) x 10^6 Btu x $2.29/$10^6$ Btu
	=	$9526.40

An annual loss of $9526.40 for a 3% drop in efficiency is substantial. Detailed audit requires careful measurements of efficiency at various loads and possible daily monitoring of stack gases and temperature; automatic control of fuel-air ratio may be economically feasible.

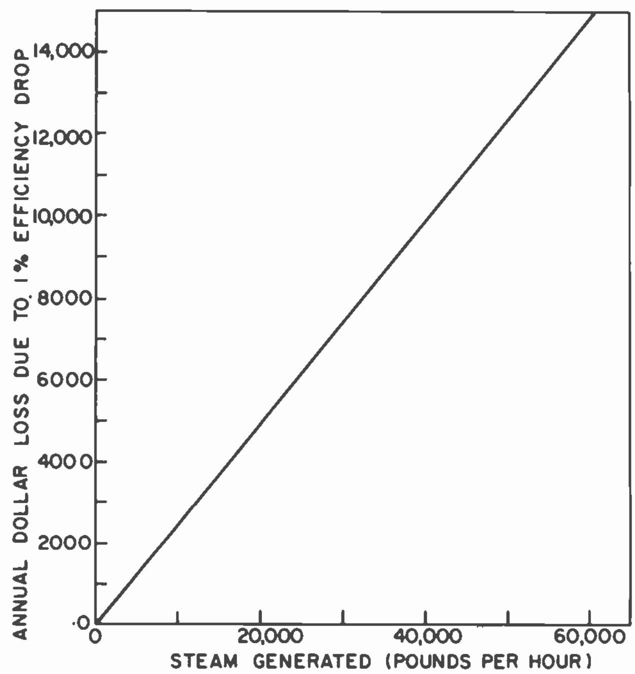

Fig. 3
Small drop in boiler efficiency can mean thousands of dollars lost annually.

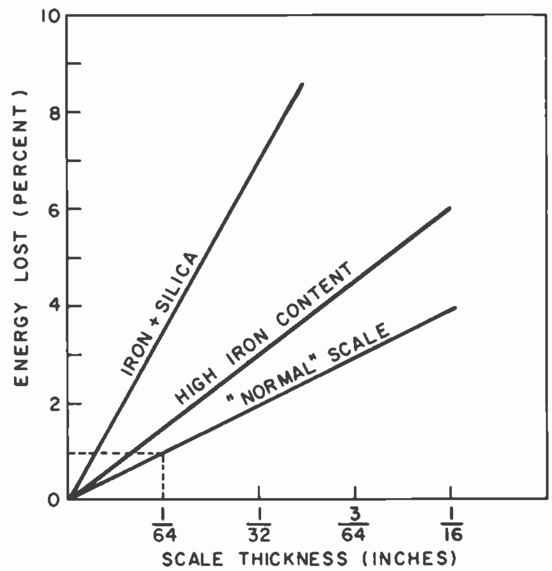

Fig. 4
Scale deposits on boiler tubes can produce surprisingly high inefficiencies. (Refs. 11 and 16.)

Fig. 3 is a plot of annual increased costs for a 1% drop in boiler efficiency, assuming initial efficiency of 75%, 1000 Btu/lb steam generated, 6000 hours annual operation, and RCA Laboratories' fuel cost of $2.29/10^6 Btu. For efficiency drops different from 1%, multiply annual loss by actual efficiency loss (reasonable approximation for values up to 5 or 6%).

Example 3

Using data of example 2, at 75% boiler efficiency, calculate the annual additional energy cost arising from a 1/64" scale deposit of Ca and Mg salts ("normal" scale) on the boiler tubes.

From Fig. 4, energy loss is 1 percent.[11]

Annual cost due to energy loss = .01 x 74883 MBtu/yr x $3.05/MBtu

= $2283.93

The boiler should be checked when down and if scale is present, the feedwater or chemical-additives schedule may require modifications. "Operating symptoms which may be due to scale include reduced steam output, excessive fuel use, and increased stack temperature."[11] A good record of normal boiler performance, plus day-to-day performance data, provides early warnings of boiler troubles; small changes in efficiency lead to large dollar penalties.

Example 4

"Initial inspections commonly reveal that as high as seven percent of the steam traps in a system are leaking."[11] Good maintenance and frequent inspection can reduce this to 1 percent.

A trap on a 20-psig steam line, orifice of ¼", is stuck open. For steam priced at $3.05/MBtu, calculate the annual dollar loss, assuming 6000 hr operation per year.

From graph in ref. 11, p. 3-24, the annual (8,760 hr) heat loss is 365 MBtu.

Annual loss = 365 MBtu x (6000/8760) x $3.05/MBtu

= $760/year

Example 5

RCA Laboratories has two swinging doors to the loading dock through which small motorized vehicles can pass, carrying materials back and forth. The vehicles push the doors open and keep them open with their sides. The seal at the interface of the two doors has been gradually deformed by wear and a permanent crack exists through which outside air can infiltrate.

Assume a 10-ft-long crack with a 1/8-inch average width. Determine the sensible heat loss per hour in January assuming a 15-mph wind, indoor temperature, T_i, of 70°F, and no traffic (doors remain closed). Use 0.24 Btu/lb/°F as the specific heat, C_p, of air and 0.075 lb/ft³ as the outside air density, ρ.

From Ref. 17, Chap. 43, the number of degree days in January (Trenton, N.J.) is 989, corresponding to an average outdoor temperature, T_o, of 33°F. A 15-mph wind corresponds to a velocity head of 0.1 inch water gage. From the graph in Ref. 7, Chap. 21.9, the volume of air per hour, V, through a 1/8-inch crack, 10 feet long, is 7500 ft³/hr.

Energy to warm outside air to T_i $= C_p V \rho (T_i - T_o)$

$= 0.24$ Btu/lb/°F x 7500 ft³/hr x 0.075 lb/ft³ x (70-33)°F

= 4995 Btu/hr

The importance of infiltration is apparent when we realize that this heat loss corresponds to just one crack and ignores the normal leaks around the door arising from construction fit and the opening and closing of doors due to traffic. (The sensible heat-loss rate due to infiltration around the sash and through the frame of 3 x 5-ft double-hung, nonweatherstripped, average-fit wood window under the same conditions is 342 Btu/hr.)

reduce wattage requirements and extend lamp lifetimes.

A study of a fluorescent lighting system[14] revealed that cleaning luminaires and relamping only once every three years dropped the illumination level to 60% of its initial value after 3 years. With cleaning every one-and-a-half years and relamping every three years, illumination was 68% of initial after 3 years; a once-a-year cleaning and one-third relamping each year yielded 78% of initial illumination after 3 years and 75% after 12 years. Cost effectiveness of this last maintenance program is determined by reduced wattage requirements, lamp replacement cost, and labor costs vs. current operating procedures.

Luminaires with heat-transfer capabilities by air or water can reduce air-conditioning loads in summer and heating loads in winter. Further considerations in design include direct and indirect glare, veiling reflection (surface reflection on task which obscures details by reducing contrast), finish of ceilings, floor, walls, and furnishings

Above box "what's involved in an audit?" provides five examples of preliminary calculations for an audit.

As indicated earlier, the detailed audit requires careful measurements of how much energy is being used before a satisfactory analysis and consideration of alternatives are possible. Large and/or complex buildings require a computer simulation; otherwise, evaluation of one or two alternatives becomes extremely time-consuming. Once the building's energy system has been simulated, it is a simple process to handle any number of alternatives and examine the consequences. The energy analysis considers the building orientation, size, shape, mass, air-moisture, and heat-transfer characteristics; outside humidity, temperature, solar radiation, and wind data; occupancy, lighting equipment, operating schedules, control set points, indoor temperature, humidity, and ventilation schedules; industrial processes, computer installations, manufacturing operations, and special-use facilities; air- and water-distribution system design and controls; and full- and part-load operating characteristics of equipment. Sophisticated calculations are based on hourly profiles for climatic and operational characteristics for a full year. Programs for this analysis are available from both the public and private business sectors.

Once the alternatives have been evaluated in terms of energy cost savings, the capital investments involved can be examined, their relative economic merits established, and recommendations made.

Control systems for energy management

Technology advances in data transmission and solid-state miniaturization, coupled with the introduction of inexpensive microprocessors and minicomputers, have made cost-effective and sophisticated centralized energy management systems feasible. Their degree of complexity should be tailored to match the building requirements and equipment to be controlled. Prior to this technological revolution (and 1973 embargo), designers generally minimized the functions to be monitored and reset because of costs; signals from sensing devices to data panels and from panels to control devices were transmitted by pneumatic tubes or electrical signals using one set of tubes or wire for each signal.

In general, there are two types of control systems—local and central.

Local controls are generally low-cost, for specified systems and equipment in a single building, and operate independently of other controlling devices. Localized automated functions and controls include status lights, alarm conditions, and time clocks to handle on/off operations, automatic temperature setback controls (day/night) and economizer or enthalpy controls. (Economizer controls sense and compare outdoor and return-air dry-bulb temperatures and determine when it pays to use outside air. Enthalpy controls monitor wet-bulb temperatures as well, and decision is based on air heat content, i.e., including humidity impact on the economics of using outside air.)

Central control systems range in complexity varying from manually controlled systems on up through various levels of computerized control.

Centrally controlled systems are operated from a single control console and may handle many more buildings over a large area, a number of equipment areas in one building, or a combination of both these conditions. The central manual control system relies upon the operator's capability and knowledge of the building equipment. The day-to-day operation of equipment is automatic, while optimization depends on the operator's decision making. The central computerized system varies in complexity, with optimized equipment operation generally determined by software programs; operator intervention is generally not required.

Typical operations handled by a central control system include monitoring fire-alarm and security devices; monitoring operating conditions of all systems and optimizing energy use by rescheduling set points and responding to room and traffic conditions; monitoring and controlling off/on system conditions; overriding normal operations as peak-load value is approached and limiting peak electrical loads via a rolling priority by load shedding and/or resetting of operational set points; monitoring and storing portions of operational-system behavior for later use in updating software; and analyzing reasons for shutdown and making decisions to shift load to other equipment, try to restart, or do nothing because load conditions had been met and operation was normal.

Central control systems are generally modular in design so that additional hardware and software can be added to the basic system if provision for expansion was made at the outset. However, once a choice of system is made and the system installed, you are generally locked in with the original manufacturer for further expansion.

Fig. 5 is a sketch[18] of a typical central control system with remote information panels (RIPs) located in different equipment rooms. The communication system between the RIPs and central console can be simple, single-core cable for serial digital transmission or multicore telephone cable for multiplexing and parallel transmission. The central console and

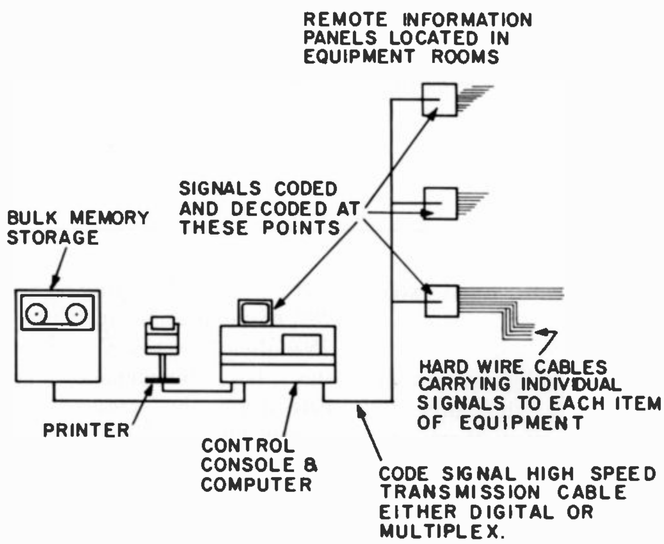

Fig. 5
Typical central energy-management control system uses stored software to send commands to and request status signals from remote information panels. (Ref. 18.)

Table II
Central control system for energy management can handle these variables.

Variable	*Examples*	*Applications*
Temperature		
Air	outdoor, return, and mixed air; boiler and incinerator stack; building zones.	monitor system performance, detect out-of-limit conditions, enthalpy control, reset control points for changing loads, boiler and incinerator combustion optimization, fire detection.
Fluid	chilled water (supply and return), condensor (supply and return), domestic hot water (storage and return), process fluids, boiler fuel input, boiler feedwater and condensate.	monitor system performance; detect out-of-limit conditions, reset control points, chiller and boiler optimization.
Machine and electrical components	bearings in chillers, fans and pumps; transformer winding.	maintenance scheduling, early warning of problems before failure.
Humidity	outdoor, return, and mixed air; critical building zones	monitor system performance, detect out-of-limit conditions, enthalpy control; reset control points.
Pressure	air, water, steam.	monitor system performance, detect out-of-limit conditions.
Pressure drop	across filters, through heating and cooling apparatus, etc.	monitor system performance, maintenance scheduling.
Flow	steam, air/gas, liquid.	consumption—energy analysis.
Power input	lights, elevators, machinery, furnaces.	demand limiting, chiller optimization, energy analysis.
Equipment status	boilers, pumps, fans, etc.	monitor on/off, start, stop, etc.
Combustion products	boiler, incinerator, equipment areas, etc.	boiler optimization; fire and smoke detection.
pH	water, processing fluids	water treatment—boilers, cooling towers, industrial processing.
Contact closure	motors, doors, etc.	equipment start/stop; security—doors locked/unlocked.

computer includes hardware items such as printer, display, CRT, and input/output keyboard.

The central unit generates operating instructions from the stored software program and transmits command instructions and status requests to the RIP and receives status, sensor, and alarm data arising from command instructions or requests.

The RIP acquires data from the sensors and status conditions of equipment and controlled devices, transmits this information to the central computer, receives command instructions (as well as status requests) from the central computer specifying desired device and equipment status, commands equipment to reflect this condition, checks execution of commands, and informs the central computer of status. Typical variables handled by a central control system are shown in Table II.

Corporate energy planning at RCA

In 1973 RCA established the Corporate Energy Planning and Conservation Committee (CEPCC) with Mr. K.D. Lawson, Corporate Vice President of Facilities, as Chairman. Each division has its own representative on the Committee (generally a plant engineer) who passes Committee recommendations on to that division's plants. Small (-energy) divisions, such as RCA Records, Global Communications, and the Laboratories, are represented on the Committee by Lawson's staff, and recommendations and information are passed on to these operations. Committee meetings have been infrequent, but Corporate Facilities has acted in an advisory capacity, issuing suggestions from time-to-time. They distribute the RCA Plant Engineer news to all plant engineers, and the RCA Plant Engineer Manual itself contains energy-savings information. Corporate Facilities also collects and issues quarterly reports summarizing energy costs at major operating units (excluding Hertz) along with comparisons with the previous year's results.

RCA is not an energy-intensive corporation, but the general housekeeping measures instituted by virtue of the Committee's and Corporate Facilities' suggestions have provided significant dollar savings.

Table III summarizes RCA's 1973-1977 performance along with total energy consumption and costs for 1977. More than 80% of RCA's total 1977 energy usage was consumed by five major operating units, as shown in Table IV. RCA can certainly be proud of its performance record. Remember, these savings are primarily the result of end-use restrictions; capital spending has been limited and system analyses have not been implemented. Obviously, significantly larger savings are possible, but in the present framework the CEPCC has probably gone as far as it can. It has operated in an advisory capacity and implementation has rested largely with local plant management. Scores of more immediate local problems have diverted attention from the variety of available energy-savings measures. Of greater significance is the general lack of awareness for the potential dollar savings attainable with modest capital investments.

The present loose energy organization is at variance with the generally recommended organization necessary for an effective corporate energy-management program; end-use restrictions instituted earlier will begin to fall by the wayside, and will be resurrected from time to time. As indicated earlier, a top management commitment, a corporate coordinator (or at least, a divisional coordinator) with clearly designated program responsibility and authority, and a set of defined realistic goals are necessary ingredients if RCA is to realize the potential dollar savings that efficient utilization of energy can provide. A new energy crisis may be the necessary catalyst for such a change, but the penalties for the delay will be higher costs for capital improvements and the inherent danger of hastily drawn decisions necessitated by serious problems requiring instant solutions.

Table III
RCA's energy performance over the last five years has been good. Energy savings are cumulative and adjusted for production. (Data includes only major locations monitored by the Corporate Energy Planning and Conservation Committee, and does not include Hertz.)

Total RCA Energy Costs, 1977	$38,716,083
Total RCA Energy Consumed, 1977	9.297 trillion BTU
RCA's accumulated energy savings (1973-1977)	$10,031,464
Energy consumption reduction	Approx. 30%

Table IV
Most of RCA's energy is used by these five operating units.

Division	*% of RCA's energy use*
Picture Tube Div.	26.6%
Banquet Foods	17.2%
Consumer Electronics Div.	16.2%
Solid State Div.	14.1%
Coronet Industries	9.8%
Total	83.9%

Research and potential business in energy management

In 1977 the Energy Systems Research Laboratory was established at RCA Laboratories under Dr. B.F. Williams and ESAG was created within this laboratory to focus on energy conservation. The initial objectives were to: 1) develop an RCA proprietary computer program for building-load simulations; 2) carry out energy audits at RCA sites and perform systems and load simulations using the developed computer program to evaluate energy-savings approaches and capital investment requirements; 3) analyze energy efficiency of in-house industrial processes and optimize where feasible; and 4) engineer cost-effective computer and/or manual control systems.

ESAG's activities began with studies of NASA's NECAP program for building-load analysis and with preliminary building energy audits to gain familiarity with pneumatic and electrical controls in general use.

In 1978 this program was revised as a result of a meeting with Mr. R.D. Weaver, Director of Facilities Management for RCA Service Company. Mr. Weaver had been (and is) actively pursuing energy conservation approaches for the complex of RCA buildings at Cherry Hill and had implemented a number of changes with significant dollar savings. Under his direction, such items as seven-day on/off timer clocks and scheduling, reflective films on glazing, manual rescheduling of set points, and an operator-dictated manually-controlled economizer cycle have been incorporated into the Cherry Hill facilities system. At this writing he is exploring the use of water-tower water in the closed chiller system (for the computer facilities area) when wet-bulb temperatures are less than 47°F.

Mr. Weaver was interested in installing a central computer-controlled HVAC management system at Cherry Hill, but outside vendors' systems were too expensive and offered a large number of unnecessary "frills." Furthermore, his responsibilities include approximately 250 leased Service Company buildings in the 5,000-15,000 ft^2 category and he was interested in cost-effective, inexpensive, microprocessor-controlled systems for these buildings. Availability of such a system could open up a new business area—a general-purpose, low-cost facilities management system handling both energy and security management for small buildings.

A microprocessor-based energy-management system is being planned for RCA Cherry Hill.

As a result of this meeting we agreed to install a central computer-controlled HVAC system at Cherry Hill, first in Bldg. 203 with provision for expansion to include Bldgs. 201, 202, and 204. The plan is for ESAG to instrument Bldg. 203 for building-load analyses and systems simulations and apply the results to software optimization and additional control points for the computer-controlled system. The objective was to establish a technical data base for feasibility evaluation and system designs for low-cost mass-produced systems suitable for small- to medium-size commercial buildings (5,000-50,000 ft^2). Expansion to Bldgs. 201, 202, and 204 would provide us with design optimization data for a complex of small, independent, commercial buildings. Safety and security alarms are to be included in the system studies and tests.

A system developed from this data base must be reliable, simple to operate, cost-effective, and a significant improvement over inexpensive on/off timer clocks and manual controls. In order to handle a large market and reduce the impact of development costs on price, and at the same time permit simple software optimization, the design and system for smaller buildings must also provide sufficient flexibility for a variety of situations where load requirements may vary because of geographical location, construction, building layout, and occupants' special equipment. Hardware (and possibly software) requirements are likely to make two general systems necessary, one for small buildings and a second for medium-size buildings.

ESAG has no microprocessor design engineer at this time, and the TV Microsystems Research Group and Systems Architecture Group headed by Drs. P.M. Russo and R.H. Roth, respectively (part of Dr. N. Gordon's Systems Laboratory), are collaborating with ESAG. A. Abramovich, assisted by A. Patel, is providing the microprocessor system engineering design while R.J. Poulo is responsible for the initial software program. ESAG's Dr. K.S. Vanguri and myself are responsible for the overall system and controls, including the building's coexisting pneumatic and electrical controls, the interface with the electronic system, building instrumentation and load analyses, and testing, evaluation, and optimization of the overall system performance. At this writing, the system has been defined, the remote information panels designed, the pneumatic-to-electric and electric-to-pneumatic interfaces installed at Cherry Hill and in operation, and the duct and remote-zone temperature sensors are wired in place.

The system is to be installed in Bldg. 203 early in 1979, at which time debugging and program optimization will start.

Summary

1) The National Energy Plan's medium- and long-term goals are plagued with political, economic, and societal problems which insure the Plan's failure to meet its time schedules.

2) Industrial conservation programs have been notably effective, with 10-30% energy savings a common occurrence.

3) Larger industrial savings are feasible with a systems approach to energy management. A company's energy organization must be backed by a strong commitment from top management, clearly designated program responsibility, and well-defined realistic goals.

4) RCA's cumulative energy savings from 1973-1977 of 30% represent a significant achievement, but larger annual savings are not likely to be realized without resorting to measures discussed in item 3 above.

5) A new business, computer-controlled facilities management for small- to medium-size commercial buildings, is a possible outgrowth of the facilities-management studies at Cherry Hill.

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P.S. Ridley

Energy conservation at RCA

The success of RCA efforts to reduce energy consumption and costs are being coupled with plans to soften the effects of future fuel curtailments.

Paul Ridley spent his career in various functions of plant and power engineering. He joined RCA in 1969 and is presently Director, Plant Engineering of RCA's Corporate Staff.

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Final manuscript received November 28, 1978.

In 1970, RCA staff facility personnel under K.D. Lawson became concerned about the possibility of an energy shortage, particularly in fuels, and in September of that year, expressed their concern to all RCA plant engineers. While none of the RCA locations seemed to be adversely affected, an increasing number of gas companies were refusing to accept new customers or new loads and this was evidence of a decline in domestic supplies of natural gas. Fuel oil remained in adequate supply but even so, there were rumors of future problems due to our nation's growing dependence on foreign oil together with a decline in domestic fuel sources. The reasons for the decline in our two most common fuels—gas and oil—need not be dealt with here, but what may be worth noting is that use of coal, the most abundant of our fossil fuels, had been falling off for years due to the abundance of the much cleaner and more economical oil and gas.

RCA is not an energy intensive company when compared with refineries, petrochemical plants or basic metals industries.

But certain RCA glass processing operations at Circleville, Marion and Scranton require large volumes of natural gas, and there has not been a satisfactory and economical alternative for this fuel. In line with the general practices of industry since World War II, plant heating has been by use of gas or oil. These fuels can be burned in boiler plants that require much less capital and labor than is the case with coal. Only two RCA locations are equipped for coal burning.

The problem, as we first saw it, was to prepare to move away from the use of gas. The only alternative for plant heating had to be oil, because, with very few exceptions, our boilers were incapable of conversion to coal. Electricity as a major heating source has never been a viable alternate in much of the United States, due to high cost. In the case of the glass operations, the only alternative was propane which when mixed with air becomes the equivalent of natural gas.

Energy conservation programs

By 1972, the need for corporate action on energy resulted in the formation of the corporate Energy Planning and Conservation Committee. This committee, with representation from all MOU's and subsidiaries, met in February of 1973 to establish programs that would not only lead to a reduction in energy usage but would address the matter of alternate energy sources, improved reliability of supplies, etc. The conservation goal of the corporation was established at a realistic 15 percent reduction, and it was agreed that 1972 would be considered the base year. All of this preceded the oil embargo by several months, the latter incident generally coinciding with public awareness of the energy problem.

In the ensuing months, our plant engineers set up programs to reduce energy consumption (see "How RCA Operations Managers are Doing It"). These actions took many forms such as lowering light levels, resetting thermostats, reducing the operating time of heating/air conditioning equipment, etc. In other cases, manufacturing operations were analyzed and economies effected wherever there would be no harm to the product. Certain cleaning operations were performed in the daytime to reduce the need for lighting. Programs were set up to involve employees in energy conservation. The results of these efforts were apparent by the end of 1974, when corporate energy savings of 16 percent over the base year of 1972 were realized. By the end of 1975, the savings had topped 25 percent, and through 1977 were more than 30 percent. It must be remembered that this exceptional performance by our plant engineers was against a target of 15 percent.

One other matter of concern was the adequacy of fuel oil storage at certain locations, since sufficient supplies need be on hand to cover plant requirements for at least a three-week period in the worst winter weather. Accordingly, large underground concrete tanks were added at the Findlay, Marion and Moorestown plants. These enlarged facilities proved their worth during the severe winters of 1976 and 1977.

Coping with future uncertainty

Our successful efforts to reduce the consumption and cost of energy are, however, no grounds for complacency. We must continue to work toward the goal of maximum attainable efficiency and the lowest possible cost of energy. Coupled with this effort must be the development of contingency plans to avoid the damaging effect of unanticipated curtailments.

It is not yet known what all of the effects of the energy legislation enacted in October of 1978 will be, but certain consequences for industry can be predicted with reasonable accuracy. The gradual deregulation of natural gas between now and 1985 will cause its price to rise, but a concomitant advantage will be a probable increase in gas availability. This, however, represents no long-term solution to the gas problem. Supplies are finite and unless substantial undiscovered sources are realized, our current usage can be sustained for no more than a few decades.

Industry will generally be required to burn coal in new large fuel burning units of over 100,000,000 Btuh, but this will not be without its problems due to the much higher first cost of coal burning equipment and the very costly pollution control equipment that will be required.

The matter of electric rate structures will be scrutinized and there is little doubt that changes will be made which will affect industrial energy costs. Changes could include time-of-day pricing, seasonal pricing, flat rates, lifeline rates, etc.

The long-term solution to our national energy problem must include a greater dependence on coal, expanded use of nuclear energy, including the breeder reactor, and, ultimately, the successful development of the inexhaustible fusion source. Other energy options such as solar, wind, geothermal, etc., have a part to play and should be used wherever practicable.

In summary, we must make every effort to conserve energy, we must design more efficient energy using systems and, on a national scale, must reduce, substantially, our dependence on imported oil, for even a relatively small reduction in energy availability could have a profound adverse effect on our socio-economic system and ultimately our political system.

How RCA operations managers are doing it

C.A. Smith, Plant Engineer
Lancaster Plant

The four high pressure steam boilers at Lancaster were operated in the traditional manner; the operator adjusted fuel/air ratio by observation and judgment for best combustion efficiency. Now, flue gas oxygen analyzers have been installed on these boilers and excess air has been cut in half for fuel savings of $10,800 per year. Pay back is only 1.1 years.

At the same location, a new 800-ton water chiller has been purchased with energy efficiency, a major factor in final selection. At current electric rates, the additional first cost will be recovered in a year.

H.C. Waltke, Manager, Operations Services
Mountaintop Plant

The manufacture of solid state devices requires the continuous exhaust of large quantities of conditioned plant air. A study was made to determine how this exhaust could be reduced to an acceptable minimum and resulted in a reduction of 26,300 cfm for an annual cost saving of $33,000. In addition to improved switching control of lamps, all fluorescent tubes in the plant were changed to the new lower wattage type for a reduction in lighting energy of approximately 15%. Heat liberating diffusion furnaces were relocated to non-air-conditioned space and the liberated heat is being recovered to preheat plant makeup air.

A.S. Williams, Manager, Operations Services Random House—Westminster, Maryland

This book Distribution Center, with 370,000 square feet of warehouse and 48,000 square feet of office space, represents quite a different pattern of energy usage and somewhat fewer opportunities for conservation when compared with a manufacturing plant. Despite this fact, electrical usage was reduced 18 percent, gas usage 56 percent and fuel oil usage 43 percent over a five-year period, notwithstanding an increase in number of books shipped by 124 percent. In addition to changes in thermostat settings and removal of lamps, more efficient metal halide lamps were substituted in the warehouse, automatic timers were installed to control air-handling units and boilers, fan speeds were reduced on air-handling units and humidification was added to the office heating system for more personnel comfort at the lower maintained space temperature. One of the most effective actions involved the installation of 113 slow speed fans in the warehouse. These fans move the warm air that has stratified in the overhead truss space in the warehouse down to floor level with a resulting significant reduction in heat loss through the roof and improved personnel comfort at floor level.

L.R. Caprarola, Plant Engineer
Somerville Plant

The Somerville plant has nearly completed the installation of a programmable controller for the automatic control of a portion of plant electrical usage. Initially, the controller will cycle 40 air-handling units and exhaust fans on an on-off basis; thereby reducing total hours of operation and, concomitantly, the power consumption. Additionally, these fans will be programmed to start and stop, as required, for daytime service, nightime service, and to suit weekend holiday requirements. Finally, there will be a reduction in plant power demand which will be realized from an electrical connection between the controller and the demand metering equipment of the power company. Temperature and humidity feedback is incorporated to prevent loss of control which could occur if cycling, alone, was utilized. Installed cost of the system approximates $55,000, and the after-tax savings are estimated to be 1.7 years at current electric rates. Future plans include automatic control of area lighting and the operation of water chillers for maximum economy.

RCA participates in energy-saving project at AUTEC

Howard Bacon, Staff Civil Engineer
RCA AUTEC Project, Andros Island

RCA Service Company is the maintenance and operations contractor for the Navy AUTEC (Atlantic Undersea Test and Evaluation Center) Project at Andros Island in the Bahamas. Under an Energy Conservation Investment Program (ECIP) the Navy Facilities Command provides funds to make retrofits on the base which have a potential for immediate savings. Three energy-conservation ideas submitted by Ken Danton, RCA Manager, Utilities, should save over one-half million dollars in the next 15 years.

Ken Danton disposing of an old 350-W incandescent bulb in favor of an energy-saving fluorescent tube in AUTEC project on Andros Island, Bahamas.

1. Conversion of incandescent lighting in the Command Control Building to fluorescent lighting. It is interesting to note that when the nerve center of this submarine and torpedo testing facility was designed, some 15 years ago, it was thought that fluorescent lighting would cause excessive radio frequency interference to the communication and computer facilities; hence, many 350-W incandescent fixtures were employed in the building's original design. Cost of replacing old fixtures: $43,000; savings of $318,500.

2. Reinsulation of chilled water lines in an air conditioning system serving three large structures. At the present time, the insulation on the piping is of insufficient "R" factor and is beyond economic maintenance. Cost of new, high "R" factor insulation: $38,000; savings of $201,000.

3. Insulation of ceiling on the top floor of three living quarters. Cost: $10,000; savings of $39,500.

The beauty of these programs, if selected for implementation, is that the funds are budgeted separately by NAVFAC and do not come out of the limited maintenance and operations budget of the RCA government contract.

Call for Papers: *Microprocessors and their applications in your work and at play*

The October/November 1979 issue of the *RCA Engineer* will feature microprocessors. In addition to the full-scale articles on the subject, the editors are also planning to include a survey article on microprocessor applications and projects developed by RCA people.

Actually, the survey article will consist of two parts—those applications and projects used "on-the-job" and those developed "off-the-job" in pursuit of a hobby. Because the article will cover many projects, a short description will suffice—two paragraphs plus a photo or illustration.

What would be the content of these descriptions? On-the-job summaries could include how microprocessors are used in manufacturing, process control, testing, design, communications, signal processing, or other applications.

Off-the-job descriptions could relate how hobbyists at RCA are using microprocessors—RCA COSMAC VIPs or X-Brand units—to add more sophistication and enjoyment to their hobbies, or how microprocessors are used to gain economic (e.g., home energy conservation) or security (e.g., intrusion systems) benefits for the user.

There are hundreds of microprocessors in the hands of, or at the disposal of, RCA employees. The *RCA Engineer* editors want to hear about their specific applications and spread the word through RCA's technical community. Remember, a short description and illustration will do. The only constraint is that all inputs are received by the end of July.

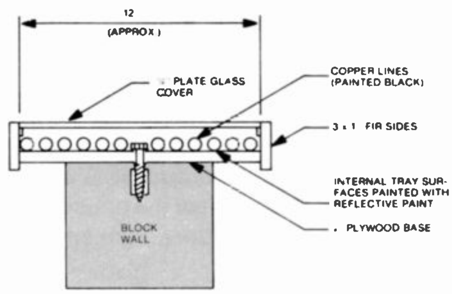
Contact the TPA or Ed Rep in your division, or send your input to the *RCA Engineer*, Bldg. 204-2, Cherry Hill, and be part of what promises to be a fascinating issue. (Ed Reps and TPAs are listed on the inside back cover of the *Engineer*.)

on the job/off the job

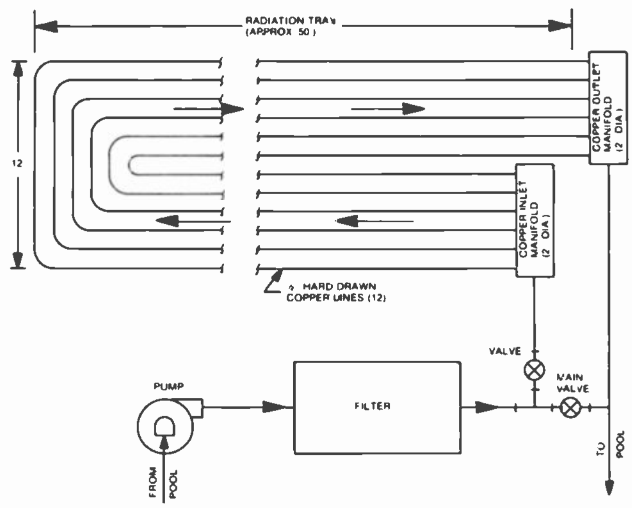
How RCA people are tackling energy problems

A quick survey of RCA people shows how they have put some unique ideas to work in home energy conservation and other energy-related areas.

Solar swimming-pool heater



RADIAT ON TRAY



My solar pool-heating system detailed in the accompanying drawings was installed in the spring of 1963. The incentive for this undertaking was primarily cost savings and was well rewarded. The material cost for the system was approximately \$250 (1963 prices) when the cost of a gas heater was \$300 to \$400. Obviously, in addition to the low initial cost, the operating cost is essentially nil.

The solar collector housing consists of a wooden tray 12 inches wide by 50 feet long, mounted on a 5-foot high brick wall. Inside the tray are 12 1/2-inch copper lines painted black. The internal tray surfaces are coated with reflective silver aluminum paint. The top of the tray is covered with 1/4-inch-thick plate glass.

If the pool temperature is cool, water can be routed through the collector system where it is heated by the sun. Regulation of the main valve permits full or partial circulation to be diverted through the heater system. On the average with full circulation through the solar heater, the pool water temperature will be maintained about 5°F above that of unheated pool water.

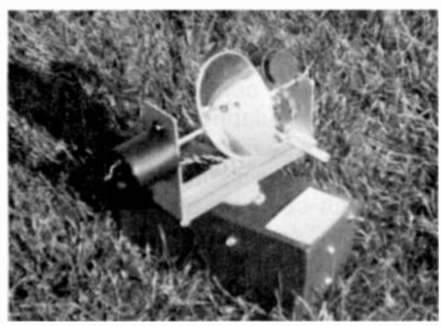
Svenn A. Norstrom
Avionics Systems
Van Nuys, Calif.
Ext. 3614

Solar tracking unit

I have built and successfully tested an experimental prototype model of a two-axis solar tracking unit. The unit tracks in both azimuth and elevation with little error.

Photocells in the tracking head signal electronic circuitry which controls the axis drive motors. My prototype model is battery operated and is fitted with a small parabolic reflector which focuses enough heat to light cigarettes approximately 3 seconds after solar acquisition.

Rick Strosnider
Picture Tube Division
Circleville, Ohio
Ext. 236



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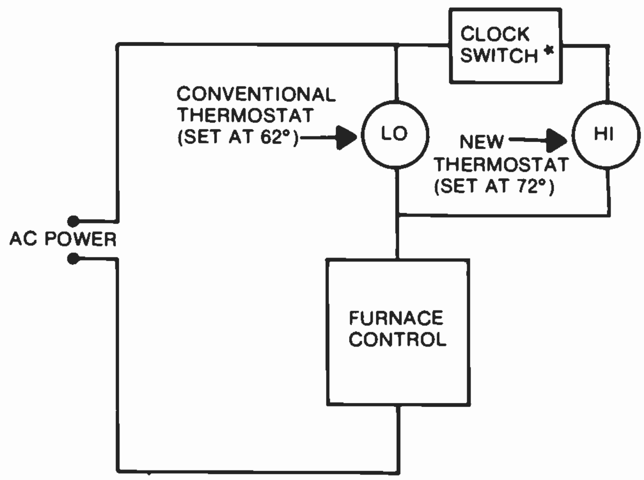
Ed. Note: This sampling of energy ideas from RCA people represents only a start in what we hope will lead to similar presentations in the future. All readers are invited to share their experiences in reacting to today's and tomorrow's energy concerns. Contact your Editorial Representative (listed on the inside back cover), or write to or call the *RCA Engineer* editorial office (TACNET 222-4254) to let us know about your energy idea. *F.J.S.*

Clock-controlled furnace thermostat

Changing the thermostat setting by hand is, of course, the simplest way to lower the temperature in your home at night or before you go away. But if you forget, your hoped-for savings go right up the flue. You also find yourself getting up earlier to turn up your thermostat so you can hop back into bed and await the removal of the morning chill. The alternative is to purchase one of those "set-back" thermostats that are now advertised. They were not available in those energy-flush days 12 years ago, so I had to do otherwise.

Operation is simple. Anticipating the need for comfortable living temperatures, the clock switches the "hi" thermostat into control at 4 a.m. and at 4 p.m. Economically, it cuts out the "hi" and leaves the "lo" thermostat in control at 7 a.m. and 9 p.m. By the time I might feel the house coasting down to cool maintenance temperatures, I am either in bed or at work.

Of course on weekends, I have to remember to set the lo thermostat up during the day (three hours in which to remember this without chill) and then down again at night (five hours grace for that). But this is a small price to pay for a simple switching system which has saved heat and money during the past 12 years.



CLOCK SWITCH SETTING: *

"MAKES" AT 4:30 A.M., 4:30 P.M.
"BREAKS" AT 7:30 A.M., 9:30 P.M.

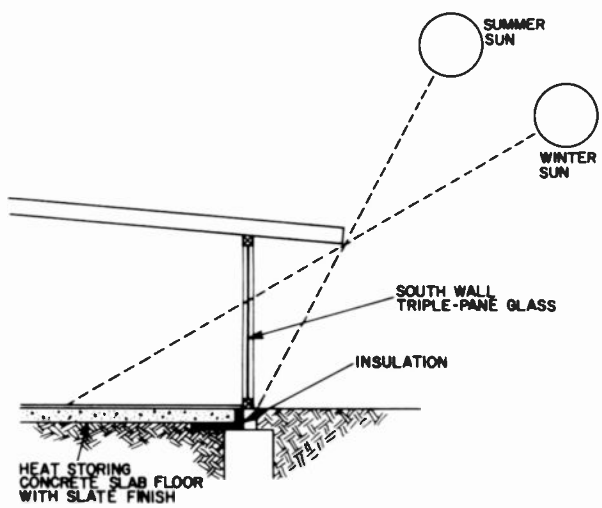
Ann S. Merriam
Advanced Technology Laboratories
Camden, N.J.
Ext. 2321

Home designed for energy conservation

I have always been interested in architecture and so designed and participated in the construction of my solar-heated home. The 1800 ft² masonry and glass house is 75 feet long, oriented so that its length runs east and west. Its 18-inch-thick masonry walls are constructed of brick, separated by an air space on the inside and outside of 8-inch cinder blocks. Additional insulation in the form of fiber glass wool was blown in to fill the 8-inch space in the cathedral ceiling.

The south wall consists of 500 ft² of permanently sealed, triple-pane insulating glass mounted in 4 x 4 cedar frames. The primary heating system consists of an oil furnace from which hot water is pumped through copper tubing buried in the 6-inch concrete slab floor which is covered by dark flagstone. The slab is insulated by a waterproof mat which wraps around and underlies it by 2 feet around its perimeter. In the winter the sun's energy streams through the south wall, preheating the water returning to the boiler of the primary heating system. A 4-foot overhang on the south wall prevents direct sunlight from entering during the summer.

The thermal capacity of the slab is sufficient to heat the house for two cloudy days with a drop in inside temperature of only 4°F. Calculations show that throughout the winter

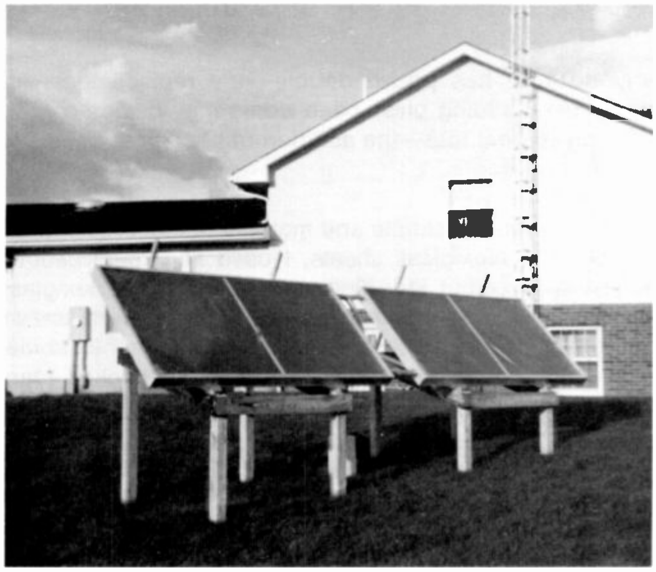


more energy enters through the triple pane glass than is lost.

Sometime in the future, I plan to install solar panels on the roof, using the floor slab for heat storage of the sun's energy gathered by the panels.

Richard L. Pryor
Advanced Technology Labs
Camden, N.J.

Solar domestic hot water heater



The solar hot water system I installed is provided as a package called "Sunset System" by Rheem, Chicago, Ill. The system consists of two 4 x 8-foot collector panels (manufactured by Reynolds Aluminum), an 82-gallon storage tank and heat exchanger, collector fluid pump, and thermostatic differential controller.

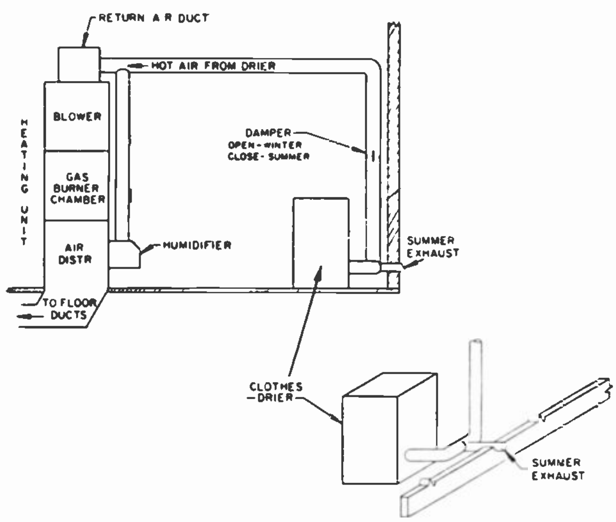
Collector fluid is a mixture of 50-percent distilled water and 50-percent ethylene glycol for antifreeze protection. The fluid is pumped to the collectors which are located in the backyard. I mounted the collectors so that they are manually adjustable in elevation for seasonal tracking. Hot collector fluid is returned to the heat exchanger and hot water storage tank where potable water is heated. The outlet of the solar storage tank supplies the inlet of the regular 52-gallon electric hot water heater and thus acts as a preheater for the domestic hot water heater.

Instrumentation includes eleven temperature and three pressure monitoring points for evaluation of system performance.

This system was placed in service in early August of 1978. Performance is such that it heats water to 150°F on cloudy, hazy days and up to 175°F on sunny days.

Rick Strosnider
Picture Tube Division
Circleville, Ohio
Ext. 236

Clothes dryer output heats home and raises humidity



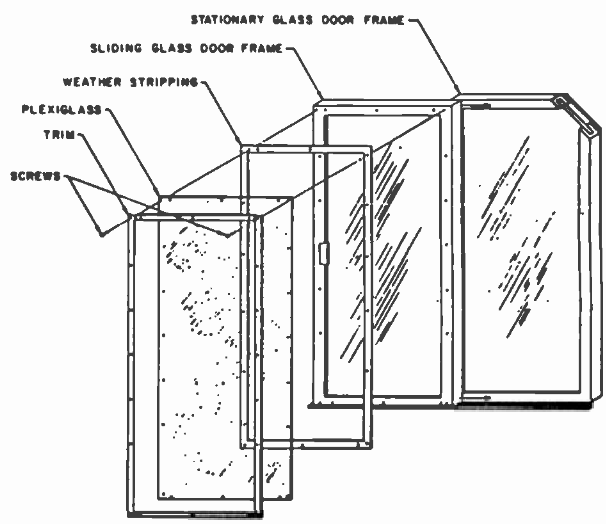
The normal procedure in most homes is to vent the output from one's clothes dryer to the outside. An alternative to this waste of a byproduct useful in the winter is to disconnect the dryer's exhaust hose and let it blow into the surrounding atmosphere inside the house to help raise the heat and humidity. However, with washday at our house scheduled twice a week, our small laundry room would become an unwelcome sauna for my wife each time she emptied the dryer and reloaded the washer.

My solution was to divert the overabundance of hot, moist air—during winter months—to the central heating system as shown. During washdays, we turn the heater blower on, and leave it on. As a result, the gas burners in the heater did not come on during most washdays during the winter (1977-78). The relative humidity increased about 5% (the humidifier keeps it near 40%). In the summer, the damper is closed forcing the air out the normal vent to the outside.

The connection between heater and dryer is relatively easy and inexpensive if the units are close together. I used standard vent duct components available from heating equipment supplies. The complete system cost less than $40, including Band-Aids for cut fingers.

Victor Reed
NASCOM Project
RCA Service Company
Riverdale, Md.
Tel. 301-864-5682

Modifying standard sliding glass doors



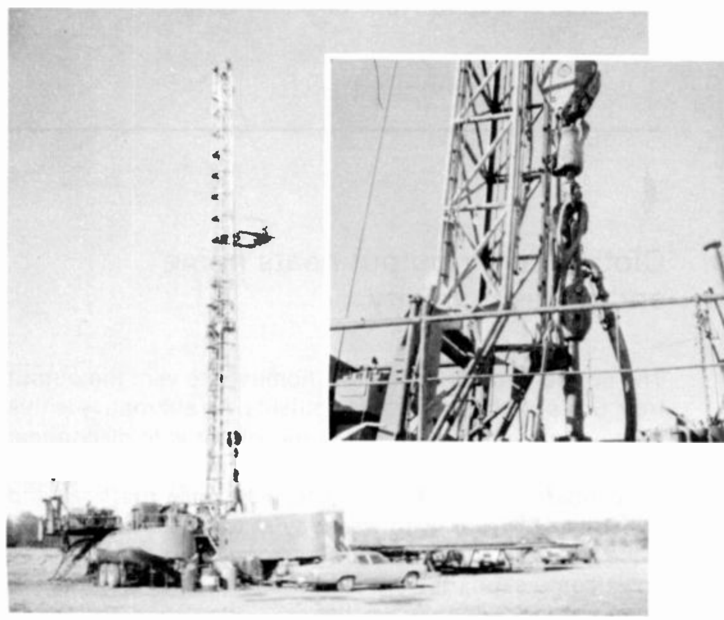
Anyone who has priced double-pane replacements for single-pane sliding glass patio doors may decide on this solution to heat loss—the addition of plexiglass panels to the existing doors.

The installation is simple and material needs are minimal. Besides the plexiglass sheets, I used aluminum cabinet edge trim, weather stripping, and screws. The plexiglass and aluminum door frame are drilled for sheet metal screws through the same holes as those pre-drilled in the cabinet edge trim. The weather stripping is sticky-backed foam rubber.

Two minor problems can develop. First the weight of the 0.25-inch-thick plexiglass increases the wear on the door rollers. Unless your door can take additional rollers to distribute the added weight, my recommendation is to use thinner (0.15-inch) panels. Second, in hot summer temperatures, the outside panel of plexiglass expands and bows in the center causing it to be scratched by the screen door. I have not found the solution to this problem.

Victor Reed
NASCOM Project
RCA Service Company
Riverdale, Md.
Tel. 301-864-5682

The risks and rewards of drilling for oil



If you look at how much the OPEC cartel has raised the price of crude oil in the last few years, you see that development of much of the previously marginal oil and gas deposits now becomes economically feasible. Using these resources would also slow the trend toward dependence on foreign oil sources.

With this in mind, I followed up any lead concerning an available site for a gas or oil well. It took several years and careful analysis to find available leases and drillers in an area where other wells had been successful and where the odds favored other successful wells. In 1977, after many unsuccessful contacts, two opportunities became available, one in Meigs County, Ohio, and the other in Eastland County, Texas. The dilemma of which to develop was solved by drilling both since they were both attractive but in different ways.

The Texas well had some risk of failure but also the potential for a very large return on the investment. The Ohio wells were much more certain because the known deposit area was five miles wide and eighty miles long, but the wells would yield a lower return.

This brought up the question of financing. The relatively shallow Ohio wells, about 1600 foot in depth, would cost $60,000. The Texas well was to be 4000 feet, total depth. Two groups of investors were organized in two limited partnerships. This type of venture has the advantage of passing the tax benefits directly to the investors while protecting them from any risk beyond their investment.

As of mid 1978, the Eastland County, Texas well was found to be unsuccessful and was abandoned with only half of the capital expended. The Ohio wells in Meigs County are successful and promise to produce gas and oil at a rate which will make this venture a very successful one.

The gas shortage of two years ago has been turned into a situation of good supply largely because of private enterprises reacting to the increased price of gas and drilling thousands of new wells in areas that were uneconomical at the old prices.

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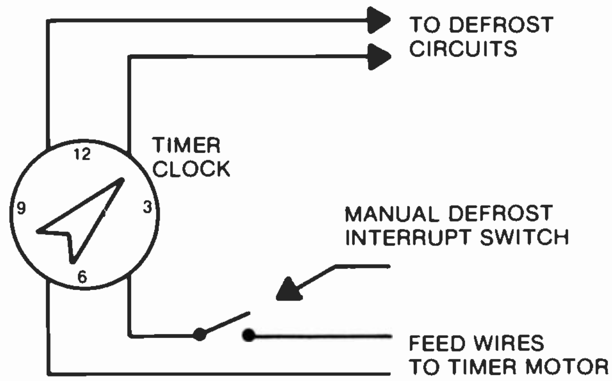
Controlling refrigerator defrosting

The modern refrigerator is an attractive big box with many convenient features including self-defrosting of the freezer compartment. Defrosting may be controlled by a clock which disconnects the compressor and turns on two heaters twice a day. The energy going into the heaters and the energy used to re-chill the freezer presents a waste if this cycle occurs more frequently than necessary. During periods of low humidity, I have found that defrosting only one day a week is quite adequate.

To enable manual control of the defrost cycle, I have installed a switch in the timer clock circuit. The switch is turned off before the clock goes into the defrost cycle. The clock stops running and will not advance to the next defrost cycle until it is reactivated. Except in the summer, turning the circuit on one day a week keeps the frost under control—provided we don't forget.

As to the bottom line, I cannot say that my energy bills have dropped greatly or that they are anything to be happy about. I am confident, however, that they would be significantly higher without my conservation measures.



Jerome Kurshan
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Zone heating for comfort and energy savings

Twenty-five years ago, well before the present concern over energy supplies, I revised my home heating system from a one-zone to a four-zone system. This modification reduces the temperature in those parts of the house less frequently occupied. The house has one story plus a partial basement and crawl space. The same energy-saving considerations, however, would apply to a two-story house.

The house is heated by a hot-air, oil-fired system. The feeder ducts are arranged so that three sections of the house are served by separate branches. A fourth section is heated by an independent gas-fired space heater to avoid over-extending the duct system. The four heating zones of the house can be readily isolated thermally by closing doors.

All the feeder ducts are suspended from the basement or crawl space ceiling. The bedroom-kitchen-dining wing constitutes one heating zone with two duct branches. The living room wing and basement constitute two more zones with one heating duct branch for each area. A converted garage, used as a guest room, constitutes the fourth zone and contains the independent space heater.

In the hot-air system, each heating zone has its own thermostat which controls a motorized damper. When a zone calls for heat, the appropriate motor is energized and opens that damper (two dampers for the bedroom wing). This action, in turn, switches on the oil-fired furnace. The furnace will stay on as long as any zone calls for heat. When the heat demand is satisfied, the dampers automatically close, switching the furnace off. Some air leakage is allowed past the dampers in their closed position. This utilizes the heat stored in the furnace after combustion ceases, with the blower continuing to run as governed by the limit control. Because of the quick response of the hot-air system, clock-controlled thermostats are not used. Heat is turned up when it is needed and down when it is not, e.g., at night or when everyone is away from home.

The bedroom-kitchen-dining wing is occupied most frequently. A small den in this wing is used for entertaining a small group, precluding the need for heating the much larger living room. When the living room is used, the central heating system is augmented by a Heatilator fireplace. Another benefit of the zone heating system is that the fireplace does not unbalance the heating of the rest of the house. As more heat is supplied by the fireplace, central heating of the living room alone is cut back by its thermostat without affecting the other zones.

This zone heating system has worked reliably and as planned over the years. Subsequently, central air conditioning was installed utilizing the same air delivery ducts and similar energy savings have been achieved.

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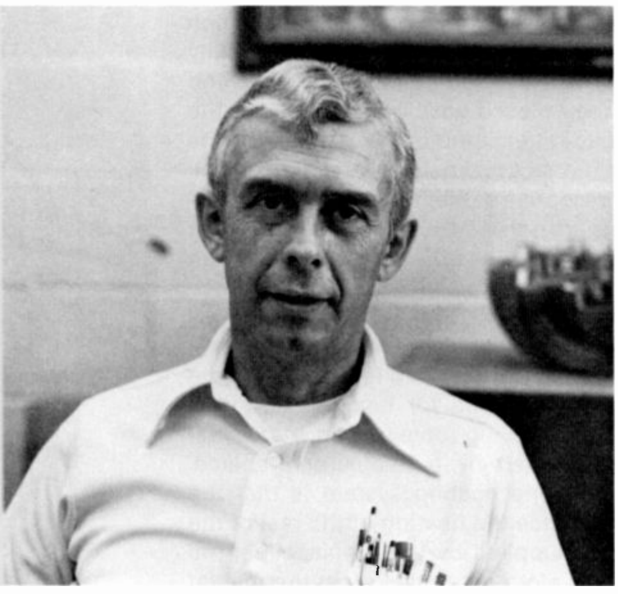
J.A. Eshleman

A new tetrode switch/regulator tube for fusion reaction experiments

This multi-million watt tube opens new doors for the large thermo nuclear power plants of the future.



James Eshleman has been a member of the power tube engineering team for the past twenty years where he contributed to the design of high power klystrons, magnetrons, coaxitrons and other gridded tubes.

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The Power Devices group of Electro Optics and Devices, RCA, Lancaster, Pa., has developed a gridded tetrode power tube that is capable of switching 22-million watts of power at pulse widths of one second or more. The tube, designated the RCA S94000E, was developed under funds provided by DOE and contracted through the Plasma Physics Laboratory of Princeton University.

The development of this tube represents an advancement in the state of the art for gridded tubes in terms of plate dissipation, voltage holdoff, and switched power at the pulse widths involved. Previous tubes were limited to below 100 kilovolts holdoff voltage with plate dissipations of the order of only hundreds of kilowatts. And these ratings applied at pulse widths in the millisecond range. The S94000E is rated for 200 kilovolts holdoff voltage with a plate dissipation of two million watts at pulse widths up to five seconds. It will provide a load or output current of 125 amperes with a tube voltage drop during the pulse between five and thirty kilovolts. The tube was developed for use with the ion accelerator portions of the four neutral beam sources that will be used in the TOKAMAK Fusion Test Reactor[1] (TFTR) being constructed at Princeton, New Jersey. RCA EO&D is also under a production contract to deliver S94000E tubes.

It is through neutral beam injection that the next plateau of plasma energy will be obtained[1] in the magnetic confinement type of experiments with the TOKAMAK Fusion Test Reactor (TFTR). Predictions are that with neutral beam injection, the TFTR should reach the "break even" point with the fusion reaction,[2] i.e., the point where fusion reaction energy output matches the energy supplied to the reaction. The hope is that data from the TFTR experiments will assist in the design of operational fusion reaction power plants.

How the tube operates

For operation of the accelerator grids of the neutral beam source, the S94000E will be required to provide approximately 70 amperes at 120 kilovolts. A simplified diagram[3] of the circuit is shown in Fig. 1. Initial operation will be with one-half second pulse widths at two pulses per minute. For this operation, the S94000E provides a pulse voltage to both the source and gradient grids of the ion accelerator, with the pulse rise time controlled to match that of the arc power supply in the source section of the device. During the flat top portion of the pulse, the tube will be required to regulate the voltage. In the event of a flash arc within the accelerator grid structure, the tube will very quickly block the voltage, so that the arc will be quenched and the structure will not be damaged. After a suitable healing time, the voltage will be re-applied and operation will continue until another arc occurs or until the one-half second "on" interval ends. Then the tube will again block the voltage until the next "on" period occurs.

The dump tube circuit provides protection for the S94000E. In the case of a tube internal arc, the dump tube is fired to quench the arc and a breaker opens the primary circuit to the HV power supply.

Tube construction

The S94000E (see Fig. 2) is constructed primarily of metal and ceramic materials. It is 36 inches high with a maximum diameter of 22¼ inches and weighs approximately 320 pounds. The plate terminal is separated from the cathode terminal and mounting plate by the plate ceramic insulator. Screen grid, control grid, filament and filament ground terminals are at the bottom end of the tube, where, in addition, an ion pump and the pinch-off cover are also located. The terminal appendages serve the dual purpose of providing an electrical contact as well as the coolant water connectors.

Something "old"

The input parts of the tube (filaments, control grid and screen grid) are identical to those in the smaller Type 4648 rf amplifier tube that has been in production for some years. The support structure of the S94000E was simply scaled-up to incorporate more of these units. The filaments are also used in other large power triode amplifier tubes with a 20-year service record, thus, providing the long-life expectancy required by the customer. The three major assemblies of the S94000E are shown in Fig. 3.

The internal arrangement of the tube is a cylindrical array of 66 individual electron optical systems surrounding a centrally located plate. Each electron gun in the tube is comprised of a directly heated ribbon filament, a control grid, and a screen grid as shown in Fig. 4. All the electron guns are connected electrically parallel and supply their output current to the plate structure. The filaments are manufactured from thoriated tungsten rods. They are hot rolled into the rectangular cross section .0245-inches thick at the Lancaster Plant.

The filament is supported in V-shaped grooves at both ends. These grooves mate with the radiused heads of the filament and provide an accurate mounting arrangement so that spacing variation between the control grid and the filament is small. At one end, the mounting groove for the filament is on a pantograph spring, providing a flexible contact to the filament and maintaining mechanical support during the filament's thermal expansion.

The control and screen grids of the tube are made from .0065-inch diameter tungsten

The Tokamak approach to controlled thermonuclear fusion*

Power generation by controlled fusion holds the promise of unlimited, inexpensive fuel, and greater safety and negligible environmental hazard relative to fission reactors. Fusion has thus become one of the preferred approaches to solving the world's long-term energy problems, although its feasibility must still be demonstrated. Research towards producing fusion power based on synthesizing the heavy hydrogen isotopes deuterium and tritium into helium has progressed, despite many difficulties, to the point where reaction rates similar to those required for fusion reactors now appear to be within immediate reach. Following up on these recent achievements, next-generation fusion devices are being developed, some of which are designed to generate about 10 MW of fusion power (without conversion to electricity), comparable to the heating-power input, to demonstrate power breakeven and scientific feasibility.

The Princeton University Plasma Physics Laboratory (PPPL), under contract to the U.S. Energy Research and Development Administration, has pioneered the development of fusion, with RCA, one of its original industrial contractors in the early 1960s. PPPL's Tokamak Fusion Test Reactor (TFTR), now under construction and planned for operation in 1981, is expected to be the first fusion device to operate at reactor-like power densities. It will burn deuterium and tritium, the reference cycle for fusion-power reactors, with the highest reaction cross-section at conditions attainable now. Experimental power reactors are expected to be in operation and producing many tens of megawatts of electricity in about 1985.

* "The Tokamak Approach to Controlled Thermonuclear Fusion," H.W. Hendel, *RCA Engineer*, Vol 23, No. 2, (Aug/Sep 1977) p. 50.

"The Future With Fusion Power," *Mechanical Engineer*, (Apr 1977).

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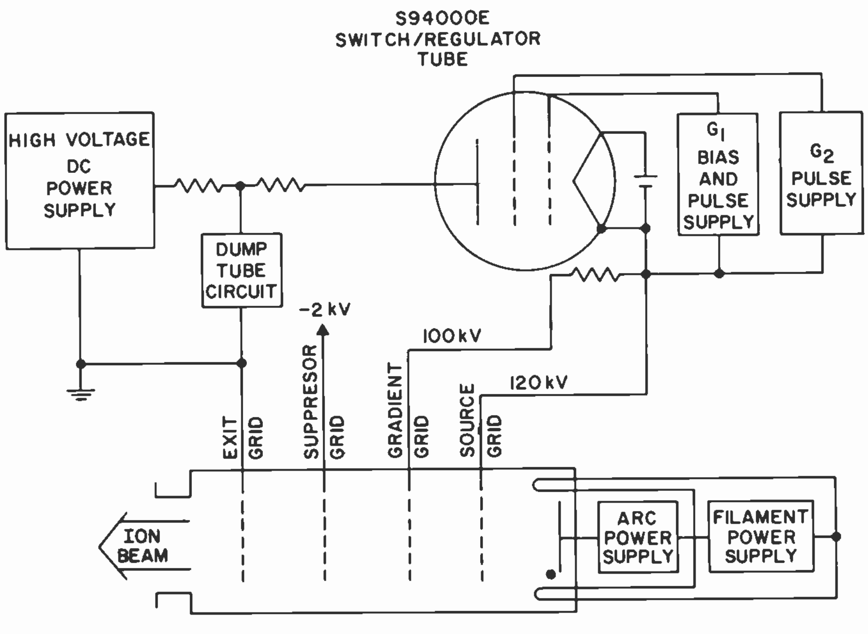

Fig. 1
Simplified diagram of the ion source control circuit.

wire. The wire is mechanically fastened to OFHC copper support rails by notching the rails, laying the wire into the notch, and then peening the notch shut. This operation is done on a lathe and provides good thermal and electrical connection between the wire and the supports.

During tube assembly, the screen grids are brazed together. When mounted, the individual control grid bars are adjusted to align the control grid wire with the screen grid wires. The control grid bars are mechanically fastened to the large support ring with a single screw through an oversized hole. This allows enough movement of the control grid bar for wire alignment with the screen grid. The grid bars are then brazed into position to the inside diameter of the large grid support ring after wire alignment is completed.

Something "new"

The plate structure of the S94000E is of unique design, representing a major advancement in tube technology. Just a few years ago, when long pulse service was discussed, it was interpreted to mean pulse lengths of several milliseconds with duty factors up to perhaps 10 percent. Under such conditions, power tube plate structures had demonstrated good operating life at dissipation levels exceeding 10 kW/cm^2. On the other hand, CW service tubes are generally not operated successfully above about 2-3 kW/cm^2. The application for the S94000E unfortunately strikes an unhappy compromise between the two types of service, i.e., required plate dissipation of the pulse types, but with pulse widths that cause the plate temperature to reach the steady-state condition during the pulse.

The plate structure of the S94000E collects the power at an oblique angle to the electron beam axis. In this manner, the collecting area of the plate is effectively enlarged and the power dissipation reduced to CW levels.

The plate is assembled from individual plate elements shown in Fig. 5. Each element is fabricated by brazing together two identically grooved OFHC copper plates. The braze joints are ribs running longitudinally along the plate. The outside joints form a vacuum-tight seal between the evacuated portion of the tube and the water coolant course. The two inside joints are for mechanical strength. The individual plate elements are brazed to header plates

Fig. 2
The S94000E switch tube.

Fig. 3
The three major S94000E assemblies. From left to right: envelope, plate-ceramic insulator and grid-filament.

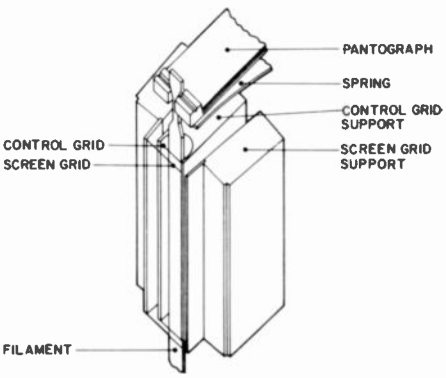

Fig. 4
Unit electron gun structure.

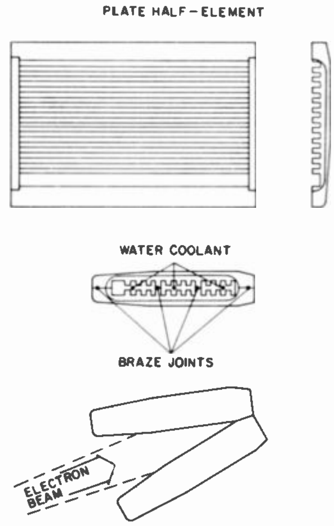

Fig. 5
Plate elements.

at both ends where the coolant ducts are combined. The coolant channel configuration and specified water flow result in an average water velocity in the channels of approximately 25 feet per second.

Even with the area enhancement utilized and the high water velocity, local boiling takes place in the coolant channels toward the end of a two-megawatt, one-second pulse. Because of this, the S94000E is required to operate with the plate terminal up, (water flow up through the plate structure) and the coolant water requirements are stringent in terms of water purity and dissolved gases. In order to control the boiling condition in the plate structure, a minimum back pressure of 20 psi is required at the plate water exit connector.

During the design of the plate structure, computer modeling was used to assess the transient thermal and mechanical behavior. The finite element[4] method of analysis was used to generate a thermal map which was then used to calculate a stress matrix. These calculations indicated that the maximum stresses applied were well below the endurance limit of the material. A small section of the tube (three filaments) was then built and life-tested to verify that the structure would indeed hold up under the equivalent of 2 MW of plate dissipation at pulse widths up to 5 seconds in duration. In addition, a model of the grooved heat exchanger part of the plate structure was subjected to ohmic heating and water cooling tests to insure that the available water flow would be adequate to prevent localized failure of the plate material.[5]

Tube performance

Because of the high voltages employed in the use of the S94000E, x-rays are generated. Measurements indicate that at the tube envelope the intensity exceeds one Roentgen per hour. Because of this, x-radiation shielding is required for personnel protection.

MAXIMUM S94000E RATINGS AT 5 SECOND PULSE WIDTHS

DC Plate Voltage	200 kV
Pulsed DC Plate Current	125 A
DC Grid No. 2 Voltage	1.8 kV
Pulsed DC Grid No. 2 Current	7.5 A
Negative Grid No. 1 Bias Voltage	1000 V
Grid No. 1 Dissipation	10 kW
Grid No. 2 Dissipation	10 kW
Plate Pulsed DC Dissipation	2000 kW
DC Filament Current	4700 A

The transconductance of the tube is approximately 1.6 Mhos, with a screen grid mu of 9 and plate mu of several thousand.

For use at plate voltages below 125 kilovolts, the tube can be operated without pressurization of the plate ceramic insulator. Above 125 kilovolts, the plate insulator must either be immersed in a dielectric fluid or pressurized by a gas for reliable voltage holdoff.

WATER COOLANT FLOW RATES

Coolant Course	*Typical Flow Rate*
Plate	260 gpm
Filament	3 gpm
Filament Ground	2 gpm
Grid No. 1	2 gpm
Grid No. 2	2 gpm

The tube is equipped with a getter ion vacuum pump that provides continuous monitoring of vacuum pressure during tube operation and can be used to restore the vacuum to operating level in the event the vacuum pressure becomes high.

Conclusion

The use of gridded power tubes for controlling the injection power of thermonuclear reactors is an exciting new application. The performance of the S94000E offers extended capability in terms of pulse width and voltage holdoff. The plate structure as it now exists provides operation at increased pulse widths and duty factors including continuous or DC operation.

For future experiments with fusion reactions that require more ion energy, the output structure of the tube provides a firm foundation for scaling to higher voltages that might be required.

Fusion energy is being considered as the hope of the future to replace the dwindling sources of fossil fuels. Predictions are that the electrical needs of the 21st century will be met to a large degree by fusion or hybrid fusion-fission power plants. Experiments to be performed on the TFTR are forerunners to the design of those power plants of the future, and RCA power tubes will play a very important role in the execution of those experiments.

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W.E. Harbaugh|W.A. Novajovsky|R.C. Bauder

"Beam catcher" handles super-high power densities for fusion research

Fusion power requires the dissipation of power levels as high as 20 kilowatts per square centimeter. RCA has done preliminary design and testing for an 8 megawatt beam dump.

Authors **Bauder, Harbaugh,** and **Novajovsky,** left to right.

Will Harbaugh joined the RCA Super Power Tube advanced development group in 1946. In addition to his power tube engineering and managerial duties, he pioneered in the development of a novel heat transfer device (the heat-pipe) which was initially used in conjunction with thermionic devices for the direct conversion of heat to electricity. He is currently a Senior Member of the Technical Staff in the Power Tube Materials and Process Laboratory.

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William Novajovsky joined RCA as an Engineering Trainee in 1952. He participated in high power transmitter development at the Camden plant until his transfer to the Electron Tube Division at Lancaster in 1964. He is currently assigned to the Power Tube Design activity.

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Dick Bauder joined RCA in 1962. From 1962 to 1965 he designed special test equipment for power tubes and photomultiplier tubes. From 1965 to 1968 he worked in color picture tube manufacturing. In 1968 he joined the environmental engineering group and since 1971 has been invólved in finite element analysis.

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Fusion energy is one of the great hopes for the future of our energy-hungry society. The Princeton Plasma Physics Laboratory is expected to make an important stride forward in the pursuit of this virtually inexhaustable energy source by achieving a sustained thermonuclear reaction in the Tokamak Fusion Test Reactor (TFTR) currently under construction at Princeton, NJ.

An important and essential part of the TFTR is the neutral-beam injection system (NBIS),[1] which will increase the temperature of the plasma in the large torus, hopefully, to the ignition point. The process has been likened to a "wet wood burner"[2] where wet wood can be burned if a blow torch is played on the surface. In this case, the blow torch is a very energetic beam of neutral atoms of deuterium. The beam is directed into the "wet wood," a tritium plasma already formed and contained in the large toroidal chamber of the Tokamak machine. As the energetic neutral atoms move through the plasma, they ionize, slow down, and give up their kinetic energy to the plasma, which has already been heated to a high temperature by other means. The addition of the energy from several neutral beams is expected to increase the plasma temperature to something greater than the one hundred million degrees C necessary to ignite a sustained thermonuclear reaction. A diagrammatic view of the neutral-beam system and its relation with the main torus is shown in Fig. 1.

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What does a beam dump do?

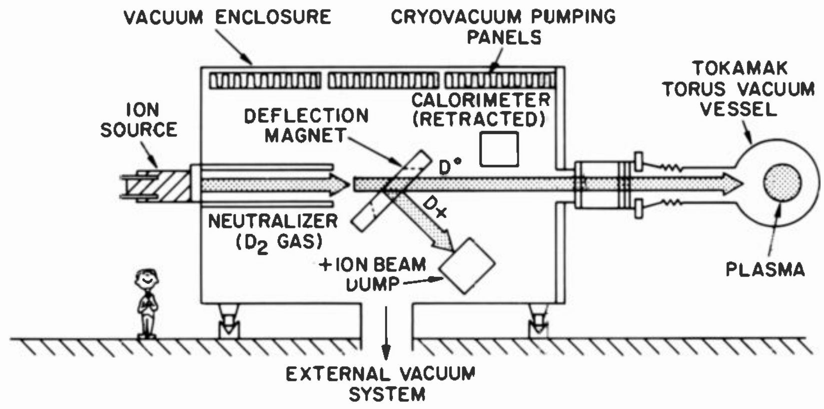


Fig. 1
Neutral-beam injection system directs high-energy deuterium atoms into the tritium plasma in the Tokamak's toroidal chamber, where the fusion reaction takes place. The ion source, far left, produces deuterium ions by electron bombardment. The ion beams then pass through a neutralizer before they enter the torus for interaction with the tritium plasma. However, not all the gas ions are neutralized, and the remaining ions are deflected into the "beam catcher" by a strong magnetic field.

The ion source, at the far left-hand side of the figure, employs electron bombardment to ionize the deuterium fuel gas. The ionized gas atoms are then accelerated to high velocities by a grid structure that is pulsed to a high voltage by RCA developed switch tubes described elsewhere in this issue. The gas ions emerge from the source as three separate beams, each having a rectangular cross-section of approximately 50 cm x 15 cm. The beams then pass through the neutralizer section, where they are deionized by charge exchange to become neutral atoms moving at high velocity. It is not possible to neutralize all of the fast moving ions; in fact, only about 40% of the gas ions are neutralized. Consequently, the remaining ions must be removed, since only neutral atoms will penetrate the strong magnetic field surrounding the main torus.

This ion removal takes place in the "ion dump" section of the neutral beam injection system. A large magnet, set at an angle to the beams, deflects the unwanted ions and turns them towards the ion beam dump. The completely neutral, remaining beam then travels through the calorimeter section before moving out of the neutral-beam injection system and into the torus. The calorimeter is normally pulled up out of the way so it does not interfere with the beam flow. However, at times, the calorimeter will be lowered into a position so that it intercepts all three neutral beams for measuring their energy.

It is to the design of the ion dump and calorimeter that this paper is addressed. Both of the devices, which are usually simply called beam dumps, must dissipate power densities many times higher than that usually encountered in other heat transfer applications. The power density varies across the rectangular beam, but it will be as high as 20 kW/cm^2 near the center of the beam. The closest prior approach to dissipating power densities of this magnitude is found in the design of water-cooled anodes for RCA's large power tubes. For example, the anode of the RCA A3012 switch tube dissipates electron-beam power densities as high as 12 kW/cm^2 by using very intensely water-cooled surfaces set at an angle to the beam. This reduces the incident power density by the sine of the angle that the beam makes with the bombarded surface. In the case of the switch tube, the 12 kW/cm^2 incident power density is reduced to 600 Watts/cm^2 by having the beam strike a V-shaped anode with an included angle of 5°.

Beam dump design

Largely because of their experience and knowledge in the design of intensely water cooled surfaces, the RCA's Power Products Engineering group at Lancaster, Pa., was selected in 1977 to develop heat transfer technology leading to a preliminary design for an eight megawatt beam dump. The work was performed for the University of California Lawrence Livermore Laboratory, which is the agency having the overall responsibility for the neutral-beam injection system for the Princeton TFTR.

There were certain size limitations dictated by the available space for the neutral-beam injection system. Both the calorimeter and the ion beam dump must be removed from the NBIS through manholes for periodic maintenance. Preliminary design analysis indicated that for the space available, the beam-smearing technique used in the RCA switch tube could be employed to reduce the 20 kW/cm^2 beam power density to an incident power density of 2 kW/cm^2. The beam dump had to dissipate this power during 1/2-second-long pulses which occured about once a minute. The beam dump must be able to withstand at least 5,000 pulses.

With the ground rules set, a team of engineers and technicians at Lancaster began the program to develop the required heat sink technology. The program had three phases. In the first phase, a finite-element computer program model was used to study the heat dissipation characteristics of several potential heat sink surfaces. An experimental program carried on at the same time provided valuable inputs to the computer model as well as providing data on some aspects of heat transfer that could not be modeled for the computer.

In the second phase, an experimental model was constructed to confirm the heat dissipation characteristics of the heat sink configuration found best in Phase 1. The model consisted of a high-power vacuum diode in which the anode was the heat sink under test. Electron bombardment was employed to test the heat sink up to power densities of 3 kW/cm^2 during 1/2-second pulses.

In the final phase of the program, the engineering information obtained in the first two phases was used to generate a preliminary design of a complete beam dump assembly capable of dissipating the entire eight megawatts from the neutral-beam source.

A brief review of the work performed and the results obtained in each phase of the program is detailed in the following paragraphs.

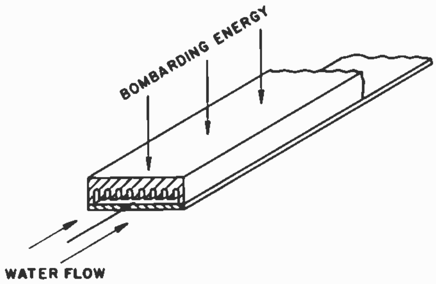


Fig. 2
Best thermal dissipation characteristics were found with this fin configuration. Basic element studied was 1 cm wide and 30.5 cm long.

Computer analysis and critical heat flux tests

Based on previous power tube anode design experience, five candidate heat sink configurations were selected for evaluation as high-power-density dissipators for beam-dump service. All of the elements considered were flat on the bombarded side and had integral longitudinal fins on the opposite side where water flows at very high velocity, usually between fifty and one hundred feet per second. The variation in heat sink elements centered around different fin and water passage designs. Fins of square, rectangular, and triangular cross-sections were evaluated along with variations in the free-flow water passage at the fin tips. The design which showed the best thermal dissipation characteristics, and the one chosen for later experimental tests, is shown in Fig. 2.

For both computer analysis and the experimental tests, the basic element studied was of oxygen-free, high-conductivity copper (OFHC) and had dimensions of 1 cm wide by 30.5 cm long. The length was deemed adequate by UCLLL (even though the final neutral beam may have greater dimensions), since the power density is more concentrated near the center of the beam.

Two-phase-flow cooling theory

The elements for the beam dump are cooled by two-phase (liquid and vapor) flow cooling sometimes called "subcooled nucleate boiling."[3] In this mode of cooling, high-velocity water is introduced below its boiling point (subcooled), and as steam bubbles nucleate and form at the metal/water interface, they are rapidly swept out into the water where they condense, giving up their latent heat of vaporization. The steam/water mixture then moves rapidly out of the device before the water gets to full boiling temperature. This cooling mode can best be appreciated after a brief introduction leading from pool boiling to forced convection cooling with two phase flow.

Fig. 3 shows a plot of log(Q/A), the heat flux in Watts/cm^2 versus log(T_w-T_s), where T_w is the wall temperature of the cooled surface at the metal-water interface and T_s is the boiling point or saturation temperature of the water. In the lower portion of Fig. 4, curve A-E shows the cooling regime when a body is heated in a still pool of water. As the heat input is increased, natural convention currents in the water result in the cooling of the test item along curve A-B. At point B, nucleate boiling begins, with more bubble sites activated as progress is made toward point C. Point C is called the critical heat flux since at this point the bubble generation is so profuse that water cannot get to the heated surface. The temperature of the surface will then jump to point D, which, if it is above the melting point of the surface material, may cause "burn-out." If the surface material has a high melting point, the process will proceed toward point E. Some additional cooling occurs because radiation becomes a factor, but, in general, burn-out usually occurs above point C.

The upper curves in Fig. 3 show the behavior of a body which is cooled by forced convection, the type of cooling used in the beam dump elements. The two curves labeled V_1 and V_2 are for two different mass velocities; V_2 has a greater velocity than V_1. With increasing heat flux, the region of forced convection begins a transition at point 1, where boiling begins. Boiling increases between points 1 and 2 until at point 2, the transition is complete and boiling is fully developed. Operation can proceed at heat fluxes above that required for fully developed boiling until point 3, the critical heat flux, is reached. At this point, the cooled surfaces will become dry and the temperature will rise rapidly until burn-out occurs.

The dry wall and burn-out usually start where the water exits from the heated zone because it has been heated to the maximum temperature at this point. This makes long heated members more susceptible to burn-out than short ones, a major difference between high-power tube anodes, where the cooled length is relatively short (about 4 inches), and the beam dump elements, which are required to be 20 inches long. The curves in Fig. 3 are for a constant exit pressure. If the pressure is increased, the burn-out heat flux will increase, since T_s will increase, giving a lower T_w-T_s. This phenomenon is used in the design of the beam dump to good advantage. In tests which will be reported later, a marked improvement in cooling capability was obtained by increasing the system back pressure.

Computer analysis

A finite-element computer model was employed as a design aid in several aspects of the beam dump development effort. The finite-element method determines a structure's thermal mechanical behavior by dividing the structure into small, imaginary elements. The behavior of each element with respect to its mechanical strain and

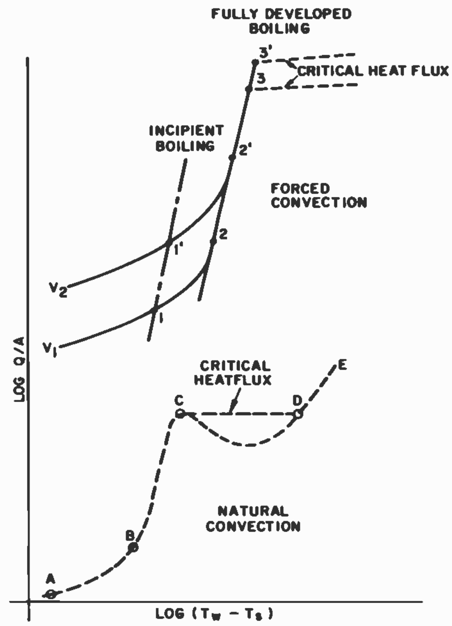
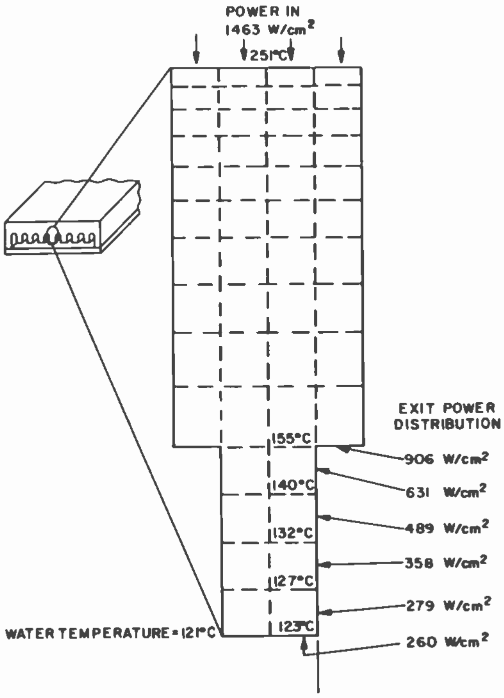


Fig. 3
Liquid-vapor cooling uses the latent heat of vaporization to cool the beam dump. Curve A-E is for natural convection; boiling begins at point B. Bubble production and cooling increase until point C, the critical heat flux. There bubble generation is so profuse that water cannot reach the heated surface, so the temperature jumps to point D. If D is above the surface material's melting point, "burn-out" will occur; if not, radiative cooling takes the curve toward E. The sets of curves are, bottom to top, for still water, low-velocity water, and high-velocity water.



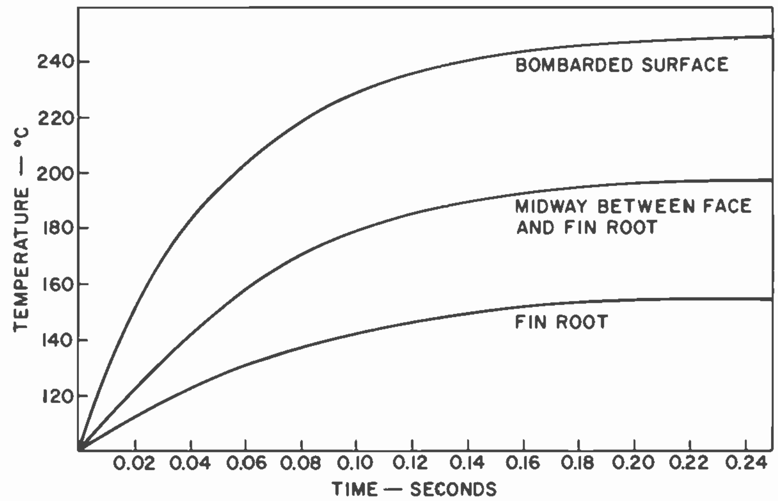


Fig. 4 (left)
Finite-element analysis for the fin structure chosen for the beam dump assembly.

Fig. 5 (above)
Transient analysis showed that the beam dump could take a 1.5 kW/cm² power input and reach a steady thermal state in 0.25 second.

thermal conductivity can easily be determined using classical theory. Joining the patchwork of elements requires a large computer with special hybrid matrix-handling routines. The finite-element code ANSYS was used because of its capability of solving nonlinear and transient thermal stress problems. A brief review of the results of the computer analyses follows:

Configuration Selection. The ANSYS program was an aid in selecting the optimum fin configuration for the heat-transfer surface. Each fin configuration studied was considered as a conduction element with heat input on the flat side and heat removal from the fins at constant water temperature. The convection film coefficient at the fin surface was taken from the work of Dormer and Bergles.[4] The fin configuration most desirable has the lowest heat transfer and temperature in the root area. Fig. 4 shows the results obtained on the fin structure chosen for the final beam dump design.

Transient analysis. Transient thermal solutions were obtained on the various fin configurations to determine whether they would reach an equilibrium temperature during the 0.5 second pulse of beam power. Fig. 5 shows the results of the transient analysis on the chosen fin configuration. The data reveal that in three locations throughout the body of material, equilibrium temperatures are reached in 0.25 second. Thus, the beam dump heat sink will reach steady-state temperature during every 0.5 second pulse. For this reason, the beam dump has often been referred to as a "water-cooled D.C. heat sink;" the final report written on this project used this title.

Stress analysis. The ANSYS computer program was also very valuable in determining the mechanical stress patterns encountered in the heat sink members. For instance, the copper heat sink elements are brazed to a stainless steel backing plate to form a complete water-tight element. Copper and stainless steel have similar coefficients of thermal expansion, so the brazes can be made with little resulting stress. However, under beam bombardment, the surface of the copper member heats and expands, causing considerable internal stress and rather high stresses at the copper-stainless steel joint. Thus, it was found necessary to provide additional strain isolation between these members in the construction of the test diode. Fig. 6 shows a typical heat-sink stress pattern with an input power density of 2.0 kW/cm² and an internal water pressure of 250 pounds per square inch.

Critical heat flux tests

As noted previously, there were insufficient computer inputs or data from the literature to predict the onset of nucleate boiling or the eventual critical heat-flux limit. For this reason, an experimental system was constructed to determine the operating parameters of actual heat sink members under conditions of high heat-flux input. The system consisted of a replica of the heat sink member, which was heated by passing current through it, and cooled by

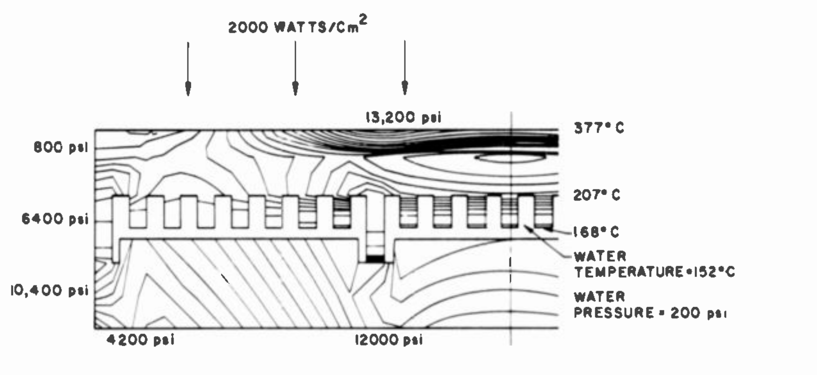


Fig. 6
Stresses are high at the copper-stainless steel joint on the heat sink, but test elements passed life tests.

internal water flow. Power input, back pressure, and water flow were controlled and measured. A differential pressure transducer across the heat sink element was the prime sensing device to indicate the onset of nucleate boiling and critical heat flux.

All five configurations were tested and evaluated in the critical heat-flux test apparatus. The tests were run by keeping the water flow and exit pressure constant and then increasing the power in discrete steps while observing the pressure drop across the test section. In all cases, the pressure dropped as the water was heated and became less viscous. At some level of power input, nucleate boiling began and the pressure started to rise. The maximum safe heat flux was deemed to be the point where the pressure drop at maximum power was equal to the original adiabatic pressure drop. This can be seen in Fig. 7, which is a plot of the pressure drop ratio versus input heat flux for the chosen fin configuration. The advantage of high back pressure in delaying the onset of nucleate boiling is obvious in this figure. The safe heat-flux level occurs at 1600 W/cm^2 at a back pressure of 33 lb/in^2, but at a higher back pressure of 93 lb/in^2 the safe heat flux has increased to nearly 2200 W/cm^2 for the same water flow.

The critical heat-flux experiments were very valuable in determining the cooling capacities of the five configurations under study at various power inputs, water velocities, and back pressures. These tests supplied data which were not available in the original computer model but can now be used to improve the input data for future computer programs.

Testing the heat sink design

Based on both the finite-element computer data and the results of the critical heat-flux tests, the most promising fin-structure configuration was selected for electron-bombardment tests in a vacuum test model. The test model consisted of a large high-voltage vacuum diode which used the heat sink element under test as its anode. The test model diode was designed to operate from a large dc rectifier which had a capability of 40 kV and 50 A. Two RCA A15034 switch tubes with suitable grid pulsing were used to turn the diode on and off at the desired pulselength and repetition rate. An 8 gal/min, 800 lb/in^2 water system was employed in the anode circuit of the test diode. Bombarding current and anode voltage were used to measure the power input to the heat sink element.

The tests were conducted by setting the water velocity to 90 ft/s through the test element and then gradually raising the input power until the desired heat input level to the anode was reached. The contract with UCLLL called for testing the heat sink element at a heat-flux input of 2.0 kW/cm^2 for a series of 5000 pulses. After some initial problems with arcing were solved by improving the vacuum environment, this objective was met. Table I shows a summary of the tests conducted and the results obtained. After the initial requirement was met, the power input was increased 30% to a level of 2.6 kW/cm^2 and the device was operated for 1000 additional pulses. In other tests, the operating pulselength was increased to as high as 4.8 seconds at 2.0 kW/cm^2 and the power input was increased to 3 kW/cm^2 at the normal pulselength of 0.5 second.

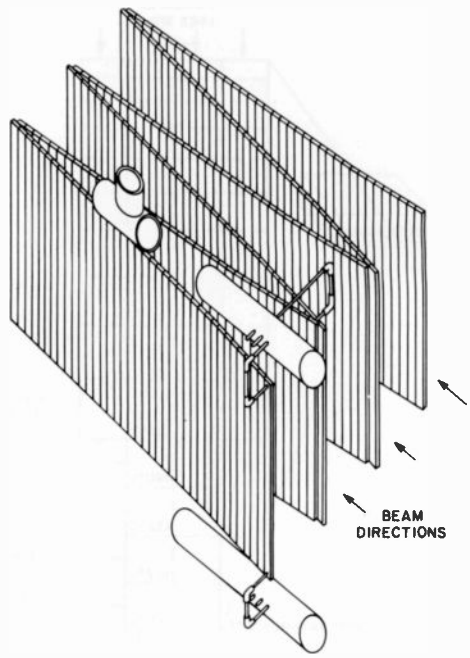


Fig. 8
Preliminary design uses three troughs to catch the three 15 cm by 50 cm rectangular ion beams. Each trough is made of 75 channeled elements connected to 4 inch diameter cooling-water manifolds.

In a final series of tests, the water flow through the test element was reduced in discrete steps to determine where destruction would occur. As it turned out, at water velocities as low as 35 ft/s, no deleterious effects occurred. When the velocity was finally lowered to 25 ft/s, the steam formation became so great that the back pressure rose drastically and the water flow tended to cut off. Even though destruction of the heat sink did not occur, it was decided to stop the tests so the device could be removed, disassembled and analyzed. The analysis showed that no serious damage had occurred to the heat sink element during any of these tests. There was, however, some minor grain separation on the bombarded surface, caused by cyclic heating and cooling of the copper member.

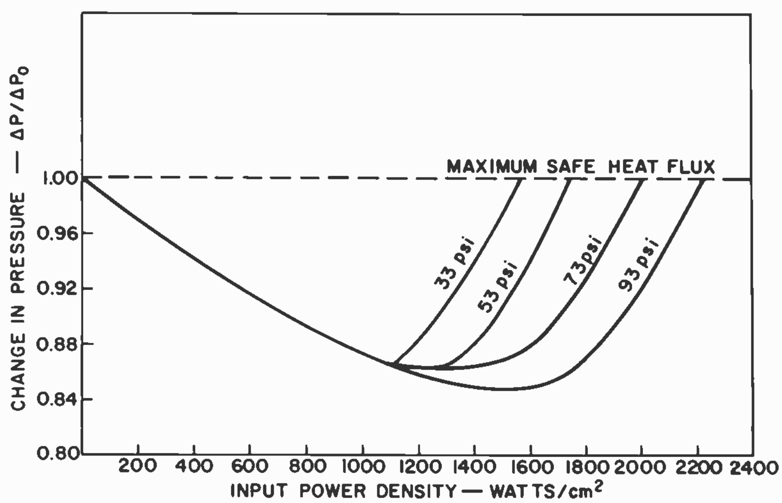


Fig. 7
Pressure drop in cooling water has significant effect on cooling. High back pressure delays the onset of nucleate boiling and thus increases the safe heat flux level.

Heat sink preliminary design

The extensive and successful testing of an internally finned water-cooled heat sink

Table I
Summary of test conditions.

	Power input (Watts)	*Power density ($Watts/cm^2$)*	*Water flow (gal/min)*	*Water velocity (ft/s)*	*Pressure drop (lb/in^2)*	*Back pressure (lb/in^2)*	*Pulse length (Seconds)*	*Number of pulses*
Life test	61,000	2050	5.3	90	342	60	0.5	5000
High-power life test	78,000	2630	5.3	90	345	60	0.5	1000
Long-pulse test	63,190	2130	5.3	90	342	61	1.0	100
Extra-long-pulse test	61,030	2059	5.3	90	341	60	4.8	148
Extra-high-power test	88,000	2966	5.3	90	341	60	0.5	100
Low-water-flow tests	68,380	2305	4.0	68	212	60	0.5	12
	59,580	2008	2.97	51	131	60	0.5	50
	60,910	2053	2.48	42	100	60	0.5	11
	60,650	2044	2.1	35	80	62	0.5	7
	60,526	2040	1.5/1.2	25/20	53	62/90	0.5	10

gave confidence that this design would be satisfactory for use in a calorimeter or ion beam dump for the TFTR neutral-beam injection system. As shown in Fig. 8, a preliminary design of a complete heat sink was generated; it used three wedge-shaped troughs to catch the three beams emanating from the source and neutralizer. Each trough, which is a collector for a 15 cm by 50 cm rectangular beam, is made up of 75 long channeled elements connected at each end into 4 inch diameter water header manifolds. The three headers on the inlet end of the assembly are connected to a single 6 inch inlet connector. Three inch outlet lines are connected to the three outlet headers, and there is a valve to maintain back pressure on each of the outlets.

To make the best use of the available space, and take advantage of the expected variation in power density over the surface of the collector, the channeled elements are set at two different angles with respect to the beam axis. The higher-power density part of the beam in the center region will hit elements that are at an angle of 5.5°. These elements will then see about 2.0 kW/cm^2 of power density during the pulse. The outer part of the beam will have a reduced power density of approximately 1.3 kW/cm^2. This part of the beam will hit elements set at 8.5° to the beam axis. The collector elements, then are positioned at 5.5° and 8.5° to the beam axis. However, the sections lie in planes which are at 5.0° and 8.0°, respectively. This provides an offset, as seen in Fig. 9, which shields the leading edge of each collector from the beam. The entire structure is attached to a supporting framework; the complete assembly will weigh approximately 1400 lb without coolant. Inlet coolant pressure will be 280 lb/in^2, back pressure will be 60 lb/in^2, and the water flow requirement is 1800 gal/min.

Summary

This development program has been successful in demonstrating that an OFHC copper heat sink, cooled by high-velocity, high-pressure water, can continuously dissipate a power density of 2.0 kW/cm^2 as required for a neutral-beam ion dump or calorimeter. This level of power density was demonstrated during 5000 pulses of one-half second duration. Even higher power densities and longer pulse lengths were obtained during a series of related tests.

The main problem area noted during the tests was that certain physical changes had taken place in the copper heat sink when repetitively bombarded at high heat fluxes. The bombarded surface showed evidence of grain separation and incipient cracking due to cyclic thermal stresses. A material study should continue to evaluate dispersion-strengthened copper, tungsten-faced copper, or other potential solutions to the surface cracking problem.

However, even if no better material is found, it has been demonstrated that OFHC copper will operate at record dissipation densities and still provide a beam dump/calorimeter with reasonable operating lifetimes.

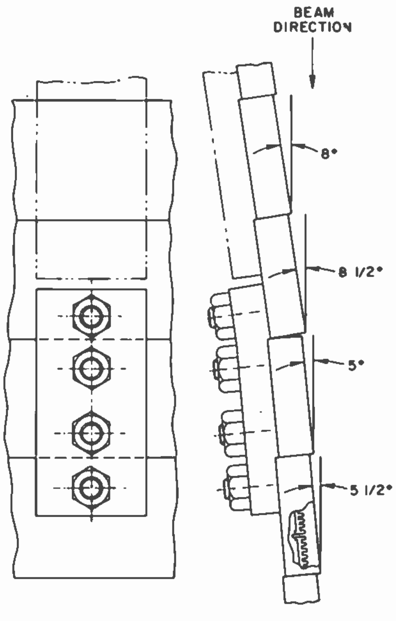


Fig. 9
Two angle collector design saves space and takes advantage of power density variation. High-power density of beam will strike elements set at 5.5° to beam; lower power density elements will hit elements set at 8.5°. Half-degree offset shields leading edges of collectors.

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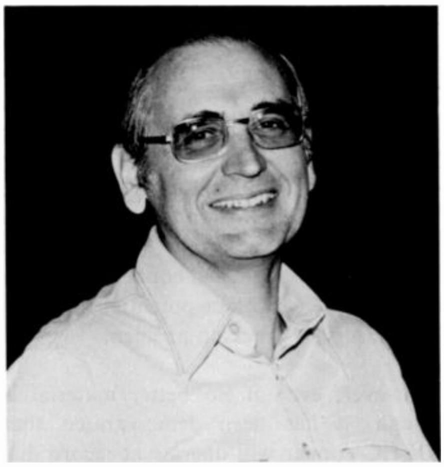
G.N. Butterwick

Oil exploration with photomultiplier tubes

Oil-exploration geologists send photomultiplier-based probes miles down bore holes to "look" at potential oil-holding rock formations.



Gil Butterwick joined RCA Lancaster in 1958. In recent years he has devoted his time to the development of various cathodes, which include silicon cold cathodes, group III-V photocathodes, and alkali photocathodes. His current efforts are directed toward the establishment of stable high-temperature photocathodes in PMT's used in oil-well logging.

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The growing demand for petroleum products has placed increasing emphasis upon the need for improved oil-exploration techniques. As the supply of easily obtained oil dwindles, exploration has had to move to more remote geographical areas and deeper fields. Thus, the search is now more difficult and expensive, and the methods of determining the location, size and yield of an oil field must be reasonably accurate. This degree of accuracy is obtained by means of various oil-well logging techniques.

Logging techniques

Logging is the term given to the method of determination of the mineral composition and structure a few miles under the earth's surface. The function is provided by oil-well logging companies that gather data by means of probes, or sondes, that examine the geological media along very deep bore holes. The probes determine various physical and chemical characteristics of the material in their vicinity; measurements made by them comprise the log.

A variety of sondes are used in selected combinations to determine various aspects of the lithology (the character of a rock formation), including density, of the media along the bore hole. The combinations of sondes used depend very much on the bore-hole media. For example, when a formation-density sonde, the sonde with which we will be most concerned in this paper, is used in combination with a neutron sonde in liquid-filled bore holes, both lithology and porosity can be determined. The same pair of sondes allows the measurement of gas and liquid saturation in bore holes drilled through reservoirs of low-pressure gas. The use of the formation density sonde, along with either an induction or a sonic sonde, permits a similar type of determination. The final result of the logging activity is information concerning the existence of hydrocarbons and other geological media of interest in establishing an oil field.

Formation-density sonde

The formation-density sonde is one of the more sophisticated logging devices. Its operational elements are encased in a rugged cylindrical housing, as shown in Fig. 1. It is designed to withstand the high temperature and shock encountered in probing bore holes miles deep under the earth's surface. The sonde contains a gamma-ray source, such as radioactive cesium 137, a detector consisting of a sodium iodide crystal and a photomultiplier tube, a gamma-ray shield for the detector, a pressure foot that presses the sonde against the bore-hole wall, and operating electronics. The objective of this sonde is to determine the bulk density of the material in the region of the probe.

The principle of operation of the formation-density sonde is based upon the modes of interaction between gamma rays and atoms in the geological medium; this mode depends upon a phenomena known as the Compton effect, which is explained briefly below. The specific factors involved are the gamma-ray mass absorption coefficients for the materials near the probe (the mass absorption coefficient of a

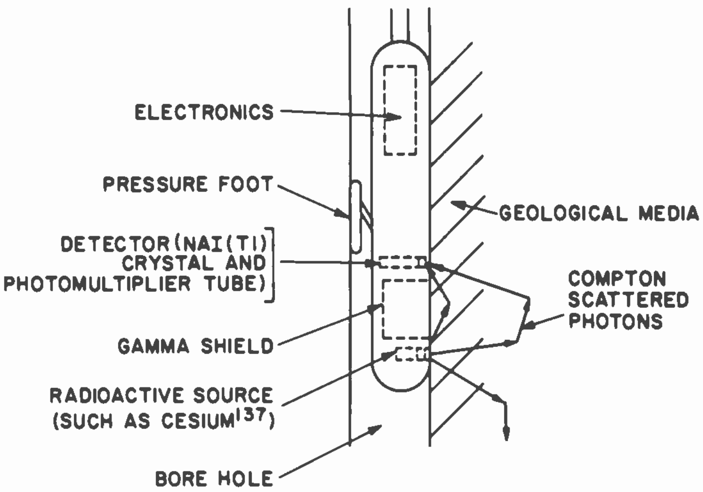

Fig. 1
Formation-density sonde works by sending gamma rays into rock formation, then detecting returns with photomultiplier.

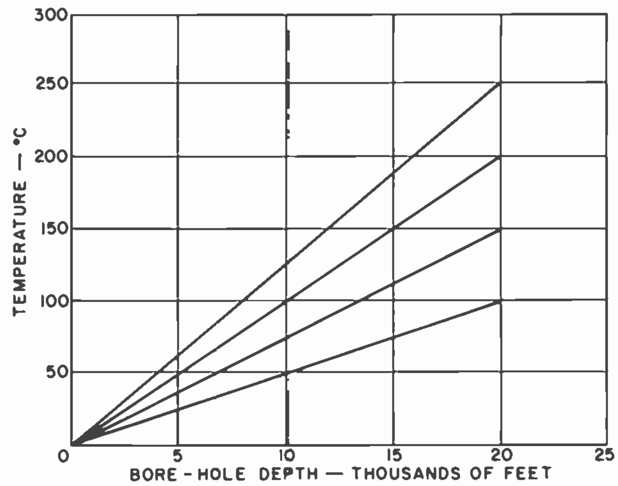

Fig. 2
Depth-temperature geothermal gradient chart shows temperature at which photocathodes must be able to work.

material depends on its density). Hopefully, for the oil man, these materials will include limestone (calcite) and sandstone (quartz), two minerals of great interest in oil-field establishment.

Sonde operation

Referring to Fig. 1, gamma rays from the cesium 137 source enter the medium surrounding the bore hole, and interactions occur among the gamma rays and orbital electrons in the atoms of the crystals comprising the medium. The interactions impart energy to the electrons and redirect or scatter photons of lower energy than the incident gamma ray in directions different from that of the incident ray (the Compton Effect)[1]. It is these scattered photons (called Compton photons) that are detected by the NaI (Tl) crystal of the sonde, which converts them to luminous scintillations. The luminous scintillations are then detected and converted into electrical pulses, which represent Compton photon energy data, by the photomultiplier tube. A knowledge of gamma-ray penetration of bulk media, mass absorption data, and the special effects resulting from the chemical nature of various geological media allows the information imparted by the pulses to be deciphered by the electronics into bulk-density data, which becomes the substance of the geological formation-density log.

Other modes of gamma-ray interaction, such as pair production and photoelectric effect, lie outside the energy range of interest and do not interfere with the counting of Compton scattered photons. In addition, lower level pulse-height discrimination is applied to the photomultiplier-tube output pulses so that only Compton-scattered-photon energies are counted, i.e., only electrical output pulses that characterize the media which is being examined are counted.

The photomultiplier in the sonde

Temperature

As described above and shown in Fig. 1, the photomultiplier tube is part of the detector. An important functional role of the detector is the provision of a predictable gamma count over a wide temperature range. Fig. 2 is a depth temperature geothermal gradient chart which shows the temperatures that might be encountered in bore holes, temperatures that the photomultiplier, particularly its photocathode, must be designed to accept.

Dr. A.H. Sommer of the RCA Laboratories was first to discover the higher quantum efficiency of multialkali photocathodes:[2] Na_2K Sb (the material in use in the photomultiplier in the sonde), (Cs) Na_2K Sb, and K-Cs-Sb. The K-Cs-Sb (or bialkali, as it is commonly known) has the highest blue sensitivity, and the (Cs) Na_2K Sb photocathode has broad-band sensitivity, and the Na_2K Sb photocathode lies somewhere between these two. That is, it is slightly lower in blue sensitivity than the bialkali and has less broad-band sensitivity than the multialkali (Cs) Na_2K Sb. As a result, it was initially considered rather useless as a photocathode. However, while experimenting with cathode stability during the late 1960s, A.F. McDonie (RCA-Lancaster) found an unexpected high-temperature stability in the Na_2K Sb photocathode.[1] His further work with this cathode material resulted in photomultipliers with functional capability to 200°C, and tubes having the Na_2K Sb photocathodes became natural selections for oil-well logging operations.

The current Na_2K Sb photocathode has a sensitivity characteristic with temperature as shown in Fig. 3. In spite of the loss in sensitivity with increasing temperature, pulse counts can be obtained in operation to 200°C. In addition, tubes with Na_2K Sb photocathodes can be cycled many times into this high temperature range with only gradual degradation of the photocathode. At the present time, as shown in Fig. 4, the photocathode of the photomultiplier tube is the primary limitation on the depth to which a sonde can be used because it is currently not capable of satisfactory operation at a temperature above 200°C.

Pulse height

The dependence of pulse height on temperature, Fig. 4, agrees with the photosensitivity data, indicating that the effect is primarily photocathode dependent and relatively independent of tube geometry and gain. As the temperature increases, the magnitude of the output pulse decreases because of a decrease in

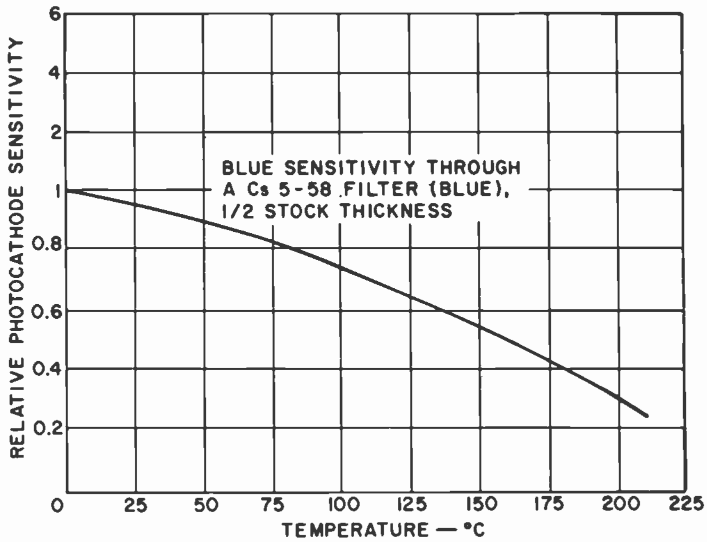

Fig. 3
Sodium potassium bialkali (Na_2KSb) photocathode sensitivity as a function of temperature.

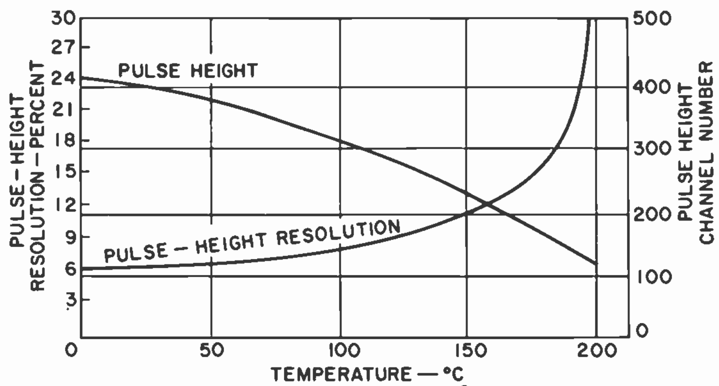

Fig. 4
Pulse height resolution and pulse height as a function of temperature in a typical high-temperature photomultiplier tube.

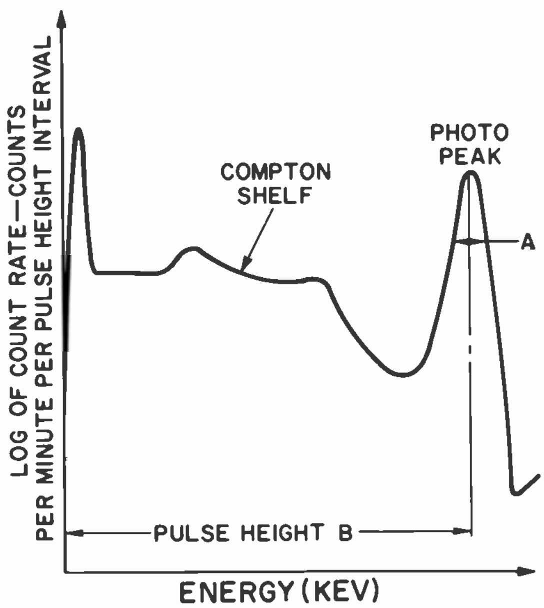

Fig. 5
Distribution of pulse heights observed in a scintillation counting experiment using gamma rays from a cesium 137 source to excite a sodium iodide (NaI(T1)) crystal.

photocathode sensitivity and crystal scintillation efficiency. At the same time, thermionic emission from the photocathode increases until, at a temperature near 200°C, the desired signal is lost in the background thermal noise.

A typical pulse-height distribution curve obtained with a cesium 137 source and an NaI (TI) scintillation crystal is shown in Fig. 5. The photopeak of the curve (662 keV) is associated with the monoenergetic gamma rays of cesium 137, which lose all of their energy by photoelectric conversion in the crystal. The intermediate shelf represents absorption of Compton scattered photons. The pulse-height distribution in the formation-density-sonde detector crystal differs from that shown in Fig. 5 because the primary gamma rays are not seen by the crystal, only the Compton scattered gamma rays from the media surrounding the bore hole.

The following formula is used to determine pulse-height resolution for the 662-keV photopeak of Fig. 5: Pulse-height resolution in percent is 100 times the ratio of the width of the photopeak at half the maximum count rate in the photopeak height (A) to the pulse height at maximum photopeak count rate (B).

Plateau test

The scintillation-crystal photomultiplier-tube detector in the formation-density sonde provides an accurate gamma-ray count until high-temperature washout occurs. Before this washout begins, a lower-level energy discriminator permits only higher energy pulses to be counted. Fig. 6 shows a set of curves indicating count rate as a function of voltage; this type of curve is called a plateau curve.

The region in which a relatively constant count can be obtained from the photomultiplier in spite of changes in sensitivity, noise, and voltage is called the plateau range. The plateau characteristic is determined in the lab by using a light-emitting diode (LED) operating in a pulsing mode to simulate a cesium 137 source and NaI scintillation crystal. The configuration of the test is shown in Fig. 7.

The two (LED) plateau curves shown in Fig. 6 illustrate the effect of temperature. The 175°C plateau curve starts at a higher voltage (gain) than the 23°C curve because of the lower cathode sensitivity at that

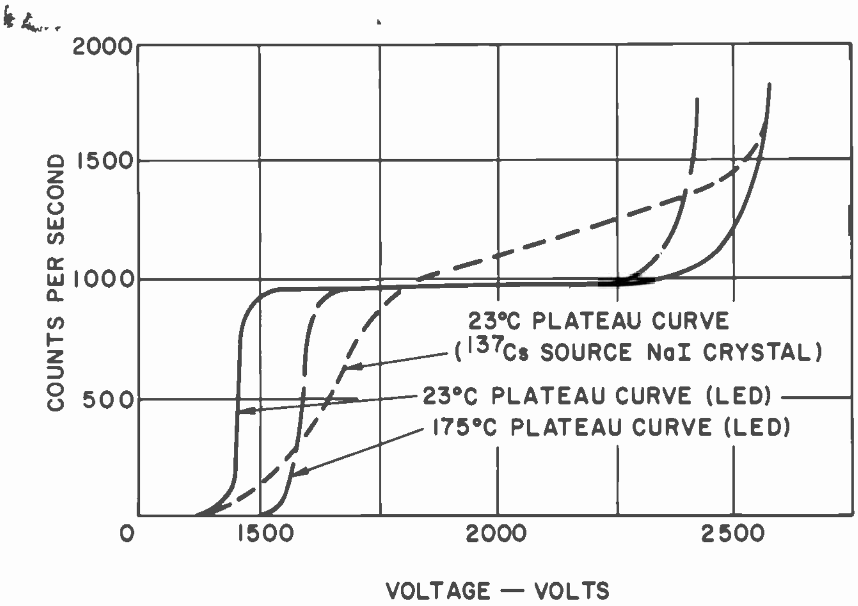

Fig. 6
High-temperature photomultiplier tube plateau curves.

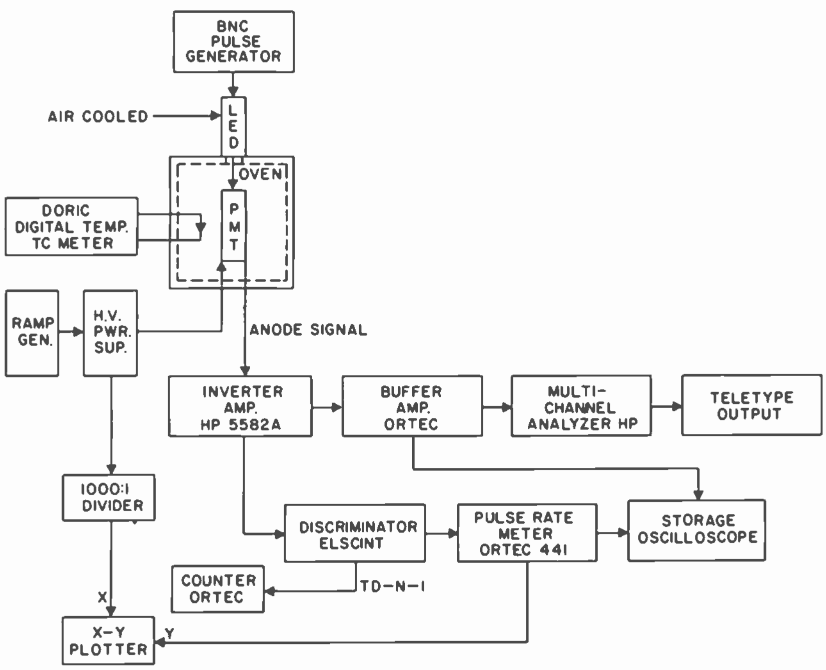

Fig. 7
Instrumentation for measuring high-temperature photomultiplier tube plateaus.

temperature. Count washout also occurs at a lower voltage because of the higher thermal-noise level. If the tubes were operated at 2000 volts, the count rate would remain constant through the temperature range indicated. The third curve shows the effect of the count rate derived from the detector in the formation-density sonde. The spread of scintillation energy accounts for the slope changes.

Conclusion

Because the photocathode material limits the depth at which a density log can be made, current developmental effort is directed toward the design of a tube having a photocathode with sensitivity stability and low thermal emission at higher temperatures; the limits of these two factors are determined by the tube's basic materials, cathode activiation, and stabilization techniques. The Na_2K Sb photocathode provides this capability at present, but only to 200°C.

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Acknowledgments

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R. Denning|J. White

New technologies advance power semiconductor state-of-the-art

Improved manufacturability, performance, reliability and adaptability are features of a new series of discrete high voltage power devices.

Silicon power devices are now taking on new dimensions in performance. Ion implanted diffused junctions, polysilicon field shields, glass passivation, moated planar junctions, aluminum titanium nickel metallization, and high lifetime wafer processing are some of the advanced technologies that are responsible.

A discrete, high voltage NPN silicon transistor has been designed, developed and manufactured using these new technologies. The application for this high voltage device is primarily horizontal deflection circuitry. Operating characteristics—voltage, current, speed, and energy—cover a wide breadth of capability to service a market of over 20 million devices per year worldwide. The design is also applicable to many other high voltage, high speed switching circuits.

Several high voltage transistors had been well entrenched in this market since the late 1960s, primarily from Hitachi, Toshiba, Sony and Texas Instruments. To be competitive, any new technological approach had to show considerable improvement in the areas of:

1. Manufacturability
2. Performance
3. Reliability
4. Adaptability

Manufacturability means the efficient use of materials and processes that can be specified and controlled with a high degree of precision and reproducibility. Maximum yield with minimum labor is the ingredient necessary to spell out peak production efficiency and low cost.

Performance. The design must serve a large, broad market in the field of high voltage switching, that requires: above 1500 V breakdown, current gain up to 10 amps., switching speed optimized for rise, storage and fall time, and forward and reverse energy satisfactory to handle overstresses in these high voltage circuits.

Reliability. The horizontal deflection application requires high stress voltage, current, temperature and energy performance from the device. Mechanical integrity, such as minimal thermal fatigue under operating conditions and the ability to withstand thermal shock and temperature cycling, is necessary for reliability in the electrical and mechanical environment. The device must also pass stringent high voltage, high temperature reverse bias stress testing to insure low failure rates in the field.

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Joseph White joined RCA in 1962 and has worked in the areas of surface effects and passivation, air and dielectric isolation processes, GaAs bipolar and field effect transistors, linear power integrated circuits, high conductivity metallization systems, high voltage multi-stage Darlingtons, and hybrid circuit technology. He is currently a senior member of the technical staff in the Advanced Power Laboratory of the David Sarnoff Research Center where he is working on the development of high voltage devices and monolithic power integrated circuits.

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Adaptability. In modern semiconductor manufacturing, device assembly has to be accomplished under a variety of conditions, generally at a location separate from the pellet fabrication plant. The chip should be capable of being completely characterized at the finished wafer stage and then mounted in various type packages—hermetic for maximum reliability, plastic for low cost, and finally, in hybrid circuits for special applications—without shifts in electrical parameters.

Power transistor technology update

The semiconductor industry is characterized by extremely rapid technological growth. A large part of this is aimed at the rapidly growing large scale integrated circuit (LSI) business, where increasing circuit and process complexity require technological improvements to maintain high yield and achieve cost-effectiveness. Where possible, some of these LSI techniques were utilized in the design of this new high-voltage transistor to improve yield, performance and parameter distribution control. In addition, recent developments[1] in the discrete device field were incorporated in the design to improve reliability and manufacturability.

New technologies have benefited high voltage power devices in the following areas:

Neutron doping

The voltage and current performance of a high voltage transistor is critically dependent on the crystal resistivity in the N-collector region of the device. Some of the important design considerations are discussed in Section III. Conventional N-type float zone crystal growing techniques tend to produce large variations in doping levels due to the low distribution coefficient of the N-type dopant (phosphorous) and the varying thermal equilibrium conditions at the growth interface.

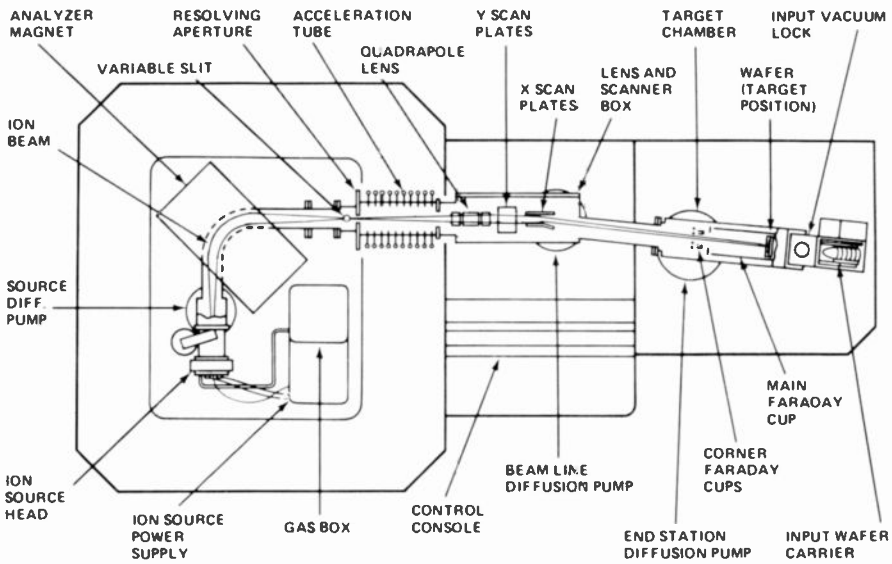


Fig. 2
Basic ion implantation machine.

Phosphorous doping by thermal neutron transmutation[2] is a doping technique in which a flux of thermal neutrons is irradiated on a high resistivity undoped single crystal to fractionally transmutate silicon into phosphorous as shown in Fig. 1. The crystal is subsequently annealed to remove radiation-induced defects in the lattice. The technique is cost-effective at low doping levels below $\sim 1 \times 10^{14}/cm^3$ ($\rho > 50\ \Omega$ cm) producing wafers in production quantities with resistivity variations less than 10 percent.

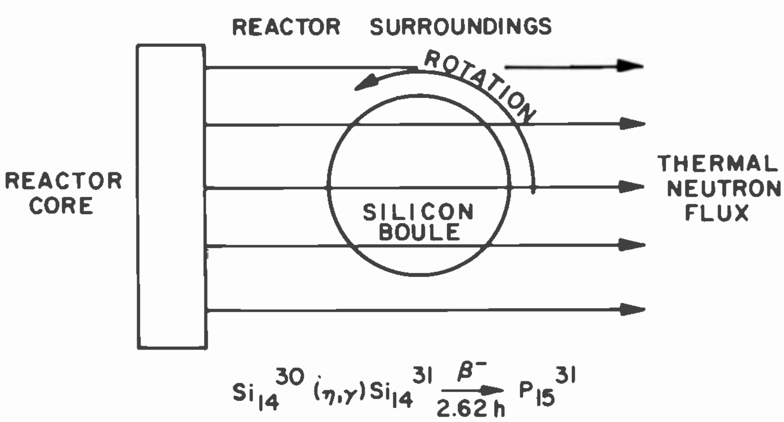


Fig. 1
Phosphorous crystal doping by thermal neutron irradiation.

Ion implantation

Control of base and collector doping profiles is also an important aspect of transistor processing. The use of ion implantation for obtaining precise doping levels for the base and collector diffusion sources has eliminated critical high temperature chemical deposition processes resulting in better yields and tighter parameter distributions. A schematic of a basic Varian/Extrion ion implant machine (Model 200-DF4) is shown in Fig. 2. The machine provides simple electronic control of the incident beam of doping ions. Mass analysis is used to assure extreme purity of the ion beam. Doping accuracy is better than one percent compared to about 10 percent for typical chemical processes. Recently, high current machines have become commercially available, providing sufficient capability for most power device doping.

Diffusion process

The diffusion process developed for production of these high voltage transistors contains only two diffusion steps as shown in Fig. 3. The base and collector regions are diffused simultaneously from both sides of the wafer. This high temperature (1300°C) process forms the basic high-voltage diode

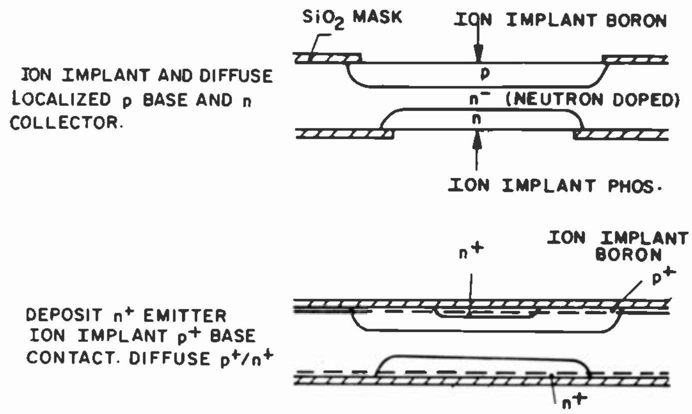


Fig. 3
Simplified diffusion process.

structure. The emitter, base-contact and collector-contact regions are then diffused in a second short diffusion step at a moderate temperature (1200° C) producing the complete NPN transistor structure. Standard photolithographic and silicon dioxide masking techniques are used to restrict the diffusion to the desired regions.

High minority carrier lifetime is necessary in a high voltage transistor to enable injected carriers from the emitter to transverse the wide base region and reach the collector before recombining.[3] Processing must, therefore, be geared to the control and maintenance of high lifetime. Even trace levels of lifetime killers such as gold and copper, which can exist as contaminants on the wafer surface or in the high-temperature diffusion environment, will severely limit the high-current performance of the transistor. The critical steps listed in Table I were instituted in the diffusion process to enable production of high-lifetime devices.

Table I
Processes instituted for control and maintenance of high lifetime.

1. Ion implantation for all doping except the N+ emitter which presently is beyond the capability of ion implant equipment.

2. Wafer scrubbing before all high temperature steps to remove particulates.

3. HCl purging of the diffusion furnaces to remove heavy metal contaminants which can diffuse through the quartz furnace liners.

4. Sub-micron filtering of DI water used in wafer cleaning.

5. Slow heat and slow cool in all high temperature furnace cycles to minimize formation of stress induced dislocations which act as precipitation sites for metal contaminants.

6. Control of environment and handling procedures to minimize external contamination.

Surface electric field control

Once the requirements are met for voltage breakdown capability in bulk silicon, special consideration of the termination of the junction with the silicon surface must be taken because the peak surface electric field for avalanche breakdown is generally significantly lower than the corresponding bulk electric field. Several common methods of reducing surface fields are shown in Fig. 4. While no method is completely successful in eliminating the surface effect, each method is capable of surface breakdown voltage within 90-95 percent of the bulk capability. For reasons described, the planar depletion moat was chosen as the best structure for a passivated high-voltage transistor.

The most common is the reverse bevel technique[4], (Fig. 4a), which is used by most manufacturers of high voltage transistors. Surface fields are reduced because the field is spread over a larger surface area due to the approximately 30° bevel. One drawback of the technique is that it requires a mechanical grinding step to produce an accurate taper, and mechanical processes are generally expensive in comparison with other semiconductor processes. Hard glass passivation of the junction is not practical due to the position of the junction, and devices of this type are generally non-passivated. The technique, however, is proven and has withstood the test of time both in volume production and in device application.

In planar junctions, the curvature of the junction tends to focus the electric field near the surface causing breakdown to occur significantly below the bulk silicon value. The planar guard band structure[5], (Fig. 4b), effectively deals with this problem. Field-limiting rings completely surrounding the collector base junction distribute the surface field over a long distance, thereby reducing its magnitude. Several rings are needed to reduce peak fields sufficiently to increase surface breakdown voltage within 90 percent of bulk capability. Pellet area utilization is ineffective. Approximately half the pellet area would be assigned to surface field control in a typical high voltage, high current design. Cost pressure has generally limited the use of guard bands to smaller, low voltage type devices.

The $\pi\nu$ design[6] (Fig. 4c) has found wide application in medium voltage transistors ($V_{CBO} \leqslant$ 1000 V) used in automotive ignition circuits. It effectively lowers surface fields by allowing significant field spreading on both the P and N sides of the junction. The structure is formed epitaxially, which offers excellent design flexibility for voltage, current and energy optimization. Higher voltage designs, however, require significantly thicker and higher resistivity epitaxial layers, pushing epitaxial technology to the limits of its present capability of resistivity and defect density control. This structure may be hard passivated although the deep mesa and position of the junction on the mesa sidewall require critical control of the passivation process.

The planar depletion moat[7] structure shown in Fig. 4d is an excellent method of high-voltage junction termination both from the standpoint of pellet area utilization and the ease of hard-glass passivation. The junction is located in a plane parallel to the top surface of the pellet several mils from the mesa etch discontinuity. This minimizes the adverse effects of certain variables in the passivation process such as photoresist adherence, mechanical stresses in the passivation layers, and glass coverage. Near-theoretical breakdown can be achieved with proper etch depth control The depth is critical because the bulk field in the P-region must just reach the bottom

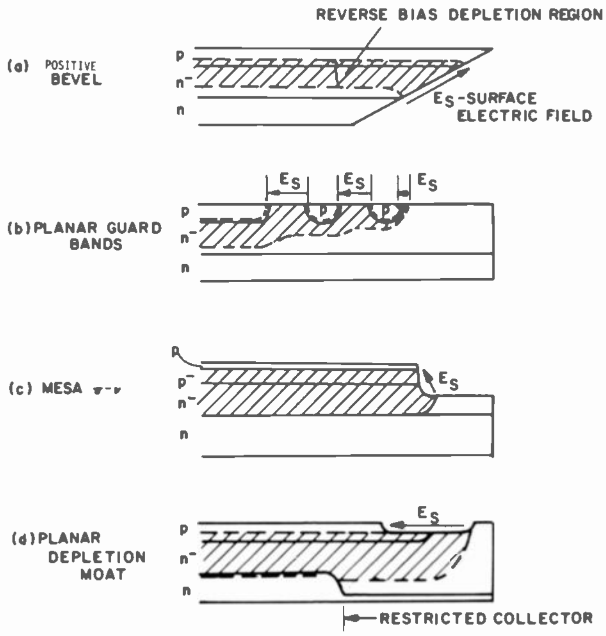


Fig. 4
Common methods of reducing surface electric fields.

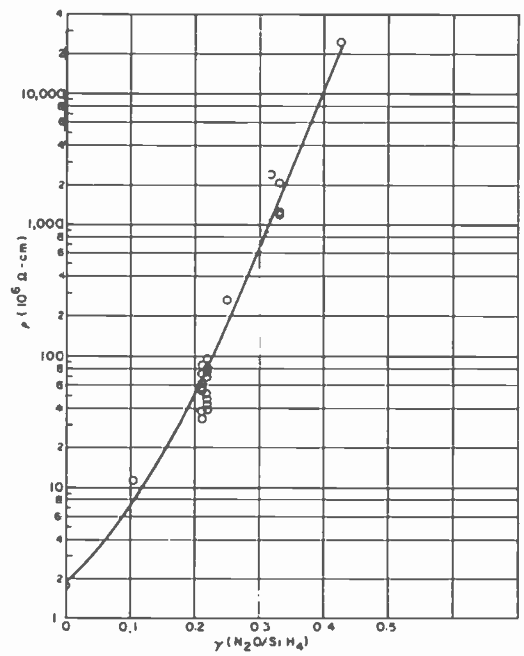


Fig. 6
Sipos restivity vs. N_2O/SiH_4 ratio (γ).

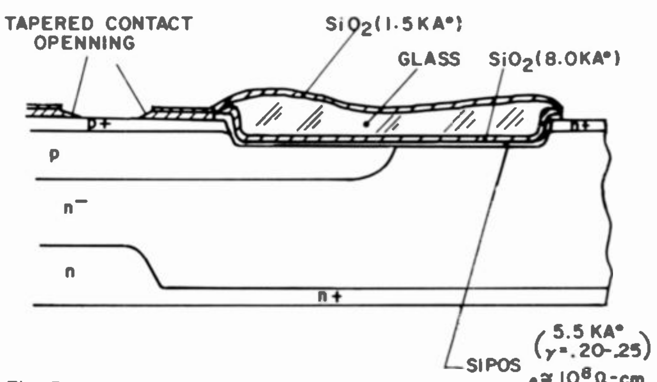


Fig. 5
Sipos-Oxide-Glass-Oxide (SOGO) passivation system.

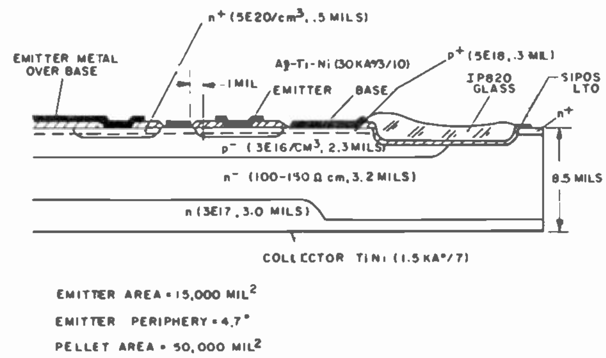


Fig. 7
TA8991 pellet cross section.

of the etch moat prior to breakdown to significantly reduce the lateral surface field. Here also, surface-field spreading occurs about equally on the P and N sides of the junction. The criticalness of the etch depth control can be reduced to a reasonable factory level (±20 percent) by shallowing the P-junction grade. This was accomplished by reducing the surface concentration and increasing the junction depth of the P-base diffusion ($C_s = 1 \times 10^{16}\ cm^{-3}$, $X_{jp} = 60\mu$).

In addition to modifications in the junction termination to reduce surface fields, the collector N-region may be restricted to the active current-carrying portions of the device allowing more field spreading in the N- collector near the surface as shown in Fig. 4d.

Sipos/glass passivation system

In any high voltage device, fringing electric fields external to the pellet are important in determining performance and reliability. Mobile ionic contaminants on the surface can play havoc with the electrical characteristics causing high leakage, unstable voltage breakdown and, in severe cases, complete destruction of the device. This is especially true in a non-hermetic environment. To desensitize the junction from external effects, the silicon surface can be passivated with insulating or semi-insulating materials which bond well with the silicon and do not contain mobile contaminants which can be thermally activated at the device's operating temperature.

Passivation of the junction serves another important economic purpose. Since the passivated system hermetically seals the device in chip form, the hard glass-passivated device can be tested, categorized and inventoried at the pellet stage, reducing inventory carrying costs and enabling more effective response to varying market conditions.

A multilayer passivation system called SOGO was developed to meet the performance and reliability requirements of high voltage devices. The basic components of the SOGO system are shown in Fig. 5. The primary passivation layer is a thin film of semi-insulating polycrystalline oxygen doped silicon (Sipos)[8] which is formed by Low Pressure Chemical Vapor Deposition (LPCVD) through the reaction of nitrous oxide (N_2O) and silane (SiH_4).[9,10] The resistive nature of the Sipos film distributes the electric field more uniformly over the P/N junction lowering the peak field and enhancing surface breakdown voltage. A design trade-off occurs between the ohmic Sipos leakage current which is in parallel with the PN junction and the maximum reverse blocking voltage. The resistivity[11] of the Sipos may be varied by changing the N_2O/SiH_4 ratio (γ) in the deposition process. This relationship is plotted in Fig. 6. Optimum resistivity for devices above 1500 V is about 10^8 ohm-cm ($\gamma = .23$). At this level, total room temperature junction leakage is below 1 μA at 1500 V and high temperature 150°C leakage below 1 mA. The high voltage junctions passivated with the SOGO system have excellent high temperature reverse bias stability under very tough stress conditions[12] (150°C, 1200 V).

The use of LPCVD primary passivant is also advantageous from the manufacturing standpoint. High throughput, excellent uniformity and reproducibility are realized with the LPCVD system. The device wafers are cleaned in situ prior to deposition by HCl etching the junction surface. This allows control of the critical interface properties which has been a serious problem in other passivation schemes.

The silicon dioxide layer between the Sipos and the glass acts as a buffer region and prevents attack of the Sipos film during the glass firing done at high temperature 925°C. A thick layer of lead alumino silicate glass is applied to hermetically seal and protect the junction using low-cost photoresist/frit spin-on technology. The glass composition is chosen to provide a good thermal expansion match to the silicon. A final thin layer of SiO_2 is applied over the glass to protect the glass from chemical attack during metal etching. The differential etch rate between this deposited oxide and the thermally grown emitter base oxide also serves to taper the contact openings in the emitter base SiO_2 layer for improved metal step coverage.

Metal system

The wide collector region and high lifetime result in large amounts of stored charge which tend to restrict switching performance of high voltage devices. In order to achieve fast switching and minimize turn-off tails (which lead to high power dissipation in turn-off), a finely subdivided discrete emitter structure was used, and a high conductivity-solderable Al/Ti/Ni metallization system was developed with metal over oxide capability to access the discrete emitters. In this metal system, a thick layer of aluminum is used to bond to the silicon and silicon dioxide and provide high lateral conductivity, minimizing voltage drops in the base and emitter metal which would tend to create current non-uniformities at high injection levels. The titanium layer serves as a buffer region preventing the formation of brittle aluminum/nickel intermetallics during the metal alloying process. Solder contact is readily made to the nickel layer. The metal layers are deposited in an electron gun vacuum evaporator and metal definition is accomplished using photolithographic techniques. A single step metal etch [13] was developed for ease of manufacturing. This metal system combines the advantages of high conductivity, fine line geometry, and metal over oxide capability of the aluminum metal system, with the advantages of a rugged nickel-lead mounting and clip bonding assembly process. An example of this technology is shown in Figs. 7 and 8 depicting the TA8991, a horizontal deflection output transistor.

Device packaging

The packaging of a high voltage device requires extra precautions to prevent internal arcing under peak voltage conditions. Fig. 9 shows a TA8991 pellet mounted on a modified TO-3 stem with large glass feed-throughs. Rugged solder connections are

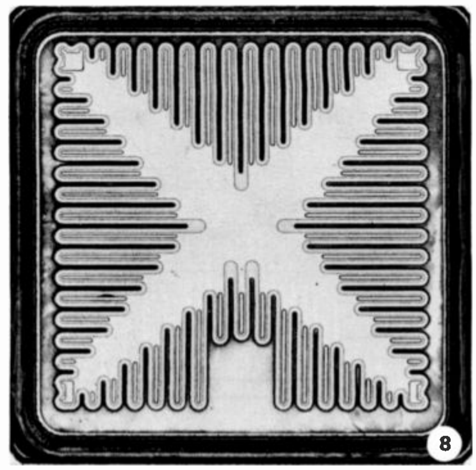


Fig. 8
TA8991 pellet top view.

Fig. 9
TA8991 mounted pellet in TO-3 package.

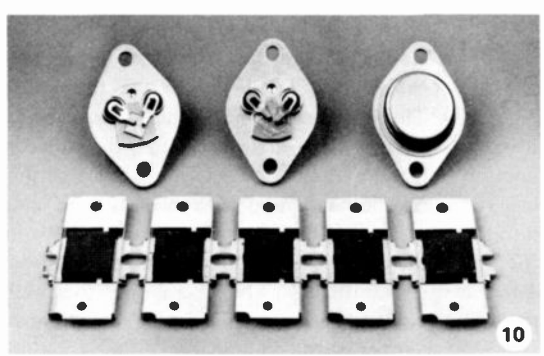
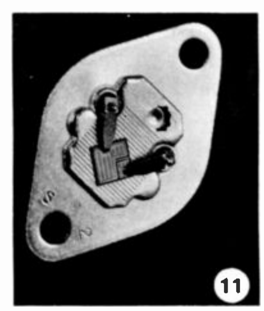


Fig. 10
TA8991 hermetic and plastic assembly.



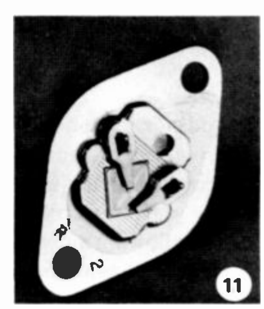


Fig. 11
Application of technology to other high voltage devices.

made at the emitter and base pads and on the back collector surface of the pellet. Grooves are provided in the nickel-clad header to allow better solder flow during mounting, resulting in a thin, void-free solder layer for better electrical and thermal resistance between pellet and header. Spacings between internal parts and the shell which will hermetically seal the unit, must be sufficiently large, and sharp edges and burrs eliminated to reduce the chance of corona discharge. A high dielectric strength silicone encapsulant[14] is applied over the pellet area to prevent arcing in the high field junction region. This sealant has to be of high purity and able to withstand thermal fatigue, thermal shock, and high temperature reverse bias stress conditions without deterioration. The device at each stage of finishing is shown in Fig. 10. Also shown is a plastic version of the device which is low cost assembled in strip form. Fig. 11 demonstrates the broad application of the passivation and metallization technology to other high voltage power devices. Shown is a high voltage Darlington TA9128 used in automotive ignition circuits and the new family of RCA super switches, TA9114.

Transistors designed for high voltage

A basic high voltage diffused base NPN transistor structure with typical doping profiles in the emitter, base and collector regions are shown in Fig. 12. The structure contains a highly doped emitter N+ region and a moderately doped P-base region insuring high emitter injection efficiency. An N-buffer layer is used in the collector to improve reverse energy capability (Es/b). The N-collector region supports a major portion of the collector base reverse breakdown voltage. This region must be high resistivity and wide enough to support the required voltage before critical field is reached at the base-collector junction. Several hundred volts are also dropped across the P-base and N-buffer regions. The amount of field expended in these regions is dependent on their doping gradients. In general, the shallower the gradients, the more voltage that will be supported. To gain some feel for the design latitude, Fig. 13 plots the theoretical breakdown voltage as a function of N-collector width (Wc). Curves are plotted for two extreme base-doping levels and collector resistivities spanning the range of interest. Base-diffusion depth is held constant at 60 microns. The parameter defining the base profile is the surface density of P doping atoms per cm^2. This number is a precise dose, controlled in the process by using the ion implant doping technique.

Table II
TA8991 Typical performance data.

V_{CES} @ .1 mA	1600 V
LV_{CEOsus} @ .5 A	700 V
V_{EBO} @ 10 mA	12 V
V_{BEF} @ 10 A	1.4 V
I_{CES} @ 1400 V	<100 μA
I_{CEO} @ 600 V	<100 μA
I_{EBO} @ 10 V	<10 nA
h_{FE} @ 3 A/5 V	12-18
h_{FE} @ 5 A/5 V	4-10
V_{BEsat} @ 5 A/1 A	.9 V
Is/b	5 A/25 VDC
Switching t_f	.3-.7 μs @ 5 A I_C
t_s	6-15 μs @ 5A I_C
Cob @ 10 V	200 pf
Thermal resistance	1.0° C/W
f_T @ 12 V, .2 A	1.0 MHz

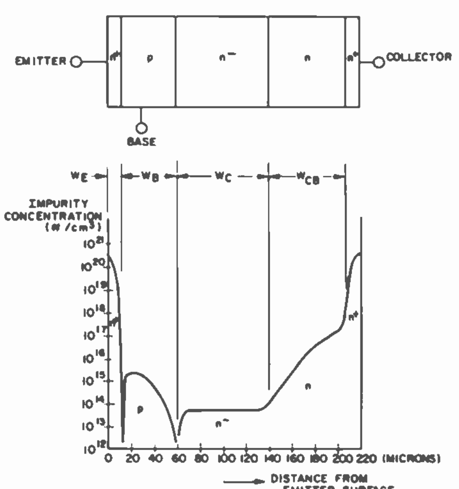


Fig. 12
Basic high voltage structure and doping profiles.

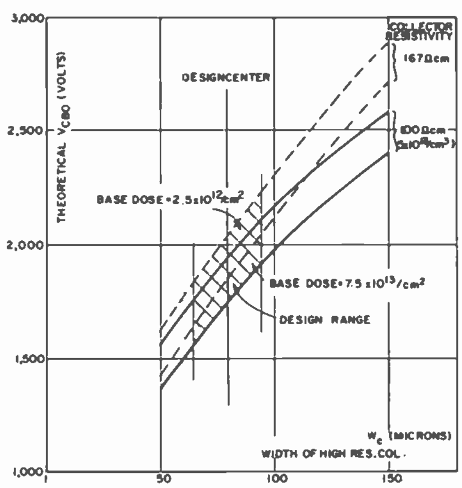


Fig. 13
Theoretical base collector breakdown voltage.

The curve shows that theoretical voltage is most sensitive to N-resistivity and collector width. Control of these parameters is important for maintaining a tight voltage distribution in the production process. Starting wafer thickness must be controlled to ±.5 mil to adequately control the voltage distribution.

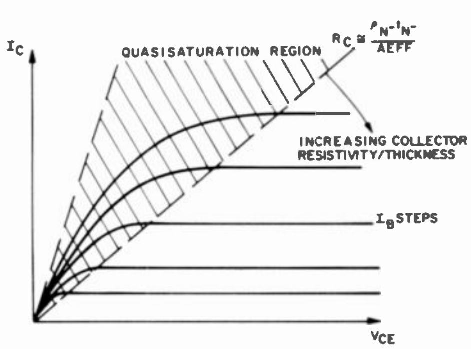


Fig. 14
Quasi-saturation region caused by base widening.

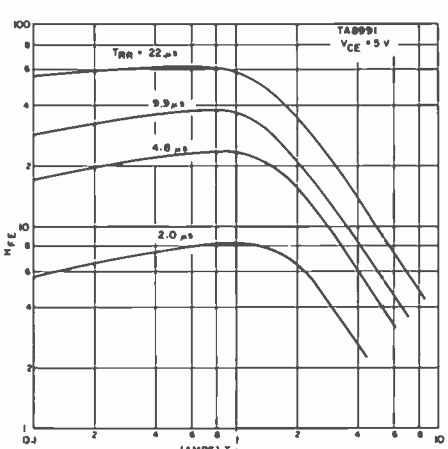


Fig. 15
Effect of lifetime on I_C characteristic.

Requirements for high current

Because of the high resistance in the wide N-collector region, high voltage transistors need a large active emitter area and periphery to operate well at high currents.

A physical effect termed base widening[15] dominates the device characteristics at low voltages and high currents where the transistor exhibits a quasi-saturation region as shown in Fig. 14. The sharp fall-off of h_{FE} at high currents is due to a widening of the base into the collector region as the current is increased. What was originally a portion of the collector becomes conductivity modulated due to the large density of injected electrons and the requirement for local charge neutrality and is now an extension of the base. First order theory predicts that the locus of voltages below which widening occurs is a straight line with a slope equal to the ohmic resistance of the collector region.

When used in switching applications, the transistor is driven hard into the quasi-saturation region where the base is effectively widened completely through the N-region into the N-buffer zone. The current gain then becomes a strong function of the base transport factor which is dependent on minority carrier lifetime in the widened base region. The pronounced effect of varying lifetime on the gain vs. current characteristics is shown in Fig. 15. Several devices from the same lot are plotted. T_{rr} is the reverse recovery time of the collector base diode which is directly related to minority carrier lifetime ($T_{rr} \sim 0.7\ \tau_{eff}$).[15]

TA8991 performance data

The technologies described in the previous section were applied to the manufacture of the TA8991 which is in volume production and has demonstrated excellent manufacturability. The unit was evaluated and accepted by several large television manufacturers. Typical electrical and reliability performance data are listed in Tables II and III. Fig. 16 is a schematic of

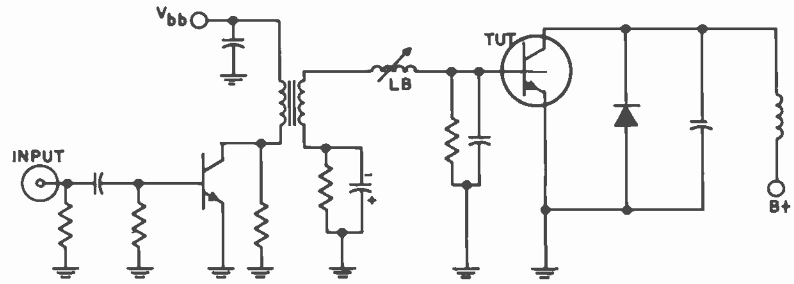


Fig. 16
Basic horizontal deflection switching test circuit.

the test circuit used to measure the switching characteristics.

In addition to high voltage and high current capability, the device has relatively fast turn-off capability (tf~.5μs). Since power dissipation occurs during the last stages of turn-off as the collector to emitter voltage starts to rise, fast fall time is important to minimize dissipation and limit the device's temperature rise for better reliability and circuit performance. Storage time is also a critical parameter due to circuit constraints and the requirement for direct interchangeability with competitive devices without circuit modification. Production control of these parameters is greatly simplified by the inherently fast, highly interdigitated discrete emitter pellet design and precise impurity doping achieved with the ion implant process.

Conclusion

A new series of discrete high voltage power devices has been developed using new technology resulting in improved manufacturability, performance, reliability, and adaptability. These technologies will expand the total scope of our discrete power business in the field of high voltage, high speed switching applications.

Table III
TA8991 reliability summary. TO-3 sample size 20, lot acceptance zero failures.

Test	*Condition*	*Duration*	*Failure Limit*
HTRB	V_{CB} = 1200 V, V_{EB} = 5 V, T_A = 150°C	96 hrs.	$I_{CBO} > 200\ \mu A$
Thermal fatigue	56W, ΔT_C = 50°C	20,000 cycs.	Catastrophic
Operating life	11W, T_C = 220°C	96 hrs.	$\Delta h_{FE} > 15\%$
Temperature cycle	−65°C to 150°C	100 cycs.	$\Delta Q_{jc} > 20\%$
Thermal shock	−65°C to 150°C	100 cycs.	$\Delta Q_{jc} > 20\%$

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Dates and Deadlines

Upcoming meetings

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

MAY 3-4, 1979—**Conference on Gigabit Logic for microwave systems** (IEEE EDS/MTT) Orlando, FL **Prog Info:** P.T. Greiling, Hughes Research Labs., 3011 Malibu Canyon, Malibu, CA 90265 (213-456-6411)

MAY 7-10, 1979—**Design Engrg. Conf.** (ASME) McCormick Place, Chicago, IL **Prog Info:** American Soc. of Mechanical Engineers, United Engineering Center, 345 E. 47th St., New York, NY 10017 (212-644-2129)

MAY 8-10, 1979—**Society for Information Display Int. Symp.** (SID) Chicago Marriott Hotel, Chicago **Prog Info:** Lewis Winner, 301 Almeria Ave., P.O. Box 343788, Coral Gables, FL 33134

MAY 14-17, 1979—**Industrial and Commercial Power Systems Conf.** (IEEE) Washington Plaza, Seattle, WA **Prog Info:** T.E. Sparling, T.E. Sparling & Assoc., 1920 Eastlake Ave., Seattle, WA 98102 (206-325-7770)

MAY 15-17, 1979—**National Aerospace & Electronics Conf. (NAECON)** (IEEE) Dayton Convention Ctr., Dayton, OH **Prog Info:** NAECON, 140 E. Monument Ave., Dayton, OH 45402 (513-255-3627)

MAY 30-JUN 1, 1979—**Clea '79,** Washington Hilton Hotel (IEEE, Optical Soc. of America) **Prog Info:** Susan C. Henman, Courtesy Associates, 1629 K St., NW, Suite 700, Washington, DC 20006

JUN 4-7, 1979—**National Computer Conf.** (AFIPS, IEEE) New York, NY **Prog Info:** Thomas C. White, American Federation of Information Processing Societies, 210 Summit Ave., Montvale, NJ 07645 (201-391-9810)

JUN 11-13, 1979—**Intl Conf. on Communications** (IEEE) Sheraton Hotel, Boston, MA **Prog Info:** Richard C. Stiles, Director Telecommunications Planning, GTE Labs. Inc., 40 Sylvan Road, Waltham, MA 02154 (617-890-8460 ext. 301) or Duane Mattisen (617-862-5500 ext. 5400)

JUN 12-14, 1979—**Intl. Pulsed Power Conf.** (IEEE) South Park Inn, Lubbock, TX **Prog Info:** Dr. M. Kristiansen, Texas Tech. U., Box 4439, Lubbock, TX 79409 (806-742-3530)

JUN 18-22, 1979—**Intl. IEEE/AP Symp. & USNC/URSI Mtg.** Seattle, WA **Prog Info:** I. Peden, Dept. of Elect. Engr., U. of Washington, Seattle, WA 98195 (206-543-0340)

JUN 19-21, 1979—**Power Electronics Specialists Conf.** (IEEE) San Diego, CA **Prog Info:** Jerrold Foutz, code 9234, Naval Ocean Systems, San Diego, CA 92152 (714-225-2752)

JUN 25-27, 1979—**Design Automation Conf.** (IEEE) Cherry Hill, NJ **Prog Info:** Harry Hayman, P.O. Box 639, Silver Springs, MD 20901 (301-981-0060)

JUL 16-28, 1979—**Annual Conf. on Nuclear & Space Radiation Effects** (IEEE-HPS/DNA) Santa Cruz, CA **Prog Info:** J.P. Raymond, Mission Research Corp., P.O. Box 1209, La Jolla, CA 92037

JUL 17-20, 1979—**Joint Intermag and Magnetism & Magnetic Materials** (MAG; AIP) Statler Hilton, New York, NY **Prog Info:** Paul Shumate, Bell Labs, 600 Mountain Ave., Murray Hill, NJ 07974

AUG 5-10, 1979—**Intersociety Energy Conversion Engr** (ED, AES) Sheraton Boston Hotel, Boston, MA **Prog Info:** Dr. J. Plunkett, Montana Energy & MHD Institute, P.O. Box 3709, Butte, MT 59701 (406-494-4569)

SEP 4-7, 1979—**Compcon Fall** (Comp) Washington, DC **Prog Info:** H. Hayman, P.O. Box 639, Silver Springs, MD 20901 (301-439-7007)

SEP 16-19, 1979—**Engineering in the Ocean Environment** (IEEE MTS/OEC) Town & Country Hotel, San Diego, CA **Prog Info:** Dr. H. Blood, NOSC, San Diego, CA 92152 (914-225-7275)

SEP 18-21, 1979—**WESCON** (IEEE) San Francisco, CA **Prog Info:** W.C. Weber, 999 N. Sepalveda Blvd., El Segundo, CA (213-772-2965)

SEP 19-21, 1979—**AUTOTESTCON** (IEEE, AES) Radisson Hotel, Minneapolis, MN **Prog Info:** A. Thornsjo, Honeywell, Inc., 1625 Zarthan Ave., S, St. Louis Park, MN 55416 (612-542-4811)

SEP 24-26, 1979—**TELECOM 79** (IEEE TAB/COMM) New York, NY **Prog Info:** R. Jerril, IEEE, 345 E. 47th St., New York, NY 10017 (212-644-7861)

SEP 26-27, 1979—**Ultrasonics Symp.** (IEEE SU) Monteleone Hotel, New Orleans, LA **Prog Info:** G.A. Alers, Rockwell International, P.O. Box 1085, 1049 Camino Dos Rios, Thousand Oaks, CA 91360 (805-498-4545 ext. 183)

Calls for papers

Ed. Note: Calls are listed chronologically by meeting date. Listed after the meeting (in bold type) are the sponsor(s), the location, and deadline information for submittals.

JUN 12-14, 1979—**Intl. Pulsed Power Conf.** (IEEE) South Park Inn, Lubbock, TX **Deadline Info: 3/15/79 150-word abs. to** M. Kristiansen, Dept. of Elec. Engrg., Texas Tech. U., P.O. Box 4439, Lubbock, TX 79409

JUN 2-5, 1979—**Ninth Int'l Conf. on Laser Atmospheric Studies** (Optical Soc. of America/German Soc. of Appl. Optics/German Meteorological Soc.) **Deadline Info: 300-word abs. to** C. Werner, Institute of Atmospheric Physics, DFVLR, Oberpfaffenhofen, D-8031 Wessling, West Germany

SEP 16-19, 1979—**1979 Fall Meeting—Electronics Div.** (American Ceramics Soc.) "Electronic Ceramics & Energy Conversion," Williamsburg, VA **Deadline Info:** David Hill, TI, Inc., 34 Forest St., MS-10-13, Attleboro, MA 02703 (617-222-2800 ext. 7338)

Pen and Podium

Recent RCA technical papers and presentations

To obtain copies of papers, check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint. For additional assistance in locating RCA technical literature, contact RCA Technical Communications, Bldg. 204-2, Cherry Hill, N.J., extension 4256.

Advanced Technology Laboratories

P.W. Ramondetta
Neutron dosimeter development model—*J. of Health Physics*, Vol. 36, No. 6, pp. 835-847 (12/78)

Automated Systems

L. Arlan|M.J. Cantella|T.J. Dudziak
M.F. Krayewsky
High resolution computer controlled television system for hybrid circuit inspection—SPIE Technical Symposium East '79, Washington, DC (4/79)

S.H. Eames|E.L. Naas
Automated logistic support analysis tools—IEEE-Boston Chapter Reliability Group Monthly Meeting, Bedford, MA (1/79)

Broadcast Systems

J.C. Adison
A new fully automatic television camera—SMPTE, New York, NY (11/78)

R.S. Hopkins|S.L. Bendell|A.H. Lind
Utilization of CCDs in broadcast color TV cameras—CCBA Convention, Toronto (10/78)

Laboratories

R. Amantea
A measurement technique and algorithm for determining the NPN and PNP alphas of a thyristor—*IEEE Trans. on Electron Devices*, (1978)

C. Anderson|A. Pelios|T. Credelle
W. Siekanowicz|F. Vaccaro
Electron guides with extraction, a potentially useful new class of electron devices—1978 IEEE International Electron Devices Meeting, Washington, DC, *Technical Digest of the* 1978 *IEDM* (12/4-6/78)

D. Botez|M. Ettenberg
Beamwidth approximations for the fundamental mode in symmetric double-heterojunction lasers—*IEEE J. of Quantum Electronics*, Vol. QE-14, No. 11 (11/78)

C.R. Carlson|P.M. Heyman
A large format optical display for the generation of generalized psychophysical stimuli—*Vision Research*, Vol. 19, pp. 99-103 (1979)

R.J. Hollingsworth|A.C. Ipri|C.S. Kim
A CMOS/SOS 4K static RAM—*IEEE J. of Solid-State Circuits*, Vol. SC-13, No. 5 (10/78)

S.T. Hsu
Influence of surface states on the measurement of field-effect mobility—*IEEE Transactions on Electron Devices*, Vol. ED-25, No. 11 (11/78)

K.M. Kim|S.H. McFarlane
Etch pits and dislocation in [1012] Czochralski sapphire wafers—*J. Appl. Phys.*, Vol. 49, No. 12 (12/78)

K. Knop
Rigorous diffraction theory for transmission phase gratings with deep rectangular grooves—*J. Opt. Soc. Am.*, Vol. 68, No. 9 (9/78)

K. Knop|M.T. Gale
ZOD micro-images: colour and black-and-white image reproduction from surface relief grating structures—*J. of Photographic Science*, Vol. 26, No. 3 (5-6/78)

R.U. Martinelli|A. Rosen
Storage time variations in silicon p^+-n-n^+ diodes—Meeting in Washington, DC, *Trans. of* 1978 *IEEE International Electron Devices*, (12/4-6/78)

G.H. Olsen|C.J. Nuese|R.T. Smith
The effect of elastic strain on energy band gap and lattice parameter in III-V compounds—*J. of Applied Physics*, Vol. 49, No. 11 (11/78)

J.I. Pankove|M.L. Tarng
M.A. Lampert|C.W. Magee
Hydrogenation and dehydrogenation of amorphous and crystalline silicon—*Inst. Phys. Conf. Ser.*, No. 43 (1979)

A. Presser
Interdigitated microstrip coupler design—*IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-26, No. 10 (10/78)

W. Rehwald|D. Bäuerle
Structural phase transitions in semiconducting $SrTiO_3$—*Solid State Communications*, Vol. 27, pp. 1343-46 (1978)

J.R. Sandercock|W. Wettling
Light scattering from thermal magnons in iron and nickel—*IEEE Transactions on Magnetics*, Vol. Mag-14, No. 5 (9/78)

G.L. Schnable|L.J. Gallace|H.L. Pujol
Reliability of CMOS integrated circuits—*IEEE Computer Society Magazine* (10/78)

E.K. Sichel|J.I. Gittleman|P. Sheng
Transport properties of the composite material carbon-polyvinylchloride—*Physical Review B*, Vol. 18, No. 10 (11/78)

G.A. Swartz|A. Rosen|P.T. Ho
A. Schwarzmann
Low-loss p-i-n diode for high-power MIC phase shifter—*IEEE Transactions on Electron Devices*, Vol. ED-25, No. 11 (11/78)

C.E. Tracy
Micromethod for refractive index determination of thin films using liquid standards—*J. of the Electrochemical Society*, Vol. 126, No. 1 (1/79)

Missile and Surface Radar

F.A. Eble|E.W. Richards, Jr.
Rapid RMA assessment—the painless plot—1979 Annual Reliability and Maintainability Symposium, Washington, DC *Proc* Symposium (1/79)

D.M. Fuerle|S.A. Steele
Software and firmware engineering—a coupling or uncoupling—Mini and microcomputers MIMI '79, Anaheim, CA *Proc.* (1/79)

R.J. Rader
A cost-effective method for adapting an existing compiler for microprocessor use—First International Symposium on Mini and Microcomputers in Control, San Diego, CA *Proc.* (1/79)

A. Schwarzmann
High power performance of a 5 kW MIC diode phase shifter—*Microwave Journal*, pp. 66-67 (12/78)

A.L. Warren
Program management (speech)—AFCEA Luncheon, Aberdeen, MD (1/79)

F.W. Widmann
Electromagnetic compatibility intrasystem analysis program applications—EMC/IAP User's Conference, Albuquerque, NM (1/79)

Patents

Astro Electronics

A. Anchutin
Plural panels deployed effectively as a single panel—4133502

Automated Systems

L.R. Hulls|S.C. Hadden
Identification of engine cylinder having fault—4133205

Commercial Communications Systems

J.R. Barkwith
Idle-busy signalling between telephone system and radiophone system—4138595

T.V. Bolger
Direct digital frequency synthesizer—4134072

D. Hampel
Multi-function logic gate with one gate delay—4133040

L.V. Hedlund|A.C. Luther, Jr.
Disc eccentricity compensating system—4138741

R.N. Hurst
Television picture size altering apparatus—4134128

Consumer Electronics

A.R. Balaban|S.A. Steckler
Gating signal generator for switched pincushion correction circuit—4132927

R.E. Fernsler
Ramp generator for harmonic tuned deflection—4134082

J.J. Serafini
Automatic beam current limiter with independently determined threshold level and dynamic control range—4137552

R.L. Shanley, 2nd
Brightness control circuit with predictable brightness control range—4135200

J.L. Smith
Magnetizing method for use with a cathode ray tube—4138628

Government Communications Systems

R.H. Chan|M.R. Mann|F.M. McDonnell
Dynamic channel allocation buffer matrix—4136399

Laboratories

A. Bloom|Hung, L.K.
Cholesteryl carbonates and carbamates of AZO dyes—4134888

C.J. Busanovich|R.M. Moore
Polycrystalline selenium imaging devices—4132918

T.L. Credelle
Modular flat display device with beam convergence—4131823

T.L. Credelle
Color flat panel television—4137478

T.L. Credelle|W.J. Hannan|F.W. Spong
Broadening the spatial frequency pass band of a thermoplastic layer—4137077

C.A. Deckert
Pretreatment of polyvinyl chloride plastics for electroless deposition—4131698

A.G. Dingwall
Insulated gate field effect transistor having a deep channel portion more highly doped than the substrate—4132998

R.E. Flory|C.B. Oakley
Raster registration system for a television camera—4133003

S.O. Graham
CCD output circuit using thin film transistor—4132903

W.H. Groeneweg
PAL identification circuit—4133002

R.S. Hopkins, Jr.
Digital video synchronizer—4134131

A.C. Ipri|D.W. Flatley
Method for fabricating MNOS memory circuits—4104087 (assigned to U.S. government)

Kaganowicz, G.|J.W. Robinson
H. Yasuda
Video disc with a dielectric layer formed from acetylene and nitrogen—4137550

W.F. Kosonocky|D.J. Sauer
Charge transfer circuits with compensation for transfer losses—4134028

I. Ladany|H. Kressel
Degradation resistance of semiconductor electroluminescent devices—4131904

L.H. Lin
Resist development control system—4136940

R.S. Mezrich
Pulse-echo ultrasonic-imaging display system—4131022

R.S. Mezrich|C.H. Anderson
Pulse-echo ultrasonic-imaging display system—4131023

R.S. Mezrich|J.Y. Avins
Pulse-echo ultrasonic-imaging display system—4131025

R.S. Mezrich|E.T. Koenig
High resolution pulse-echo ultrasonic-imaging display system—4131021

J.A. Rajchman
Cathode addressing system—4137551

M.D. Ross|J.K. Clemens
Transcoding apparatus—4136358

J.M. Shaw|K.H. Zaininger
Planar silicon-on-sapphire composite—4133925

J.A. VanRaalte
Image display block scanning method—4137485

D.H. Vilkomerson|R.S. Mezrich
Pulse-echo ultrasonic-imaging display system—4131024

P.K. Weimer
Charge injection devices and arrays and systems including such devices—4134031

C.E. Weitzel|D.R. Capewell
Method of making silicon-on-sapphire field effect transistors with specifically aligned gates—4131496

C.M. Wine
Memory type tuning system for storing information for a limited number of preferred tuning positions—4138647

Missile and Surface Radar

W.T. Patton|N.R. Landry
Short radiating horn with an S-shaped radiating element—4138683

Picture Tube Division

T.W. Branton
Cathode ray tube with stress-relieved slot-aperture shadow mask—4131822

W.R. Kelly|R.L. Barbin
Method and apparatus for optimizing color purity in a color kinescope—4137548

A.M. Morrell
Family members: 68805, 68805B cathode ray tube having improved shadow mask—4136300

RCA Ltd., Canada

C.K. Mok
Dual mode filter—4135133

SelectaVision

F.R. Stave|L.A. Torrington
Video disc package—4138703

L.A. Torrington
Record handling system for a video disc player—4133540

Solid State Division

A.A. Ahmed
Retrace blanking pulse generator with delayed transition—4134046

H.W. Becke
Gate turn-off thyristor with anode rectifying contact to non-regenerative section—4137545

W.F. Dietz
Horizontal deflection system with boosted B plus—RE29885

R.D. Larrabee
Power transfer apparatus—4131827

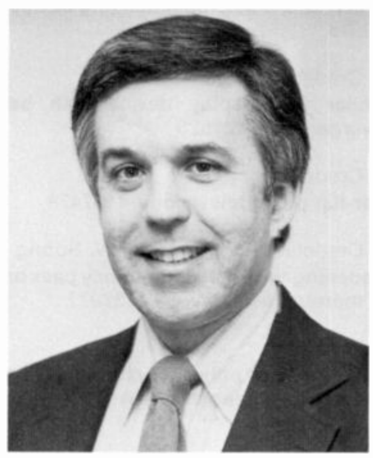
M.A. Polinsky
Bipolar transistor with high-low emitter impurity concentration—4136353

Engineering News and Highlights

Santilli named Division Vice President, Integrated Circuits

Richard A. Santilli has been named Division Vice President, Integrated Circuits, reporting to Bernard V. Vonderschmitt, Vice President and General Manager, Solid State Division. In his new position he is responsible for the design, manufacture and marketing of digital integrated circuits, bipolar integrated circuits, microprocessor components and systems, and semiconductor memories.

Mr. Santilli has been serving as Division Vice President, Sales and International Operations, a post he has held since 1976. He previously had been Division Vice President, Linear Integrated Circuits. He joined RCA's semiconductor activity in 1957 as a design engineer on transistor circuits for radio and TV receivers and subsequently held a series of management positions in design engineering, applications engineering, and marketing.



King is new Editor of *RCA Engineer*

Thomas E. King was recently appointed Editor of the *RCA Engineer*. He succeeds Mike Gevard, who has returned to Brian Advertising Company.

Mr. King began his career in the editorial department of the American Institute of Physics in 1966, working primarily on the *Journal of the Acoustical Society*, *Physics of Fluids* and the *Journal of Mathematical Physics*. In 1968 he joined D. Van Nostrand Co., Publishers, and since 1970 worked for the Society of Motion Picture and Television Engineers. With thirteen years' experience in technical editing and publishing, he was most recently editor of the *SMPTE Journal*. In this capacity, he was responsible for manuscript acquisition, editing, production, manufacturing and distribution of the *Journal*, as well as for the SMPTE book program. In his new position, Mr. King reports to Hans K. Jenny, Manager, Technical Information Programs.

Cassidy to manage Cablevision Systems

John H. Cassidy was recently appointed General Manager for RCA Cablevision Systems, a business unit of the company's Commercial Communications Systems Division.

One of the nation's largest contractors of cable TV installations, Cablevision Systems designs, supplies, constructs and tests complete systems, ready for the CATV operator to connect subscribers and to begin TV program service. Its offices and plant are at 7355 Fulton Ave., North Hollywood, CA.

Before his promotion, Mr. Cassidy was Manager, Antennas and Technical Services, for RCA Broadcast Systems, Camden, NJ, also a part of the commercial systems organization. In this capacity he supervised construction of major broadcast equipment installations for RCA customers, including TV networks and stations, teleproduction companies and for such large overseas projects as the Austrian Broadcasting Corporation's television center in Vienna.

Mr. Cassidy reports to Neil Vander Dussen, Division Vice President and General Manager, Commercial Communications Systems Division.

British Institute of Physics honors Sandercock

Dr. John Sandercock has been awarded the 1978 Duddell Prize of the British Institute of Physics in recognition of the development of the multipass Fabry-Perot interferometer and its application to Brillouin scattering spectroscopy.

John is a graduate and postgraduate of Oxford university and joined RCA Zurich laboratories in 1969. His work has been concentrated in the field of spectroscopy applied to the study of the physical properties of solids.

Pat Fasang joins Corporate Engineering Education Activity

Patrick P. Fasang joined RCA Corporate Engineering Education as Administrator, Engineering Education Programs, in December 1978. He received a B.S. degree from California State University at Fresno, a M.S. degree from California State University at San Jose, and a Ph.D. degree from Oregon State University, all in electrical engineering. Previously, he was a design engineer with Sprague Electric Company and an associate professor of electrical and computer engineering at University of Portland, Portland, Oregon. He also taught electronic and computer courses at Tektronix, Inc., and was associated with the Bonneville Power Administration where he was concerned with the applications of microcomputers to high-voltage power system problems. He served as chairman of the IEEE Electronics Group and chairman of the IEEE Computer Society in Oregon. He received a Dow Chemical Outstanding Young Faculty Award in June 1978. A senior member of IEEE, he is also a member of the American Society for Engineering Education and ETA KAPPA NU. Dr. Fasang will be engaged in identification of engineering educational needs and implementation of courses to meet these.

MSR honors authors

J.C. Volpe, Chief Engineer, congratulates authors during a reception in honor of the 76 MSR people who authored papers during 1978

GCS technical accomplishment awards

NASA Certificates of Recognition have been awarded to **E.R. Starner** and **E.J. Nossen** of Government Communications Systems for their work in Fine Frequency Measurement Techniques. The citations read: "For the creative development of a scientific contribution which has been determined to be of significant value in the advancement of the aerospace technology of NASA."

Gene Starner (second from left) received his certificate from **Jack Santoro,** and **Ed Nossen** (second from right) received his from **Ernie Jellinek.**

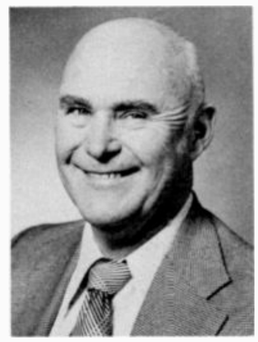
Bugglin

Phelan

Pschunder

Raciti

Simonetti



Wylde

Six receive Technical Excellence Awards at Moorestown

Award winners for the fourth quarter 1978 included:

R.J. Bugglin—for contributions to the development and test of computer programs for the Beamformer Alignment Function, an essential part of the Near Field Test Set for indoor pattern measurements of the AN/SPY-1A antenna. His program eliminates laborious manual measurements, and it includes its own sophisticated self testing.

E.G. Phelan—for developing concepts for 18 different array radars, all variants of the AN/SPY-1A and suitable for a variety of new business applications. Exploiting advanced technology, his system designs include power, aperture, and performance tradeoffs, plus radar time budgets, scheduling requirements, and search profiles.

R.J. Pschunder—for development of DYNA3, a new computer program for analyzing behavior of structures under static and dynamic loads. Based on experience with predecessor DYNA2, Dr. Pschunder has created a superior new analysis program that has demonstrated its utility in the structural analysis of the World Trade Center TV tower.

S.A. Raciti—for planning and directing the technical effort required in fulfilling AEGIS Intermediate Milestone No. 1 (AIM-1), an operational tracking demonstration at the CSED Site. The success of AIM-1 is due largely to Mr. Raciti's realistic test goals, well-defined tasks, and leadership of a multi-discipline team which met the goals.

J.A. Simonetti—for development of MOVIES, an advanced general program for plotting both recorded data and simulations. MOVIES generates 2D and 3D time-and-event plots, in the form of a "moving picture" display of graphic data on a CRT. The program is entirely data driven and is applicable to all graphic terminals.

D.V. Wylde—for systems engineering definition of an aircraft-carrier version of the AN/SPY-1A radar. After familiarizing himself with carrier operations and associated radar requirements, he then led the technical effort to define an AN/SPY-1A variant suitable for carrier use. The study report was favorably received by the Navy.

Schecter receives NSIA award

Edwin S. Shecter, Director of Product Assurance for "SelectaVision" VideoDisc Operations, has been awarded a certificate of merit by the National Security Industrial Association (NSIA) for his services as chairman of its quality and reliability assurance committee.

The award recognizes Mr. Shecter's direction of the committee's projects during his two years as chairman, including a joint industry-Space and Missile System Organization symposium on mission assurance and a software conference.

Automated Systems TE award goes to STE/ICE team

The STE/ICE team was selected to receive the February 1979 Technical Excellence Award. Team members are:

J.S. Brodie	**H. Logemann, Jr.**
H.L. Fischer	**J.A. Maurer**
A.H. Fortin	**A. Muzi**
D.A. French	**D. Nowak**
M.J. Gilbert	**H.N. Parkhurst**
R.E. Hanson	**C.O. Siu**
R.W. Jack	**E.M. Sutphin**
J.B. Lynch	**R.E. Tetrev**

STE/ICE is a microprocessor-based, automotive test system, designed for ease of use, low cost, and high reliability. It performs a variety of static and dynamic measurements including pressure, temperature, voltage, current, resistance, starter compression balance, dwell, timing, RPM, power and vacuum, etc. for diagnostic analysis of vehicle engines and accessories. Eleven RCA inventions were used in the development of the system. Thirteen military vehicle classes are supported. They range from small vehicles (jeeps) to large diesel vehicles, such as tanks and amphibious troop carriers.

Pschunder receives TE award

Ralph J. Pschunder, Principal Member, Engineering Staff, at Missile and Surface Radar in Moorestown, was recently selected as the winner of the 1978 Annual Technical Excellence Award.

Dr. Pschunder was selected because of his development of DYNA3, a large computer program for finite-element structural analysis. DYNA3 is used to predict the stresses, deflections, and mechanical resonances of complex structures under static loads and dynamic forces such as shock, vibration, wind gusts, and gun blasts.

DYNA3 embodies new sophisticated approaches. Based on experience with a predecessor program, DYNA2, Dr. Pschunder has devised a program that exceeds the capability of the large commercial codes, and it includes Navy-approved analysis techniques that are not automated in any other programs.

Photo at right:
Joseph C. Volpe, MSR's Chief Engineer, presents 1978 Technical Excellence Award to Ralph J. Pschunder.

RCA authors win best paper award

A technical paper presented by **Thomas Fitzpatrick** and **Richard Hanson** of Automated Systems, Burlington, was judged the best paper at the Vehicle Testing Session of the 1978 AUTOTESTCON Conference. The paper, "STE/FVS—Total Combat Vehicle Support with Simplified Test Equipment," outlined the use of portable test equipment, developed by RCA, for field testing of Army vehicles. (STE/FVS stands for Simplified Test Equipment for a Fighting Vehicle System.)

Obituaries

Frank J. Gardiner, who helped develop NASA's lunar orbiting techniques, died January 31, 1979.

Mr. Gardiner, who was killed in an automobile accident in California, had been technical director with Honeycomb Roll Systems, Inc., Saco, Maine, since 1975. From 1961 to 1971, he was associated with RCA in Burlington as lunar module program manager with overall responsibility for RCA's defensive and spacial systems engineering, from which came contracts for radar stabilization and control of electronics and ground support equipment for the lunar modules.

Merrill A. Trainer, a pioneer in television research and development for 43 years, died October 13, 1978.

Mr. Trainer entered the television field in 1927, and during the next three years was associated with Dr. E.F.W. Alexanderson in television research at the General Electric Company. He joined RCA in 1930 and was intimately associated with most of the major RCA television developments.

In 1932, Mr. Trainer assisted in the first successful television relaying between Philadelphia and New York. In 1933, he helped produce the first iconoscope camera. Three years later, Mr. Trainer participated in designing, building, and installing NBC's pioneer television station WNBT, in New York. In 1937, he was engaged in RCA's program for perfecting all-electronic television. Mr. Trainer also helped design the television studio equipment installed in 1938.

In 1940, Mr. Trainer was appointed Supervising Engineer of RCA's Television Terminal Equipment Section. During the war, he supervised the company's development of airborne television equipment, and television-guided missiles for the military services.

In 1947, Mr. Trainer was named Manager, RCA Television Equipment sales. In succeeding years, Mr. Trainer held several managerial posts in engineering and marketing in the broadcast equipment field. At the time of his retirement from RCA on August 1, 1970, he was Manager, Customer Relations, Commercial Electronic Systems.

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to *RCA Engineer*, Bldg. 204-2, RCA, Cherry Hill, N.J. New listings (and corrections or changes to previous listings) will be published in each issue.

Astro-Electronics

I. Brown, Hightstown; PA-001536E

L. Freedman, Hightstown; NJ-19297

B. Jacks, Hightstown; CA-QU2654

G. Pigage, Hightstown; NJ-21310

D. Roda, Hightstown; PA-007990E

E. Zier, Hightstown; CA-QU2838

Avionic Systems

J.F. Cronin, Van Nuys; CA-MF3492

G.A. Lucchi, Van Nuys; CA-CS4306

Consumer Electronics Division

J.F. Roy, Indianapolis; ONT-44590503; M.I.E.R.E.—304084

Record Division

J.C. Ruda, Indianapolis; IN-18100

Promotions

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Bruce E. Ayer III from Engineering Representative to Associate Systems Analyst.

Douglas I. Clark from Supervisor, Field Installation to Engineer A.

Missile and Surface Radar

P. Edgar from Senior Member, Engineering Staff, to Unit Manager, Engineering Systems Project.

R. Jones from Senior Member, Engineering Staff, to Unit Manager, Engineering Systems Project.

H. Olson from Senior Member, Engineering Staff, to Unit Manager, Engineering Systems Project.

I. Schottenfeld from Principal Member, Engineering Staff to Unit Manager, Engineering Systems Project.

H. Seppannen from Principal Member, Engineering Staff, to Unit Manager, Engineering Systems Project.

M. Trachtenberg from Principal Member, Engineering Staff, to Unit Manager, Engineering Systems Project.

Picture Tube Division

Henry E. Bolinsky from Technician to Associate Member, Technical Staff.

John A. Hear from Member, Technical Staff, Manufacturing, to Manager, Production Engineering.

Solid State Division

Marlan Vincoff from Member, Technical Staff, to Leader, Technical Staff.

George Waas from Leader, Technical Staff, to Manager, CMOS Design and Support.

Staff announcements

Commercial Communications Systems Division

J. Edgar Hill, Division Vice President and General Manager, Broadcast Systems, announced the appointment of **Bruno F. Melchionni** as Manager, Antennas and Technical Services. Mr. Melchionni's organization was announced as follows: **John W. Barbour,** Manager, Major Projects; **Richard J. Broadhead,** Manager, Antenna Product Management; **Mario Lazzari,** Manager, Project Implementation; **Daniel G. Mager,** Manager, Tech-Alert; **Albert T. Montemuro,** Manager, Systems Engineering and Custom Shop; **David S. Newborg,** Manager, Antenna Engineering; **C.D. Phillips,** Administrator, Mobile TV Van Projects; and **John W. Wentworth,** Manager, Broadcast Technical Training.

Stanley E. Basara, Manager, Studio and Control Equipment Engineering and Product Management, Broadcast Systems, announced the following organization: **Norman L. Hobson,** Manager, Camera Product Engineering; **Robert S. Hopkins,** Manager, Camera Product and Control Equipment Engineering; **Raymond J. Smith,** Manager, Camera Product Engineering.

Consumer Electronics Division

J. Peter Bingham, Division Vice President, Engineering, announced the following organization: **Larry A. Cochran,** Manager, Signal Systems and Components; **Eugene E. Janson,** Manager, Video Systems Engineering; **Arthur Kaiman,** Manager, Systems Applications; **Eugene Lemke,** Chief Engineer, New Products Laboratory and Engineering Development; and **Perry C. Olsen,** Manager, Product Design.

Laboratories

William M. Webster, Vice President, RCA Laboratories, has announced that responsibility for research and development on the VideoDisc player has been assigned to **Nathan L. Gordon,** Staff Vice President, Systems Research. Reporting to **David D. Holmes,** Director, Television Research Laboratory for the VideoDisc player will be: **Jon K. Clemens,** Head, Signal Systems Research; and **Eugene O. Keizer,** Head, Video Recording Research.

Marvin A. Leedom has been appointed Director, Electromechanical Research Laboratory. He will report to **Nathan L. Gordon,** Staff Vice President, Systems Research. His organization is as follows: **Charles B. Carroll,** Head, Electromechanical Systems; **Marvin A. Leedom,** Acting, Advanced Control Systems; **William G. McGuffin,** Manager, Instrumentation Systems.

Henry Kressel, Director, Materials and Processing Research Laboratory, announced the organization as follows: **Vladimir S. Ban,** Head, VideoDisc Materials and Diagnostics Research; **Glenn W. Cullen,** Head, Materials Synthesis Research; **Richard Denning,** Manager, Advanced Power Engineering (Somerville); **Leonard P. Fox,** Head, VideoDisc Applied Process Research; **Charles J. Nuese,** Head, Semiconductor Devices Research; and **Daniel L. Ross,** Head, Organic Materials and Devices Research.

James L. Miller, Director, Manufacturing Systems and Technology Research Laboratory, announced the organization as follows: **David P. Bortfeld,** Head, Manufacturing Systems and Process Control; **Luke Dillon, Jr.,** Head, Manufacturing Test and Control Systems; **Istvan Gorog,** Head, Manufacturing Research; **Lubomyr S. Onyshkevych,** Head, Electronic Packaging Research; **Louis E. Potter,** Manager, Advanced Development—Manufacturing Technology (Lancaster); and **D. Alex Ross,** Staff Engineer.

Daniel A. Walters, Director, Communication Systems Research Laboratory, has announced the organization as follows: **Marvin Blecker,** Head, Systems Analysis Research; **Leonard Schiff,** Head, Communication Analysis Research; **Paul Schnitzler,** Head, Transmission Technology Research; and **Harold Staras,** Staff Scientist, Satellite Programs.

Appointment of **Dr. Allen J. Korenjak** and **Dr. Richard H. Roth** as Research Group Heads was announced by **Alfred H. Teger,** Director, Advanced Systems Research Laboratory. Dr. Korenjak is in charge of the Automation Systems Research Group and Dr. Roth, the System Architecture Research Group.

RCA Service Company

Raymond J. Sokolowski, Division Vice President, Consumer Services, announced the appointment of **Joseph E. Steoger,** Manager, Engineering Support.

Solid State Division

Richard A. Santilli, Division Vice President, Integrated Circuits, announced the following organization: **Marvin B. Alexander,** Manager, Operations Planning & Control; **Larry J. French,** Director, Photomask Technology; **Larry J. Gallace,** Project Manager, IC Quality and Reliability Programs; **Heshmat Khajezadeh,** Director, Bipolar & MOS Logic Operations; **Richard L. Sanquini,** Director, Memory, Microprocessor and Timekeeping Operations; **Richard A. Santilli,** Acting, Offshore Manufacturing; **John E. Schaefer,** Director, Government and Hi Reliability Operations; **Joseph H. Scott,** Director, IC Technology; and **Norman C. Turner,** Manager, IC Engineering Support.

Heshmat Khajezadeh, Director, Bipolar and MOS Logic Operations, announced the following organization: **Stephen C. Ahrens,** Manager, Manufacturing Support; **Richard E. Davey,** Manager, Findlay Operations; **Martin Geller,** Manager, Product Marketing; **Alfredo S. Sheng,** Manager, Design Engineering; and **Bruno J. Walmsley,** Manager, Applications and Test Engineering.

Richard L. Sanquini, Director, Memory, Microprocessor and Timekeeping Operations, announced the following organization: **Richard W. Ahrons,** Manager, Microprocessor Systems; **Donald R. Carley,** Manager, Automotive Programs; **Michael V. D'Agostino,** Manager, Product Marketing—Memory, Microprocessor and Timekeeping Components; **Michael S. Fisher,** Manager, Applications Engineering and Test; **John A. Kucker,** Manager, Palm Beach Gardens Operations; and **Alex W. Young,** Manager, Design Engineering.

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