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23rd Anniversary Issue

Sapphire ribbon for SOS

RCA Engineer

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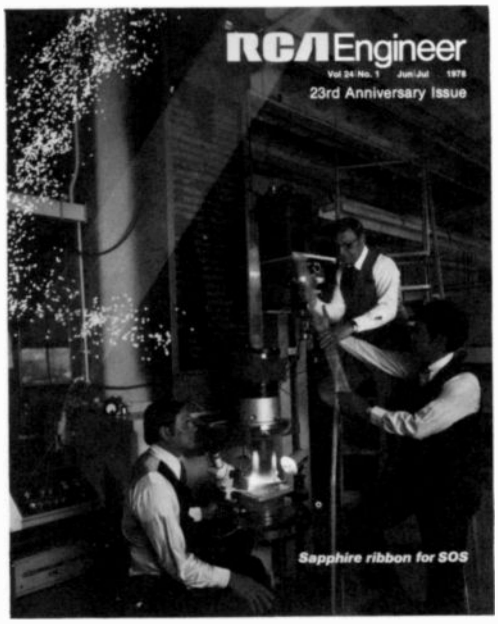
- To disseminate to RCA engineers technical information of professional value
- To publish in an appropriate manner important technical developments at RCA, and the role of the engineer
- To serve as a medium of interchange of technical information between various groups at RCA
- To create a community 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.



Our cover: Competitively priced silicon-on-sapphire circuits have been a goal of the solid-state industry for years. Now, RCA has developed a process for making sapphire ribbon, a major step toward that goal. Our cover photo was taken on the first day of ribbon production at the Solid State Division's Mountaintop, Pa. plant.

The aluminum oxide crystals at the upper left-hand corner are the starting point for the process, and the ribbon running diagonally across the cover is a typical unpolished output. Rich Novak, (RCA Laboratories, Princeton), seated by the console, was responsible for the technology transfer of the puller concept from RCA Laboratories. Nick Gubitose (SSD, Mountaintop), who was responsible for the design of the ribbon puller, is handing down a sample ribbon to Ural Roundtree (SSD, Somerville), a wafer user—he was responsible for developing the epitaxial reactor that will be used in processing the SOS wafers. Read more about the advantages of SOS technology in Bernie Vonderschmitt's article starting on page 4.

Photo credit: Tom Cook, RCA Laboratories, Princeton, N.J.

The life cycle— it's a fact of industrial life

Today's RCA management is determined to ensure our corporate vitality by participating in electronic-based industries in their growth and development cycles.

Every successful product has a life cycle—development, followed by growth, maturity, and then decline. During development, it is often true that expenses are high, income is low, and the product loses money. The picture reverses during the growth period, where income rises sharply and variable costs drop as we gain production experience. Then comes maturity. Sound management, engineering, marketing, and manufacturing programs to improve the product can maintain or enhance profitability for many, many years. It is income from such products that seed other products during their growth and development periods. Eventually, however, most products become obsolete, revenues drop, and the decline is underway.

Industries too are bound by this cyclical pattern. Railroads are often used as an example of an industry that has gone through development and maturity, and is now declining. We can apply this life-cycle model generally to any industry—if we use a narrow definition of "industry" (e.g., transportation obviously doesn't fit).

It follows, then, that if an industrial organization ties its future to a single product—or even a single (narrowly defined) industry—it is on its way to an inescapable decline.

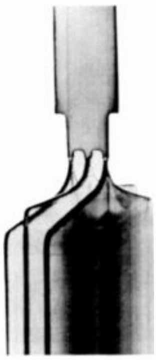
These facts of industrial life are well understood at RCA. Our management recognizes the need to adequately support current mature businesses to maintain their vitality and profitability as long as possible. And our management is determined to take the steps necessary to ensure growth and corporate vitality by developing innovative new electronic products that will, in some cases, spawn new industries. In both cases, management recognizes that, in an electronic-based company like RCA, a highly skilled and competent technical staff is the primary force that will carry our new products and industries through development, growth, and product improvement to successful maturity.

I am confident that our engineering community will respond to lead this continued development and growth.

Howard Rosenthal

Howard Rosenthal
Staff Vice President
Engineering
Princeton, N.J.

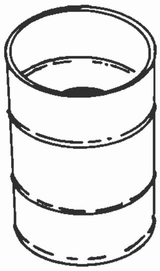
23rd anniversary issue



SOS technology

SOS circuits used to be "advantageous, but expensive," but costs are dropping substantially.

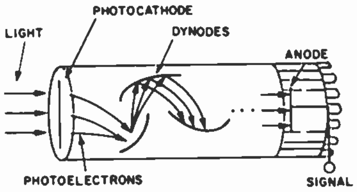
4



Energy

Is this barrel half empty or half full? What's going to replace the missing oil?

10



Photomultipliers

Starting as a very small research effort, they've become a large and diverse business.

18

RCA undersea

What are 700 RCA employees doing at Andros Island in the Bahamas?

40

coming up

Our next issue (Aug/Sep) covers RCA space technology—weather, communications, and navigation satellites, and even amateur radio in space.

Future issues will cover RCA at the Missile Test Project, manufacturing, and energy.

RCA Engineer

Vol. 24|No. 1 Jun|Jul 1978

general interest articles

on the job/off the job

engineer and the corporation

departments

Silicon-on-sapphire (SOS): an LSI/VLSI technology

B.V.Vonderschmitt

A new process for making sapphire wafers should bring the cost of SOS circuits down to a level competitive with bulk silicon circuits.

A cost-effective manufacturing technique for placing an epitaxial layer of silicon on a passive substrate has been the goal of semiconductor and, particularly, IC technologists for a number of years. The reason for this interest is the potential that isolated-device elements offer from the standpoint of circuit performance, flexibility of design, and density. There is nearly uniform agreement among those engaged in research related to IC technology and product development that a system that virtually eliminates parasitic components has significant merit. The silicon-on-sapphire (SOS) technology meets all of these requirements, but has not caught the interest of IC manufacturers for one main reason—the cost of the sapphire substrate, currently six to eight times that of bulk silicon material.

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Bernie Vonderschmitt holding a sapphire ribbon and a substrate.

But the outlook is changing. Developmental effort over the past five years has brought significant progress in the processes used in manufacturing sapphire substrates. Analysis indicates that, within the next several years, sapphire-substrate costs will be within 25 to 35 percent of bulk silicon wafer costs. Analysis further indicates that the increased densities and higher yields resulting from the use of a passive substrate (SOS) rather than a semiconductor material substrate (bulk silicon) will result in system costs that are nearly equal. In some applications, SOS costs will be lower than those of alternative, existing technologies. This reduced cost could well be the ingredient required to provide the impetus for an increased effort on the part of the IC industry to develop the SOS technology into the most significant new large-scale integration (LSI) technology of the future.

SOS advantages

The basic difference between an SOS component and a standard bulk-silicon component is that in the SOS component the active devices are constructed within a silicon island that is electrically isolated by either oxide or sapphire from other such islands within the same IC. Once the islands have been defined, standard silicon gate processing is used to construct the active devices. Fig. 1 is a simplified illustration of the initial SOS processing steps.

The silicon-island concept in itself increases the component's density potential through the elimination of the guard bands or p-n junctions conventionally used for isolation. Silicon islands also increase yields because a "killer defect," which would normally cause component failure on a semiconductor material substrate, can occur between silicon islands, and yet have no effect on an SOS IC. For an extensive list of SOS advantages, see the box at the right.

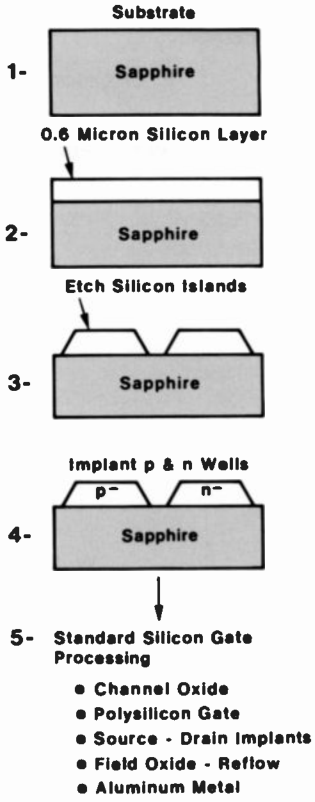


Fig. 1
Electronically isolated silicon "islands" represent the basic difference between SOS components and standard bulk-silicon components. In this simplified illustration, the nonconducting sapphire substrate (step 1) is coated with a thin layer of silicon (step 2). The islands are then etched out (step 3), and *p* and *n* wells are added (step 4) in preparation for standard silicon gate processing (step 5). The result is a very densely packed integrated circuit without the parasitic devices obtained with bulk silicon processing.

SOS history

The development of SOS as a viable technology began in the mid-to-late 1960s.

RCA's effort began more than ten years ago at RCA Laboratories in Princeton, N.J. Other companies, such as Rockwell, Westinghouse, General Electric, and Hughes, have had, and still have, active programs in SOS aimed primarily at specialty applications and focused on the advantages of SOS, particularly in radiation-hardened circuits. Inselek, a venture-capital company that discontinued operations nearly three years ago, attempted to develop and manufacture SOS devices for the commercial market. The company could not make SOS competitive with bulk complementary MOS at the SSI level, an area where the fundamental advantages of SOS offered little or no cost-performance improvements.

Two U.S. companies are currently visibly active in SOS for commercial applications: Hewlett-Packard, an original equipment manufacturer of instrumentation and computers, and RCA, an IC supplier.

Hewlett-Packard's interest, according to published information, lies in the performance and application advantages that accrue to the end-equipment design. RCA's interest is in exploiting SOS commercially, entering it into competition directly against other MOS technologies in both performance and, ultimately, cost.

Many companies have demonstrated the significant technological and performance advantages that SOS has over bulk CMOS, PMOS, and NMOS, particularly in static devices. However, the manufacturing costs of SOS devices have remained high, primarily because of the high sapphire substrate cost. To make it commercially viable, an innovation in SOS substrate manufacture was required; the gradual improvement of the technology with time could never surpass the experience or "learning curve" that Czochralski silicon wafers have undergone over the last fifteen years.

Although certainly not universally believed, there is general agreement that if SOS could achieve cost/price parity with other technologies, the fundamental attributes of SOS would make it an attractive LSI/VLSI technology. It is, therefore, important to examine the cost fundamentals of sapphire substrates.

Why design in SOS?

SOS electrical isolation provides fundamental advantages in design and application development which, for the first time, free the circuit, product, and system engineer from limitations dictated by alternative technologies. Some of these advantages are:

1) Field inversion problems that can create extraneous parasitic devices cannot occur in the SOS technology because the field region is not a semiconductor material. Therefore, the designer can ignore the presence of parasitics that his design may inadvertently include, and need not expend development time in protecting his design from such possibilities.

2) The designer cannot encounter latch-up problems caused by parasitic SCR devices. An SOS component design is not susceptible to the spike voltages that trigger parasitic devices.

3) The absence of parasitic devices enhances the reliability of SOS devices.

4) Power dissipation, particularly static power, is low enough to relieve the device and system designer of the concern for the power-down techniques currently required, for example, in many memory applications.

5) Once a proved-in set of standard "building block" circuits has been developed, the potential for a successful first-pass design is significantly improved. If the logic is correctly simulated and the circuit "blocks" are properly interconnected, the device is not subject to unexpected parasitic effects.

6) IC debugging is greatly simplified because SOS circuitry is completely static and has no parasitic effects.

7) Operation over a wide temperature range is assured without significant changes in either device characteristics or power dissipation.

8) The system designer can take greater liberties with his power-supply design since an order of magnitude less power is required. Complementary SOS also allows the system voltage supply to vary over a wider range, and requires less regulation circuitry.

9) The complementary SOS technology has high noise immunity, which reduces the amount of circuitry required to protect data lines from ripples and spikes.

Ribbon-pulled substrates: the cost breakthrough

There are two fundamental approaches to the manufacture of sapphire substrates.

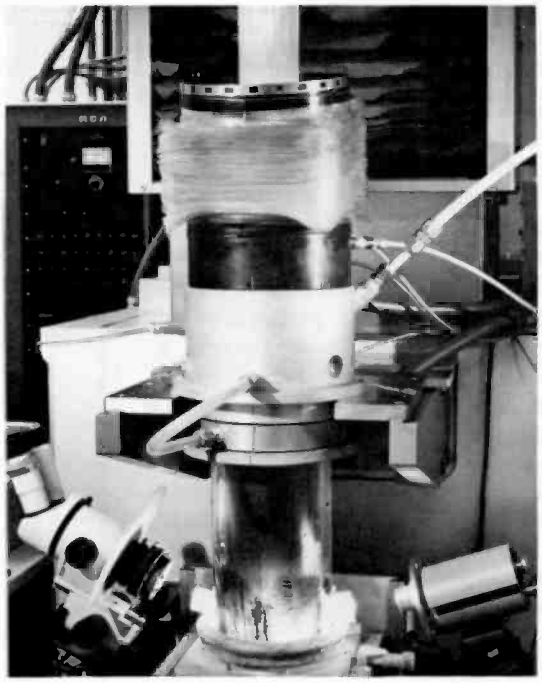
One approach is the familiar Czochralski process used for fabricating bulk silicon wafers, except that high-purity Al_2O_3 is used to grow sapphire crystals. This process results in a crystal three inches in diameter that is then sliced into individual wafers. The considerable cost and loss of material (approximately 45 percent) associated with the slicing operation fundamental to this approach provided the stimulus for an alternate process for sapphire manufacture. The apparent

RCA's ribbon-growing process

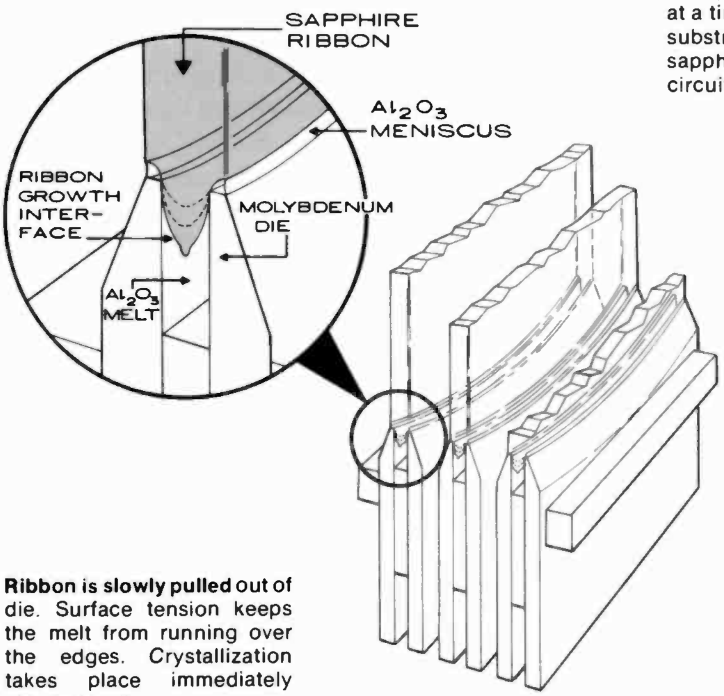
RCA is using a new shaped crystal growth technique to produce low-cost sapphire substrates for CMOS/SOS processing. The technique is called edge-defined film-fed growth, or EFG, and is currently used to grow three-inch-wide ribbons, three at a time, as shown in the diagram below. Grossly simplified, the process consists of melting sapphire (aluminum oxide) crystals, contacting the melt with a seed crystal, and slowly pulling the resulting shaped crystal through a special die.

The die must be made of material that the melt will wet but not react with too severely; either tungsten or molybdenum will fulfill this condition for an aluminum-oxide melt. A capillary is created by closely parallel spacing the two plates of the die. The aluminum-oxide melt will climb to the top of the capillary if the theoretical maximum capillary height is not exceeded, which is typically the case for all practical growth conditions. Surface tension will hold the melt to a properly oriented seed crystal dipped into the capillary. Slow withdrawal of the seed will lift the melt onto the top surfaces of the die with the melt spreading to the external edges of the die. The melt is constrained from running over this external edge by surface-tension forces. An isothermal temperature distribution is maintained across the die top coupled to a very steep, vertical gradient. This will crystallize the melt immediately above the die before surface-tension forces can relax the shaped melt, thus producing a shaped single crystal.

—Rich Novak, RCA Laboratories

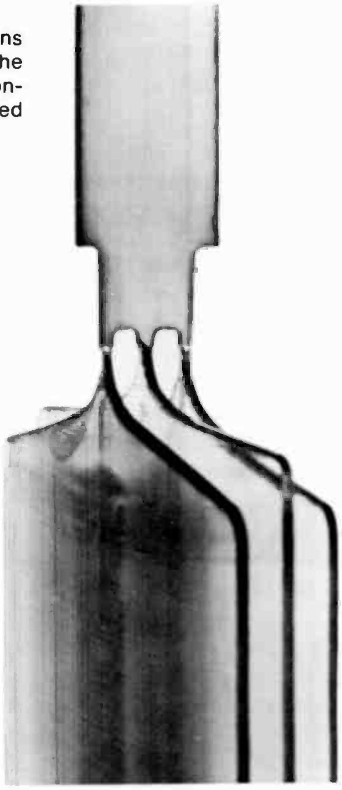


Ribbon-pulling machine. Note glow from heated crucible containing melted sapphire at bottom. Ribbon is emerging at top of picture.



Ribbon is slowly pulled out of die. Surface tension keeps the melt from running over the edges. Crystallization takes place immediately above the die.

The product—three ribbons at a time—will be used as the substrate for silicon-on-sapphire (SOS) integrated circuits.



answer is a proprietary process called edge-defined film-fed growth (EFG), which involves pulling a continuous "ribbon" of sapphire from a shaping die that determines the ribbon's thickness and width.

Fig. 2 illustrates the EFG manufacturing technique. Capillary action pulls the molten Al_2O_3 up through the shaping die, where a seed crystal is brought into contact with it and pulled to form the sapphire ribbon. It is possible to pull more than a single ribbon from the same crucible simply by adding additional shaping dies and pullers, thereby increasing manufacturing volume significantly and leading to broader amortization of equipment and labor expenses. Growing the substrate in the form of a ribbon eliminates the need to saw the crystal into individual wafers and so saves labor and reduces material losses or eliminates the expense of material reprocessing for recycling.

EFG can be applied to SOS substrate manufacturing today.

However, additional development will be required before it can be applied to silicon substrates. Because the sapphire substrate is only used as a mechanical support for silicon islands, its crystal orientation does not need to be as exact as that required for the silicon substrate, which is eventually used for the construction of active devices.

Once a ribbon has been pulled, it is scribed into square wafers, as shown in Fig. 3. Currently, three-inch ribbons are pulled, and the resulting three-inch-square wafers are converted to mechanical replicas of the rounded bulk-silicon wafers to permit the use of existing wafer-handling fixtures. However, this method is only a temporary expedient; eventually the square wafer will be processed directly, and manufacturing output will be increased even further because of the increased wafer area.

The rounded wafers are then polished before the 0.6-micron epitaxial silicon layer is grown. Ultimately, the rounding will be eliminated and, possibly, the polishing. Continuing development has demonstrated the feasibility of growing the epitaxial layer directly on the scribed square wafers. Elimination of rounding and polishing will, of course, further reduce labor costs and material losses.

SOS substrate costs

Ribbon-pulled sapphire costs less than standard round sapphire wafers.

A comparison of the cost per square inch of various sapphire substrates with a polished silicon substrate is plotted in Fig. 4. Costs for Czochralski silicon and sapphire were obtained from various U.S. suppliers; the costs for sapphire ribbon were developed based on the EFG manufacturing methods within RCA. All costs are stated on a normalized basis (with appropriate markups) and include the epitaxially grown silicon layer on the sapphire wafer. Based on information from suppliers, little if any cost benefits can be realized from increases in silicon wafer volume; inflationary labor and material costs will tend to offset any benefits derived from these increases. As a result, the cost/price per unit area of wafer is not expected to change significantly.

The basic ribbon substrate represents less than half of the total cost of a given component. Since a large percentage of the remaining cost is for surface preparation, a significant cost improvement potential ex-

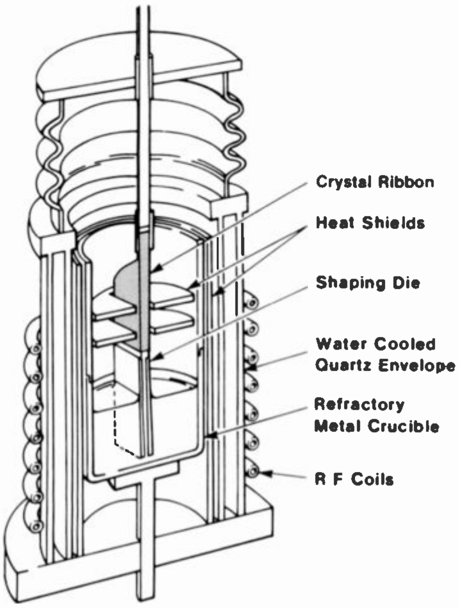


Fig. 2
Ribbon-pulling technique for the edge-defined film-fed growth (EFG) process. RF coils heat the sapphire into a molten state, and capillary action pulls it up through the shaping die. There, it contacts a seed crystal and is slowly pulled up to form the sapphire ribbon. Wafers made in this manner do not require the expensive and material-wasting slicing operation otherwise required.

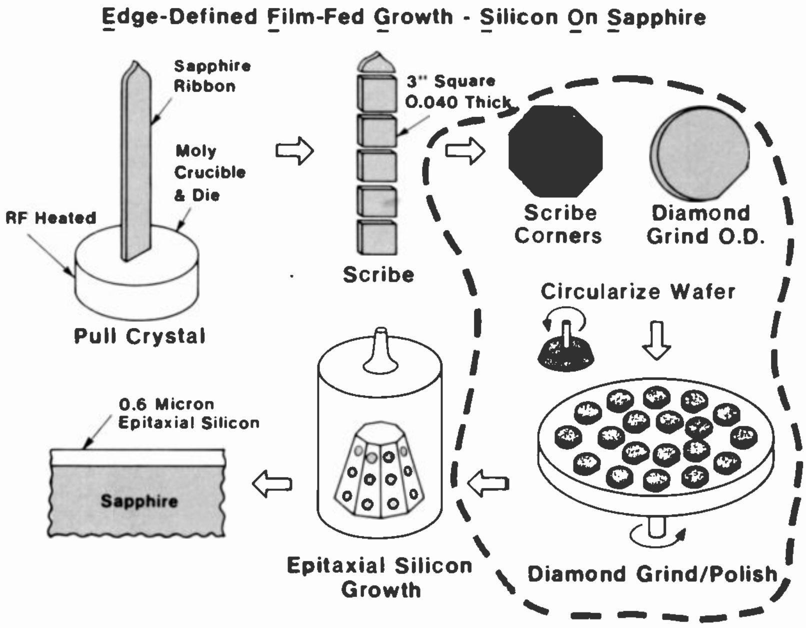


Fig. 3
Once a ribbon is pulled, it is scribed into square wafers. The silicon layer can then be grown on the wafer, but presently a number of steps (inside dashed line) are needed to make wafers compatible with existing wafer-handling equipment. Ultimately, these steps will be eliminated to further reduce materials losses and labor costs.

ists with any surface-condition improvement that would allow sapphire ribbons to be processed "as grown", i.e., no rounding or polishing. This potential, plus the reduced cost of pulling multiple ribbons, has not been included in Fig. 4.

The future cost of a sapphire wafer is estimated to be 30 to 40 percent greater than that of a bulk silicon wafer.

This figure is for cumulative volumes shown in Fig. 4. The benefit of EFG manufacturing of sapphire substrates is quantified by the difference between the cost of the three-inch round Czochralski sapphire wafer and the three-inch ribbon. The cost benefits of eliminating rounding and polishing are represented by the four-inch-square ribbon curve. Because of the normal manufacturing learning curve and the breakthrough in substrate manufacturing represented by the EFG process, the cost of a sapphire wafer will begin to approach that of a silicon wafer at relatively low accumulated volumes.

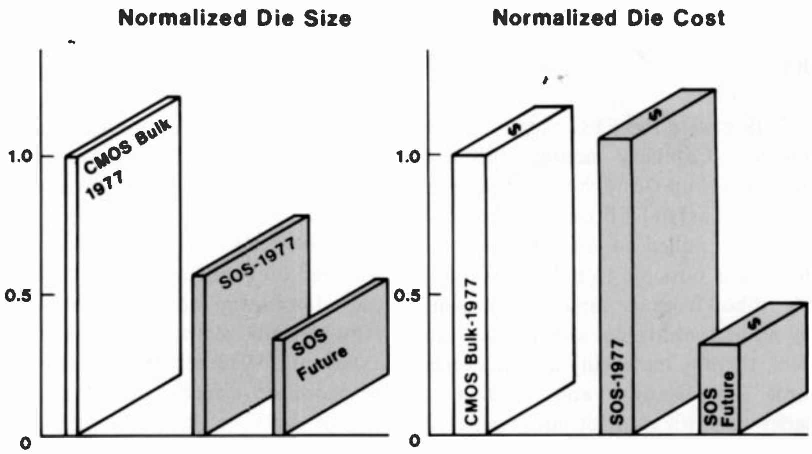


Fig. 5
Comparison of CMOS die sizes and costs, based on 8-bit microprocessors. SOS die size is presently about 50% of bulk-silicon die size, but should shrink to about 35%. Die cost is still high at present, but will drop as ribbon process produces wafers in the future.

Die size for SOS is about half that of CMOS, and should get smaller.

An analysis has been made of the relative die size and die cost for a CMOS eight-bit microprocessor and for a 16k static RAM using various technologies. The following ground rules were used:

1) For existing devices, the die sizes represented the range of those available in the marketplace.

2) For scaled-up or extrapolated devices, critical dimensions were responsive to evolutionary improvements expected to occur with time for each technology analyzed. The smallest critical dimension assumed on any device is 2 microns.

3) The device costs were determined from the basic material, labor, and directly associated expenses. The yields were determined from a consideration of mask levels and the potential for a defect to be fatal.

4) The probability of defects per unit area were assumed to be the same for all technologies. Different defect rates were assumed with time but were equitably applied to all technologies.

5) Material costs for sapphire compared to bulk silicon were taken from Fig. 4.

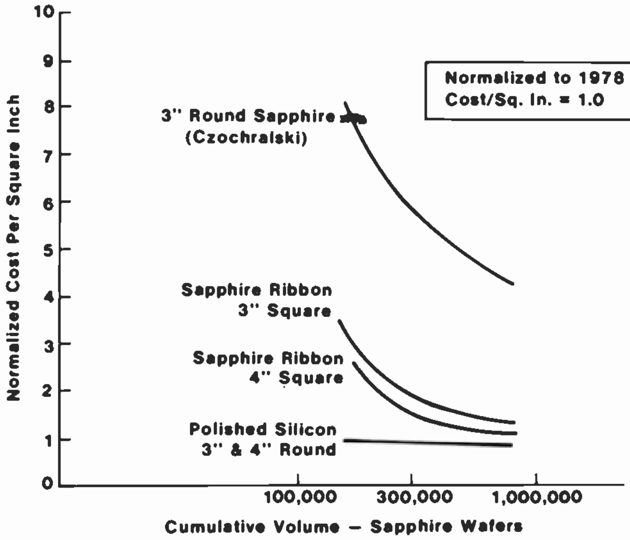


Fig. 4
Cost comparison shows the advantage sapphire ribbon has over conventionally grown round sapphire. Eventually, sapphire wafers should cost only 30 to 40% more than silicon wafers. (This estimate does not include the possibilities of improved surface conditions or multiple ribbon-pulling.)

For an eight-bit microprocessor, such as the RCA CDP1802, the die size for the current SOS design is slightly greater than 50 percent of the bulk silicon size and, with some process enhancements and tighter design rules (3.5-micron critical dimension), approximately 35 percent of bulk silicon size. Currently, the die cost for SOS is slightly greater than that of bulk silicon, primarily the result of the current Czochralski sapphire cost. But this cost will diminish to 25 to 35 percent of the bulk silicon cost in the future, as illustrated in Fig. 5.

SOS should eventually be cost-competitive with NMOS in terms of normalized die costs.

The economic impact of the EFG process is dramatically illustrated in a plot of the normalized die size and cost for 16k static RAMs fabricated by means of various technologies. Although not economically feasible, four existing devices were scaled

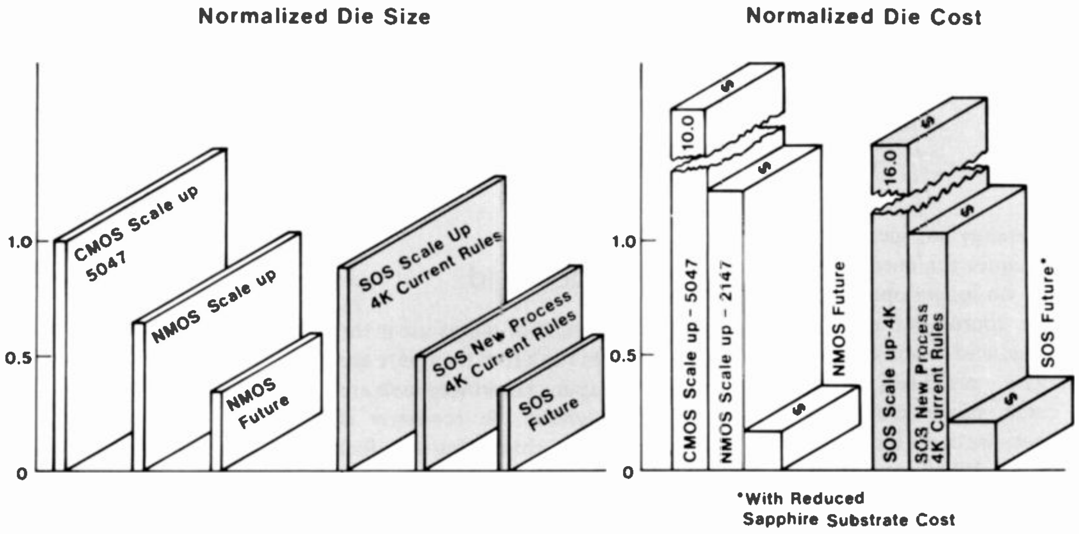


Fig. 6
Comparison of die sizes and costs for competing technologies. (See text for description of scaling and normalizing process used.) SOS should eventually be cost-competitive with NMOS, but SOS will also have a number of system advantages.

up to 16k RAM products for the purpose of comparison; that is, their die size and costs were extrapolated to reflect the same technology design capability and manufacturing costs had a 16k RAM been fabricated. To complete the analysis, the future capabilities of NMOS and SOS technologies, the two technologies capable of producing an economically feasible 16k RAM, were also compared. The items scaled up include the CMOS 5047, the current NMOS design rules, and the current- and enhanced-process SOS 4k design rules. The "NMOS Future" label assumes an enhanced "new process" currently in development that uses a 3.5-micron critical dimension. In determining the normalized die cost, sapphire substrates were assumed to cost 30 percent more than bulk silicon substrates.

As illustrated in Fig. 6, the impact of SOS and EFG substrates on the "SOS Future" normalized die costs places the "SOS Future" process in a competitive position relative to NMOS, even at the component level. Other system advantages discussed earlier provide additional end-equipment savings. With the availability of a viable solution to the fundamental sapphire-substrate cost problem, additional equipment manufacturers will begin to recognize the advantages that accrue to their system designs with the use of SOS, such as Hewlett-Packard has already demonstrated. It is certain, therefore, that, with time, other semiconductor manufacturers will also demonstrate a marked acceleration of interest in SOS.

Market size

As noted above, SOS is a technology for LSI and VLSI.

The dynamic-memory market for large memory systems will, as a result of momentum and cost considerations, remain in the province of n-channel technology for the foreseeable future. The high-speed market (less than five nanoseconds propagation delay) is the province of ECL and similar technologies. However, much of the rest of the systems requirements could, from a performance standpoint, be served by SOS.

The market size for digital signal-processing applications, excluding ECL and dynamic memories, is shown for the year 1977, and projected for 1980, in the table below:

	1977 $M	1980 $M
Total MOS	1315	2100
Total bipolar (excluding ECL)	985	1200
	2300	3300
Potential for SOS	1800	2500

The "potential" shown is that portion of the market that is identifiable as being technically and economically served by SOS. Penetration into this commercial market will begin in 1978 and accelerate over the next few years as the cost reductions discussed above are realized. In addition to the cost reductions in the SOS technology, primarily resulting from the EFG process, the technical advantages of SOS complementary static devices, already recognized in military and custom applications, will further expand their commercial markets.

Conclusion

It now appears that SOS has an identifiable, practical solution—the EFG process—to the last major obstacle blocking its widespread commercial application. As a result, the SOS technology will no longer be limited to only those applications that can afford to pay a premium for its technological advantages, but will find broad application in industrial, consumer, automotive, and other price-sensitive, commercial markets.

Acknowledgments

Norman C. Turner, Eugene M. Reiss, and Gerald K. Beckmann, all of the Solid State Division, helped prepare this article.

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Energy—a review and survey

B.F. Williams

The world's changed energy situation has implications for RCA in terms of its existing businesses and new business opportunities.

Because the cost of energy has increased, the traditional techniques for energy use and management are no longer optimum. Further, uncommon sources of energy, from liquid fuels produced from coal to heat and electricity produced from sunlight, have come much closer to economic viability because of the increased cost of traditional fuels. What constitutes an appropriate RCA response to this new situation depends on one's view of its long-term seriousness and on RCA's capabilities to address the problems raised. The situation *is* serious and has its roots in worldwide industrial development, and RCA does have capabilities to address some of the problems raised. In this article, we will discuss the evolution of the present energy situation and describe the response of the U.S. Government (the National Energy Plan). The specific RCA programs addressing near- and long-term opportunities will be the subject of individual articles in the Feb/Mar 1979 issue of the *RCA Engineer*.

U.S. energy supply and demand

Fig. 1 shows the pattern of energy use in the U.S. for 1977.[2] On the left of the figure are the various fuel inputs. How those fuels are distributed throughout the economy is shown by the pipes connecting the fuel sources with the end uses. As can be seen from the figure, in those cases where the fuels are used primarily for heating, such as in the industrial, residential, and commercial sectors, the efficiency of use is relatively high. In the case of electricity generation and in the transportation sector, the efficiency is low because of the fundamental inefficiency of the generating plants and the gasoline engine.

We are running out of oil.

With the ready availability of low-cost, convenient oil and natural gas, essentially all of the growth of U.S. energy consumption in the last thirty years took place using these fuels. As can be seen in Fig. 2, oil itself grew from 30% of the total energy use in 1947 to 50% in 1977,[3] while total energy use doubled. This is an increase from 5.5 million barrels of oil per day (MBD) in 1947 to over 18 MBD today. At this rate of oil consumption, the U.S. has enough reserves for only ten years.[4] Including the "undiscovered recoverable resources" might give an additional seven to twenty years worth of oil at present consumption rates.[4]

Fig. 1 clearly shows that the U.S. is now importing half of the oil it uses. This is a new situation, as evidenced by Fig. 3. This recent and explosive growth in the amount of oil we import reflects the state of our own resources and present consumption patterns, and has created financial and political problems. This situation is aggravated by the increase in the world's energy consumption and the finite quantity of the world's conventional energy resources.

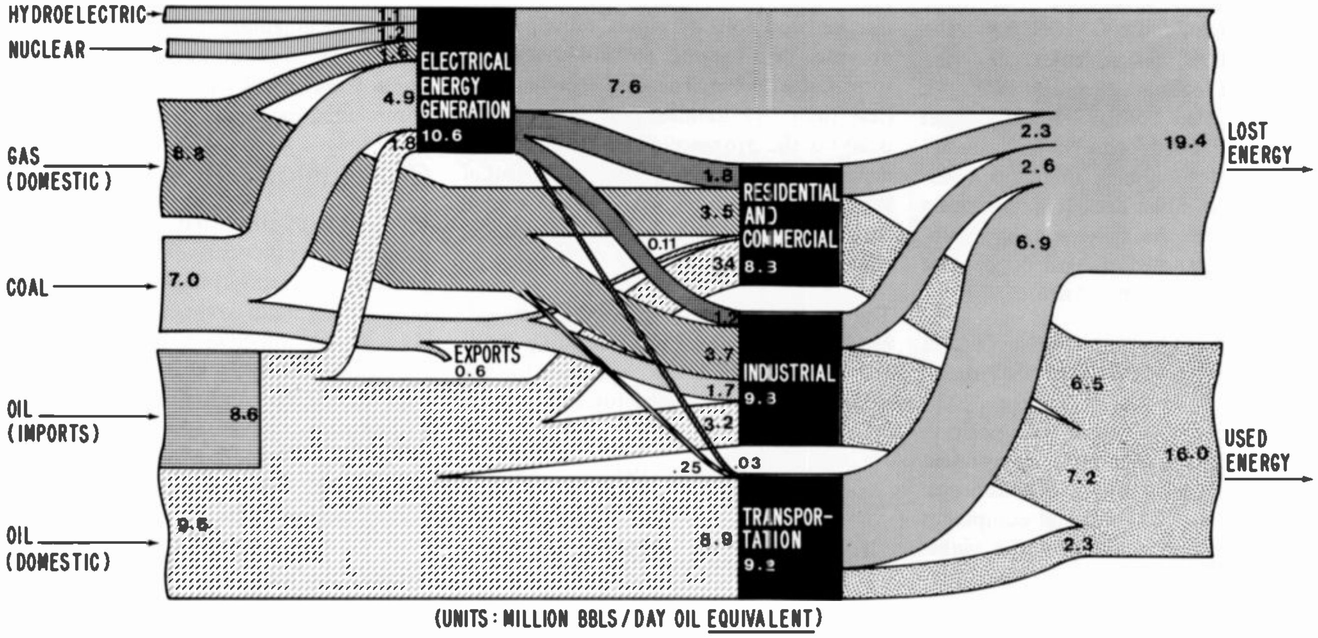

Fig. 1
U.S. energy sources and sinks, 1977. (The format for this figure is borrowed from Ref. 1.) Numbers in the figure are in millions of barrels of oil per day (MBD) equivalents; e.g., for natural gas the numbers reflect the amount of oil that would give the same heat energy as the amount of gas used. These data were taken from the January 1978 issue of the Monthy Energy Review (Ref. 2). Data for the full year of 1977 were estimated from the use through November 1977, and are accurate to about 5%.

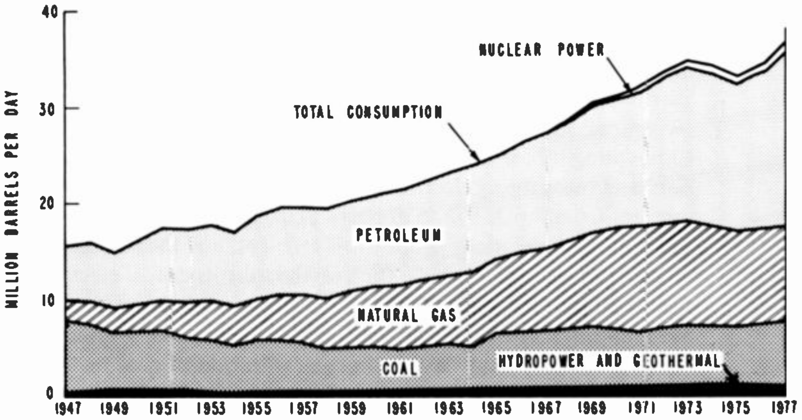

Fig. 2
Total U.S. energy consumption, Ref. 3. Note that the reduction in consumption caused by the 1973 oil embargo took almost 4 years to be eliminated.

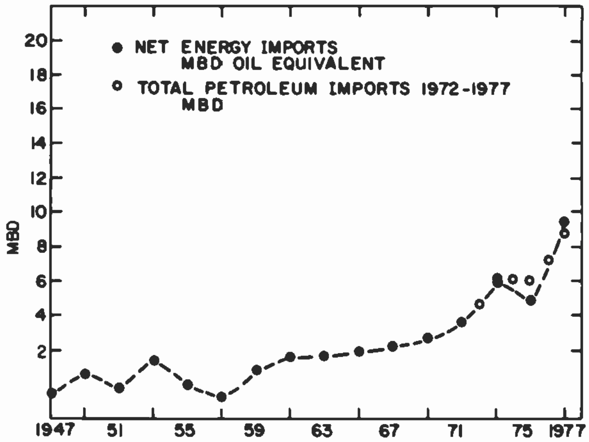

Fig. 3
Net U.S. energy imports and recent oil imports, Ref. 3. Importing such large amounts of oil is a recent phenomenon.

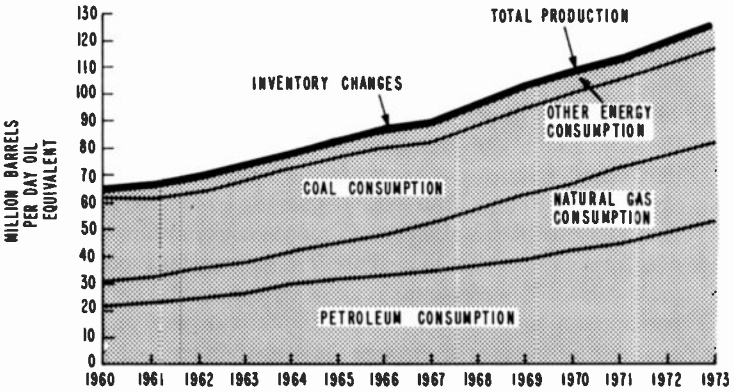

Fig. 4
World energy consumption, Ref. 3. As in the U.S., world energy use increases have been met by oil and natural gas.

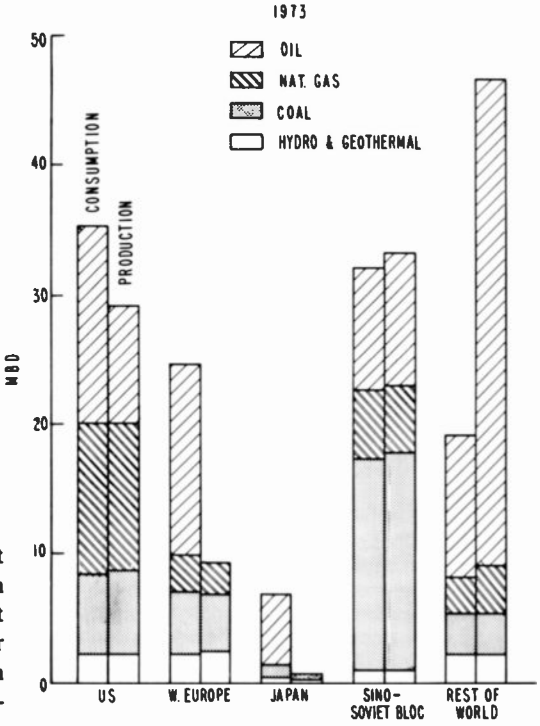

Fig. 5
World energy use and production, Ref. 4. The vulnerability of Japan and Western Europe to curtailments in oil supply is apparent.

For the past thirty years, U.S. energy consumption has increased at a rate of about 3% per year, while the total world energy consumption has increased at a rate of 5% per year (Fig. 4). The U.S. share has dropped from 34% in 1960 to just under 30% today. The growth in the world energy use took place using oil and natural gas, as it did in the U.S. As a result, much of the developed world faces an energy situation similar to, or worse than, that in the U.S. Fig. 5 is a summary of who is using the world's energy resources and who is producing them. Present OPEC exports are 32 MBD, practically all of the production shown in Fig. 5 labeled “rest of the world.”[5] Fig. 6 shows the present production capacity of the OPEC countries. Note that because of excess capability (6 MBD), the Saudis are in a position to reduce oil-price inflation for the time being. Within the next several years, some analysts believe production *growth* from Alaska and the North Sea will be slowing and that the Soviet Union will switch from an exporter of oil to an importer.[5] The result will be a dramatic increase in demand for OPEC oil, with a concomitant increase in prices when excess OPEC capacity is exhausted. One estimate of the timing for this development is shown in Fig. 7. Whether it is believed that the time for the next dramatic increase in oil prices is three or ten years away, we are running out of oil. While an increase in oil prices will make more resources available through the use of difficult-to-recover oil, such increases will have dampening economic effects and destabilizing political effects world-wide.*

We do have alternatives.

From a world-wide energy point of view, a potential solution to this problem is a shift to a more plentiful energy resource or to a source that is renewable. From a U.S. political point of view, a shift to a more plentiful or renewable resources over which we have control is a desirable solution. The U.S. is fortunate in that this is possible.

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*In the last two years our imports of oil have increased from 6 to 9 MBD. To appreciate how difficult it is to bring on line additional capacity at any price, note that production from the Alaskan North Slope is presently running at 0.7 MBD, scheduled to increase to 1 MBD. We would have had to discover and develop three more Alaskan North Slopes in the last two years to stay even.

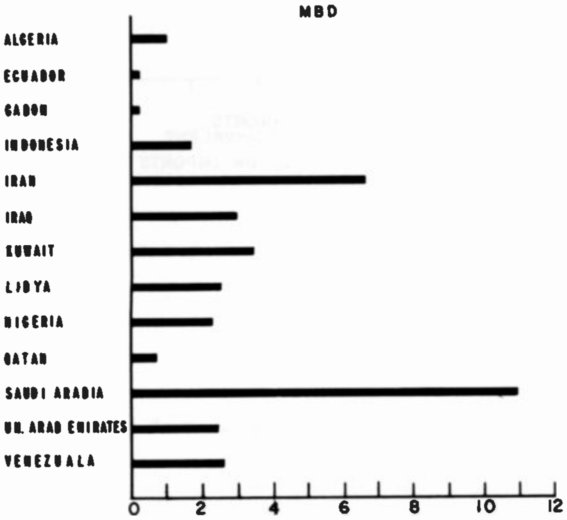


Fig. 6
OPEC production capacity as of March 1977, Ref. 5. The total capacity is about 38 MBD.

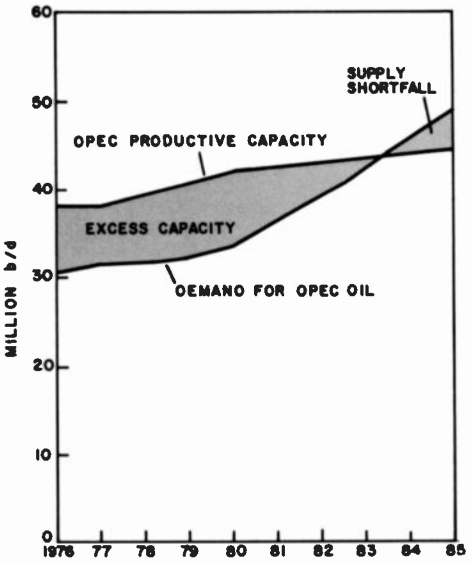


Fig. 7
OPEC oil will not supply the rest of the world forever. In this OPEC supply and demand projection, Ref. 5, note that there is excess capacity today, but a projected sharp rise in demand for the immediate future. Crossover point is projected for 1984, even with an increase in production capacity (which will, paradoxically, have to be made during a period of excess supply.)

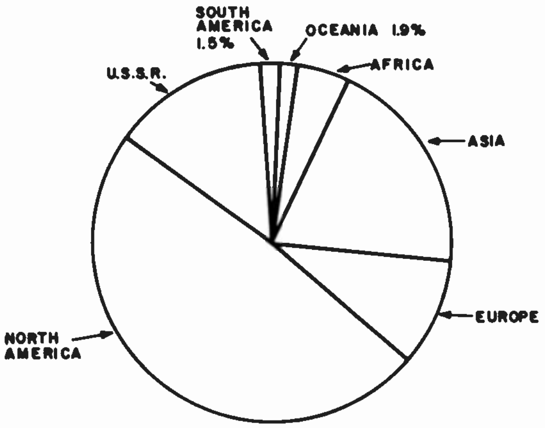


Fig. 8
World's measured recoverable energy reserves, Ref. 4. See Fig. 9 caption for a definition of reserves.

Half of the world's measured recoverable energy reserves are in North America, principally in the form of coal (Figs. 8 and 9). Coal may be readily used to generate electricity, assuming that the environmental costs are acceptable and transportation is available. (A ton of coal has the same heat energy as 4 barrels of oil.) Eliminating oil for all uses except petrochemicals and transportation, and substituting electric heating for oil heating would drop oil imports from 8.6 MBD to about 3 MBD. However, because the generation of electricity is only 30% efficient, and the direct use of oil for heating is about 80% efficient, the substitution of electricity from coal for oil would require an increase of coal equivalent to 12 MBD of oil, an *increase* twice as large as present coal production. More reasonable may be the direct substitution of coal for oil in heating. This requires an increase of only about 5 MBD equivalent of coal production (an 80% increase) and implies a return to domestic, commercial, and industrial coal-fired furnaces; also a seemingly unattractive prospect.

A similar situation exists with natural gas, although not so serious, for while the supply is comparable to oil's, we use it at about half the rate. Again, coal may be substituted for gas in electricity generation with the same environmental and transportation problems, but switching from gas to coal in domestic, commercial, and industrial heating and processing may be extremely difficult to achieve.

The reduction of our dependence on foreign energy resources for the near term and development of renewable or essentially inexhaustible sources of energy for the long term is the subject of the National Energy Plan (NEP).[6] (See the box on the next page.) Basically, the plan is designed to reduce consumption and in the near term cause a shift to coal use. The strategy for accomplishing these goals is to increase the price of oil and natural gas through a combination of increased price ceilings and taxes. The long-term goals are to be obtained through the support of research programs. The NEP is presently being debated in Congress with progress impeded by great interest in the section on oil and natural gas pricing.

What are our alternatives now?

In the following discussion, the various energy sources are discussed separately in the following categories: conservation and energy efficiency; oil and natural gas; coal; nuclear electric energy; hydroelectric generators; and new sources of energy.

Conservation and energy efficiency

"The cornerstone of the National Energy Plan is conservation, the cleanest and cheapest source of new energy supply."

Decreasing the growth rate of energy consumption can have substantial effects, as seen in Fig. 10. In this case, decreasing the rate from 3.5 to 2.3% would save 5 MBD by 1985. As might be expected from an inspection of Fig. 1, the transportation sector offers great opportunity for satisfying overall national goals, since the energy potentially conserved comes directly from oil. In 1975 Congress enacted legislation which required that the sales-weighted average of new-car mileage be improved to 20 mpg in 1980 and 27.5 mpg in 1985. There has been progress in this direction, but the NEP has further provisions to encourage this conservation. A proposed tax on new cars will penalize purchasers of cars that have mileage poorer than that legislated in 1975 and reward purchasers of cars which have better mileage. Further, the Plan provides for a standby gasoline tax to be imposed in the event that administration

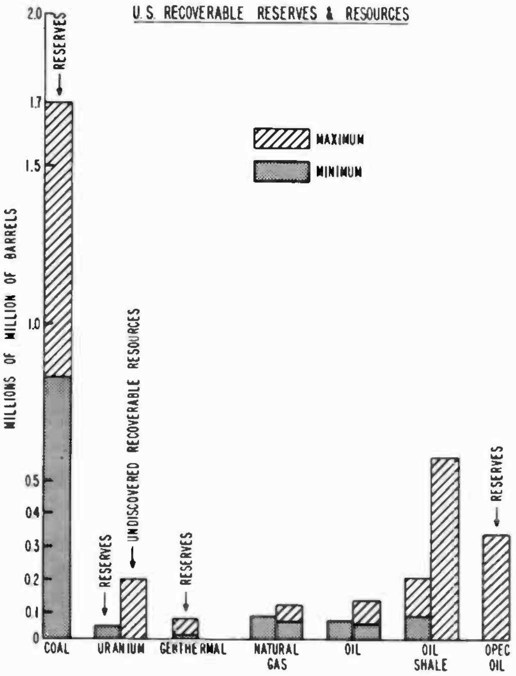
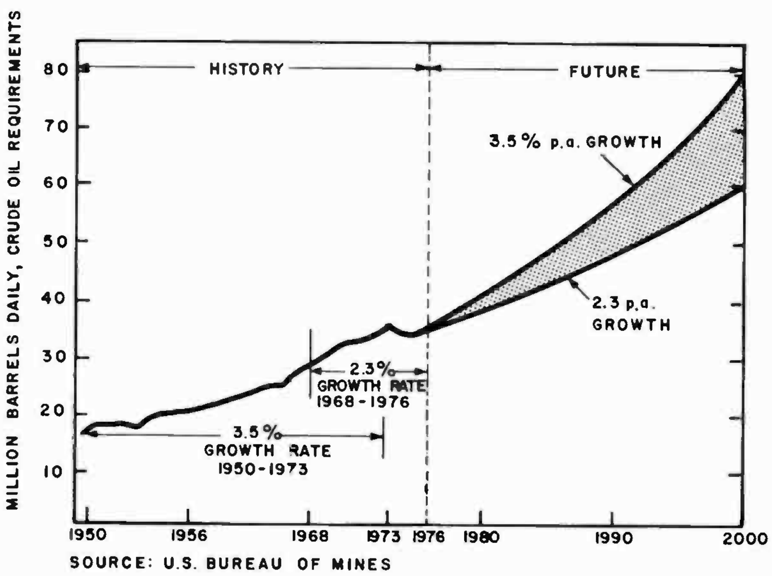


Fig. 9
Distribution of U.S. fuel supplies, Ref. 4. It is extremely important to differentiate between "reserves" and "resources." While custom has it that these words mean different things for different fuels, in general, reserves are fuel supplies that may be tapped with existing technology without dramatic increase in cost. Resources, in contrast, are estimates of total existing supplies.



SOURCE: U.S. BUREAU OF MINES

Fig. 10
Conservation can have a dramatic effect on energy demand. Decreasing our annual energy growth rate from 3.5% to 2.3% would save 5 MBD by 1985.

consumption goals are not met. Removing the excise tax on buses, increasing the tax on non-commercial aviation fuel, and eliminating the rebate of half the Federal tax on motorboat fuel are also proposed.

Tax credits for conservation investments in residential, commercial, and industrial situations are proposed. Reform of the utility rate structure is also proposed. Promotional rates would be eliminated and rates reflecting costs implemented. Therefore, off-peak and interruptable service would be encouraged.

Oil and natural gas

Both oil and natural gas are price controlled and cost less to use than their replacement cost.

In the case of gas, the intra-state prices in the producing states are higher than the regulated interstate prices, leading to gas shortages in the nonproducing states. The

The national energy plan*

"The U.S. has three overriding energy objectives. As an immediate objective, which will become even more important in the future, the U.S. must reduce its dependence on foreign oil to limit its vulnerability to supply interruptions. In the medium term, the U.S. must weather the stringency in world oil supply that will be caused by limitations on productive capacities. In the long term, the U.S. must have renewable and essentially inexhaustible sources of energy for sustained economic growth. The strategy of the Plan contains three major components to achieve these objectives.

"First, by carrying out an effective conservation program in all sectors of energy use, through reform of utility rate structures, and by making energy prices reflect true replacement costs, the nation should reduce the annual rate of growth of demand to less than 2 percent. That reduction would help achieve both the immediate and the medium-term goals. It would reduce vulnerability and prepare the nation's stock of capital goods for the time when world oil production will approach capacity limitations.

"Second, industries and utilities using oil and natural gas should convert to coal and other abundant fuels. Substitution of other fuels for oil and gas would reduce imports and make gas more widely available for household use. An effective conversion program would thus contribute to meeting both the immediate and the medium-term goals.

"Third, the nation should pursue a vigorous research and development program to provide renewable and other resources to meet U.S. energy needs in the next century. The Federal Government should support a variety of energy alternatives in their early stages, and continue support through the development and demonstration stage for technologies that are technically, economically, and environmentally most promising."

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*This quotation and others appearing in this article are from the National Energy Plan, which, contrary to widespread belief, does exist. This document (Ref.6) is available from the U.S. Government Printing Office, Stock #040-000-00380-1.

authors of the NEP recognize that new gas and oil are more expensive to find and produce than old gas and oil. However, they do not feel that the U.S. producers with oil in existing fields should benefit from the three-fold increase in oil prices that the foreign producers imposed. Presently, old oil has a price ceiling of $5.25/barrel and new oil a price ceiling of $11.28/barrel. The cost for an oil user depends on the mix of old, new, and foreign oil he has available. It is proposed that the price of new oil be allowed to increase to the 1977 world price ($13.50/barrel) and thereafter increased to account for inflation. In order to curtail oil use, it is proposed to tax old oil ($5.25/barrel) and previously discovered new oil ($11.28/barrel) an amount to bring the cost to the consumer up to the world price. The revenues received would be distributed back to consumers in general in the form of an "energy payment," a credit against other taxes, or a general tax reform.

When the cost of oil increased, demand for natural gas increased. Natural gas is price controlled; it is now underpriced and there is excess demand. It is proposed to increase the price ceiling for new gas from its present $1.49/1000 ft^3 so that it equals the average price of the equivalent amount of all domestically produced oil, about $1.75/1000 ft^3. Gas made available from existing intra-state production would also qualify as new gas. The new higher-priced gas would be allocated to industrial users, since it is felt that they have the best opportunity to convert to other fuels. Cheaper old gas would be conserved for domestic use.

Industrial users of gas would be subjected to a tax to bring the cost of gas to 1-⅓ times the world price of gas. A phased-in conservation tax, increasing from $0.9/barrel to $3/barrel, will be levied on industrial and utility oil users. The intent of these pricing structures is described as making the consumer bear (something like) the replacement cost of the energy, while not providing windfall profits for the energy companies.

Coal

"Expansion of U.S. coal production and use is essential if the nation is to maintain economic growth, reduce oil imports, and have adequate supplies of gas for residential use."

The tax structures described above for oil and gas are designed to provide this shift to coal use. Further, industry and utilities would be prohibited from burning oil and gas in large new boilers. Utilities burning gas will have to shift to other fuels entirely by 1990 and would require a special permit to shift to oil instead of coal.

The environmental impact of this shift to coal-burning facilities is the subject of some concern, and "the Administration intends to achieve its energy goals without endangering the public health or degrading the environment."[6] This may not be so easy to do. In areas with serious air-pollution problems, oil may continue to be burned. The pollution problem associated with coal burning is being addressed with research and demonstration programs on flue-gas desulfurization systems, fluidized-bed combustion, coal grinding and washing, solvent-refining coal to remove sulfur, and manufacturing low-BTU gas from coal for industrial purposes and high-BTU gas from coal as a potential replacement for natural gas. A research and demonstration program to develop the technology of coal-to-oil conversion is also in progress.

While the coal is available in the ground, it is appropriate to note some of the problems the NEP for coal production and utilization poses.[7,8] The Plan calls for a 90% increase in coal production by 1985, for a total of 1.2 billion tons. This will require 200 to 250 new mines, or almost three new mines opened per month; about 150 large mining shovels or drag lines, and the industry can barely keep up with today's demands. The coal industry's long-range plans, which emphasize Western coal, call for 80,000 new underground miners and 45,000 new surface miners to be hired and trained by 1985. The NEP intends to increase the production of high-sulphur Eastern coal because of the transportation problem of bringing Western coal East to be used. This proposal to expand Eastern and contract Western production will increase the manpower numbers and add to the capital investment because surface-mined Western coal productivity is ten times greater than Eastern. The requirement of comparable pollution controls for combustion of low-sulfur Western coal as for high-sulfur Eastern coal adds to the costs, as does the additional investment for upgrading the poorer Eastern roadbeds.

Rapid expansion of coal use depends on cost and availability of pollution-control equipment and industrial boilers. The average cost of pollution-control equipment itself for large industrial boilers is $4 million per installation; the cost of converting to coal, including new boilers of 6000-MW generating capacity, is $4 billion. To burn the additional coal that the Plan assumes industry will use, 2500 new coal-fired boilers will be needed by 1985 to replace existing boilers. To meet these goals, increased production capacity must be on line soon. Faltering of demand or production will result in 1985 goals falling short.

Potential coal users must be assured of adequate and reliable supplies. This implies about 100 new rail and ship or barge transportation systems; several 500- to 1000-mile coal-slurry lines and about 8,000 new locomotives and 150,000 new coal cars. This means about three new locomotives and 60 new coal cars every day for the next seven years.

In the environmental area, let us assume that the NEP goal to achieve coal conversion without sacrificing air-quality standards is met. Nevertheless, the Plan's goals will lead to other adverse environmental and societal impacts which were not addressed.

The best available control technology is not adequate for nitrogen-oxide emissions from coal burning. Radioactive materials, carbon monoxide, and heavy metals (gas, liquid, or solid state) from coal combustion are not regulated. Coal releases more carbon dioxide during combustion than oil or natural gas. Since an increase in carbon dioxide may contribute to global climatic changes, accelerated use of coal may aggravate long-term adverse effects on climate.

Scrubbers produce about 3,000 tons of solid suspended in several thousand tons of water per day, per gigawatt day of energy generated. Present nationwide electric capacity using all fuels is 400 gigawatts. Disposal of all this sludge presents a serious land-use problem which includes contamination of ground and surface water by the sludge's moisture.

Western coal mining implies competition with the farmer for water for surface reclamation and potential contamination or loss of groundwater aquifers; Eastern mines pose the threat of acid-water runoffs.

Longer and more frequent train trips will affect rural towns in terms of sustained noise levels, air pollution along rights-of-way, increased accidents, crossing delays, and railroad congestion. Energy-related population increases in small Western localities will tax existing schools, medical services, water and sewer facilities. Loans from banks for homes and private facilities will be difficult to obtain because of the boom and bust nature of the development. This can lead to a degradation in the quality of life of these communities.

If the program to cause a shift to coal is successful, the impact of a coal strike such as experienced this past winter could be enormous.

Nuclear electric energy

The most abundant energy source in the ground in the U.S. after coal is uranium, about one-tenth of the coal reserve.

The uranium supply shown in Fig. 9 is the supply of U^{235}. This rare isotope is used to fuel light-water reactors. In a plutonium breeder reactor, the abundant U^{238} is converted to plutonium, which can be used as a fuel. In this case, the uranium fuel supply should be increased fifty times, to five times the coal reserves.

Although it may be possible to generate gas and oil from coal, nuclear energy simply produces heat, which may be used to generate electricity. In the absence of the environmental impact of massive coal burning, there is not a clear domestic reason to develop nuclear electric technology, particularly since it has its own waste-disposal problems. However, not all countries are blessed with our coal reserves and nuclear energy plays a major role in the planning of many.

The common reactor in this country is the light-water reactor, which uses enriched uranium as a fuel and produces small amounts of plutonium as a by-product. There is particular interest overseas in the breeder technology because it manufactures fuel and few countries have the uranium supplies of the U.S. The liquid-metal fast breeder reactors use plutonium as fuel, however, and plutonium may be used to produce nuclear weapons. Because of the dangers with plutonium-based technologies (plutonium breeder reactors), the U.S. has elected to delay the demonstration phase of such power systems. Further, the U.S. is asking foreign governments with nuclear capacity to do the same. In order for this to be possible, the U.S. is offering to provide supplies of enriched uranium for use in light-water reactors so that foreign breeder reactors will not be necessary. In view of the disruptions experienced by foreign governments caused by the increase in the price of OPEC oil, it is not clear that these same governments will be willing to rely on another external source of energy, this time in the form of enriched uranium.

RCA's energy-related programs

As described in the accompanying article, the U.S. government response to the new energy situation is two-fold. First, through conservation and a switch to coal use, reduce consumption of oil and natural gas. Second, for the long term, develop renewable sources of energy. RCA is addressing both the near- and long-term situations with programs devoted to optimizing energy-use practices in this new environment and exploring opportunities for new business activities in both the near and long term.

Briefly reviewed below, a description of RCA's programs will appear in the Feb/Mar 1979 issue of the *RCA Engineer.*

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.

Several research activities evaluating the usefulness of recent RCA developments for using solar energy are under way. A new optical coating that will improve the efficiency of solar thermal collectors is under study. Techniques for low-cost manufacture of single-crystal silicon solar cells and the utility of an inexpensive RCA-developed, sun-tracking solar-cell array are being evaluated. The practicality of amorphous-silicon solar cells, an inexpensive thin-film alternative to the single-crystal devices, is receiving considerable attention. A technique for storing hydrogen as formic acid is being developed and its energy efficiency is being improved. This energy-storage technique could affect present energy use as well as the future solar-based technologies.

In order for the U.S. to play a continuing international role in the control of fissionable materials, it would seem necessary to maintain an active effort in the development of nuclear technologies, particularly in the development of non-plutonium-based breeder reactors, (e.g., thorium-based systems).

Hydroelectric generators

When available, hydroelectric power costs ten times less than that generated by thermal (nuclear, gas, coal, and oil) power plants.

The year 1977 was the first one in which more energy was generated by nuclear power than by hydroelectric power, principally because of a reduction in hydropower because of poor rainfall. In 1975 and 1976 hydroelectric power accounted for 15% of the nation's electricity generated, while nuclear power increased from 8.7% to 9.5%. In 1977 the hydro portion dropped to 10%. As it has been estimated that capacity at existing sites might be increased by about one-third, the plan calls for a Department of Defense (Corps of Engineers) study to evaluate this potential. The use of smaller-scale hydro plants in New England is also being considered.

New sources of energy

Solar

By far the largest energy source available to the U.S. is solar energy.

On the average, the sunlight deposits an amount of energy equivalent to our total coal reserves in one or two months, depending on how big our coal supply really is. The problem with solar energy is that it is difficult to collect, as it is distributed over the whole country. The year-long average power density is 200 W/m^2 with a peak insolation (sunlight power density) of 1 kW/m^2 at noon on a clear day.

The energy falling on the roof of a 1500-ft^2 house has a yearly, country-wide average of 2 million BTU/day, at a rate of about 75 kW during the day. This energy can be collected and used for heating and cooling purposes or for generating electricity. If the energy is to be used as heat, it can be collected with an efficiency of between 30% and 60%, depending on the temperature of the delivered energy. If the sunshine is to be used to generate electricity, it can be collected and converted to electricity with an efficiency of about 5%. With these conversion rates, the energy needs of such a house could be supplied by the sun if it shone in this average fashion.

Brown Williams became Director of the Energy Systems Research Laboratory at RCA Laboratories in 1977. He had previously been responsible for RCA's solar-energy studies.

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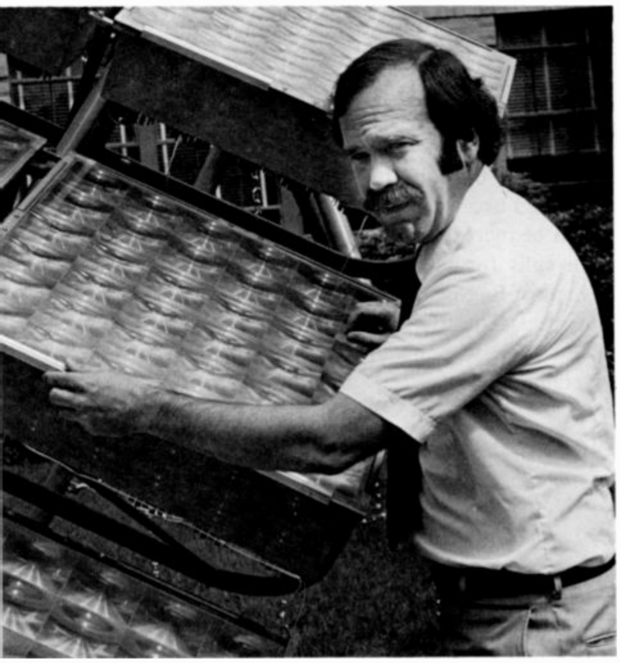

Author Williams with a concentrating solar array.

Solar hot water and space heaters are available commercially and, compared to other solar technologies, are relatively cost-effective. The NEP proposes tax incentives to make their cost to the consumer less. A tax credit of 40% of the first $1000 of the purchase price and 25% of the next $6400 (for a total of $2,000) is proposed. This credit would decline with time, but some credit would be available for expenditures from April 20, 1977 to December 31, 1984. Some states have already exempted solar equipment from property-tax assessments. Solar equipment also qualifies for the proposed 10% tax credit for conservation in industrial use.

Direct generation of electricity from sunshine is cost-effective at the moment only in very remote regions. The installed system costs must be reduced by a factor of 50-100 for these technologies to represent a credible alternative to conventional sources of electricity.

Two basic approaches are under development for direct electricity generation. First, photovoltaic devices; i.e., solar cells, which are semiconductor devices that convert light to electricity, are having their costs reduced. The cost of power supplies based on these devices does not benefit from large economies of scale, so that such systems might be installed wherever the energy is used. The deployment of large arrays duplicating the performance of central power stations is also an alternative. A 1000-MW solar power supply, comparable to the new nuclear or coal plants, would occupy about 20 square miles of land. A proposal to locate such large arrays in space where daily and seasonal variations in the power output do not exist is under study. Second, electricity can also be generated from sunshine using the energy to heat a fluid and using the fluid to drive a heat engine. A 10-MW generating plant of this type is under construction in Barstow, California. In this facility, an array of mirrors focuses the sunlight on a boiler, which drives a generator as in a conventional power station.

Technologies that use solar energy indirectly are also under development. Wind, ocean thermal, and biomass systems are in various stages of implementation. A number of novel wind-driven electricity generators are under study and a federally sponsored 200-kW machine is being coupled into the power grid in Clayton, NM. The ocean thermal devices are heat-engine electricity generators that operate on the temperature differences between surface and subsurface water in the ocean. In this case the supply of energy is vast, although the efficiency is low because of the small temperature differences. Very large quantities of fluid must be moved, and warming the cold, nutrient-laden subsurface water may result in some fouling. This type of electricity generator is in an active study and research phase.

The use of agricultural and forest byproducts for energy production is already well known. The growth of products specifically for energy generation and as feedstocks for liquid and gaseous fuels is under development.

Geothermal

Geothermal energy is in practical use now.

Geothermal energy in the form of steam is presently used to generate 500 MW_e in northern California, and there are numerous sites in the West where hot water is available. (If the temperatures are high enough, electricity may be generated; otherwise the heat energy may be used directly.) The NEP proposes to extend to geothermal drilling exploration the same tax benefits now available for oil and gas exploration. There is an active R&D program to develop this resource.

Fusion

There are two approaches to generation of electricity using fusion: magnetic confinement and inertial confinement.

With magnetic confinement, a magnetic field is configured to form a cavity that contains the ionized gas fuel for a time long enough, and at a temperature and density high enough, that the fusion reaction can take place. In inertial confinement, a fuel pellet is compressed by a shock wave resulting from the ablation of the surface of the pellet. This compression should produce the needed time, density, and temperature to initiate fusion. In both cases, the fuel is hydrogen or its isotopes and the fusion reaction results in the formation of helium and energy. So far, these systems have not fulfilled a criterion known as "breakeven," (i.e., producing more energy than they consume) by a considerable margin.

What is the government's emphasis on these programs?

Some insight may be gained on the relative importance the administration places on

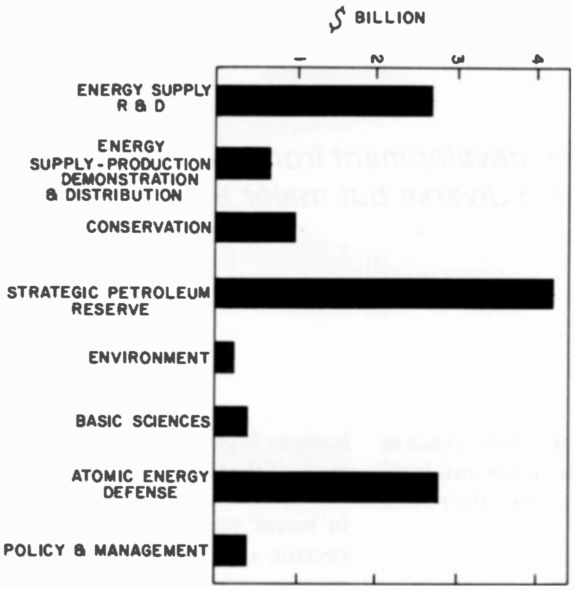

Fig. 11
How the Department of Energy allocates its money. Energy-supply R&D is third, behind the strategic petroleum reserve and atomic-energy defense. Program areas are explained in text.

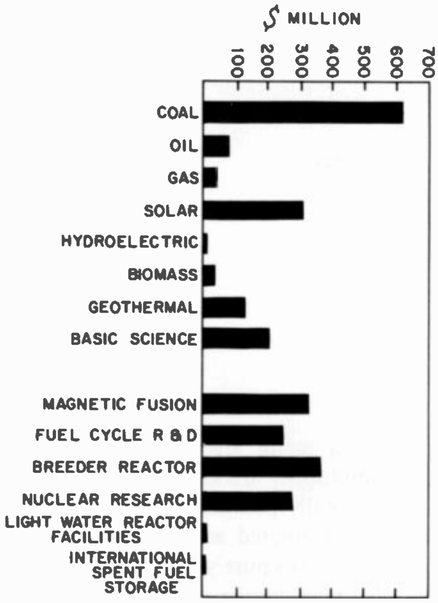

Fig. 12
How DOE research is allocated. Coal research takes the lion's share. Next-largest is the fusion/fission area, followed by solar-energy research, which is being expended mostly on solar cells.

the programs outlined above by an inspection of Fig. 11. The makeup of the R&D program will be discussed in the paragraph below. The Energy Supply—Production Demonstration and Distribution Programs include Naval oil reserves, solar heating and cooling demonstration, uranium enrichment and resource assessment, alternate fuels demonstration, and electric power marketing administration. The Conservation area includes conservation programs in all sectors of the consuming environment, government and private. The strategic petroleum reserve, by far the largest single item in the budget, is a program to stockpile 500 MBD (30 days supply at present consumption rates) by December 1980. The Environment program is principally biomedical and environmental research. Basic Sciences is a program in life sciences, nuclear physics, and support for several high-energy particle accelerators. Half of the Atomic Energy Defense budget is for weapons activities. The rest is the inertial-confinement fusion program, Naval reactor development, materials production, and security and safeguards.

Ignoring the strategic petroleum reserve and the defense activity, the R&D program is the largest by far. Fig. 12 shows how the various parts of the R&D program are allocated. Half is for nuclear electricity programs and half for new energy sources or new uses of old energy forms. With the importance that coal has in the overall strategy, it properly is the largest program. Work on liquification and gasification constitutes half of the expenditures, an amount about equal to the solar program.

The solar program is almost all electricity generation, with solar-cell development and solar thermal-electric generation accounting for most. It is interesting that while an inspection of Fig. 1 and most newspapers reveals that our massive consumption of oil, principally for gasoline, is our major problem, there is such a large emphasis in the R&D budget on alternative sources for electricity generation.

Summary

As in the U.S., the growth in energy use throughout the world has been met almost exclusively with oil and natural gas. These resources are finite and, as we are approaching the point where their finiteness is apparent, their costs are going up. The U.S. response to this new and permanent situation is two-fold. First, through conservation and a switch back to the use of coal, conserve natural gas to insure availability for domestic use and conserve oil for use in transportation. Second, for the long term, develop renewable energy sources such as solar energy or sources with enormous fuel supplies, such as fusion.

For RCA the challenge is also two-fold. First, the energy environment has changed and is going to continue to change. While RCA is not a particularly energy-intensive company ($30 million/year), we must adapt to these changes to maximize profit opportunities in our existing businesses. Second, opportunities for exploiting electronic device, materials, and systems expertise in the enormous energy field do exist. Energy is one of the largest business activities in the nation and its changed economics means that companies that have not traditionally been in the energy field may now participate. Matching RCA's capabilities to this opportunity presents exciting prospects for the future.

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PHOTOMULTIPLIERS—then and now

R.W. Engstrom

An account of their development from a very specialized and minor business to a diverse but major enterprise.

Today, RCA has a major share of the important photomultiplier market, but we got there without really planning to. To begin with, the very limited market for photomultiplier tubes was purely scientific in orientation. No mass market was foreseen. Competition was minimal. A favorable attitude of RCA's management toward high-technology products nurtured the product line. The evolution of the wide variety of photomultiplier tubes was largely guided by our responses to several unanticipated applications.

Beginnings

The origin of the photomultiplier is rooted in early studies of secondary emission.

In 1902 Austin and Starke[1] reported that metal surfaces impacted by cathode rays emitted a larger number of electrons than were incident. A great deal of research was done in the 1920s and 1930s on the properties of secondary emission.[2] The development of radio and television led to several practical applications of this phenomenon; amplifier-power tubes exploited secondary emission for additional gain as did television camera tubes (such as the image dissector, the image orthicon, and the isocon) and, of course, the photomultiplier.

The distribution of emission energies of secondary electrons from metals is generally reported to be as shown in Fig. 1. The number of secondary electrons emitted per incident primary electron is, of course, very important in many practical applications. For the photomultiplier, it is also useful to have a relatively high yield at modest primary energy to minimize applied voltage. Typical secondary-emission yield curves are shown in Fig. 2 for a number of surfaces that have been used in photomultiplier tubes. In the first photomultiplier tubes made, the photocathodes were Ag-O-Cs, a red-infrared-sensitive photoemitter, and it was found expedient to use the same material for the secondary-emission surfaces (or dynodes). Later, with the development of the very sensitive Cs_3Sb photocathode it was found that the same material also made a very good secondary emitter, although not as stable at moderate current levels as MgO of CuBe. Major use today is made of the Cs_3Sb and the CuBe emitters.

In recent years, a remarkable "negative-electron-affinity (NEA)" secondary-emission material (Cs-activated GaP) has been reported by R.E. Simon.[3] Very high secondary-emission yields are obtained (see Fig. 2) because of the reduction of the surface energy barrier. This NEA material is used primarily for special applications where the very high gain results in a reduction of the statistical noise associated with the secondary-emission amplification process.

Secondary electrons are directed to the first and succeeding dynodes by electron optics.

In 1934, Philo Farnsworth[4] reported on a *multipactor* device in which electrons were directed back and forth between two secondary-emitting surfaces. Energy was applied by means of an alternating electric field whose frequency was timed to the time of flight of the electrons. The multipactor never evolved into a practical photomultiplier; Farnsworth's principal interest in this idea was in applying it to the image

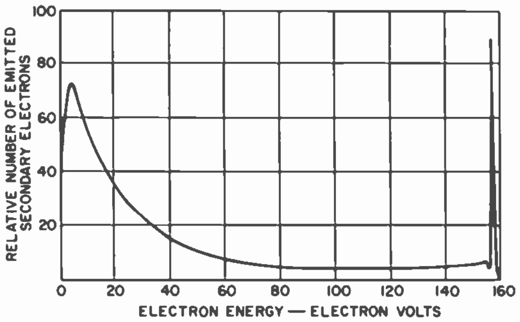


Fig. 1
Typical energy distribution of secondary emission of electrons; the peak at the right is caused by reflected primary electrons. In metals, secondary electron energies generally range from 0 to 10 eV.

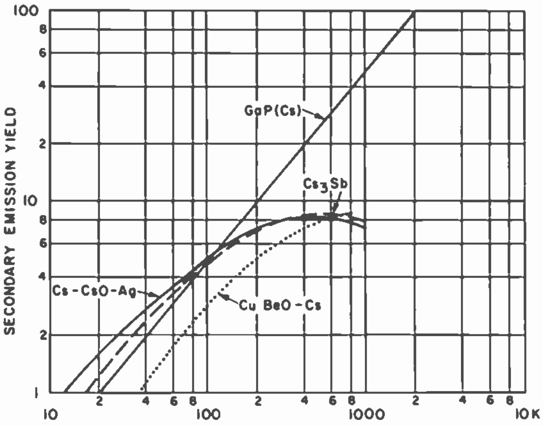


Fig. 2
Secondary emission yield plotted as a function of accelerating potential of primary electrons for various emitters that have been used in photomultiplier tubes. With the newer negative-electron-affinity (NEA) materials—e.g., GaP(Cs)—secondary electrons can be created at greater depths and still escape.

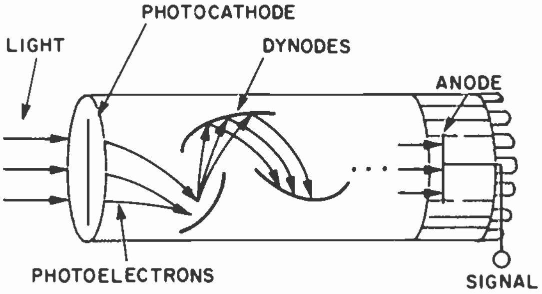
dissector for television pick-up applications.

Also, in 1934, Georg Weiss in Germany was working on a photomultiplier in which the secondary-emission surfaces were fabricated of mesh.[5] The mesh dynodes were mounted in a parallel arrangement so that primary electrons impinged on one side of the mesh and secondaries were extracted and accelerated to the next mesh from the opposite side. No commercial devices resulted.

In 1935, Iams and Salzberg[6] of RCA reported on a single-stage photomultiplier. The device, Fig. 3, consisted of a semicylindrical photocathode, a secondary emitter mounted on the axis, and a collector grid surrounding the secondary emitter. The tube was basically intended as an improvement over the gas-filled phototube which was used as a sound pickup for movies. It had a gain of about eight and a much better frequency response, but despite these advantages saw only a brief developmental sales activity before it became obsolete. This electron-optical arrangement for a single stage of secondary emission was relatively unsophisticated; electron-optical problems become more difficult when a number of stages of secondary emission are required.

The photomultiplier tube: how it works

The photomultiplier is a very sensitive detector of light.



When light strikes the *photocathode*, located inside the vacuum envelope, *photoelectrons* are emitted and directed by an appropriate electric field to the next electrode or *dynode*. For each primary photoelectron hitting this dynode, a number of secondary electrons are emitted. These secondary electrons, in turn, are directed to a second dynode to produce more secondary emission—and so on until a final gain of perhaps 10^6 is achieved. The electrons from the last dynode are collected by an *anode* which provides the *signal current* that is read out. Because the photomultiplier's high gain is practically noise-free, tube performance is close to the ideal, limited only by the shot noise of the initial photoelectron current.

In applications where speed of response is important, the photomultiplier also does well because of the short electron emission and transit times.

In 1936, Zworykin, Morton, and Malter, all of RCA[7] reported on a multistage photomultiplier. The principal application contemplated was sound-on-film pickup. Their photomultiplier used a combination of electrostatic and magnetic fields to direct electrons to repeated stages of secondary emission, Fig. 4. Each successive secondary emitter was operated at a higher voltage—perhaps 100 V—than the previous emitter. Above each emitter was a field plate whose potential was set to be equal to that of the next emitter down the line. As a result of this electrostatic-magnetic configuration, electrons emitted from the photocathode, or from one of the emitters, were caused to follow approximately cycloidal paths to the next electrode.

The design of the Zworykin magnetic photomultiplier was based on relatively straight-forward calculation of electron trajectories. Developmental samples were built and tested, Fig. 5. But although the magnetic-type photomultiplier did provide high gain, it had several difficulties. The

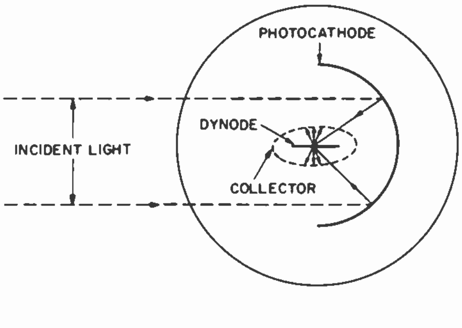


Fig. 3
Single-stage photomultiplier reported by Iams and Salzberg in 1935. Photoelectrons leaving the concave photocathode strike the dynode strip and eject secondary electrons that are collected by the flattened spiral collector grid surrounding the dynode.

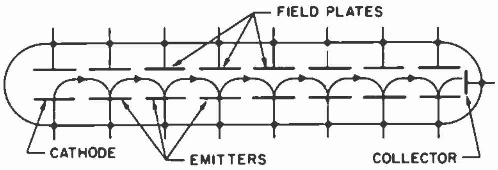


Fig. 4
Magnetic-type multistage photomultiplier reported by Zworykin, Morton, and Malter in 1936. A magnetic field, perpendicular to the plane of the drawing, and an electrostatic field, produced by the upper field plates, combine to bend the paths of electrons leaving the lower plates so that they strike the next target to produce secondary electrons which are in turn deflected to another target and so on to the collector.

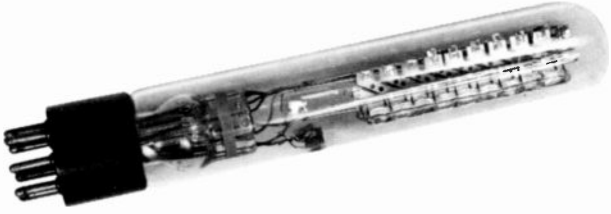


Fig. 5
Developmental sample of the Zworykin magnetic photomultiplier described in Fig. 4.

adjustment of the magnetic field was very critical, and to change the gain by reducing the applied voltage, the magnetic field also had to be adjusted. Another problem was that the rather wide open structure resulted in high dark current because of feedback from ions and light developed near the output end of the device. For these reasons, and because of the development of electrostatically-focused photomultipliers, commercialization did not follow.

The design of multistage electrostatically focused photomultipliers required an analysis of the equipotential surfaces between electrodes and of the electron trajectories. Before the days of high-speed computers, this problem was solved by mechanical analogue. A very convenient and successful model was a stretched rubber membrane. One such analogue model, as used by Jan Rajchman, is shown in Fig. 6. By placing mechanical models of the electrodes under the membrane, the height of the membrane was controlled and corresponded to the electrical potential of the electrode. The vertical position at any point on the membrane between electrodes also corresponded to its electric potential. Small balls were then allowed to roll from one electrode to the next. The trajectories of the balls were shown to correspond to those of the electrons in the corresponding electrostatic fields. With appropriate configurations, friction and depression of the membrane by the ball were made negligible, and the analogue was essentially exact. The model, however, was only valid for geometries in which the electrodes could be assumed to be cylindrical surfaces (generated by a line parallel to a fixed direction and moving along a fixed curve) sufficiently long to be considered infinite in extent.

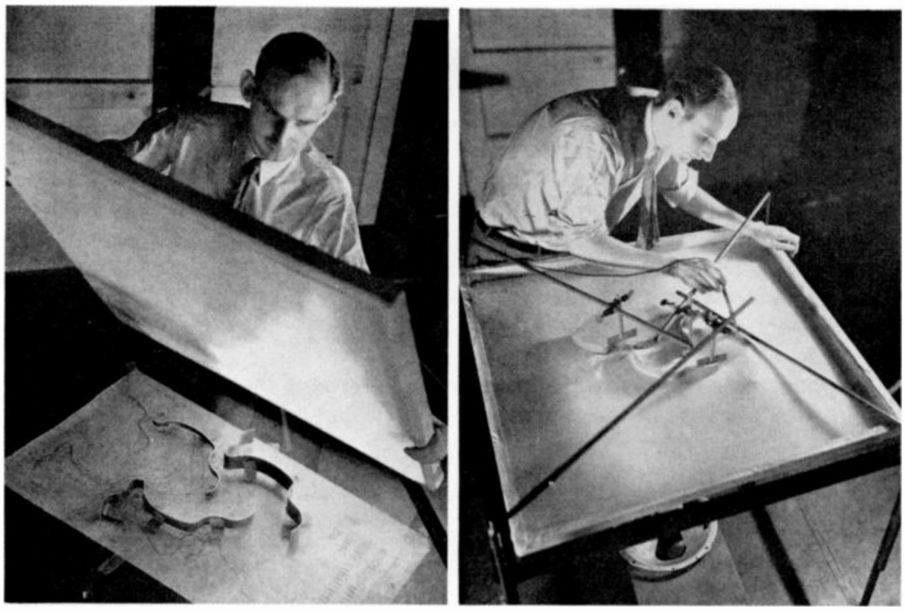


Fig. 6
Rubber sheet mechanical analogues were used long before the computer to analyze electron trajectories and equipotential surfaces between electrodes. This photo from the February 20, 1939, issue of *Life*, shows Jan Rajchman of RCA Laboratories using the rubber-dam analogue to analyze photomultiplier focusing potentials.

Working with the rubber-dam analogue, both J.A. Pierce[8] of Bell Laboratories and J.A. Rajchman[9] of RCA devised linear arrays of electrodes that provided good focusing properties. Details of Rajchman's original linear design are shown in Fig. 7. Although commercial designs did not result immediately from the linear dynode array, the Rajchman design, with some modifications, eventually was, and still is, used in photomultipliers—particularly for high-gain wide-bandwidth requirements.

The first commercial high-gain photomultiplier was the 931, now the 931A.

The 931 tube has a circular array of nine dynodes, which provides a very compact arrangement, Fig. 8. The first such circular arrangement was described by Zworykin and Rajchman.[9] Modifications were later reported by Rajchman and Snyder[10] and

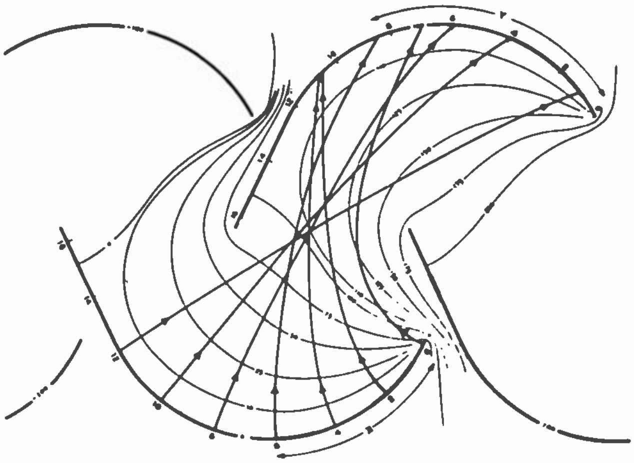


Fig. 7
Equipotential lines and electron trajectories in Rajchman's linear dynode configuration (circa 1938). The linear dynode array is used today for high-gain wide-bandwidth photomultipliers.

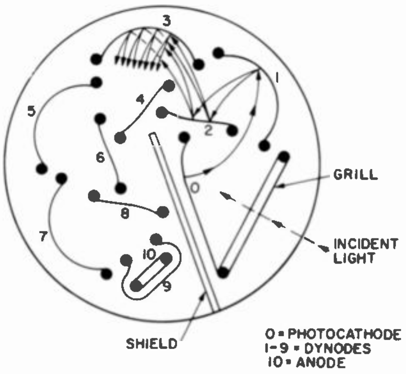


Fig. 8
Circular-dynode arrangement used in the first commercial high-gain photomultiplier—the 931. This very compact array was first described by Zworykin and Rajchman in 1939.

by Janes and Glover,[11] all of RCA. The basic electron-optics of the circular cage was thus well determined by 1941 and has not changed to the present time although improvements have been made in processing, mounting, and performance of the 931A product.

The success of the 931 type also resulted from the development of a much improved photocathode, Cs_3Sb, reported by Gorlich in 1936. The first experimental photomultipliers had used a Ag-O-Cs photocathode with a typical peak quantum efficiency of 0.4% at 800 nm. (The Ag-O-Cs layer was also used for the dynodes.) The new Cs_3Sb photocathode had a quantum efficiency of 12% (higher today) at 400 nm. It was used in the first 931s, both as a photocathode and as a secondary-emitting material for the dynodes.

Applications and designs

When Jan Rajchman began working for Zworykin on January 1, 1936 in Camden, (the Princeton Laboratories were not occupied until 1942) his assignment was to design a photomultiplier that would be useful for sound-on-film pickup. The magnetic focus tube described above was already on hand but was not considered physically or economically feasible for the sound-on-film application. At the time, the 931 seemed a logical replacement for the phototube plus amplifier then being used. Although tests were made, the application of photomultipliers to sound movies was not adopted by the industry. Instead, the early applications of photomultipliers were principally in astronomy and spectroscopy.

Because the effective quantum efficiency of the photomultiplier was at least ten times that of photographic film, the application to astronomy was obvious, and many astronomers used the tube to considerable advantage.[13] The output of the photomultiplier is linear with the incident radiation, and so the tube could be used directly in photometric and spectrophotometric astronomy. Zwicky of Mt. Wilson was probably the first astronomer to use photomultiplier tubes in this manner. He used early experimental tubes which Jan Rajchman supplied to him in the late 30s. Before photomultipliers, phototubes with high-gain amplifiers were used. (Today, many astronomers are intensifying images with image-intensifier tubes which not only provide high quantum-efficiency detection but image information as well.)

The 931 and a similar tube, the type 1P28 with an ultraviolet-transmitting window, were also useful in spectroscopy. The size and shape of the photocathode were quite suitable for the observation of line spectra, and the very wide range of available gain proved very useful.[15] Note in Fig. 9 how the gain can be varied over a range of five orders by varying the voltage applied to the photomultiplier tube. By using the voltage required for constant output current, an approximately logarithmic calibration is achieved which nicely accommodates the wide range of intensities encountered in line spectra.

The photomultiplier became a radar jammer during the war.

A totally unexpected application for the new photomultiplier tube occurred during World War II. The development of radar for detecting and tracking aircraft led to the simultaneous need for wideband electronic-noise sources as radar jammers. Gas tubes were tried, but were deficient in high-frequency noise. Thermionic-emission shot noise was suitable, but required very high amplification. The newly developed photomultiplier tubes, however, provided high gain and wide bandwidth. During the early 40s, RCA participated in a contract* sponsored by the Office of Scientific Research and Development. Participants in this contract were Alan Glover (later RCA vice president, now retired), myself, and W.J. Pietenpol (who left RCA after the war to obtain a PhD in Physics, and who is now teaching at the University of Colorado, Boulder). Operation of the 931A as a noise source was done by illuminating the photocathode with a dc light source and running the tube at a high gain.

The amplified shot noise from the photocathode is given approximately by

$$I_{rms} = \mu \, (2 e i_k B)^{1/2}$$

where μ is the gain of the tube, e is the electron charge, i_k is the photocathode current, and B is the bandwidth of the system. Note that the noise current varies directly with the gain and with the square root of the photocathode current. The bandwidth of the 931A is several hundred MHz (10 dB down at 500 MHz) and, thus, was adequate for jamming World War II radars. The gain of the tube could be as high as 10^7, but too high a gain led to unwanted breakdown in the tube. Photocathode current could be increased readily by means of the light source, but as the photocathode current increased so did the output current. Too high an output current led to short life and loss of noise output. One of the tasks of the contract was to improve tube life; the modified 931 (the "A" version) was developed and run at an output current of 2.5 mA.

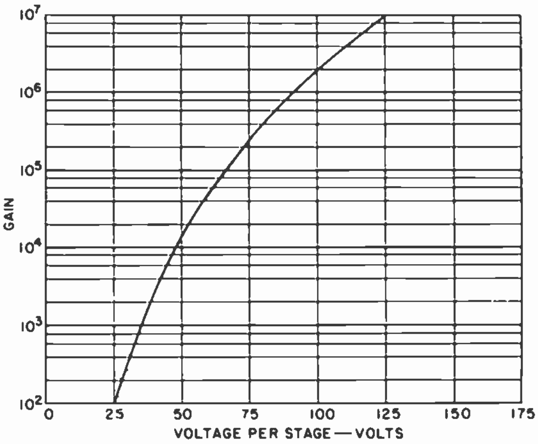


Fig. 9
Logarithmic gain characteristic of the 931A photomultiplier as a function of voltage per stage. Note that the gain can be varied over five orders by varying voltage. (The 9-stage 931A is a modern modification of the early type 931).

A particular advantage of the 931A for the jamming application was the fact that its noise spectrum was "white." The RCA photomultiplier design group was elated and amused at the first report of the jammer's application in Italy: allied radar operators who were not told about the test shut down their equipment because of "atmospheric conditions."

During part of the noise contract, a modified photomultiplier was tried in which a planar grid was mounted close to the photocathode. We hoped to achieve a higher noise output by feeding back part of the output noise to the grid. This scheme was not exploited because, although it did provide increased noise, the output noise spectrum was no longer flat.

Prior to this jamming application, production of photomultipliers was measured in only hundreds per year. The wartime application required thousands of photomultipliers per month. J.J. Polkosky, RCA's phototube manufac-

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*Contract No. OEM sr 1060 (Final Report, 3/7/45).

turing manager at the time, did a remarkable job of increasing our production in a very short time.

Scintillation counting was the next major photomultiplier development.

The scintillation counter is a direct extension of Rutherford's very early "spinthariscope" device in which alpha particles impinging on a fluorescent screen caused light flashes which were observed by means of a microscope. In the modern scintillation-counter, gamma rays produce light flashes in a scintillator such as thalium-activated sodium iodide, NaI(Tl). A photomultiplier optically coupled to the scintillator detects the light flashes, allowing them to be counted and their magnitude measured.* The count rate provides a measure of the intensity of the gamma-ray source. The magnitude of the flash, or pulse height, is proportional to the energy of the gamma ray. This latter property provided a means for the nuclear physicist to identify energy levels in nuclear disintegrations. It also enabled the user, by means of pulse-height discrimination, to select the scintillations of interest and eliminate other background.

Invention of the scintillation counter shortly after World War II is generally credited to Kallmann[16] working in Berlin and using moth balls (naphthalene) as a scintillator. At nearly the same time, Coltman and Marshall[17] of Westinghouse published a similar application paper.

Fig. 10
Scintillation counting stimulated the development of several photomultiplier types. Left to right (starting on top) are the **5819**, probably the first tube designed specifically for scintillation counting; the **6199**, a smaller tube used by early uranium prospectors and also placed aboard a satellite by Dr. Van Allen and used to discover the radiation belts that now bear his name; the **6342A**, which has a flat faceplate to provide an easier interface with the crystal; the **6810A**, a 14-stage linear dynode tube for higher gain and less feedback between photocathode and collector (the circular arrangement is limited to 10 stages and the photocathode and anode are close to each other); the **7850**, with improved electron optics for higher speeds needed to time certain nuclear events; the **8054**, which handles larger crystals (about 3 inches) for better absorption of high-energy gamma rays; the **8055**, which accomodates 5-inch crystals and contains RCA's "venetian blind" optics; the **8575**, an improved 7850 with a flat faceplate; and the **8854**, developed for the AEC for use in high speed measurements with plastic scintillators.

Following the invention of the scintillation counter, scientists and engineers in this country and in Europe began a feverish effort to improve the device and to exploit its capabilities. The scintillation counter became the most important measurement instrument in nuclear physics, nuclear medicine, and radioactive tracer applications of a wide variety.

During this early period, Hofstadter[18] investigated various scintillators and discovered that by doping NaI with thallium, an excellent scintillator resulted. This scintillator was used almost exclusively for the next two decades in scintillation counter applications. Hofstadter had patent rights for the NaI(Tl) and is generally believed to have done very well on the royalties.*

Because of the early work on photomultipliers, RCA was in a favorable position to profit by the expansion of the new scintillation-counting field. RCA's position was advanced rapidly by George Morton and his associated laboratory group in Princeton, frequently financed by the AEC. The Lancaster development group took advantage of Morton's initiative and commercialized numerous types of photomultipliers. My own timely application paper[19] served as a primer for many new users and advertised RCA's involvement.

RCA's competitors—DuMont, EMI, and LEP (Philips)—were also very busy, and during the next decade there was a proliferation of photomultipliers developed particularly for scintillation counting. Much of the work during this period was reported by RCA and its competitors in the biannual meetings of the *Scintillation Counter Symposium*. These symposia have been reported fully in the IRE (and later the IEEE) *Transactions on Nuclear Science* beginning with the meeting in Washington, January 1948.

A number of the RCA tubes that were developed for scintillation-counting applications are shown in Fig. 10. One of the early design problems was to improve the light-coupling system between the scintillator and the photomultiplier tube. Although the 931A was used early as a scintillation-counter tube, the fact that the photocathode was located some distance

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*Incidentally, the geiger counter is only useful in counting events and does not measure the energy of the gamma ray. Because it uses ionization of a gas, with relatively low absorption of gamma-ray energy, to trigger the count, the efficiency of counting is much less than that of a scintillation counter.

*Hofstadter's Nobel Prize in 1961 did not relate to the NaI scintillator for which he is so well known, but to his studies of the size and internal structure of the atomic nucleus.

within the envelope prevented really good light collection.

For a precise measure of energy in a gamma-ray spectrum, it is important to detect as many of the photons per scintillation as possible. The first commercial tube designed for better light collection from the scintillator was the 5819, which provided a semitransparent Cs_3Sb photocathode on the inner surface of the end-on window. The tube had a drawback; the window to the photocathode was not quite flat, thus requiring the user to shape the NaI(Tl) crystal to match. The 6342A provided a flat coupling surface. The 6199, a 1½-inch end-on tube, reasonably priced, was used in large numbers in applications such as portable scintillation counters, which many prospectors used to find uranium ores.

A series of tubes with different diameters was made to accommodate different scintillator dimensions. The very largest tubes were made on an experimental basis only because of the great expense of the very large NaI(Tl) crystals. The requirements for the large crystals was related to the absorption of high-energy gamma rays. (Even a crystal 10-cm thick absorbs only about 90% of 1 MeV gamma rays.)

Nuclear physicists were particularly interested in obtaining photomultiplier tubes that had a very fast response. Special scintillators were also required because NaI(Tl) has a relatively long time constant of about 0.25 μs. Organic plastic scintillators, such as p-terphenyl in polyvinyltoluene, which has a decay time of 3 ns, were developed. Typical experiments in nuclear physics involved measuring time of flight and lifetime of decay products. The discovery of the antiproton with the Bevatron machine at the University of California, Berkeley, in 1957, was accomplished with the RCA type 6810, one of the early high-speed tubes (Fig. 10). Time discrimination with this tube was possible to better than 1 ns. Design for short-time discrimination in photomultipliers was a matter of electron optics and equalizing electron paths.[20]

Scintillation counting has revolutionized many areas of science, engineering, and medicine.

An agronomist may observe the location and uptake of trace elements in growing plants without destroying the plant. Archeological dating of very old samples of wood is accomplished by measuring the residual ^{14}C, a radioactive isotope of ^{12}C, which decays with a half life of about 5000 years. The original equilibrium ratio of ^{14}C:^{12}C is established in the living tree through interaction with atmospheric CO_2. An engineering investigation of tool wear may be made by incorporating a small amount of radioactive isotope in the metal. Detergents can be evaluated by producing a "trace" oil from ^{14}C, combining it with other oils and measuring the remaining radioactivity in a fabric or in the rinse water. Scintillation counting is regularly used to log the type of subsoil in oil-well exploration.

In medicine, scintillation counting was first applied experimentally to the location of brain tumors in the 1950s in a few hospitals such as the Massachusetts General, associated with the Harvard Medical School. The patient was given an intravenous injection of radioactive-arsenic-doped chemical which was known to concentrate more actively in carcinogenous tumors than in healthy parts of the body. The tumor was then located by scanning the patient's head with a scintillation-counter probe. These techniques have been actively pursued in many fields, and particularly in medicine. The latest techniques, the associated devices and the related business will be described later in this chronicle. Let us now deviate to a practical application of photomultipliers unrelated to scintillation counting.

RCA developed a $5 photomultiplier for use as a headlight dimmer.

The General Motors Company (Guide-Lamp Division) had worked periodically on a photoelectric headlight dimmer since the early 1940s. But a successful device was not produced until the 1950s. RCA collaborated closely with General Motors during this period. The headlight dimmer—first made available only on Cadillacs and Oldsmobiles—was basically a 931A, redesigned and tested to G.M.'s particular requirements. The optical engineering problem was to sense the oncoming headlights or tail-lights being followed without responding to street and house lights. Vertical and horizontal angular sensitivity was designed to match the spread of the high beams of the automobile. A red filter was installed in the optical path to provide a better balance between sensitivity to oncoming headlights and to tail-lamps being followed. Life characteristics again were a critical problem because slight changes in each dynode gain—taken to the 9th power—could easily result in an annoying maladjustment!

Despite all the problems, the device achieved a remarkable success, partly because of the novelty, although many thought the device would have been more successful if it had caused the dimming of headlights on the oncoming car! For a few years, RCA sold General Motors many thousands of these photomultiplier tubes per month. There was continual pressure by G.M. on RCA to reduce price. The price, less than $5.00, was the lowest of any photomultiplier RCA ever marketed. Subsequently, G.M. developed their own supplier and then went to a simpler photocell pick-up. Today, one rarely sees a headlight dimmer. Perhaps, manual operation is not too difficult, after all.

Developments in photocathode and secondary-emission materials kept pace with other photomultiplier developments.

Much of the development work on photomultiplier tubes that has been described in this history relates to physical configuration and electron optics. But a very important part of the development of photomultiplier tubes was related to the photocathode and secondary-emission surfaces and their processing. RCA was very fortunate through these years in having on its staff, probably the world's foremost photocathode expert, Dr. A.H. Sommer.* He joined the Associated Princeton Laboratories in Dr. Morton's group in 1952, and during the next two decades, contributed not only improved photocathode formulations but provided considerable help in the processing of photocathodes to the Lancaster development and factory groups. His treatise on *Photoemissive Materials*[21] continues to provide a wealth of information to all photocathode-process engineers.

Sommer explored the properties of numerous photocathode materials—particularly alkali-antimonides. Perhaps his most noteworthy contribution was the multialkali photocathode (S-20 spectral response). This photocathode, $(Cs)Na_2K$-Sb, is important because of its high

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*Since his retirement from RCA in 1974, Dr. Sommer has been consulting at Thermo Electron Corporation in Wellesley, Massachusetts.

sensitivity in the red-and near-infrared; the earlier Cs_3Sb photocathode spectral response barely extends through the visible, although it is very sensitive in the blue where most scintillators emit.

Bialkali photocathodes were also developed by Sommer and have proven to be better in some applications than the Cs_3Sb photocathode. Thus, the Na_2K-Sb photocathode has been found to be stable at higher temperatures than Cs_3Sb and, in addition, has a very low dark (thermal) emission. It has been particularly useful in oil-well-logging applications. Another bialkali photocathode, K_2Cs-Sb, is more sensitive than Cs_3Sb in the blue and is, therefore, used by RCA to provide a better match to the NaI(Tl) crystals used in scintillation counting.

Negative-Electron Affinity (NEA) is an exciting new concept applied to materials used in photoemission and in secondary emission.

Electron affinity, Fig. 11a, is the required energy, in electron volts, for an electron at the conduction-band level to escape to the vacuum level. By suitably treating the surface of a p-type semiconductor material, typically with Cs, the band levels at the surface can be bent downward so that the effective electron affinity is actually negative with reference to the bulk conduction-band level, Fig. 11b. Thermalized electrons in the conduction band are normally repelled by the electron-affinity barrier; the advantage of NEA materials is that these electrons can now escape into the vacuum as they approach the surface. In the case of secondary emission, secondary electrons can be created at greater depths in the material and still escape, thus providing a much greater secondary emission yield (Fig. 2) than can be accomplished with ordinary materials. In the case of photoemission, it has been possible to achieve extended-red and infrared sensitivities greater than those obtainable with any other known materials. The impact of these new NEA materials has so far been primarily in scientific applications.

The NEA concept was the brainchild of Dr. Ralph E. Simon while working at the RCA Princeton Associated Laboratory. The early work was sponsored by the U.S. Army Research and Development Laboratories, Fort Monmouth, NJ, and was reported in the first quarterly report.[22.] In this report, Simon defined the concept of NEA and the conditions necessary for NEA together with data on photoemission from Cs-covered polycrystalline GaP. The first publication of the NEA concept in the open literature was by Scheer and Laar[23] of Philips, Eindhoven. The early work at RCA was carried on particularly by R.E. Simon, B.F. Williams, and W.E. Spicer.

The first practical application of the NEA concept was to secondary emission. An early paper by Simon and Williams[3] described the theory and early experimental results of secondary-emission yields as high as 130 at 2.5 kV for GaP(Cs), Fig. 2.

The particular advantage of the high-gain GaP dynode is in the improved statistics of multiplication when the dynode is used in the first stage of a photomultiplier tube. Thus, the distribution in the number of secondary electrons at the first dynode is proportional to the square root of the average secondary emission. For the GaP dynode, the number of secondaries may be 36 as compared with 4 for a conventional dynode. Such GaP-dynode tubes can be used effectively to discriminate single photoelectron events,[24] and are used to great advantage in astronomy and spectroscopy.

The high gain of the GaP dynode also led to the development of very fast photomultipliers because high gain could be achieved with fewer stages.[25] For example, the RCA developmental type C31024 is a five-stage tube with GaP dynodes providing time measurement capability

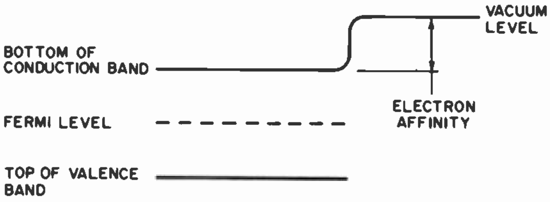

Fig. 11a
Energy-band model of a typical semiconductor photoemitter; electron affinity is the energy required to allow an electron to escape the conduction band.

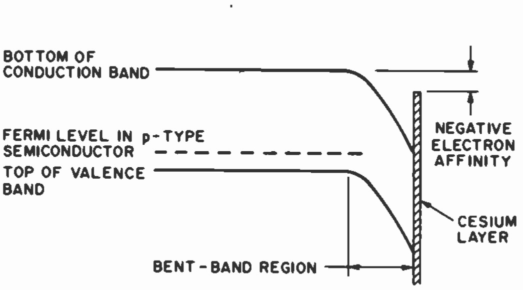

Fig. 11b
Energy-band model of a p-type semiconductor with a surface layer of cesium. Note that the band levels at this surface are bent so that the effective electron affinity is negative.

Fig. 11
Negative Electron Affinity (NEA) materials allow secondary electrons to be released from greater depths.

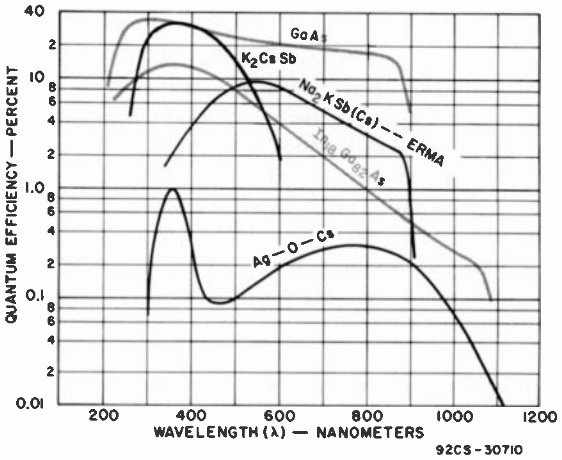

Fig. 12
Spectral responses of several NEA photocathodes (gray lines) compared with those of an Ag-O-Cs, a bialkali, and a modified multialkali photocathode.

down to 300 ps (as determined by variations in pulse transit time).

Much of the early work on NEA materials for photocathodes was done at the RCA Laboratories in Princeton.[26] The initial technology transfer to the Lancaster operation was primarily the responsibility of Fred Hughes.[27] The impetus for the work was the requirement for near-infrared sensitivity, particularly in relation to applications involving the Nd:YAG lasers operating at 1.06 μm. The evolution of the development was from GaAs to various combinations of $In_xGa_{1-x}As$. Longer wavelength threshold was achieved with an increased percentage of In.

Some of the early work on NEA photocathodes for the near-infrared was done in relation to their application to image tubes.[28]* The technology was, of course, readily applied to photomultiplier development. Fig. 12 shows the range of responsivities of the new NEA photocathodes (GaAs and $In_{18}Ga_{82}As$) compared with those for the Ag-O-Cs, multialkali [$Na_2KSb(Cs)$] and bialkali (K_2CsSb) photocathodes.

Gamma cameras have been built with as many as 91 photomultipliers.

The gamma camera originally described by Anger[29] is a more sophisticated version of the scintillation counter, but used for locating tumors or other biological abnormalities. The general principle of the gamma camera is illustrated in Fig. 13. A radioactive isotope combined in a suitable compound is injected into the blood stream or ingested orally by the patient. Certain compounds or elements are taken up preferentially by tumors or by specific organs of the body—such as iodine in the thyroid gland. The radioactive material disintegrates and gamma rays are ejected from the location of the concentration.

A lead collimator permits gamma rays to pass through it only when they are parallel to the holes in the lead; gamma rays at other angles are absorbed in the lead. In this way, the location of the gamma-ray source may be determined because gamma rays originating on the left side of the organ are caused to impact the left side of the scintillation crystal, etc. The crystal is quite large and covers an area about 10 inches or more in diameter.

Behind the crystal are, perhaps, 19 photomultiplier tubes in an hexagonal array. The light of the individual scintillation is not collimated but spreads out to all of the 19 tubes. The location of the point of scintillation origin is obtained by an algorithm depending upon the individual signals from each of the photomultipliers. Resolution is obtained in this manner to about ¼ inch. Each scintillation is then correspondingly located by a single spot on a CRT. Counting is continued until several hundred thousand counts are obtained and the organ in question is satisfactorily delineated. Fig. 14 is a reproduction of such a scintigram. The particular advantage of the gamma camera over other techniques such as the CAT scanner (described below) is that the gamma camera provides functional information. For example: Tc-99m polyphosphate is used to reveal bone diseases; ^{123}I is used in thyroid studies; ^{127}Xe is inhaled to provide information on lung ventilation.

The photomultiplier business resulting from the proliferation of gamma cameras throughout the major U.S. hospitals has been quite significant because of the number of tubes per camera—in some

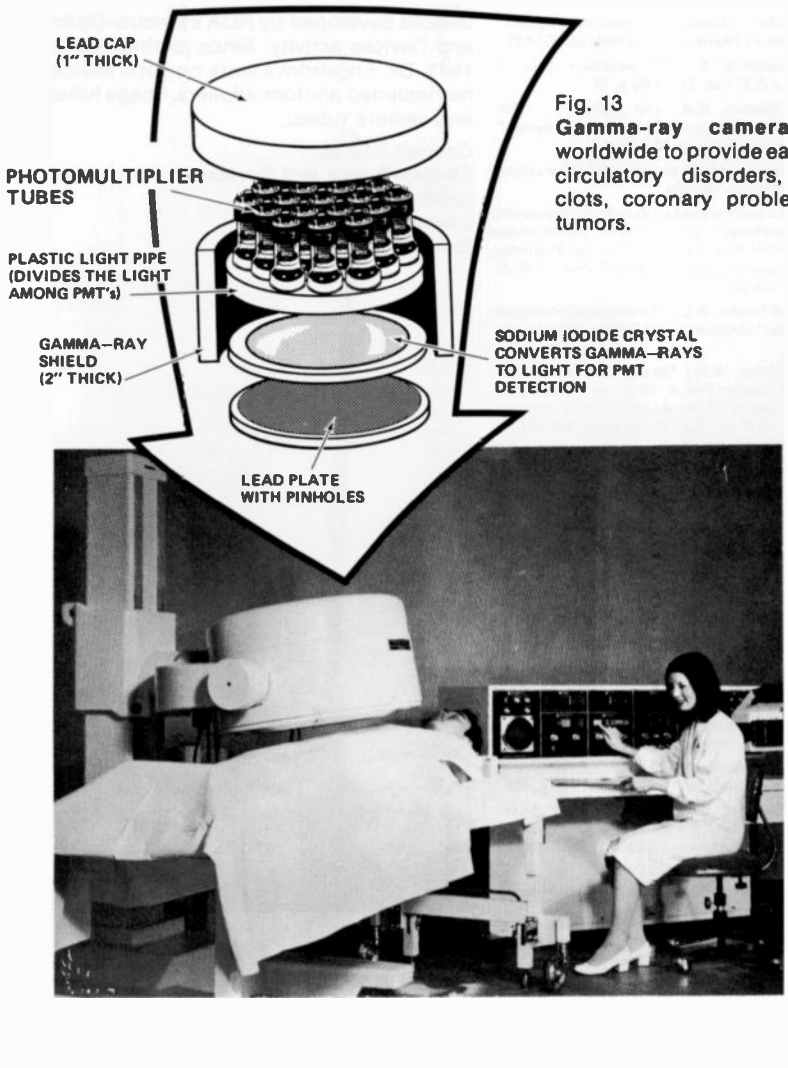

Fig. 13

Gamma-ray cameras are used worldwide to provide early diagnosis of circulatory disorders, cancer, lung clots, coronary problems, and brain tumors.

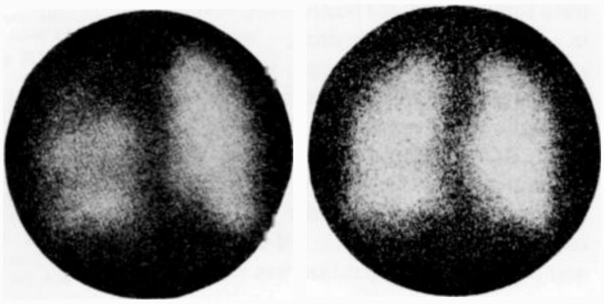

Fig. 14

These scintigrams were obtained by Lancaster General Hospital using a gamma camera. The scintiphoto on the left shows multiple emboli in the right lung; photo on right shows lungs after clearing. The isotope Technitium-99m was used to tag Albumin microspheres—a colloidal form of the albumin protein, with particles ranging in size from 2 to 50 microns. These particles are injected into the bloodstream and are filtered and trapped in the lung capillary bed; the scan can then determine those areas where the capillary bed is intact. Areas of diminished blood flow show as "cold spots."

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*The RCA work on NEA photocathodes for image tubes was sponsored by the U.S. Army Electronics Command, Night Vision Laboratory, Fort Belvoir, Va.

cases as many as 91. In 1977, RCA delivered many thousand 2-inch and 3-inch end-on photomultipliers for this purpose. The business has been profitable and a rewarding humanitarian effort.

The CAT scanner is another relatively new medical instrument that is making a major impact on photomultiplier sales.

The Computerized Axial Tomographic (CAT) scanner was introduced to this country in 1973.[30] The device uses a pencil or fan-beam of X-rays which rotates around the patient providing X-ray transmission data from many directions. A scintillator coupled to a photomultiplier detects the transmitted beam—as an average photomultiplier current rather than by a pulse count—and a computer stores and computes the cross section density variation of the patient's torso or skull. The photomultipliers are ½-inch and ¾-inch end-on tubes which couple to the scintillator, commonly BGO (bismuth germanate). The CAT scanner is being sold to major hospital units at prices exceeding $500K. Each unit may be equipped with 600 or more photomultipliers. The demand for these small photomultipliers accelerated rapidly and facilities in Lancaster were expanded to manufacture tubes at a high rate. Recently, the demand has dropped because of governmental concern over increased hospitalization costs.

Conclusion

RCA's investment in the photomultiplier business began with Zworykin's interest in utilizing the tube as a pickup for sound movies. That business did not materialize, but a small specialized business did develop in scientific applications, such as astronomy and spectroscopy. RCA maintained research and development programs throughout the years since 1940 that have kept RCA's photomultiplier products diversified and among the best in the world. At the outset, sales and design efforts were modest but self-supporting and profitable. Competition was minimal.

Unpredicted markets developed—radar jammers, headlight dimmers, scintillation counters, and CAT scanners—which greatly stimulated the development of new types, sales, and competition. Some of RCA's present competitors have a broad range of photomultiplier product. These competitors include Philips (and their various subsidiaries), EMI, Hamamatsu TV, DuMont, Centronic and ELORG (an entry from the Soviet Union). There are also those who supply special photomultipliers: Galileo, EMR, Varian, ITT, Photoelectric, and SRC.

Today, RCA competes on a broad front for a very diversified photomultiplier business. The photomultiplier sales were negligible in the early 40s. By 1956, the annual sales were about $0.6M. RCA's present photomultiplier business is very large by comparison.

The photomultiplier is a good example of RCA's technology base paying off even though no major business opportunities were anticipated at the outset. With patience and cultivation, perhaps other sizable and unforeseen markets would develop from some of RCA's smaller but profitable areas of technical superiority.

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Optical video disc for very large digital memories

R.F. Kenville

The ultra-high packing density of the optical disc—up to 5 x 10^{10} bits per disc side—makes it a prime candidate for large information-storage systems.

The need to store and retrieve large quantities of tv programming at modest cost has generated the requirement for an economical, compact, high-speed mass data-storage medium. Significant improvements in the state of the art in mass storage have resulted from the development of video disc systems throughout the world. Developmental systems typically use 12-inch discs to store approximately 30 minutes of tv video information at a data rate of about 5 MHz. Information packets approximately one micrometer in diameter are stored serially in tracks with a pitch of approximately 1.5 micrometers. Most video-disc developments to date have been directed at consumer-oriented systems, with emphasis on playback-only of unalterable prerecorded discs. RCA, however, has developed two video disc systems, which employ completely different techniques: capacitive pickup with mechanical tracking; and optical pickup with servo tracking. Table I compares the two systems.

Table I

Comparison of two video disc systems. Optical system has better bandwidth and signal-to-noise qualities than capacitive system, but requires relatively complex tracking and focusing systems.

Parameter	*Home entertainment*	*Optical video disc*
Master recording method	Electron beam	Laser beam
Media processing	Master-stamp	None
Playback	Mechanical (capacitive)	Laser beam
Bandwidth	3 MHz	5 MHz to 30 MHz
Signal-to-noise ratio	40 dB	50 dB
R/min	450	1800 (nominal)
Playing time	Two hours	30 minutes
Stop action	No	Yes
Tracking	Mechanical (grooves)	Servoed galvanometer
Focus control	None	Servoed lens

Author Kenville and a prototype optical video disc memory system.

Dick Kenville began working with advanced data recording systems in 1959 when he joined RCA. In his current position as Manager of the Applied Physics Laboratory in ATL, he directs advanced development of optical disc recorders, laser scanners, reconnaissance equipment, sensors, CCD signal-processing subsystems, and photovoltaic energy systems. His group supports both commercial and government product divisions with mechanical, thermal, and optical design and analysis.

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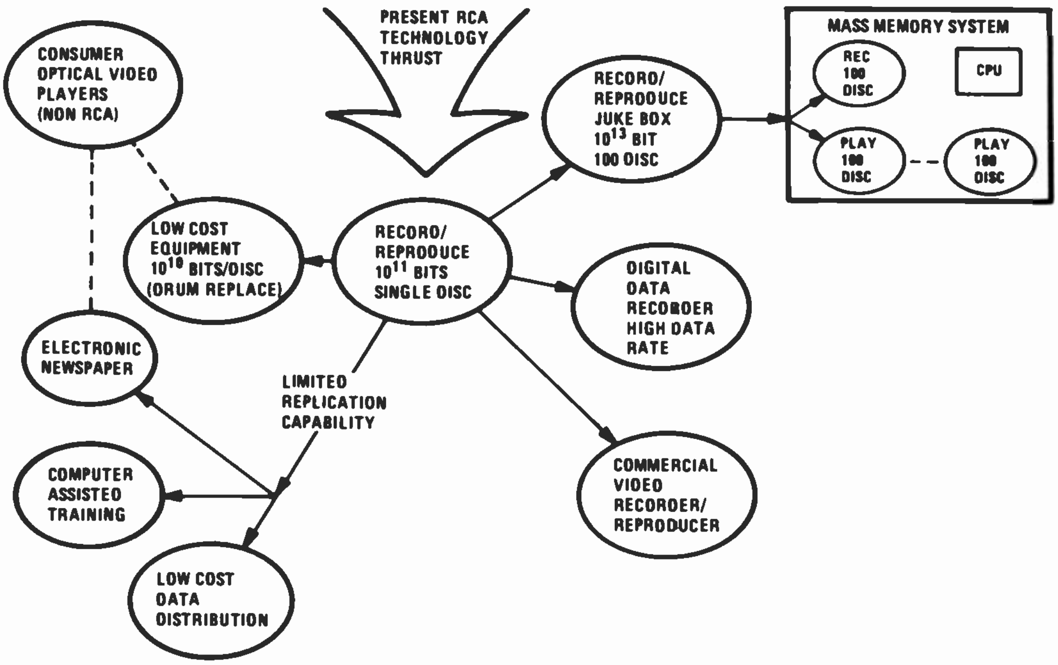

Fig. 1
Low in cost relative to magnetic recording systems, optical video disc may find its best application in mass memory systems. Other applications are possible, however.

The capacitive pickup system was developed for home-entertainment applications. Its low-cost playback-only records are made by a master-stamp process, with an electron beam used to generate the disc master. This system generates full-color programming (with sound), using a unique color encoding scheme that requires only 3 MHz of video-signal bandwidth. A one-hour recording, with a 40-dB signal-to-noise ratio, is stored on each side of the disc.

The RCA optical video disc (OVD) system was initially developed for use in broadcast-studio applications. This system records and plays back high-quality video with a 5.3-MHz bandwidth and a 50-dB signal-to-noise ratio. The extension of OVD techniques to storing digital data, the subject of this paper, is one of the more interesting applications of this technology.

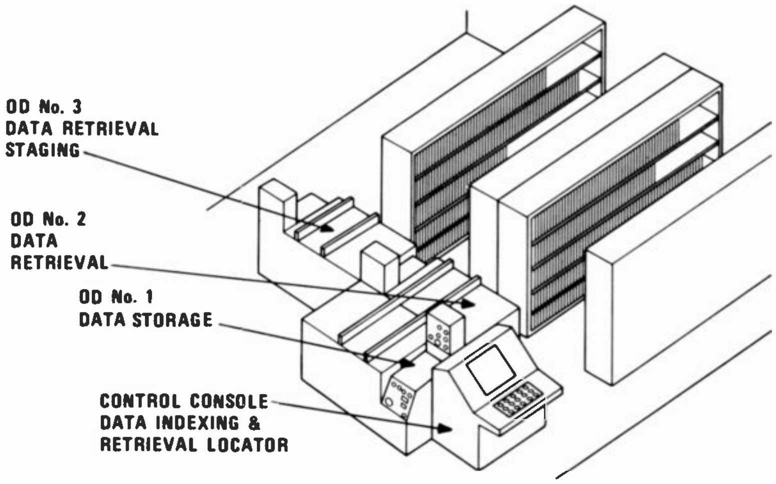

Fig. 2
Archival data storage system is one potential application. Discs would be filed in cabinets (as magnetic discs now are stored in some systems) and retrieved by clerks as needed.

Optical video disc applications

The optical disc has two primary advantages over magnetic recording systems for digital data storage—the cost of the storage media is low and the optical disc is more amenable to automatic information handling.

These advantages give the optical disc a big edge in mass data storage systems and our present technical effort is directed toward this type of application, as indicated in Fig. 1. The principal objective of this effort is to demonstrate 10^{11} bits of storage on a single disc. With this basic capability, an archival storage system holding 10^{15} bits of data will be possible.

The archival data-storage system shown in Fig. 2 would function in a semiautomatic fashion. Clerks would pull discs from the library for information retrieval, while monitoring a recording unit. Such a system could be housed in a 100-m^2 room.

A more automatic system could use the "jukebox" configuration shown in Fig. 3. Here 10^{13} bits could be stored on 100 discs contained within a single unit. Access to information would be less than 3 seconds with this arrangement. For additional on-line capability, several jukeboxes could operate in parallel under the control of a host computer.

RCA is not working on replication techniques for the optical disc at present, but replication is a near-term possibility. With this added capability, the electronic newspaper, computer-assisted training, and low-cost data-distribution applications could be addressed. In these applications, the user would have a low-cost "play only" machine and prerecorded discs would be supplied. The disc would be played on an interactive basis under the control of the user. The inherent ability to still-scan segments of the disc and to automatically hop from segment to segment is an advantage for this type of application. High-rate digital data recording and broadcast video recording are other obvious uses for this technology.

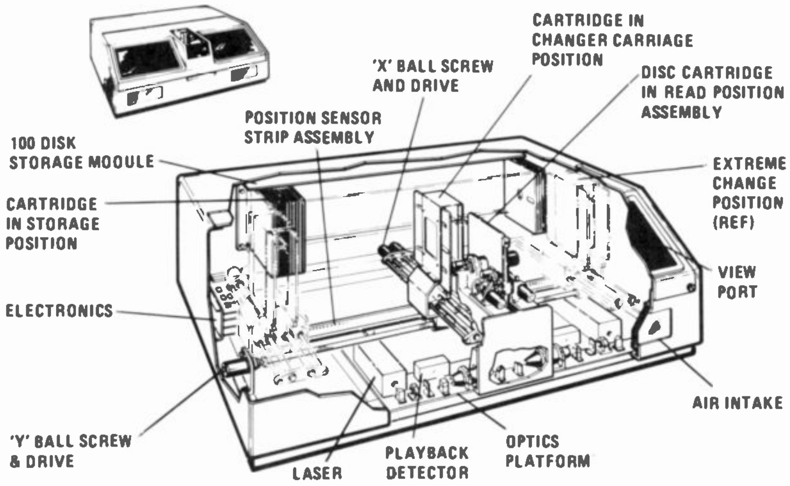

Fig. 3
"Jukebox" configuration operates more automatically than the system shown in Fig. 2. With 100 discs stored in each self-contained unit, 10^{13} bits of information could be stored with a 3-second access time.

OVD system description

A modulated laser beam records a string of spots on a proprietary recording medium.

Fig. 4 shows how the system would work in either analog or digital storage systems. The disc is placed on a turntable which is supported by a high-precision air bearing. Recording takes place when the disc is exposed to modulated laser radiation, which is passed through beam-forming optics and directed towards the disc by the track mirror. The laser beam is focused onto the disc to form a series of very small spots, whose spatial relationships are determined by modulation.

The RCA OVD system uses a proprietary material[1,2] for the recording/playback medium. This medium can be deposited on several types of substrate; however, the vinyl substrate now used is similar to an ungrooved phonograph record. During playback the disc rotates at 1800 r/min and stores the equivalent of 30 minutes of

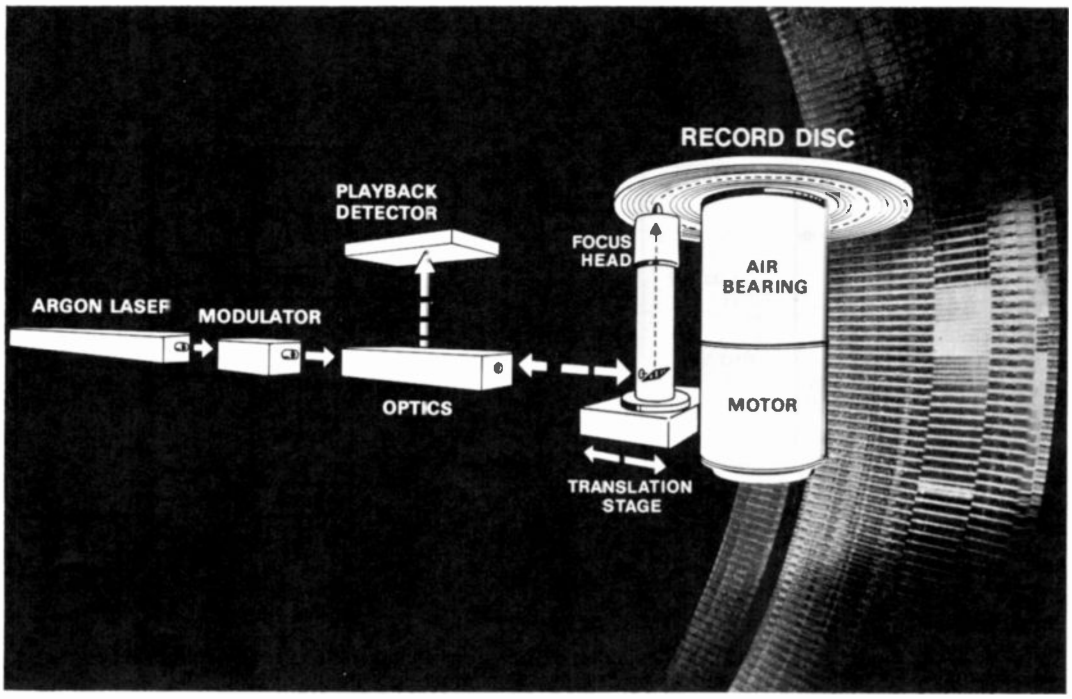

Fig. 4
System works by using modulated laser beam to record a series of very small spots on the disc. For playback, laser power is reduced, and reflected modulation is picked up by a photodetector. Servo system maintains very closely fixed distance between focusing lens and disc surface.

programming when used as a video recorder/reproducer. A blank disc is inserted onto the turntable and recorded live, using a modulated laser beam. Playback can take place immediately following recording or at any time thereafter by operating the laser at lower power and using a photodetector to pick up the reflected modulation.

Since the optical system has a very short depth of focus, constant repositioning of the focusing lens is required to keep the laser spot focused onto the microscopically uneven disc surface. The focus servo maintains a fixed distance between the focus lens and the disc surface by sensing the instantaneous distance and then driving an objective lens mounted on a speaker-type coil.

The position of the laser spot on the disc is determined by the position of the tracking mirror. During recording, this position is determined by the motor-driven translation stage. The control logic can move the translation stage so that either a spiral or a circular track can be traced.

Playback is done by reflecting low-power laser light off the spots and to a photodiode.

During a playback, the laser power is reduced by changing its operating mode, and the illumination level to the disc is held constant by the optical modulator. Light reflected from the recorded disc passes back through the focus lens, tracking mirror, and optics to an avalanche photodetector.

Here again, the translation stage is used to determine what portion of the record is played back. The translation stage controls the readout laser's position on the disc to the nominal track position. Since the tracks were not recorded as perfect circles, a small amount of disc runout occurs as a result of removing and imperfectly replacing the disc. Finer tracking control is obtained by a dither tracking servo, which wobbles the tracking mirror to modulate the position of the readout laser beam. This wobbling introduces modulation into the detected return signal, and is used to close the loop and to keep the optics aligned to the center of the recorded track.

The recording and playback signal-processing electronics determine the storage format and the type of information stored. Since the recorded information consists of a series of spots (determined by laser modulation), information is coded by variations in the local arrangement of the spots. In the case of analog video, information is impressed by an fm coding scheme.

Digital-data recording

Using the optical video disc system for recording digital information requires the optimum selection of modulation, coding format, and error detection and correction (EDAC) codes.

The information on the OVD is a two-level signal (binary coded)—recording is done by using the "write" laser to remove material from the disc. The recorded signals are formed in a series of spots of varying length and spacing. Therefore, pulse coding must be used to store information on the disc efficiently, and a complementary form of decoding must be used to recover the information during playback.

Fig. 5 is a block diagram of the general signal processing that would be used in recording and playing back digital data on the optical video disc. Serial input information must first be buffered to accommodate nonsynchronous data entry and then formatted into appropriate data blocks. The buffering handles both asynchronous data and data rates lower than the maximum rate of the OVD. Data blocking and the addition of appropriate header information make it easier to organize the data into convenient segments for addressing and error control.

The next step in the signal processing adds error detection and correction (EDAC) information. This step is most important in digital recording systems where bit error rates (BER) of 10^{-7} and lower are desired.

The objective of EDAC is to recover the original input data even though various undesired changes have been made in the data processes of recording, storing, and/or reading the data. In the recording mode, check bits are added to the data and the resulting information is redistributed with respect to itself. In some EDAC systems, a 1000-to-1 improvement in BER can be achieved with check bits adding only a 10% overhead.

The next step in the signal processing encodes the information for recording onto the OVD. We are currently examining several encoding formats for applicability to the OVD system. Some formats require the addition of timing information to ensure proper decoding upon playback. The encoding portion of the system can also be set up to feed the data into the disc on parallel tracks. The number of tracks used here can be different than that used in demultiplexing and EDAC.

Retrieving information recorded on a disc involves the inverse of the processing used for recording. Information read out of the tracks is first decoded to yield the basic input information with EDAC bits. Timing information obtained during playback is fed back to the disc drive to adjust

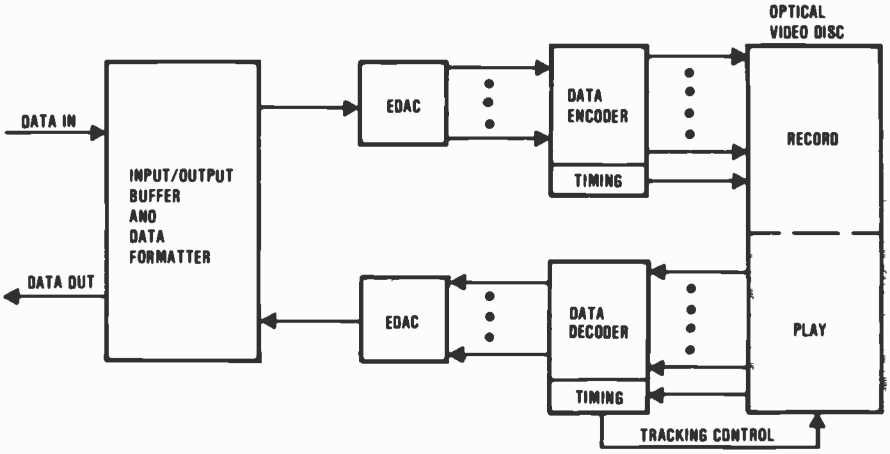

Fig. 5
Signal processing includes buffer for nonsynchronous data. Error detection and correction (EDAC) step can reduce error rates by as much as a factor of 1000.

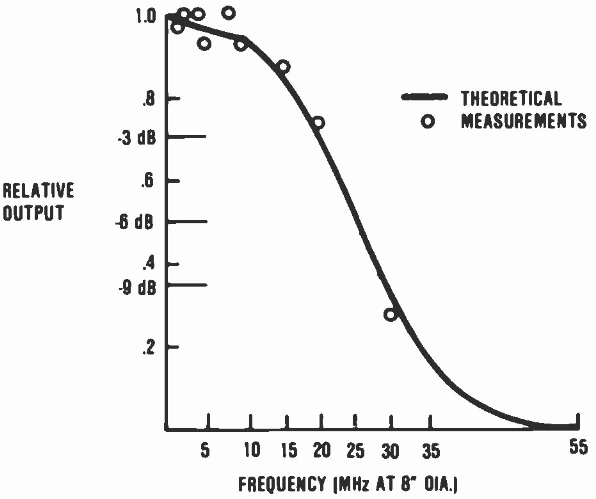

Fig. 6
Frequency response of the RCA optical video disc. Curve is for 1800 r/min.

rotational speed for optimum readout. The EDAC circuitry checks the information out of the decoder and corrects the errors within the capability of the EDAC code. Finally, the signals out of the EDAC circuitry are stripped of their EDAC bits and fed to the multiplexer for recombination into the original input data format.

Modulation and coding

Before selecting the optimum data format for high density, high data rate, and low BER, certain characteristics of the basic record/playback mechanism must be determined. Fig. 6 is a plot of relative output vs. frequency for the RCA-proprietary optical video disc. The curve is for a disc rotational speed of 30 r/s. Higher speeds will produce wider bandwidths, but not necessarily with a one-to-one correspondence.

High signal-to-noise values are possible with the optical disc.

The signal-to-noise characteristics of the optical video disc are also important parameters to be factored into a system design. Used as television signal recorders, present discs exhibit exceptionally high S/N of about 50 dB. These measurements were made by using an fm recording scheme, with the carrier at 9 MHz and a video bandwidth of 6 MHz. Disc speed was 30 r/s, and the S/N was measured at the demodulator output. Recent measurements made of high-frequency tones have demonstrated that the total information capacity of the disc is 40 dB S/N over a 30-MHz bandwidth. The disc noise does increase at low frequencies, so it is not desirable to use a modulation scheme that requires dc or low-frequency response.

Delay modulation presently appears to be the best coding method for the optical disc.

In our work at RCA, we are investigating coding approaches to identify the optimum scheme. The encoding techniques that appear most applicable are phase-shift keying, pulse-amplitude modulation-fm, multi-track nonreturn to zero, and delay modulation. Although the scope of this article does not permit thorough discussion of tradeoffs, it is appropriate to describe some of the important features of the leading candidate: delay modulation.

Delay modulation has been used in several high-density magnetic recorders and our preliminary studies indicated that it will be optimum for the optical disc as well. It uses a coding relationship whereby transitions at the centers of bit cells are "1s" and the absence of transitions at the centers are "0s." When a sequence of "0s" occur, transitions are made at the bit cell barrier. The principal features of delay modulation are that it requires only a half-cycle of bandwidth per bit, it is self-clocking, and its dc response is low. Operating at 30 r/s, we expect to achieve a 50-Mb/s data rate with an uncorrected BER of 10^{-5}. Analysis and testing are currently being conducted to verify our selection.

We are concerned about developing the optimum coding scheme because it will ultimately lead to a system having the highest bit-packing density and the lowest cost/bit. We believe that eventually a cost of 10^{-8} cent/bit is possible for the OVD storage medium.

Conclusion

The ultra-high packing density, wide bandwidth, and high signal-to-noise capability of the RCA optical disc, coupled with its potential for ease of handling and instant recording and playback, have made the system attractive for many information-storage applications.

The user requirement that will lead the initial development of digital OVD systems will probably be for mass data storage. We have seen a number of future systems requiring 10^{15} bits of storage capacity. If we use $10 as the disc cost, such a requirement would result in storage media cost of $100,000. The equivalent cost for a high-density magnetic system would be at least ten times higher. Thus, in a 10^{15}-bit storage system, the savings in storage media alone justify the OVD approach.

For the mass data-storage application, we envision a "jukebox" configuration that would contain 100 to 1000 discs on line. In this system, depending on the data traffic requirements, there would be a number of read/write stations. The entire mass data-storage system could be configured in a square room, each side 75 ft. long.

Our research is concentrating on how to make best use of the disc's unique properties of signal-to-noise ratio and packing density. We see the high-data-rate OVD application paving the way for other ones, such as mass data archives, electronic newspapers, expanded memory for mini- and microprocessors, as well as the traditional role of the OVD as a television device.

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Government-related programs in the Solid State Division

E.J. Schmitt

Making special devices for the Government produces profit and technological spinoffs for commercial devices.

The Government market

Solid-state devices for military and satellite-system use represent a very significant part of the total sales of the semiconductor industry.

The U.S. semiconductor market in 1977 was about $2.8 billion, with the Government market approximately $400 million (14%); the 1978 market promises to be even higher. In the electro-optics area, the Federal market was about $76 million (about 35% of the U.S. market). While much of this market can be serviced by commercial and industrial-grade products, a large portion still requires product that is screened to custom specifications or that must be redesigned to meet specific mission requirements. In some cases, entirely unique devices are needed, and the only relationship between the Government device and a commercial/industrial product is that a similar technology is used in manufacture.

The Solid State Division (SSD) selectively undertakes the development of special products for Government end use if 1) the market represents a profitable enterprise or 2) if the combination of the military market need and the spinoff of the technology into commercial products together warrant a return consistent with the investment in engineering and manufacturing costs.

In the past few years, military and space hardware procurement budgets have been deliberately reduced and, in addition, have eroded as a result of inflation. It has become more and more obvious to the Federal agencies that they must concentrate their remaining financial resources by using or adapting mainstream commercial technologies and products whenever possible and by coordinating their requirements so that tri-service or multi-agency funding is used to develop specific technologies or classes of devices. One consequence of the funding decline is that Government programs have become more directed and applications-oriented. Specifically, two new approaches to funding have recently been advocated by the Department of Defense.

In R&D block funding, the Government commits a major block of funds to one company for a few years instead of simultaneously pursuing two or three smaller contracts with different companies.

This new concept (favored by the Navy) implies that a company desiring to participate in the Government R&D market must make larger investments in the initial development cycle of a technology or device to show a clear, early superiority over the competition. Typical R&D block funding is in the range of $200k to $500k over a two-to three-year period.

The Government is also increasing its emphasis on Manufacturing Methods and Technology (MMT) Programs.

This is the next evolutionary step in the life cycle of the new device or process after feasibility has been demonstrated in R&D programs. All services have been directed to significantly increase MMT funding over the next five years, and the key to a company's success in winning MMT contracts will be its ability to clearly demonstrate a large return-on-investment to the Government for their funding. The electronics part of the tri-service MMT budget is presently about $15 million per year. This level is expected to rise to $50 million per year by 1981, and thus will present major opportunities for industry participation.

It is not always necessary for a company to participate in a Government-sponsored R&D program from its very inception to qualify for the MMT programs. It is possible that a company, because it desires to keep a development proprietary for commercial-market and patent-licensing reasons, will fund most of the R&D from its own resources. Then, once it has established its commercial/industrial market base, it may choose to expand its market opening by soliciting Government MMT programs to further develop the product or manufacturing facility to qualify for military applications.

The Government has two basic reasons for investing in an MMT program. The first is an *urgent, critical* need within the Government for the device and/or process required to make the device. Usually, the intent of the Government program is to accelerate the introduction of the device into production and field use. In situations in which an industrial concern is already investing in production, the Government will frequently either cost-share or identify additional Government-related requirements and create the funding necessary to accelerate the preproduction phase. Much of the funding of this nature is directed toward producing higher-reliability devices, radiation-hard devices, and parts that meet unusual shock, hermeticity, and other environmental requirements.

The second reason for the Government's investment in MMTs is the need for a product for which no comparable industrial or commercial requirement exists. Typical electronic-component and subsystem programs that fall into this category are fuzes, seekers for missiles, and circuits that will operate reliably in severe nuclear-radiation environments.

Fortunately, MMT programs pay large returns to both industry and government. Industry benefits because many of the manufacturing techniques developed are directly applicable to the industrial and commercial product base. The Government benefits because their supplement to industry's capital-facility investment is highly leveraged and results in a very large return-on-investment to them. MMT program funding typically ranges from $500k to $1.5M over a two- to three-year period.

Some of the more significant R&D programs, MMT programs, and product developments presently underway in SSD and the Solid State Technology Center (SSTC) are described in succeeding sections. These programs can have significant commercial/industrial product impact and technology spinoffs in the future.

COS/MOS semiconductor programs

The principal Government agency involved in the selection and approval of high-reliability (MIL-M 38510) parts is the Defense Electronics Supply Agency (DESC). However, concurrence of each military service and NASA is also solicited.

SSD is presently the major supplier of high-reliability MIL-M 38510 Class A COS/MOS circuits, with twenty-seven device types presently on the Government qualified parts list (QPL). Additional circuits are in the qualification cycle.

Among the more visible applications of high-reliability COS/MOS circuits are their use in NASA and Department of Defense satellite systems such as Satcom, the Atmospheric Explorer Series, Nimbus, TIROS, the Defense Meteorological Satellite Program (DMSP), and the Voyager satellites, which will fly past Jupiter and Saturn. Other major Government application areas include fuzes, remote sensors, mines, and secure digital communications systems.

Predicting the reliability of COS/MOS IC devices is an area of great concern to the military user.

The Government maintains large staffs of reliability R&D engineers at most agencies to continually monitor device reliability and to provide R&D contract support to industry in the development of new methods for testing and assessing the reliability of electronic parts.

The Solid State Technology Center is presently under contract to the Marshall Space Flight Center to determine the validity of the presently used accelerated tests (life tests run at elevated temperatures, with and without electrical bias, in operating and non-operating modes) for predicting the reliability of COS/MOS devices. The problem being investigated is the possible existence of new failure modes that could arise as a result of accelerated testing but that are unrelated to failure modes that would eventually occur when a device is operated within its specified rating. In other words, how far can accelerated testing be extended as a valid means of determining normal end-of-operational-life failure characteristics.

The radiation hardening of COS/MOS devices is extremely important in many Government applications.

The radiation hardness of a device is generally specified in two ways—total-dose susceptability and transient-dose susceptability. Total-dose susceptability is measured in rads (silicon) and is associated primarily with spacecraft applications in which cumulative radiation exposure levels occur over a period of months or years as a result of natural radiation environments existing around the earth, the planets, or as a result of solar activity. The transient-dose susceptability is usually associated with applications in which radiation from nuclear bursts is involved.

As a result of considerable in-house R&D and a joint program with the NASA Jet Propulsion Laboratory, a radiation-hardened high-reliability COS/MOS product capable of routinely achieving 2 x 10^5 rads (Si) has been achieved in production. This hardness was accomplished by optimizing the gate-oxide annealing method, a first-order effect for total-dose hardness in COS/MOS devices.

In continuing R&D programs sponsored by the Wright Paterson Air Force Base Materials Laboratory and the Naval Research Laboratory, it now appears that the standard commercial RCA CD4000 series COS/MOS circuits can be hardened to levels in excess of 10^6 rads (Si), and a comprehensive program is underway to achieve this capability, in production devices, in 1978. This COS/MOS hardness capability is now seriously challenging the 10^7 rads (Si) level of the bipolar devices presently used in many systems.

Additional radiation-hardening studies are also underway to characterize the hardness of the new microprocessor and memory circuits. The microprocessor circuit and some of the peripheral circuits use the new Closed COS/MOS Cell (CCL) geometry with a silicon gate structure.

These devices appear to be somewhat "softer" than the aluminum-gate devices used in the CD4000 series, but recent processing modifications made under contract to the Naval Research Laboratory and Sandia have resulted in significant improvements in hardness. In addition, work is underway to increase the total dose hardness of the silicon-on-sapphire (SOS) COS/MOS circuits used primarily for the high-speed random-access memories in the microprocessor family. The SOS-type circuits have a much greater capability to survive transient-dose radiation environments (i.e., SCR-type high-current latchup induced by nuclear-burst radiation), and additional R&D programs are underway to optimize both processing techniques and device geometry to achieve the highest possible transient-dose hardness level.

The Radiation Effects group at the Naval Research Laboratory recently awarded RCA the first phase of a contract to study and evaluate the impact of ionic impurities and structural defects on the radiation hardness of MOS devices, and to study techniques for eliminating or modifying the impurities so that maximum radiation hardness can be achieved. This study will, in the first phase, evaluate bulk silicon structures. In later phases, silicon-on-sapphire devices will be investigated. RCA also has had government contracts to improve the radiation hardness of linear circuits.

While standard high-reliability devices fulfill the majority of military COS/MOS applications, an important class of applications requires custom circuits.

Military systems use custom circuits because of serious cost or packaging constraints. Essentially three options are now available to military users for circuit development: the hand-crafted custom circuit, a Universal or APAR Array, or a microprocessor-based approach.

The hand-crafted design results in the smallest functional circuits and is the most cost effective if large-volume production is anticipated (i.e., typically 20,000 or more circuits). Fig. 1 shows a typical hand-crafted circuit.

The Universal/APAR Array, Fig. 2, has the lowest initial design cost, a short design and fabrication (and rework) cycle, and is

Fig. 1 (near right)
A hand-crafted custom LSI general-processor circuit, the TCS-074. This general-purpose unit is an 8-bit slice of a self-aligned, silicon-gate, silicon-on-sapphire circuit capable of being linked with additional GPU units to construct larger-word-size ALUs. It, in conjunction with the SOS TCS-075 ROM (1024 bits), the SOS TCS-093 (632 Gate Universal Array, shown in Fig. 2), and the CDP1821 (1024x1 SOS RAM), form the basic building blocks of a family of high-speed COS/MOS/SOS circuits that are being considered for use as processors in military applications. Circuit speeds up to 50 MHz will be possible. The three TCS circuits were developed as part of a Manufacturing Methods and Technology program for Wright Paterson Air Force Base.

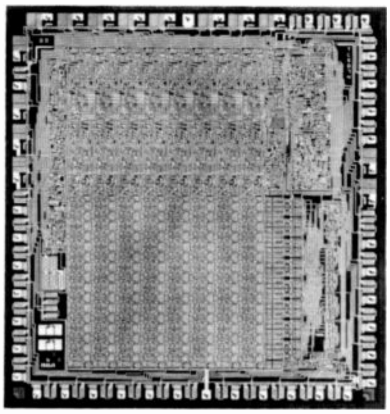


Fig. 2 (top far right)
Universal array using a self-aligned silicon-gate COS/MOS device on a sapphire substrate. This 235x235-mil chip, the TCC-093, has 632 gates and can be fabricated in a package having up to 64 pins.

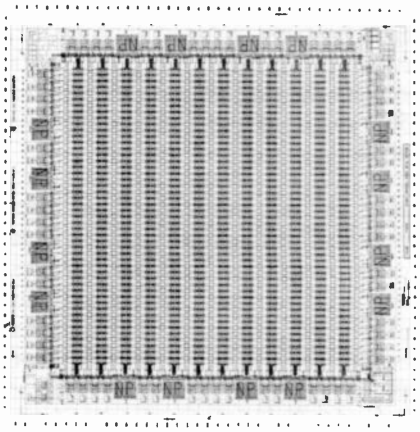
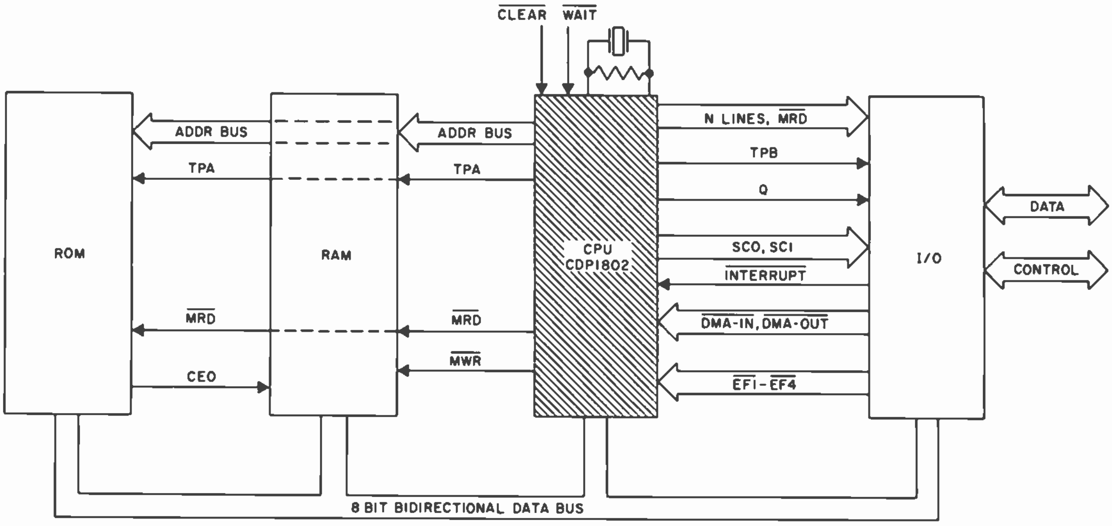


Fig. 3 (bottom)
A typical four-circuit CDP1802 microprocessor system that, in a high-reliability and radiation-hardened version, will meet the requirements of many military applications.



particularly applicable to small-quantity production or prototype equipment.

The microprocessor, Fig. 3, has the advantage of extreme versatility in permitting the rapid introduction of design and/or field changes and of being adaptable to multifunction system operations while using the same basic hardware.

In practice all three techniques are in wide use, each being justified on the basis of its particular application and cost goals.

In 1974, the SSTC won a key MMT program for the development of custom silicon-on-sapphire circuits; the program promises significant long-term benefits for both user and manufacturer. The MMT program goals were the establishment of a production process for silicon-on-sapphire LSI technology and the development of three LSI circuits to demonstrate reproducibility and reliability. The processing effort was successfully completed in 1975, and three basic circuits of a new family of high-speed COS/MOS/SOS LSI devices were then developed. Two of the circuits are shown in Figs. 1 and 2.

The three circuits, plus the 1024-bit COS/MOS/SOS random access memory, can form the basic building blocks of a general-purpose processor with extremely high performance capability. It could be fast enough to effectively emulate other processors for which software presently exists. This means that an SOS processor can be designed as a pin-for-pin replacement, or as a functional replacement, for computers that are in existing systems, particularly in TTL-based systems, with a considerable reduction in power consumption and equipment size. Some of the future major military systems that may be able to use this new SOS logic family include the Advanced Minuteman Missile (MX), the Defense Meteorological Satellites, and the AF Global Positioning System.

Fuzes are a uniquely Government market.

While almost all military applications are candidates for the custom-circuit approach, the fuze area is one that highlights many of the unique requirements and constraints faced by military users. The high-volume fuzes (artillery, mortar, bomb, and mine applications, etc.) usually employ hand-crafted custom circuits because of the cost savings inherent in the higher yields associated with the smallest possible IC die size. However, since all fuze programs start as exploratory development programs, and since most are terminated early, the low-cost, fast turnaround of the universal array design approach is attractive in the early development cycle.

Because physical space is limited in a fuze, hybrid circuits using IC chips are frequently specified. Sometimes, because of the acceleration in the gun firing phase, plastic ICs are specified since the encapsulation material supports the wire-bond connections.

In the future, particularly in remote-set fuze applications, the flexibility of microprocessors will be desirable because one circuit can sequentially provide the functions that now require three mechanical/electrical subsystems (i.e., safe and arm, time of flight count, and detonation control). However, it is possible that all three of the fuze-circuit design options described above will be used at some time between the exploratory development phase and the final production phase.

Typical fuze programs using SSD COS/MOS devices include the Navy's FMU117B bomb fuze and the 5-inch cannon-launched guided projectile, the AF FMU112 bomb fuze, and the Army's Stinger missile fuze.

Some special Government applications require very dense packaging.

In most cases Government applications use standard high-reliability COS/MOS devices in the dual-in-line ceramic package or the smaller ceramic flat package. However, many applications have only limited space available for electronics and so require very dense packaging. In these applications a ceramic substrate is used with either a beam lead or a wire-bonded chip.

In addition, two new approaches presently being developed show good potential for future miniaturized-equipment application. One is the leadless flat pack, and the other is the tape-carrier trimetal interconnect system. Fig. 4 shows the various packaging approaches; there is significant Government funding for the development of all of the approaches.

Ion-implantation research is an example of Government funding for special requirements.

The Government is funding semiconductor processing programs so that higher-performance, lower-cost, and more-

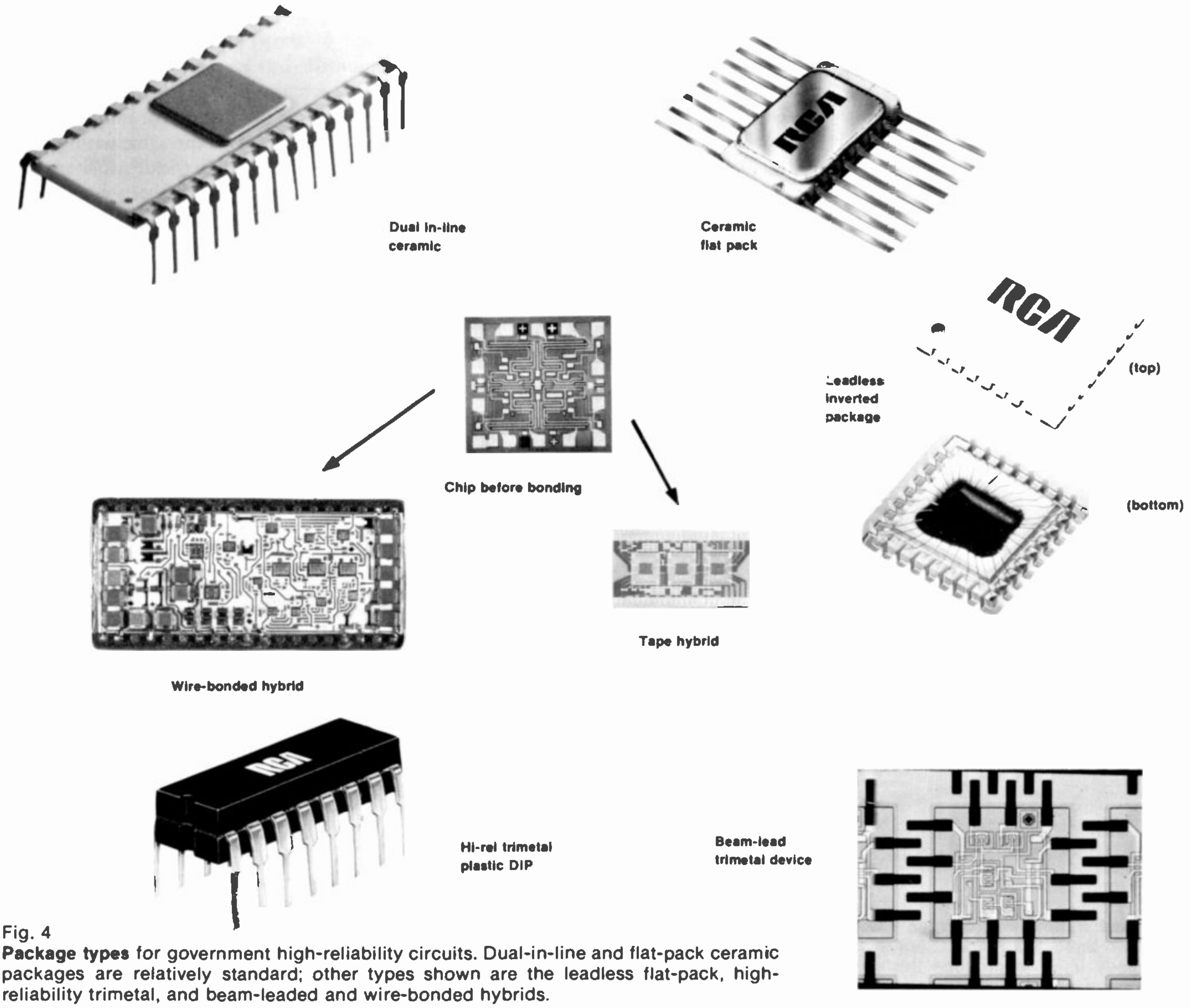


Fig. 4
Package types for government high-reliability circuits. Dual-in-line and flat-pack ceramic packages are relatively standard; other types shown are the leadless flat-pack, high-reliability trimetal, and beam-leaded and wire-bonded hybrids.

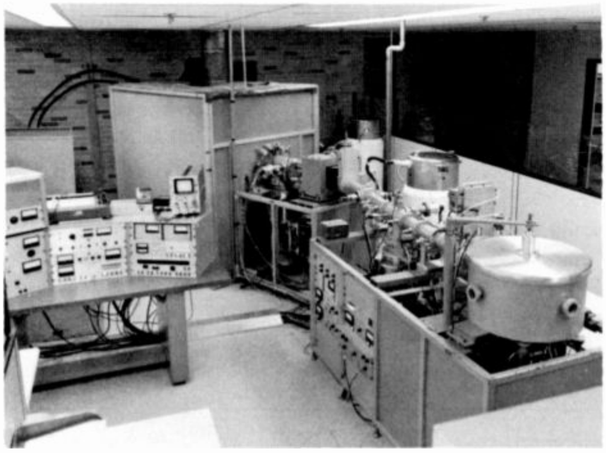


Fig. 5
Ion-implantation system is being explored for use in SOS circuits. It should provide better impurity doping at high and low levels.

reliable, radiation-hard circuits will be available for its more sophisticated requirements. A key program presently being conducted by SSTC for the Marshall Space Flight Center involves the use of ion-implantation techniques for silicon-on-sapphire COS/MOS circuits. Ion implantation is a process that introduces controlled numbers of impurity atoms into the surface of a semiconductor substrate by bombarding it with ions in the keV to MeV energy range. Fig. 5 is a photograph of an ion-implanter system.

Until recently, most impurity doping of bulk silicon and silicon-on-sapphire circuits was done either by exposing the silicon surface to the impurities contained in a dopant gas flowing past the substrate, or by applying a doped oxide to the substrate surface. A heating cycle was then used to diffuse the impurities, typically boron and phosphorus, into the bulk of the substrate.

This latter technique has two basic limitations. For light impurity doping concentrations (1 part in 10^6), the process variables are such that precise control of gas concentrations, flow rates, and temperatures is difficult. For high dopant concentrations (1 part in 10^4), the diffusion profiles tend to spread laterally, resulting in limitations on device size and, consequently, the restriction of device operating frequency. Ion implantation avoids these problems.

Linear integrated circuits

Packaging improvements have produced an important technology spinoff.

Because of the dense packaging requirements of the electronic subsystems on most strategic missiles, the radiation-hard dielectrically isolated linear and digital TTL circuits used have been developed as hermetic chips with either beam-lead or wire-bonding interconnections to ceramic substrates and PC boards. The hermetic character of the chip and the corrosion-free characteristic of the gold-lead interconnect system on a microbridge substrate (i.e., the substrate printed wiring is also gold) results in a hybrid-circuit package that is free of corrosion under severe environmental conditions and that need not be sealed in a larger hermetic hybrid package.

The major military application for this technology is presently the Trident missile system, for which SSD is under contract to Lockheed. Other potential applications include the advanced Air Force Strategic Missile System (MX) and the Site Defense Missile and Radar Support Systems (i.e., SPRINT/Safeguard Class).

Fig. 6 shows the beam-lead circuits mounted on a microbridge substrate. These circuits are unique in that there is presently no commercial or industrial circuit requirement of the same nature (i.e., fabrication on a dielectrically isolated substrate). It has, however, been possible to adapt some of the processing, metallization, and passivation technology to the bulk silicon substrate devices that are widely used in both military and commercial/industrial applications. This technology spinoff has resulted in the RCA Gold Chip plastic-packaged IC product, Fig. 7.

In 1976 the Navy Electronics Systems Command awarded SSD a $1.4 million contract to further improve the Gold Chip

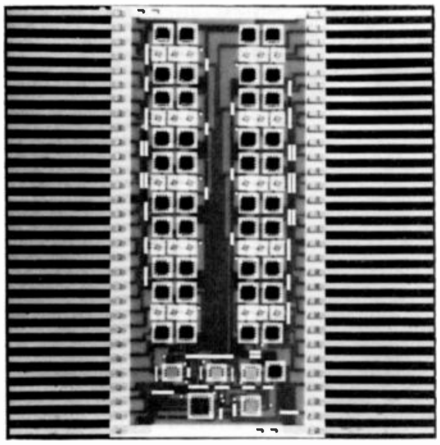


Fig. 6
Beam-lead trimetal microbridge substrate using two-level interconnect. Some of the technology used to produce this type of circuit resulted in the spinoff product shown in Fig. 7.

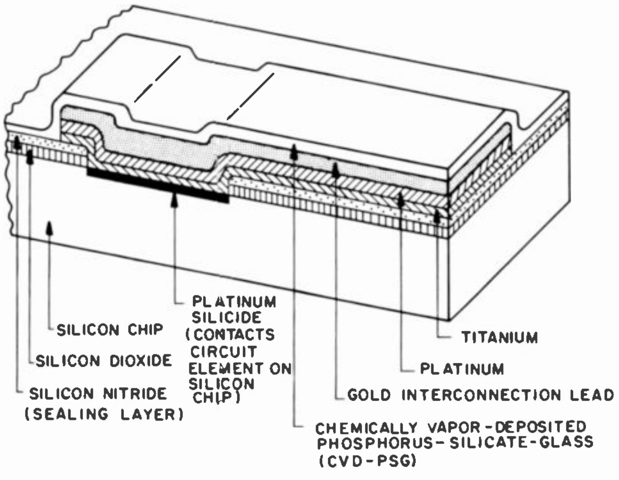


Fig. 7
"Gold Chip" plastic-packaged IC has a silicon-nitride-passivated trimetal structure. Devices are useful in intermediate-reliability applications.

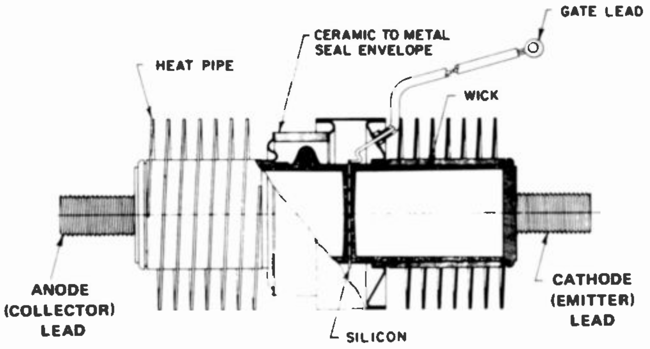


Fig. 9
Transcalent thyristor has very good heat-dissipation qualities because of its heat-pipe cooling. The gate lead may also be brought through the wall of the ceramic insulator between the emitter and collector of the device by brazing a feedthrough to it.

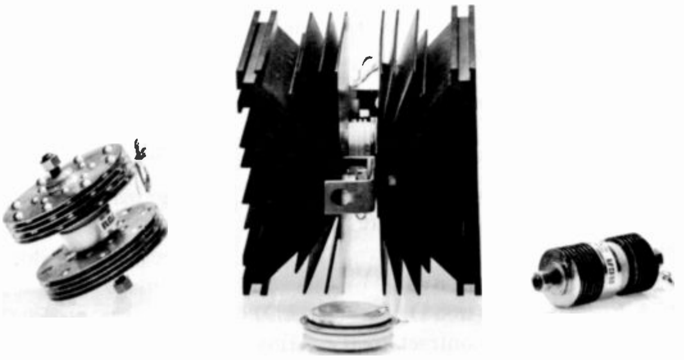


Fig. 10
Transcalent thyristors (left and right) are rated at 400 A (rms). Device in center is a competitive method of cooling high-current solid-state devices in which a disc-shaped device (like the one in the foreground) is clamped between the large fins in the background. The two methods have the same current capability when the case temperature and the heat-pipe temperature of the respective devices are both 100°C.

plastic-packaged IC so that it could meet the intermediate-level Class B military-reliability specification (0.005% failure rate at 60% confidence level). In addition, the contract requires that the price of a device be no more than 20% higher than a comparable IC made using the standard aluminum metal, SiO_2 passivated, plastic-package approach. The steps taken to fulfill this goal involved the use of silicon-nitride junction passivation, titanium-platinum-gold metallization, and the development of automated assembly systems. Fig. 8 shows the various elements used in the automated, beam-tape, chip-carrier assembly.

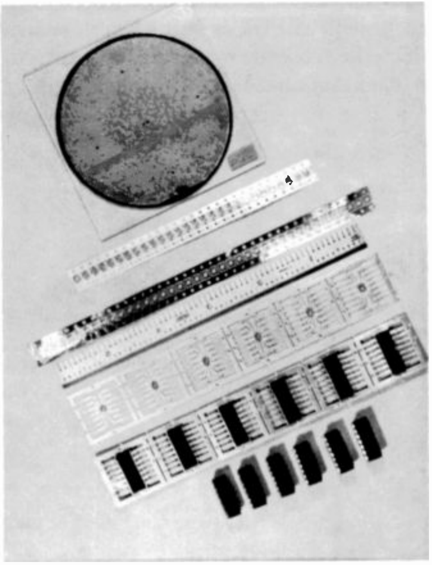


Fig. 8
Elements used in automated assembly of the high-reliability trimetal system. From top: mounted, scribed, trimetal wafer (thinned and presliced) ready for automated bonding to beam tape; ICs on copper-clad Kapton film (beam) tape (inner-lead bonded); IC on metal frame; and final HiRel injection-molded plastic IC.

In an attempt to develop as broad an area of application as possible for the trimetal plastic-package IC system, the circuits selected by the Navy for this contract included specific digital bipolar TTL circuits, linear bipolar circuits, and COS/MOS devices. All of the circuits were already on the Government Qualified Parts List (QPL) as aluminum metal, SiO_2 passivated, ceramic-package devices. The manufacturing and reliability studies planned as part of this contract will result in quantitative comparison data between large numbers of trimetal high-reliability plastic-encapsulated parts and aluminum-metalized devices in ceramic packages, for which a large Government and industry reliability data base already exists.

Power devices

The Government is a major user of power transistors in a wide variety of applications including avionics equipment, missile systems, communications sets, and power conditioners.

SSD, under contract to the Draper Laboratory, recently developed the TA9107 radiation-hard power transistor. This device can operate in radiation environments with cumulative neutron flux levels to 1 x 10^{14} neutrons/cm^2 and gamma intensity to 2 x 10^8 rad (Si)/second.

Heat-pipe cooling has improved the thermal dissipation abilities of power devices.

A new configuration called the transcalent solid-state power device promises to reduce device size and weight and simplify supplementary thermal dissipation equipment (e.g., fans, liquid coolants) an order of magnitude over present, equivalent power devices.

The transcalent device consists of a silicon wafer bonded to a heat pipe. It achieves its high thermal conductance by the evaporation of a heat-transfer liquid from the silicon surface. The liquid is delivered to the silicon surface by wicking action in a self-contained thermodynamic system. A cross section of a transcalent thyristor is shown in Fig. 9; Fig. 10 compares present devices with their transcalent equivalents.

Development work for transcalent rectifiers, thyristors, and transistors has been funded through R&D programs and MMT programs from the Army (MERDC and ERADCOM) and the Navy (NADC). These devices have the potential for wide application in solid-state contactors, motor speed controls, dc/ac inverters, and ac/dc converters.

Electro-optics

Government-sponsored R&D in silicon vidicon tube development for tv cameras has had a long history.

The RCA vidicon presently being used in systems such as Maverick, Walleye, Hobos, and Pave Strike, and in NASA systems such as Apollo, Landsat and JPL planetary satellite programs are results of this sponsorship.

RCA Electro-Optics and Devices (EO&D) is presently under contract to the Army Missile Command to develop a rugged silicon vidicon assembly for use in future Army missile systems. This tube is of metal and aluminum ceramic construction with the silicon target bonded to the glass faceplate. The gun is of stacked brazed ceramic construction to minimize tube size, and the focus coil and deflection components are potted. This 1-inch tube will operate in the 0.71 to 1.1-micrometer spectral range and has an antiblooming capability. Fig. 11 is a photograph of one of the first tubes developed under this contract.

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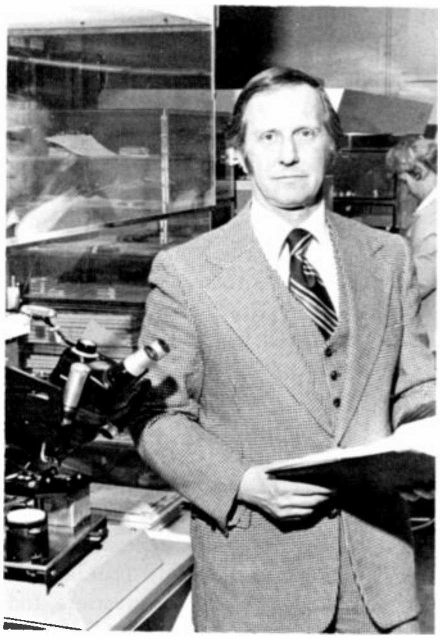

Charge-coupled-device cameras have advantages for reconnaissance and surveillance systems.

Recognizing the potential of small, monolithic structures for direct digital readout and possible remote monitoring of the image, the Army Night Vision Laboratory at Ft. Belvoir has become interested in the charge-coupled device (CCD), a solid-state sensor with its own integral internal scanning system on the array that, consequently, needs no electron-beam scan assembly or associated vacuum enclosure. The Night Vision Lab has given RCA EO&D a contract to modify the commercial CCD imager so as to extend its detection capability into the infrared region and to enhance its ability to operate with covert illumination systems in reconnaissance and guided-missile delivery systems.

Fig. 12 is a photograph of the present CCD imager, which has the capability of producing the same picture quality as a conventional ⅔-inch silicon vidicon. Other military applications for the CCD imager include aircraft gunfire recording systems and star trackers.

In addition to optical imaging, the Electro-Optics and Devices activity is developing silicon photodetectors, which find wide use in the military for the less sophisticated guided munitions with optical seeking capability. The Army (ECOM) has funded development work in silicon avalanche detectors, the type of detector that is compatible with the requirement for the Army's cannon-launched guided projectile, Copperhead.

Another area of Government need is that of surveillance and security systems. A program called BISS (Base Intrusion Security System) is currently a joint services project; the purpose of the project is to evaluate imaging and display products and to define Government requirements for security systems. Commercial RCA CCTV cameras and video display and switching equipment are being evaluated for and adapted to the severe environmental conditions encountered in military field operations.

Government-supported R&D programs in the future

The developmental areas described below are candidates for future Government R&D program support.

Sapphire materials—Reducing the cost of semiconductor substrates, particularly the sapphire substrates used in the manufacture of silicon-on-sapphire COS/MOS circuits, is a major goal in the semiconductor industry. A new process, edge-pulled film-fed growth (EFG), is being developed in which the substrate material is pulled from an aluminum-oxide melt through a set of dies as a flat ribbon rather than being

Fig. 11
Rugged silicon vidicon tubes are used in many military tv surveillance and reconnaissance applications.

Fig. 12
Silicon imaging device intended primarily for use in generating standard-interfaced 525-line television pictures. This self-scanned device uses an array of charge-coupled device (CCD) shift registers for photosensing and readout. The device contains 512 vertical x 320 horizontal pixels (163,840 picture elements); chip size is only 500 by 750 mils.

grown as a large cylindrical boule which must then be sliced into wafers and polished. Fig. 13 shows a portion of the EFG process.

Automated processing systems—One of the major factors in the yield of LSI devices is the initial defect density of the substrate and the additional defects that occur as the wafer proceeds through the processing cycle. The additional defects are caused by dust particles that settle on the surfaces, scratches from contact masks, residue from photoresists and oxides, metal imperfections, and handling. Techniques and processes that minimize the sources of defects and damage are mandatory if LSI devices are to be manufactured in the future with reasonable yields.

A generic name for a system presently under study and development by SSTC for SSD is Production Monitoring Control. Key elements of this system include an environment with extremely low airborne-particle concentrations, automated wafer movement through photolithographic operations, doping, and subsequent chemical processing steps; sensors to measure the electrical and physical characteristics of the devices on the wafers as they proceed through processing; and comparison of measured data to known reference parameters contained in a computer data base.

The National Bureau of Standards is funding RCA Laboratories and SSTC for development work to define a family of test circuits that can be used to perform the in-process device evaluation. The techniques will permit pinpoint assessments of the specific processing step (e.g., gas flow, film thickness, material resistivity) that may be causing devices to deviate from their prescribed values.

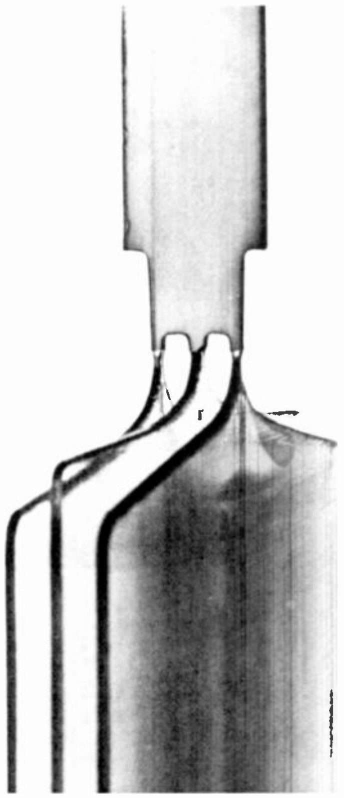

Fig. 13

Sapphire ribbons being pulled from the melt during edge-defined film-fed growth process. Sapphire ribbon will be used for making substrates for silicon-on-sapphire integrated circuits, which are a prime candidate for very-large-scale integration.

Advanced design-automation—Presently, most of the design-automation techniques used in the industry consist of separate elemental computer programs for simulating logic, reducing logic to artwork, and generating test patterns to exercise the logic. A new area of development is the consolidation of these programs with respect to a common database and a common data specification and command language. A system that can be used to extract data from the database in a format compatible with the requirements of each service program is required. A user of this new system should be able to specify, in a macro language, a description of the circuit or logic net that he wishes to fabricate. The operating system should, in turn, develop the logic, test the logic, simulate and exercise the actual circuit parameters for that particular configuration, evaluate the circuit response, and transform the logic into artwork. The operating system could then return from the artwork through a reverse set of simulations to assure that the final artwork did indeed reflect the macro definitions developed in the initial specification of the logic. Once this is proven, the artwork would be transformed into the final masks.

Another goal of this development is to create a sophisticated graphic system that will permit real-time interaction between the software and the designer as he moves the design through the development cycle.

Advanced lithographic techniques—As devices become smaller, and as line widths approach one micrometer, the mask aperture size approaches the diffraction limit of the light used to expose the mask. Consequently, the exposed patterns on the wafer surface lose their sharpness, and the metallization and impurity diffusion steps are less controlled.

A radically new technique designed to overcome this limitation is the use of electron-beam exposure techniques to make the masks or to expose patterns on the wafer. The new electron-beam resists that are being developed are much more sensitive and have considerably greater resolution than resists sensitive to visible light. The SSTC recently began operating an electron-beam mask-making system and is already providing extremely precise VLSI microprocessor and memory circuits.

Additional areas for future Government support include: software systems to convert present artwork generators into generators capable of controlling the electron-beam pattern, further development of electron-sensitive resists, and ultraviolet and short-wavelength radiation sources for mask-alignment systems compatible with the very small geometric patterns made by the electron-beam exposure.

Summary

Government support of semiconductor R&D has been one of the main reasons for the sophistication of the capability of the U.S. in military electronics technology. The support has also stimulated a vigorous commercial semiconductor industry. Every evidence indicates that a strong and mutually beneficial program will continue between industry and the Government in the future.

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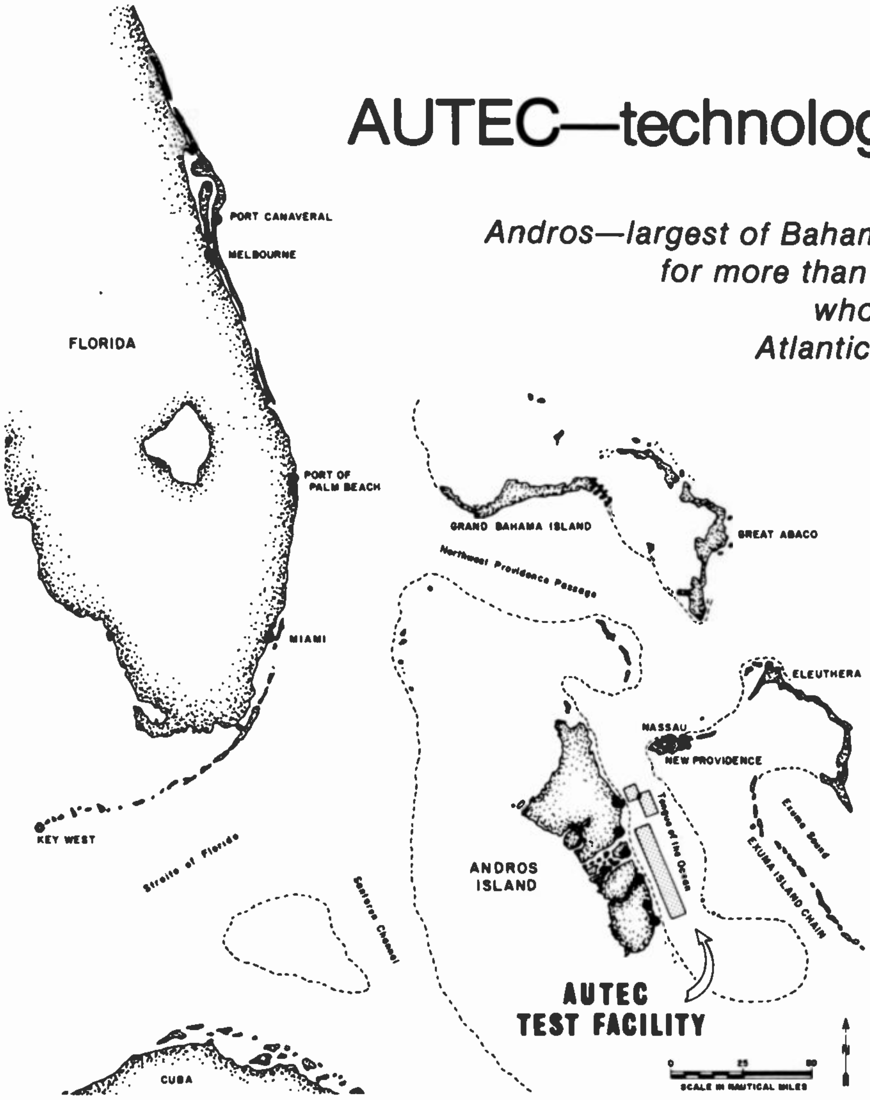
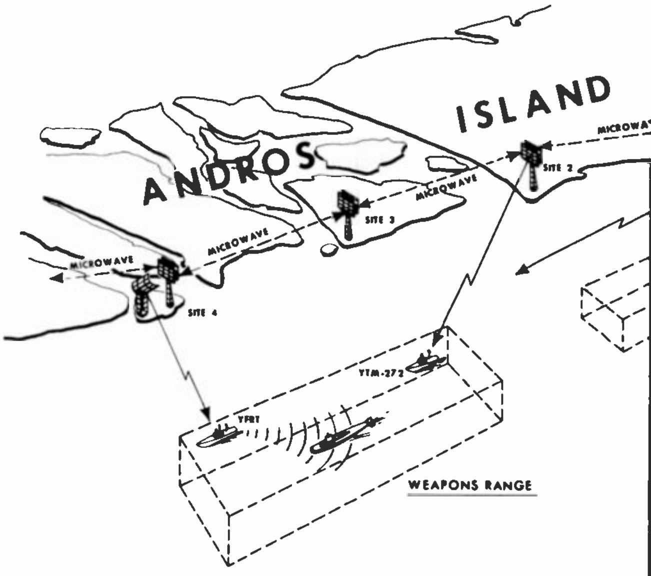
AUTEC—technology at the tip of the tongue

*Andros—largest of Bahama's picturesque Out Islands—is home for more than 700 RCA Service Company personnel who operate and maintain the U.S. Navy's Atlantic Undersea Test and Evaluation Center (AUTEC).**





E. Erickson|R. Kennedy|G. Virgin

AUTEC is a deep-water test facility used to track surface ships, aircraft, submarines, and weapons precisely, to measure their underwater acoustic profiles, and to test and calibrate sonar systems. These functions are performed in support of R&D projects as well as Anti-Submarine Warfare (ASW) missions using three separate ranges—the weapons range, the acoustic range, and the FORACS range.**

The AUTEC ranges

The AUTEC ranges are located about 180 miles southeast of West Palm Beach on Andros Island, along the "tongue of the ocean," a unique 6,000-foot deep trench. This area is ideally suited for AUTEC's mission because it provides low ambient noises, freedom from shipping lanes, and a year-round mild climate. More specifically, the ranges are adjacent to the eastern shore of Andros Island within the 20-mile-wide, 100-mile long tongue-of-the-ocean, surrounded by coral banks. The main base and five downrange sites are on Andros, along the western border of this basin.

The weapons range *uses sonar, radar, and optical systems to track several targets in water and in air.*

For in-water tracking, the weapons range uses a large array of bottom-moored hydrophones augmented by a small array of hydrophones located further downrange. Acoustic pulses emitted by target-mounted pingers are received by the various hydrophones, amplified, and transmitted via cable to shore-based terminals where they are recorded, discriminated for target identification, and digitized for transmission to the main base for processing and display. Targets are distinguished from one another by us-

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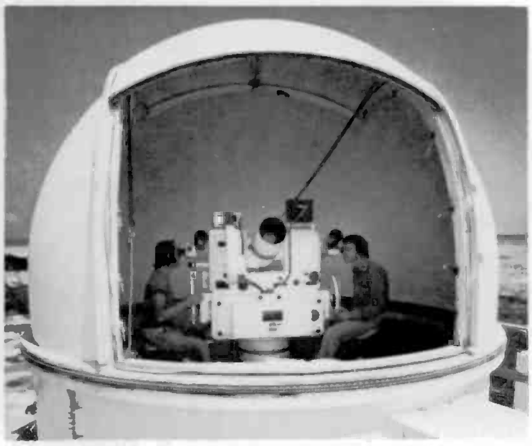
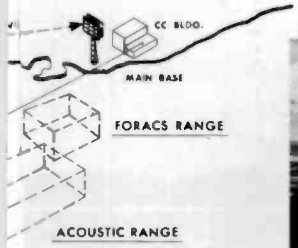
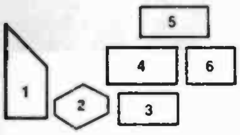
*RCA Service Company operates and maintains AUTEC under contract to the Naval Underwater Systems Center, Newport, R.I.

**FORACS—Fleet Operational Readiness Accuracy Check Site

e of the ocean







1. The tongue of the ocean—a mile-deep trench extending southward through the Bahamas about 180 miles southeast of West Palm Beach, Florida—is an almost ideal spot for testing undersea weapons and technology. The Bahama island chains protect it from the turbulence of the Atlantic; it runs parallel to, and within a half mile of, the eastern shore of the largest of the Bahama Out Islands—Andros; and it is relatively undisturbed by ship traffic. **2. The three AUTEC test ranges**—Weapons, Acoustic, and FORACS—border Andros Island on the east; these ranges provide an ideal area for R&D and ASW (anti-submarine warfare) tests conducted at AUTEC. **3. Aerial view of the main base at Andros Island** in the Bahamas, viewed from the south. Marine department and pier can be seen at right center. Operations Control Center is at lower right with range support at left-center. Housing, dining halls and administration offices are located at far left. **4. CDC 3400 computer systems** located at the command control building on Andros perform real-time and post-test processing tasks in support of test on the AUTEC range. **5. The Operations Control Center** is the center for all testing and terminus of all data acquired by instrumentation systems over the entire test range. **6. This cinetheodolite tracking camera** is one of five used on the Weapons range to film test events.

ing unique frequencies and pulse repetition rates for each. Two computers at the main base select optimum groups of hydrophones for tracking, determine real-time position, and process post-test data.

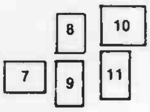
In-air tracking is accomplished by two radars operating in beacon or skin mode and equipped with closed-circuit television for initial acquisition. Radar angle and range data are also transmitted, in digital form, to the main base computers for real-time tracking and post-test data reduction.

Five cinetheodolites produce films which, when processed and read, also provide post-test data.

The acoustic range *can accurately profile the noise signature of a ship.*

The acoustic range consists of a bottom-moored hydrophone array, backed-up by a computerized data acquisition, processing, and display system. The underwater array includes noise-monitoring hydrophones mounted along a vertical cable as well as tracking hydrophones mounted horizontally along tracking arms at the base of the main array. Acoustic and tracking data are transmitted via cable from the array to the main base.

A tracking system carried aboard the test vessel uses a pinger and other electronics to keep the test vessel on an



7. **A mobile target** being loaded aboard AUTEC's 182-foot vessel, the IX-306, in preparation for firing during an on-range test. In the background is a torpedo recovery vessel. 8. **AUTEC's IX-306 launch vessel** has two torpedo tubes: one for surface and one for submerged launch capabilities. Additional electronics on board also enable this vessel to simulate a target. 9. **RCA divers** surround a torpedo preparing to fasten a harness for helicopter transport back to main base. 10. **RCA divers** performing routine inspection on deep-moored acoustic hydrophone. In addition to inspections and maintenance, divers recover torpedoes and provide underwater photographic services. 11. **AUTEC diver** surfacing.

accurate course during a test run, which is necessary to determine accurately the level of the vessel's radiated noise.

The acoustic range is used to evaluate noise-quieting techniques and to establish criteria for noise reduction. Data from this range have been used to study radiated noise directivity pattern and cavitation, to analyze comparative data collected by other facilities, and to systematically collect and correlate noises from ships of a particular class.

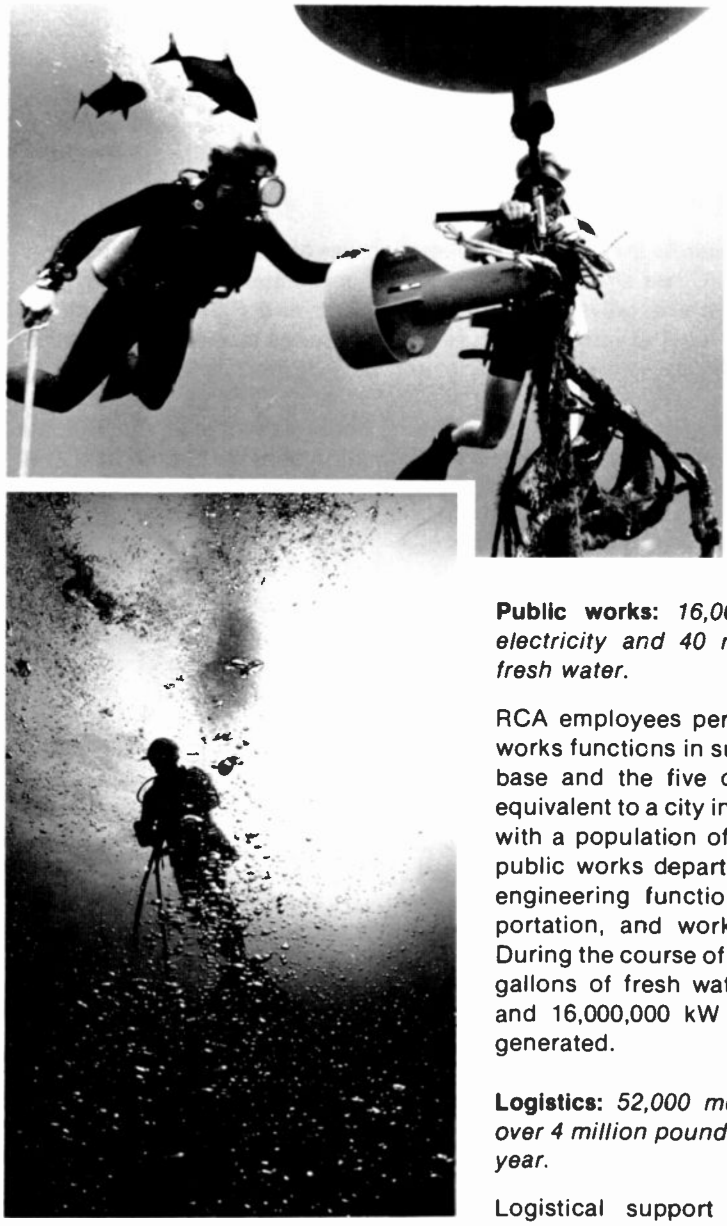
The FORACS range *uses many different sensors to measure performance of shipboard ASW, radar, ESM, and navigation systems.*

The FORACS (Fleet Operational Readiness Accuracy Check Site) range consists of three optical tracking stations one-half mile offshore near the reef line, active and passive radar targets, ESM (electronic support measures) targets, and one deep and two shallow sonar transducers capable of providing signals for testing active and passive sonars. The sonar transducers are connected via underwater cable to the main base. The mission of the FORACS range is accomplished in three phases: dockside calibration and setup, on-range test, and post-test data reduction.

During the dockside phase, base personnel mount a deck transit cross-leveled to the reference plane of the ship's fire control system. They also determine ship's centerline forward, mount a deck transit over this centerline, and transfer the transit to the centerline aft for use during on-range tests. The gyrocompass settle error is measured and parallax data on the ship's systems are obtained. The ship's crew is thoroughly briefed on test procedures. If the ship is a submarine, the periscope is calibrated.

On range, the ship travels a predetermined course while 250 to 400 data points (range and azimuth) are collected. An optical marker on the ship's bow is tracked by the three shore-based tracking stations while the ship's crew use on-board equipment and the aft transit to track their respective targets. A series of marks are called and, on each mark, all stations record bearing and/or range information to their respective targets. This procedure is repeated until sufficient data, over a wide spectrum of ranges and bearings, are acquired.

After the on-range phase, the data acquired is keypunched, processed, analyzed, and furnished via Navy channels to the vessel for action.



Range-support facilities

Main base *houses range management and is the nerve center for range operations.*

In addition to being the terminus for all test and tracking information collected by instrumentation at the downrange sites, the main base houses two CDC3400 real-time computer systems which collect, process, and distribute data. To increase the real-time processing availability of these systems, most MIS-type programs, including payroll, have been placed on the RCA Spectra 70 in West Palm Beach. The associated peripheral and communication equipment needed to support test operations are also located at main base.

Public works: *16,000 Megawatts of electricity and 40 million gallons of fresh water.*

RCA employees perform in all public works functions in support of the main base and the five down-range sites, equivalent to a city in the United States with a population of 1,000. Within the public works department are the civil engineering function, utilities, transportation, and work control groups. During the course of a year, 40,000,000 gallons of fresh water are processed and 16,000,000 kW of electricity are generated.

Logistics: *52,000 meals each month, over 4 million pounds of supplies each year.*

Logistical support for the AUTEC ranges is a continually varying requirement filled by RCA personnel. Housing is provided for 820 U.S. Navy, Government, and RCA employees, and their dependents, and hotel services for a daily average of 60 transient personnel. An average of 52,000 meals are served each month by the dining services department. The supply department handles an average of 4,290,000 pounds of goods in the course of a year. RCA personnel also operate the lounge and the retail store.

Fire, security, and medical facilities: *around-the-clock operation.*

A fire and security force provides for the physical security of the Andros ranges. This includes access control, visitor control, fire prevention, and a fire fighting and guard capability around the clock, 365 days per year.

A fully equipped medical dispensary, staffed with a registered resident physician, nurse, and Navy medical corpsmen, provides for routine and emergency medical treatment for AUTEC personnel on Andros.

Marine operations: *boats, divers, and repair and calibration facilities.*

RCA operates and maintains a fleet of ten vessels, up to 180 feet in length. These vessels launch and retrieve torpedo-type targets and weapons, provide logistics support to the down-range sites, and are used to transfer personnel to and from test vessels at sea.

Within the framework of marine operations is the range-support shop which provides diving services, electronic equipment calibration and repair services, marine electronics and radar maintenance, and machine-shop capabilities. In support of on-range testing, the range-support shop helps the range users prepare, check out, retrieve, maintain, and load torpedoes or targets.

Air operations: *three helicopters and a twin turbo-prop aircraft*

RCA owns the Fairchild FH 227 twin turbo-prop aircraft which daily flies from West Palm Beach to Andros Island. Capable of carrying 44 passengers in addition to a crew of three, this aircraft converts readily to carry cargo when needed to haul torpedoes back to West Palm Beach or to transport fresh foods and cargo to Andros Island.

RCA, through an aviation subcontract, operates and maintains three twinjet helicopters which are used to launch and recover torpedoes and perform logistics and personnel transfer functions between main base and down-range sites.

Torpedoes may be recovered by helicopters using either of two recovery methods: diver or diverless. In diver recovery, AUTEC divers, who are RCA employees, are dropped from the helicopter in the vicinity of the floating torpedo. They attach a harness to the torpedo and are then lifted back aboard the helicopter to return to main base. To prevent damage, the torpedo is deposited on a trampoline.

In diverless recovery, the helicopter hovers at low altitude and lowers a funnel-shaped cage over the nose of the torpedo. (A spent torpedo floats vertically with its nose above the surface of the water.) Compressed gas is released causing retaining rings to capture and hold the torpedo within the cage. The cage is then pivoted to a horizontal position and the entire assembly is raised out of the water and returned to main base.

Mainland operations: *overall project direction from West Palm Beach.*

West Palm Beach, Florida, is the headquarters site for overall project management, interfacing directly with the U.S. Navy.

Test Planning Engineering, Technical Services, Purchasing, and Mainland Transportation functions are also located in West Palm Beach. Personnel within these areas commute to Andros Island as required to plan, support, and document the on-range operations.

Financial administration and project administration functions are also based in West Palm Beach. The Finance department operates and maintains an RCA-owned Spectra 70/46 computer system used to provide financial, MIS, and support computer services.

Conclusion

Understandably, this brief description cannot give all the facets of a project such as AUTEC. The variety of the skills and the depth of RCA management required to maintain and operate a vital Navy test range of this size could fill several volumes if described fully. However, the information presented here should provide a fresh perspective on one of RCA's exciting programs, being carried out in a beautiful setting, by dedicated people.

A typical day on the range —putting a submarine through its paces

Preparations

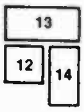
Before the submarine that will undergo tests arrives at Andros, the Scheduling Officer at AUTEC has already interfaced and coordinated test requirements. Government representatives, program managers, and RCA test planning engineers then meet to verify the nature of the on-range test, range resources to be committed, personnel scheduling, and data desired from the test.

After the planning meeting, the test planning engineer writes an Operations Directive (OD) which contains detailed information pertinent to the test. The OD specifies arrival times on the range and establishes schedules for support vessels, radars, hydrophones, communications networks, theodolites, helicopters, and targets needed for the test.

The submarine crew and test personnel are fully briefed beforehand to verify that they understand all phases of the test and what will be required of them from test commencement (COMEX) to test completion (FINEX).

Torpedoes to be used in the tests have been loaded aboard the submarine at stateside Naval bases. While this was being done, the Range Support Shop at Andros was busily preparing a mobile target—an instrumented device that simulates a submarine in maneuverability, speed, and acoustical characteristics and is shaped somewhat like a torpedo.

For this test, the mobile target "submarine" is transported to the pier and loaded aboard the IX-306, a 182-foot vessel containing two torpedo tubes. (In some tests, the target might be carried to the heliport and attached, via a special launching harness, to one of the SH-3G helicopters for air launching.)



12. **AUTEC boat** working with submarine to transfer personnel at sea. 13. **Loading of MK 48 torpedoes** on RCA's FH227 twin turbo-prop aircraft. 14. **After a diverless recovery,** an AUTEC helicopter transports the torpedo within its retrieval cage directly to main base. RCA and aviation subcontract personnel were instrumental in perfecting this safe, faster method of torpedo recovery.

Countdown to COMEX

T minus 24 hours ...	check all instrumentation—radar, communication sonar, optical, computer, etc.
T minus 3 hours ...	thoroughly exercise the entire instrumentation net to be used for this test.
T minus 60 minutes ...	all stations report manned and ready; begin countdown to first target launch.
T minus 30 minutes ...	target launch vessel (the IX-306) arrives on station and prepares for first target launch. The submarine maintains its scheduled position, course, and speed (as outlined in the Operations Directive) and prepares to detect a running target and launch its torpedo. In the Operations Control Center, real-time tracking data is being displayed to the Test Conductor, Range Safety Officer, Program Manager, and Planning Engineers. Plotboards, with input data from the real-time computers, are providing three-dimensional tracks of all on-range participants. Radar data and in-water tracking data are displayed to the Range Safety Officer to enable him to monitor course, speed, and depth of all participants to ensure range safety.
T minus 0 ...	COMEX (commence testing) is announced by the Test Conductor. The target is launched by the IX-306 to begin its preprogrammed run.

The test

The submarine searches for the mobile target, which is now simulating another submarine. The submarine acquires the target and launches a torpedo which searches, acquires, and tracks the target through a number of predetermined maneuvers. At end-of-run, the submarine-launched torpedo and the target torpedo surface for recovery. The torpedo fired by the submarine is retrieved by a torpedo recovery vessel. The mobile target is retrieved by helicopter and transported to main base for turnaround and preparation for later tests.

After the test

As soon as the test is completed, the Data Processing Department produces an abbreviated data package and delivers it directly to the submarine via a rendezvous vessel. At a later date, the fully documented test data and results are sent to the range user.

Ray Kennedy, at left, joined RCA in 1972 as an Engineer on the FORACS Range. In 1974, he became the leader of FORACS and later was reassigned to Test Planning, where he was responsible for the coordination of ASW test programs. In his present position as Manager, FORACS Range, he is responsible for ASW sensor performance measurements on Naval vessels of the United States and Allied Countries.

Ed Erickson, center, joined RCA in 1965 as a Technical Writer with RCA Service Company in Cherry Hill, New Jersey and transferred to the Computer System Division in Palm Beach Gardens, Florida as Manager, Maintenance Documentation. He joined RCA AUTEC in 1975 as Manager, Technical Services and worked there until this year. Recently, Mr. Erickson left RCA.

George Virgin, at right, joined RCA in 1968 as a Leader, Technical Writers with the RCA Management Services Project in Huntsville, Alabama. In 1969, he transferred to the RCA AUTEC Project in West Palm Beach, Florida, where he presently is Leader, Publications Services and responsible for production, control and publication of documentation.

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A computerized drawing control system by and for the engineer

W.S. Sepich|N.C. Lund

EDICS, an on-line drawing information/control system, lets engineers find out about updatings and revisions instantly. The system saves engineering time and effort, and also has a number of side benefits.

The Engineering Drawing Information Control System (EDICS) is a computer-based system that was developed to help prepare and revise Broadcast Systems engineering drawings and to provide accurate, instantly available information about these drawings. It is expected to increase the efficiency of managing product development and increase productivity by aiding in the documentation of design information and by improving engineering and manufacturing access to information about drawings.

EDICS is a real-time terminal-based (time-sharing) program that stores information about product drawings such as:

complete drawing trees for all products;

status of drawings;

revision levels and dates of drawings;

codes to indicate if parts are standard, nonstandard, or custom-made;

production shop orders for products;

spare-part stock numbers;

labor, test, and material costs for components and assemblies, which may be summarized at any level;

codes for special handling of components where required; and

for components on printed wiring boards, the standard lead mounting length and a key for automatically insertable parts.

EDICS will print out parts lists either in a batch mode or directly at a terminal, and perhaps of most significance, Engineering Change Packages, ECPs,[1] will be "written" by the engineer at a terminal.

Historical background

Several years ago Broadcast Systems, with the aid of a study performed by Corporate Research and Engineering Staff, recognized the need for a modern computerized drawing control system for its products. A committee was formed consisting of representatives from Engineering, Operations Control, MIS, Parts & Accessories, Industrial Engineering, Materials, QC, Production Administration, Test Engineering, and Central Engineering. The committee was chaired by a member of Corporate Research and Engineering Staff and a final report was issued in January of 1974. That report recommended a real-time terminal based system as opposed to the batch systems being used at many other RCA business units. The system was called EDICS, an acronym for Engineering Drawing Information Control System.

The EDICS system is a modification of commercially available software.

Because of the prohibitive cost of developing the software for such a system, the idea remained in limbo until late 1974. At that time, an outside software company, Mitrol Inc.,[2] was found to have a program containing many of the features desired for EDICS. Their program is called MIMS (Mitrol Industrial Management System). With the assistance of Corporate Research and Engineering Staff, Mitrol was contracted to modify their software to perform the functions of EDICS, and place the modified program on the Cherry Hill 370/168 VM/CMS computer. Actually, EDICS is a "module" that has been added to the MIMS software, thus making both EDICS and MIMS available to RCA users. The detailed specification delineating the requirements and usage of EDICS was written by the authors and followed closely with Mitrol. Since the first priority for EDICS was to benefit the design engineering organization, it was important for people with design engineering experience to write the specification. The benefits to manufacturing, materials, etc., although important, were nevertheless considered of secondary priority. The system became operational in late 1976 and is presently being used in Broadcast Systems on a limited number of projects in order to assess its cost effectiveness.

The system is operational now.

At present all standard and commonly used parts have been incorporated into the EDICS database, along with the product structures, or drawing trees, for one large product and several smaller products. All early releases of components have been made for one product using the computer to simplify this task. Output was transmitted via magnetic tape for direct input into the Manufacturing computer system.

The major distinctions of EDICS

The system is on-line, rather than batch.

The EDICS system is, in many respects, similar to computer programs being used in other RCA business units for storing drawing information and generating parts lists—CRP in GCS, MCS in MSR, and EMCE in AS. The difference between EDICS and these systems, however, is significant; so much so that the writers feel EDICS can be classified as the next generation of programs for controlling drawings.

An examination of EDICS vs the batch systems used in other business units shows a similarity in basic software structure: i.e., 1) a drawing or document file, 2) a part file,

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[1] The ECPs (Engineering Change Packages) used in Broadcast Systems are similar to ECNs (Engineering Change Notices) at many other locations, except that a number of related drawing changes may be entered on an ECP, as opposed to the common practice of limiting one drawing change per ECN.

[2] Mitrol Inc., 1050 Waltham St., Lexington, MA. 02173

and 3) a product structure or breakdown file. However, as presently configured, the real-time EDICS system is designed primarily to support an engineering/design activity, while in the writers' opinion most of the batch systems are of greatest benefit to a manufacturing/production environment. With these alternatives, the on-line system was chosen out of a desire to support the engineering organization. In the early stages of a design, and particularly when parts are being released to manufacturing, it is imperative to keep timely data about revision levels of drawings, and changes, additions, or deletions to parts lists. This allows engineering to have better control of the drawing system for their programs and also permits rapid and accurate transmittal of this data to manufacturing. The production organization must be quickly advised of changes so that the cut-in of these changes does not cause wasted effort and unnecessary expense.

The following advantages should explain why we chose an on-line system instead of a batch system:

Engineers will write ECPs on the terminal.

EDICS gives engineers immediate and accurate information required for the ECP, such as latest drawing revision levels, pattern revision levels, production shop orders, and "where-used" data. Because this information is accurate, it eliminates the errors commonly made and the resulting ECP re-issues or rewrites required. An additional benefit is that the database will be automatically updated as soon as the ECP is approved. Therefore ECPs can no longer be the cause of drawing information not being up-to-date, since it is now contained in the computer.

Engineers can create, revise, and print parts lists rapidly at the terminals.

Although EDICS will input long parts lists by keypunching to save computer connect time, verifying inputs, correcting the ever-present errors, adding components, and printing is done at the terminal. This reduces the time cycle to manufacturing release and gets the finished parts lists to engineering in the shortest possible cycle. An additional advantage is that engineers can build up parts lists and drawing trees at the terminal in the initial design phase.

Information about drawings can be obtained instantly and accurately.

Anyone with access to a terminal can immediately obtain current information about drawings from the drawing file, the part file, or the product structure file without referring to a printout that may be several days old. This is particularly important to engineering and drafting management during the design and early manufacturing cycle, when drawings are being added or revised daily. It is also an aid to manufacturing, since they can determine at a terminal, without walking to the print room, if one or more tracings have been changed to reflect the latest ECP.

Engineers can produce and revise cost estimates rapidly and accurately on the terminal.

While other systems can perform cost-estimating functions in the batch mode, the time cycle from input, through revisions to output, is not comparable. When changes are made to component or labor costs, where these are used throughout the product, the effect on overall cost can be immediately determined. This is especially useful in early cost estimates, when many iterations are required in an effort to meet product cost goals.

It's possible to get immediate, up-to-date, specialized reports (without programming).

The unusual flexibility of the EDICS software does not limit the user to standard

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Bill Sepich has been Manager of Engineering Technical Support in Broadcast Systems since 1974. He has been responsible for bringing a number of computer-aided systems into Broadcast engineering, such as the Applicon interactive graphics system, the EDICS software program, and a word-processing system. Prior to his assignment in Broadcast he had been in MSR for 20 years, where his last position was Manager of Mechanical Engineering.

Contact him at:
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Camden, N.J.
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Authors Sepich (left) and **Lund** at an EDICS terminal. Wall charts explaining system operation are at rear.

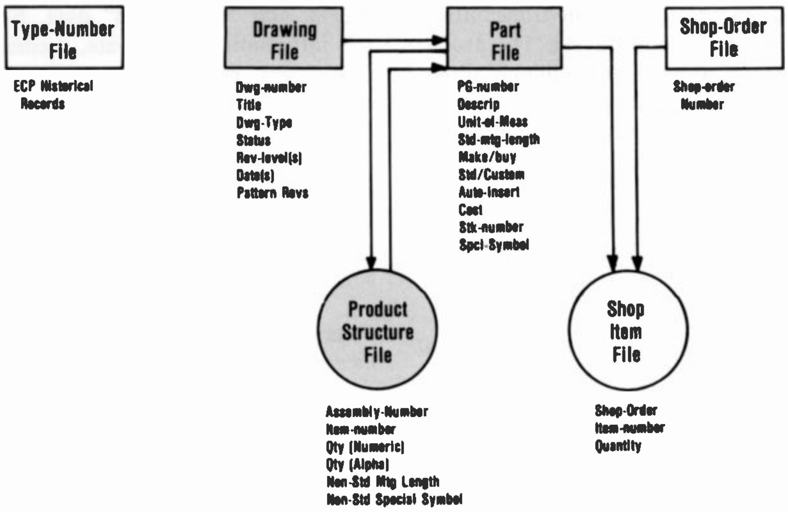

Fig. 1
All drawing and product-structure information is stored in three EDICS files—the drawing file, part/group file, and product-structure file. Fields in each file are shown in figure. The other files are not used directly during design engineering.

requests or commands for printouts of information contained in the database. Any type of data listing desired, selected to pass certain criteria and sorted on any fields, may be requested at the terminal using simple, English-like language. If the database structure must be modified, for example to add new data fields, there is no need to schedule a programmer to rewrite the program; the database administrator[3] does this in a few minutes directly on the terminal. Major changes, of course, would require program modification.

These reports have proven to be of immeasurable value. During product design, changes are so frequent that reports produced in the batch mode would be sufficiently outdated to be of questionable usefulness. Also, if engineers and managers were required to go through an MIS activity to obtain special reports and then wait one to several days for the output, they simply would not bother. This is one of the key features that sets EDICS apart from batch systems and makes it a useful tool to increase productivity.

Commonly used reports have been assigned one-word macro names, which allow them to be called up with a one-word command.

Examples of reports obtainable in this category are:

lists of components with accumulated quantities for building prototypes of modules (assembled printed wiring boards);

lists of standard or non-standard parts, used for design review;

lists of drawings still preliminary or having pre-assigned numbers (used by management to monitor progress on a program and to assure completion of documentation prior to manufacturing release);

lists of automatically-insertable parts (useful to manufacturing);

lists of drawings of a particular type (schematics, detail-assemblies, etc.) in a given assembly or product; and

lists of parts having a certain special symbol that identifies those components or assemblies requiring special handling in manufacturing.

Other repórts can be prepared for specific needs.

Here a series of commands must be entered using the system reference manual as a guide. Note, however, that this does not involve programming; furthermore, if a frequent need develops for such a report, the series of commands is simply given a macro name, thereafter becoming available for anyone's use.

Examples in this category that have been generated and used include:

a list of all drawings in Broadcast Standards Books;

three separate lists (ICs, transistors, and diodes) in the database sorted by type number;

a list of all electrical components on a new product for advance ordering by Purchasing;

lists of a particular type of component on a product such as ICs, crimped contacts, sockets, etc.; and

a list showing the count of electrical components on selected parts lists to aid an engineering cost estimate.

Most of the foregoing were spur-of-the-moment needs; without instant results, the reports could not have served their intended purpose, that is to say, the users would have proceeded to compile the data by hand at significant cost in time and schedule.

Structure of the EDICS database

All of the drawing information and product-structure data is stored in three EDICS files called the *drawing file,* the *part/group file* and the *product-structure file.*

The drawing file contains information about drawings that are common to all of the parts or groups that are owned by a drawing. See Fig. 1 for a listing of the fields in this file.

The part/group file contains data unique to the particular parts or groups on drawings. Fig. 1 lists the fields in this file.

The product structure file may be referred to as the drawing family trees of all products manufactured by Broadcast Systems. For each product, it starts with the top MI, and stores information relating to a top-down breakdown of all drawings used to manufacture the product. For each part/group that owns components, i.e., parts lists and detail assemblies, there is a link to each of its components. Additionally, each component has a link back to each assembly that owns it. This is a significant feature since a "Where-Used" request does not require a search through many parts lists; the owning assembly is read directly using the product structure records.

In addition to the three major files, there are also a *type-number file* for ECP month-to-date and year-to-date historical records for a product, a *shop-order file* containing production shop order numbers, and a

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[3] The database administrator is the pérson who has access to the entire database as opposed to limited access for general users—see section on database security.

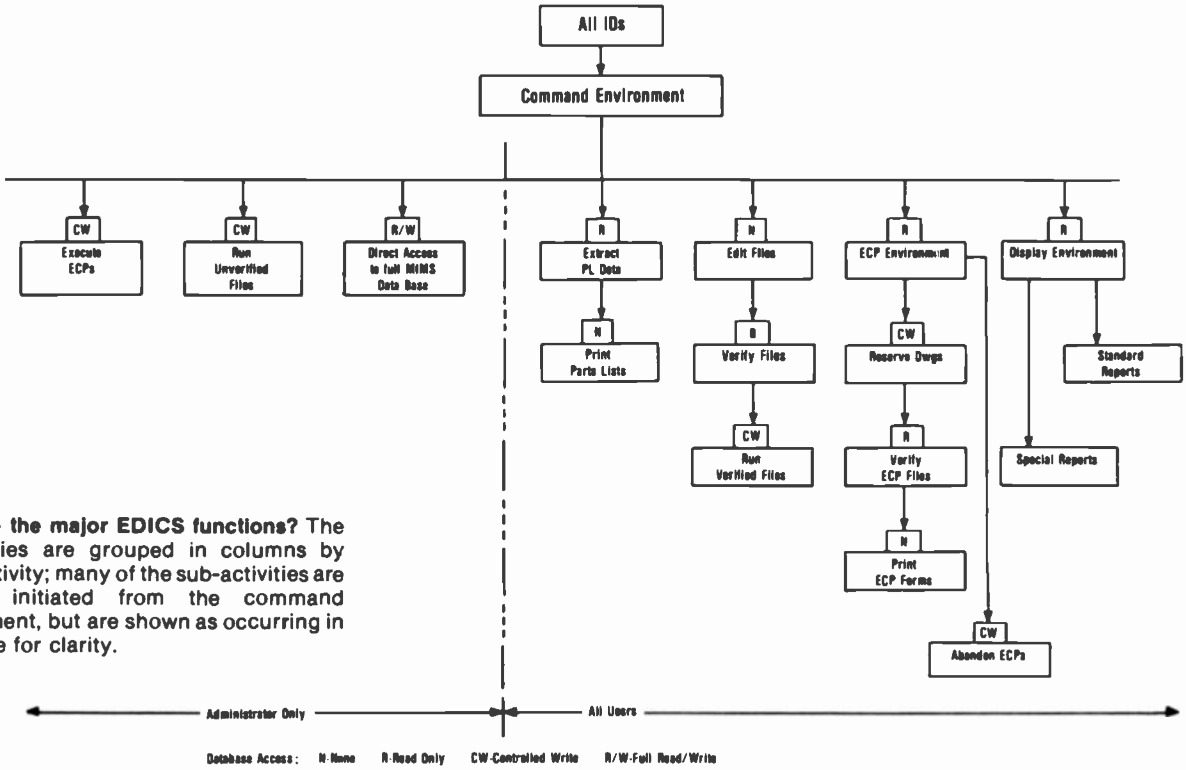


Fig. 2
What are the major EDICS functions? The possibilities are grouped in columns by major activity; many of the sub-activities are actually initiated from the command environment, but are shown as occurring in sequence for clarity.

shop-item file listing the major assemblies and their quantities for a given shop order. See Fig. 1.

Database access and security

Only the Database Administrator has general access to the database via a unique ID, which gives him complete READ and WRITE access.

All other users have complete READ access to the database, but are limited in their WRITE access. Examples of WRITE access capability for general users include:

- creation of drawings, parts, and parts lists, and changing them, provided their status is not "final" (approved);
- ECPs (but *not* ECP approvals)—this is the only way that general users can change final drawings, i.e., by writing an ECP at the terminal and having it approved ("executed") by the ECP Administrator; and
- cost fields, stock numbers, and production shop-order numbers.

In order to allow for multiple user access, the program has been structured to minimize the time that a user is in the WRITE mode, since other users are necessarily locked out of READ/WRITE operations during such periods.

An engineer wishing to create or change records first constructs a file with the computer's editor (known as the CMS Editor) using standardized "Create" and "Change" requests. A "Verify" process then checks for duplications, syntax errors, etc., and when the file is error-free it is "RUN" into the database in a controlled WRITE mode. The time to perform the WRITE operation is thereby kept to a minimum since there is no need to wait for interactive input from the user.

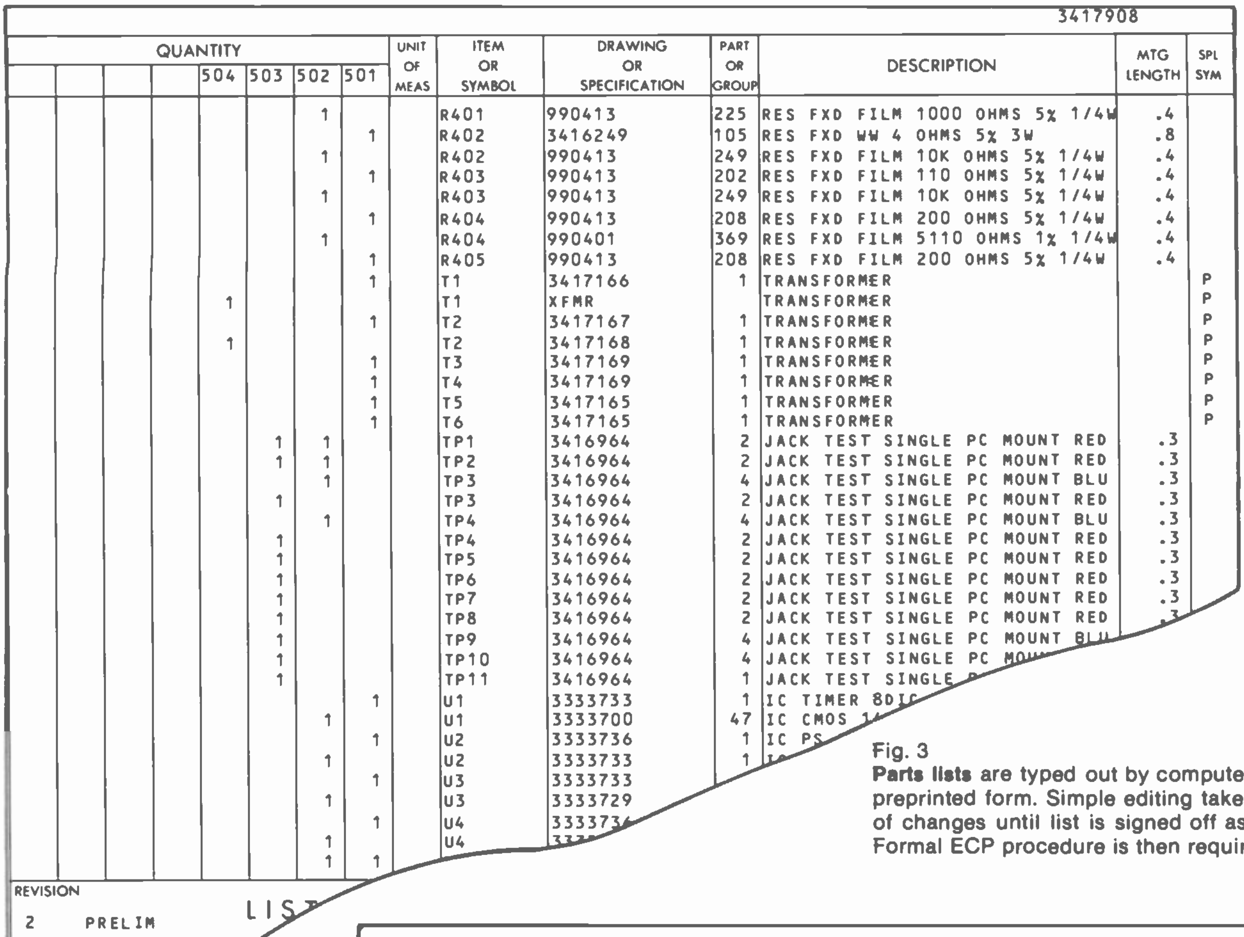
Fig. 2 shows the various activities that a user may perform after logging in to EDICS, together with the database access required for each. For most READ requests the process is a simple matter of typing a pre-defined one- or two-word request (macro). This procedure has been printed on two large cards that are placed on the wall at each EDICS terminal. One card describes the steps for logging on to the system and the second card details the most frequently used requests. Nothing further is required. For ECPs, the use of the CMS Editor and Verify process is required. To simplify this, a third large card is also placed at each terminal. This card leads the engineer in step-by-step instructions through the ECP procedure.

In general, engineers need not concern themselves with the creation of new drawings, parts, and parts lists, although they are able to do so if they wish to create preliminary product trees for such purposes as cost estimating. Normally, the functions of creating new drawings, parts, and parts lists are handled by the database administrator.

Using EDICS in product design

In order to describe how EDICS may typically be used, let's follow a product through its development cycle. The use of EDICS on a new project is initiated by the entry of an outline of the drawing tree. This is done by entering pre-assigned part numbers for major assemblies or subassemblies in their proper structural relationship. The tree indicates the relationships between parts and is useful in planning a project well before any of the actual drawings are prepared. It will also aid in performing the first cost estimate, which will be refined throughout the development cycle.

As the product is developed, additional drawings and part/groups will be added to the tree as they are identified, and components will be added to subassembly parts lists. For new drawings, the new drawing numbers and part numbers will be entered. If an existing drawing is being used in a new design, its part/group number need only be added to the new parts list; all fields associated with that drawing or part/group will already exist in the database. Preliminary parts lists are entered into EDICS, one or more items at a time, as they are developed. In preliminary form, these parts lists can be freely edited and easily modified without using any control documents.



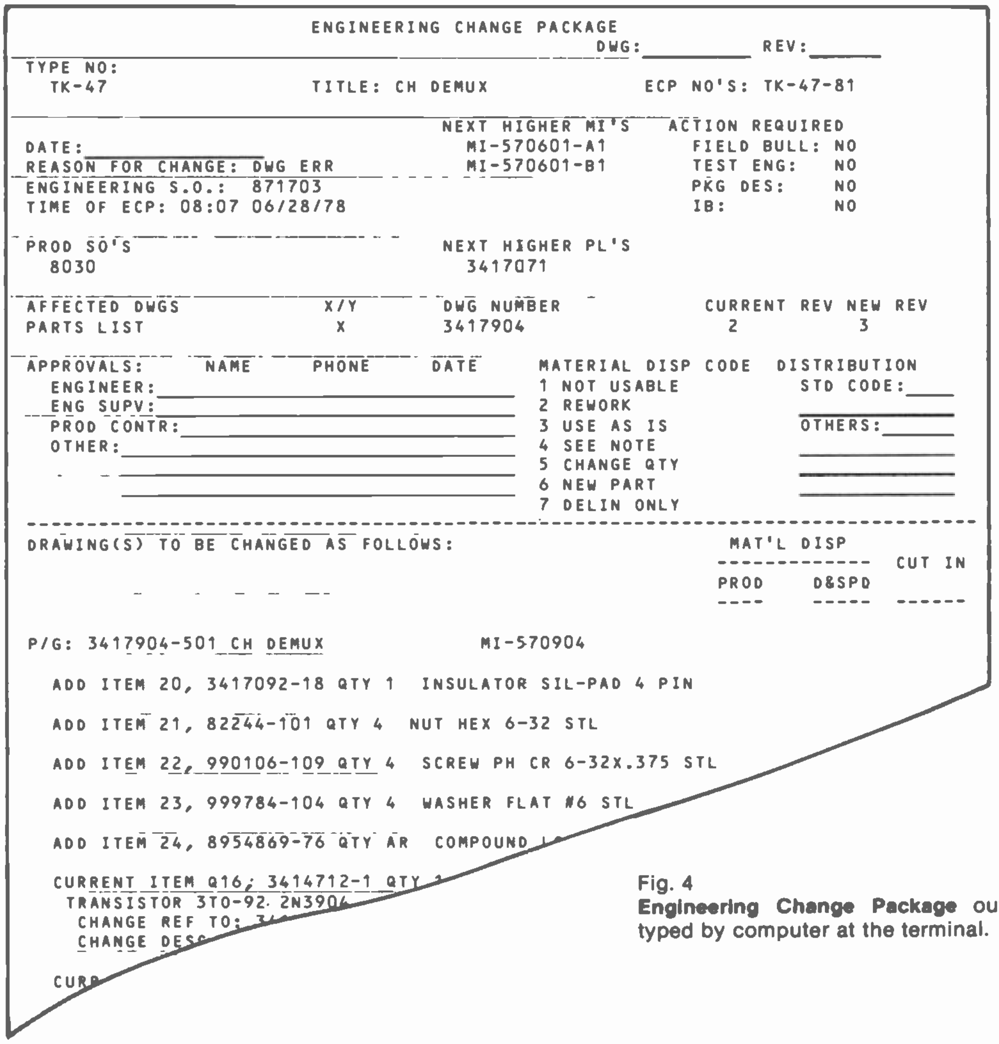
3417908

QUANTITY								UNIT OF MEAS	ITEM OR SYMBOL	DRAWING OR SPECIFICATION	PART OR GROUP	DESCRIPTION	MTG LENGTH	SPL SYM
				504	503	502	501							
						1			R401	990413	225	RES FXD FILM 1000 OHMS 5% 1/4W	.4	
							1		R402	3416249	105	RES FXD WW 4 OHMS 5% 3W	.8	
						1			R402	990413	249	RES FXD FILM 10K OHMS 5% 1/4W	.4	
							1		R403	990413	202	RES FXD FILM 110 OHMS 5% 1/4W	.4	
						1			R403	990413	249	RES FXD FILM 10K OHMS 5% 1/4W	.4	
							1		R404	990413	208	RES FXD FILM 200 OHMS 5% 1/4W	.4	
						1			R404	990401	369	RES FXD FILM 5110 OHMS 1% 1/4W	.4	
							1		R405	990413	208	RES FXD FILM 200 OHMS 5% 1/4W	.4	
							1		T1	3417166	1	TRANSFORMER		P
				1					T1	XFMR		TRANSFORMER		P
							1		T2	3417167	1	TRANSFORMER		P
				1					T2	3417168	1	TRANSFORMER		P
							1		T3	3417169	1	TRANSFORMER		P
							1		T4	3417169	1	TRANSFORMER		P
							1		T5	3417165	1	TRANSFORMER		P
							1		T6	3417165	1	TRANSFORMER		P
					1	1			TP1	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1	1			TP2	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
						1			TP3	3416964	4	JACK TEST SINGLE PC MOUNT BLU	.3	
					1				TP3	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
						1			TP4	3416964	4	JACK TEST SINGLE PC MOUNT BLU	.3	
					1				TP4	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1				TP5	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1				TP6	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1				TP7	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1				TP8	3416964	2	JACK TEST SINGLE PC MOUNT RED	.3	
					1				TP9	3416964	4	JACK TEST SINGLE PC MOUNT BLU		
					1				TP10	3416964	4	JACK TEST SINGLE PC MOU		
					1				TP11	3416964	1	JACK TEST SINGLE		
							1		U1	3333733	1	IC TIMER 8DI		
						1			U1	3333700	47	IC CMOS 14		
							1		U2	3333736	1	IC PS		
						1			U2	3333733	1			
							1		U3	3333733				
						1			U3	3333729				
							1		U4	33337				
						1			U4	333				
						1	1							

REVISION

2 PRELIM LIS

Fig. 3
Parts lists are typed out by computer on a preprinted form. Simple editing takes care of changes until list is signed off as final. Formal ECP procedure is then required.



```
                         ENGINEERING CHANGE PACKAGE
                                                   DWG:__________  REV:_______
 TYPE NO:
   TK-47                  TITLE: CH DEMUX              ECP NO'S: TK-47-81

                                        NEXT HIGHER MI'S   ACTION REQUIRED
 DATE:_______________                     MI-570601-A1       FIELD BULL: NO
 REASON FOR CHANGE: DWG ERR               MI-570601-B1       TEST ENG:   NO
 ENGINEERING S.O.:  871703                                   PKG DES:    NO
 TIME OF ECP: 08:07 06/28/78                                 IB:         NO

 PROD SO'S                              NEXT HIGHER PL'S
   8030                                   3417071

 AFFECTED DWGS             X/Y          DWG NUMBER             CURRENT REV NEW REV
 PARTS LIST                 X           3417904                  2           3

 APPROVALS:    NAME     PHONE     DATE      MATERIAL DISP CODE   DISTRIBUTION
   ENGINEER:______________________________  1 NOT USABLE           STD CODE:____
   ENG SUPV:______________________________  2 REWORK
   PROD CONTR:____________________________  3 USE AS IS            OTHERS:______
   OTHER:_________________________________  4 SEE NOTE
         _________________________________  5 CHANGE QTY           _____________
         _________________________________  6 NEW PART             _____________
                                            7 DELIN ONLY           _____________
-----------------------------------------------------------------------------------
 DRAWING(S) TO BE CHANGED AS FOLLOWS:                         MAT'L DISP
                                                            ------------  CUT IN
                                                            PROD   D&SPD
                                                            ----   -----  ------

 P/G: 3417904-501 CH DEMUX              MI-570904

   ADD ITEM 20, 3417092-18 QTY 1  INSULATOR SIL-PAD 4 PIN

   ADD ITEM 21, 82244-101 QTY 4  NUT HEX 6-32 STL

   ADD ITEM 22, 990106-109 QTY 4  SCREW PH CR 6-32X.375 STL

   ADD ITEM 23, 999784-104 QTY 4  WASHER FLAT #6 STL

   ADD ITEM 24, 8954869-76 QTY AR  COMPOUND

   CURRENT ITEM Q16; 3414712-1 QTY
    TRANSISTOR 3TO-92. 2N390
     CHANGE REF TO:
     CHANGE DES

   CUR
```

Fig. 4
Engineering Change Package output is typed by computer at the terminal.

The data on part/groups stored in EDICS will eventually include the most recent material cost from purchasing and an indication of the labor costs to assemble the part and test the assembly. The estimated cost of a part/group never used before will be entered by engineering or cost estimating. Parts lists will include an indication of the costs attributable to each item totalized by the computer and an indication of the total cost of the assembly. EDICS will help the engineer make tradeoffs to obtain the required product performance at the lowest cost. The existence of readily retrievable preliminary parts lists will help the cost-estimating activity prepare cost estimates for the product being developed. Separate fields are provided for these formal cost estimates as opposed to the preliminary cost estimates.

A parts list becomes final when the engineer signs the preliminary parts list, which had been typed by the computer on a preprinted form (Fig. 3). The engineer's approval for parts lists or any other drawing is entered into EDICS via a terminal, thereby changing its status from prelim to final. After the drawing status is final, this drawing may no longer be changed by a simple editing procedure. A formal engineering change package (ECP) must be prepared and approved. Since the preparation and handling of ECPs is the key to controlling changes during the production of a product, the procedure for preparing these documents is described below.

ECP procedure

The ECP procedure is inherently interactive between the computer terminal and the engineer.

The contents of the computer's database is used to remind the engineer of the situations that must be covered by the ECP, and the engineer decides how to resolve each of these situations. Specifically, when the engineer has decided on the changes needed to achieve the desired product performance, he identifies himself through an on-line terminal and enters the number(s) of the drawing(s) to be changed. The computer responds with the products, MIs, next-higher PLs, and current production shop orders where this drawing is used. It also identifies the associated drawings or parts lists for PWB drawings. For example, if the drawing is a PWB parts list, the associated drawings would be the schematic/assembly and board detail, which includes photo masters, solder masks, and marking information.

In response to computer prompting, the engineer enters the reason for change, and answers questions as to whether field bulletins, test engineering, packing design, or instruction books are affected. The engineer then indicates which drawings he will be changing. This, in effect, reserves those drawings for his ECP. The computer responds with the new revision levels of these drawings. If the change is to a parts list, the engineer types in the actual changes to be made.

With the above data, the computer can type a formal version of the actual ECP (Fig. 4.) If the drawing to be changed is other than, or in addition to, a parts list, the engineer writes the instructions for the needed change, by hand, in the space provided on the form.

The engineer now obtains the necessary approvals for the ECP. When it is fully approved, it is checked by an ECP Administrator, who enters a code signifying approval through a terminal, "executing" the ECP. When the ECP affects a parts list, "execute" initiates the actual change to that parts list stored in the database. A new copy of this parts list can then be obtained at the terminal on a preprinted form. The drawing revision level in EDICS would be automatically increased by the ECP approval. Changes to tracings other than PLs would have to be made by a draftsman in accordance with the instructions on the ECP. When the tracing has been changed and approved, this information will also be entered into the EDICS database.

If the preliminary ECP does not get approved, the engineer deletes it from the EDICS database using the "abandon" command. The system will not accept a second initiation of an ECP to a particular drawing by a different engineer before the first is approved. EDICS provides the name of the engineer who reserved the drawing to the second engineer.

Additional benefits

Besides the advantages of using EDICS during product design, the system has a number of "fallout" benefits:

EDICS can be an important aid for design reviews.

The data field that indicates whether a component is standard can be used in several ways. Not only does EDICS identify whether a part is contained in the Broadcast Standards Books, it further identifies parts defined as "Restricted Usage" (high-cost components) and parts that have been superseded by a different drawing number. Before conducting design reviews, the design review chairman can request, at a terminal, a listing of all nonstandard, restricted usage, or superseded parts in the assembly he will be reviewing. The designer must then justify his need to use these parts. The usage frequency of particular classes of nonstandard parts may indicate a need for further standardization. This can be checked by requesting, at the terminal, a count of how many times parts are called for on parts lists on all products.

EDICS can also check nonstandard mounting lengths for printed wiring boards.

The listing of standard lead-mounting lengths for PWB-mounted axial lead components is used as a check against the draftsman's layout. Parts lists are keypunched together with the mounting length used by the draftsman. The computer automatically flags the nonstandard ones.

EDICS provides a better way to select parts for spares.

During the course of new-product development, the engineer places an "X" in this field for all components he recommends to be spared. When stocking takes place, D&SPD can use this as a guide, and replace the "X" with their stock number.

Summary and conclusion

In the development and production stages, EDICS can provide a number of benefits such as:

- improved management control of programs through the use of computer-generated status reports of drawings;
- better control of product cost during the early stages of design;
- increased use of standard components by readily identifying non-standard part usage;
- improved availability of component cost information to aid engineers in cost-performance tradeoffs; and
- decreased errors in preparing parts lists and ECPs.

There is no question that EDICS will cost more to operate than existing batch systems. However, the features available from an on-line real-time system should have significant value to Engineering in saving time, allowing a better-quality job to be done, and in reducing some costs. Results obtained from EDICS to date are gratifying. However, many features such as compiling component cost data have not yet been tried in a production environment. The computer costs, with the limited usage so far, have been approximately as predicted. For 1978 it is planned to expand the usage to cover another major product, in addition to the one presently being processed. In this way additional experience will be gained aimed at weighing the benefits against a better projection of cost.

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Developing and managing large computer programs

R. W. Howery

When software projects get very large, something must be done to keep them from getting very inefficient. That something is management.

The challenges and problems associated with managing the development of large, complex systems have become the focus of increasing attention in recent years. This is especially true in the defense/aerospace industry, where the need for the systems, the need for assurance that systems under long-term development will actually perform as required, and the potential for serious cost overruns are all critical.

A great deal of study and analysis of this management process has yielded an assortment of management tools and techniques to help maintain control and direction over development efforts. (Success in the application of these tools and techniques generally shows a direct correlation with the maturity and experience of the managers responsible.)

The standard problems of managing a major system development apply to an even greater extent to large computer-program development tasks. As a relatively new kid on the block and one that has grown "like Topsy," the computer-program development process looms as a behemoth, frightening in size and scope, and frustratingly difficult to understand and control.

Notwithstanding these well publicized difficulties, the fact remains that computer program development *must* be controlled and managed. And the truth is that large computer program development projects *have* been managed with success, along with many small ones.

What's different about managing a large software effort?

The differences between developing small and large computer programs are significant, but not as great as the similarities. Quite simply, the development of large computer programs includes all of the technical and management tasks required in the development of a small computer program. The difference is in the size and complexity of the system, plus the additional problem of managing large numbers of people on a task that must be coordinated as if it were produced by a small, well-run chief programmer team.

Unless good management is used, more programmers means less efficiency.

Behavioral scientists have determined that the largest size team for coordinated effective work is nine members and that team efficiency falls with each added team member.[1] This would imply that a large team of hundreds of programmers would accomplish nothing. Since a number of large computer-program developments have been completed successfully, something must have been done to avoid the team limitations described above. This something is management, and it consists of:

effective team organization;

formal division and organization of tasks;

use of a systems development approach;

standardization of design practices;

thorough technical and management review;

management visibility and control; and

timely decision for change.

Government and industry both realize that software management must be improved.

During the 1970s, the growing emphasis on improving management of computer-program development projects has resulted in a spate of articles and a number of academic and professional society conferences and seminars. Examples are the series of seminars at the University of Southern California on "Modern Techniques for the Design and Construction of Reliable Software" and the three-phase "Software Management Conference"[2] sponsored by the American Institute of Aeronautics and Astronautics and the Data Processing Management Association, with speakers from government and industry. (The terms "software" and "computer program" are used interchangeably in the computer-program development industry.)

Because of its annual investment of about $3 billion in computer programs, the Department of Defense is also intimately involved. DoD is interested because computer-program development has become a greater factor than hardware in the total weapon-systems costs of some systems. Also, serious cost and schedule overruns have occurred on many computer-program development projects. Accordingly, DoD directives have been aimed at increasing management visibility into the process for both government and industry. In addition, DoD has sponsored a number of software-management conferences to communicate the use and value of new practices and techniques to all government/industry team members.[3-6]

Throughout this paper, the AEGIS Combat System computer-program development is used as an example since AEGIS is a major system (see box) comprising multiple systems with embedded computers, all integrated by a central computer suite. Although the management techniques described are producing outstanding results on AEGIS, they are applicable in principle and in practice to both large and small projects.

a large-scale software system

The AEGIS Ship Combat System

For the past several years Congress and DoD have been working to determine the size and makeup of the Navy's new surface fleet. In support of this effort, the Navy has established an AEGIS development plan to support the long system-development lead time and handle changing Combat System configurations with minimum impact on already developed systems. The plan provides for unified and standardized ship baseline systems for cruisers (CGN-42 class) and destroyers (DDG-47 class), with potential for selected fleet modernization of current ship classes.

AEGIS Combat System development began during the 1960s with a number of Navy studies on approaches to countering the airborne missile threat of the 1980s and beyond. Following an industry contract design competition, RCA was awarded a contract in December 1969 to develop the AEGIS Weapon System.

The AEGIS Ship Combat System development program implementation has been set up in four major phases:

1) Concept development and system prototype for the basic AEGIS anti-air warfare weapon system—completed in the early 1970s.

2) At-sea prototype testing of this system—conducted during 1974-1976.

3) Engineering development of the total AEGIS Ship Combat System—currently in progress.

4) Ship and system production of AEGIS destroyers and cruisers—underway in April 1978.

The system

The AEGIS Ship Combat System consists of virtually every functional combat element on a ship, excluding the hull, propulsion, and auxiliary equipment, but including all sensors, communications equipments, and weapons. The 24 principal elements illustrated in Fig. A indicate the multiplicity of functions and complexity of the overall Combat System.

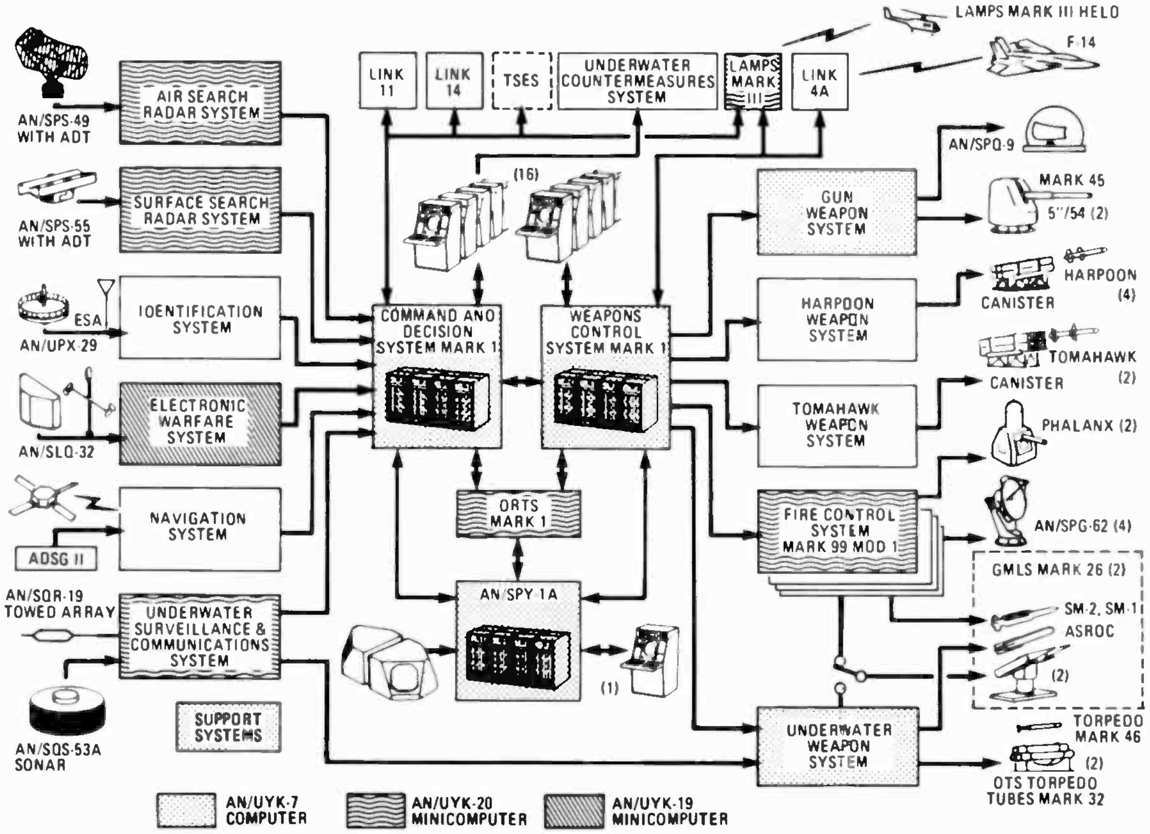

Fig. A

Complexity of the AEGIS Combat System should be evident from this system diagram. There are 24 combat-system elements in all. (Don't try to follow all the abbreviations—the point of the diagram in this discussion is to show the complexity of the software work, and thus the good management system needed, for AEGIS and other complex software operations.)

Controlling this diversity of elements is a central Combat Direction System, which includes the *Command and Decision System* for sensor control and tactical command functions, and the *Weapons Control System* for scheduling and managing all weapon systems. The AN/SPY-1A radar is shown separately since it functions as the major ship sensor and provides missile tracking and control as an integral part of the anti-air warfare weapon system.

Immediately obvious in the figure is the proliferation of computers, from the three centralized 4-bay standard Navy general-purpose AN/UYK-7 computers to the ten individual AN/UYK-20 minicomputers and two AN/UYK-7 single-bay computers applied in the various other system elements. As a major ingredient of the system, the central computer complex has been designed to support the very high system availability required, taking into account equipment and computer-program failure/repair/recovery characteristics.

The three 4-bay AN/UYK-7 computers used in the central computer suite are standardized. Each computer consists of four bays containing four central processing units (CPUs), eight standard single-density memories, four double-density memories, and four input/output controllers, providing a total core of 262,000 32-bit words for each 4-bay computer. The standardization includes double-density memory locations, backplane wiring, and input/output controller fast/slow quantities and locations.

The computer programs

The AEGIS Ship Combat System has a number of computer programs embedded in the channelized sensor, weapons, and communications systems. The programs under development by RCA for Combat System Engineering Development are those which reside in the central computer suite. They include: 650,000 words of instruction and data that are part of the tactical system; about 2 million words of disk-based Operational Readiness Test System test routines, tables, and fault detection and isolation messages; and about 1 million words of development and test support computer programs. Fig. B illustrates the relative size of these computer programs.

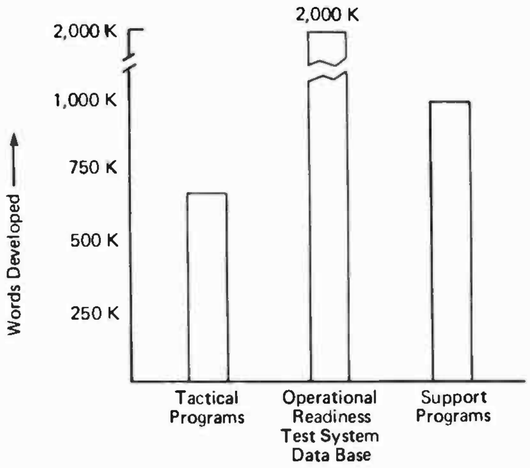

Fig. B
Sheer size of the AEGIS software-development task requires special management techniques.

The complexity of the five tactical computer programs ranges from the AN/SPY-1A real-time radar control program (where computer execution time is critical) to the Command and Decision and Operational Readiness Test programs (where functional requirements result in critical core-allocation problems). The Weapons Control System and Fire Control System computer programs also have time-critical real-time requirements in support of total AEGIS Weapon System reaction time. Another dimension of programming complexity is the interface complexity—program design complexity increases with the *power* of the number of interfaces, rather than linearly.

Development support programs include the Operational Readiness Test System Data Base Generator and Analyzer; the AEGIS Tactical Utility System, which supports program debug and unit test and builds tactical load tapes and disks; and the AEGIS Source Code Preprocessor, which provides indented source-code listings, narrative flow, indented narrative, and a structured flowchart. Test-support programs include a data reduction and analysis system to reduce, analyze, and print test reports and graphs from the data extraction tapes produced during tactical program testing, and the Interface Simulator System, which provides scripted test scenarios for program testing in a computer-system-simulated environment.

The development process

The basis for understanding the computer-program development process for large systems is a clear perception of how major systems are developed. Accordingly, this section reviews, in summary form, the development sequence for a major system, and then relates this process to computer-program development. The system-development sequence and computer-program development phases described here are based on AEGIS experience and formal Navy requirements.[7]

The system development sequence has six steps.

The development process starts with the initial system concept development and is only complete when the system is tested and operational. The six steps in the system-development sequence of a major system are shown in Table I, with the computer-program development phases highlighted.

The *project plan* breaks the job down into manageable tasks and assigns task responsibility to specific organizations.

System definition establishes performance requirements for major system elements (for our AEGIS example, one of the major system elements is the three-dimensional electronically scanned multiphased array radar) to support the total mission. The system specification documents specific performance and test requirements and allocates these requirements to the major system element specifications.[8] This element specification further defines the system performance requirements and allocates them to the specific equipment, computer program, or human interface specifications.

During the *element design* process the tradeoff analysis is made (state of the art, cost, computer execution time, etc.) between allocating the specific functional performance requirements to equipment, computer program, or operator. Element design includes development of the system architecture and design of the algorithms implemented in the computer program.

Computer-program development is only one of the system-development phases, but it has eight phases of its own.

The first phase of *computer-program development* is *program requirements definition*. Both performance and test requirements are documented in individual specifications.[8]

Table I

Software development for large systems must be considered as a system-development sequence (left), of which computer-program development is only one phase of the program-development sequence.

System development sequence	*Computer program development sequence*
Project planning/task allocation	Program requirements definition
System definition	Top-level design
Element design	Detailed design
Computer-program development	Coding and debugging
Element integration	Unit testing
System integration and test	Program integration
	Multi-program integration
	Acceptance test

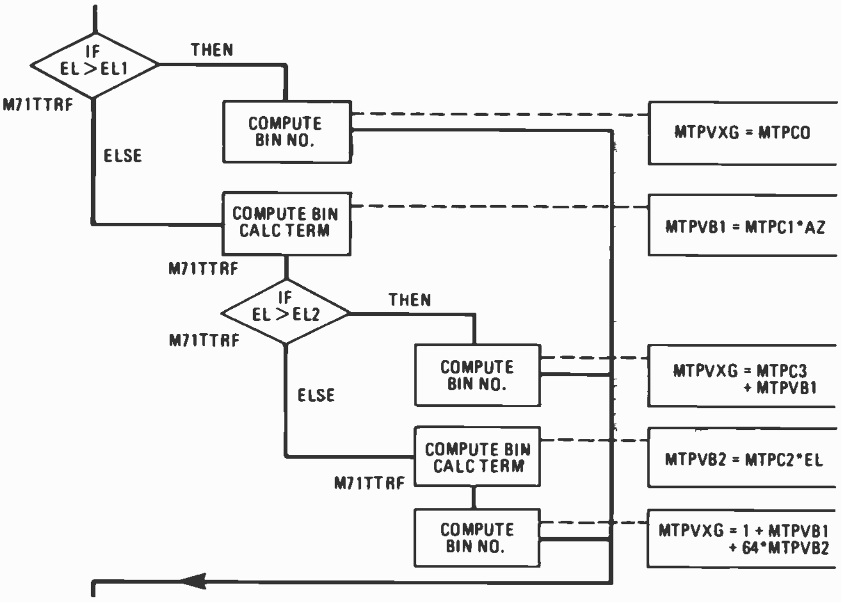

Fig. 1

Flowcharting is part of the computer-program design process. The AN/SPY-1A flowcharts have seven levels of indentation and provide a continuous flow of control through the complete subprogram. Coding and debugging are much faster when flowcharts are used.

Top-level design of the program includes design of the program architecture, the data-base structure and the allocation of functional requirements to both the program modules and the computer process units. This is beginning to look like a top-down design approach. Watch out! It isn't this simple. System and computer-program design are iterative creative tasks. The key to good design is not elimination of iteration, but orderly review and improvement with careful control of the process.

The "build-a-little, test-a-little" approach makes for manageable-size programming tasks.

For large programs it is not practical to develop the total program all at once. This would cause a large peak load on both programmer and computer resources and result in a massive integration problem when the results of the many programming teams were brought together all at once. The build approach (build-a-little, test-a-little) has been established to solve this problem. A computer program build is a functional and operational subset of the final computer program, with stubs for the missing procedures and data. The build approach allows the establishment of manageable-size tasks, supports early integration with equipments and other programs, and provides early visibility into program performance in critical high-risk areas.

The *detailed design* of the program modules and data bases is done on a build basis. Detailed design includes flowcharting the program logic (Fig. 1) and designing the private and common data bases, which are documented[8] and reviewed by system engineers and senior programmers prior to release for coding.

Coding and debugging form the shortest and simplest phase of the development process because of the thoroughness of the design process.

Unit testing validates the module operation to the design requirements in the environment of the executive and the common data base. Test points, inserted at all program branch points, provide checks for assuring that all code is executed during the test.

The next phase is *program integration,* which is performed on a build basis. The integration process starts with the program shell. (In AEGIS, with 4-bay AN/UYK-7 computers, the shell is a 4-bay version of the executive, with stubs for all tactical application modules.) After this shell program checks out in the computer, groups or clusters of modules supporting a specific functional capability are added and checked out, again with stub (or dummy) modules filling in for missing modules. Finally, the total program build is tested with a simulator test program that emulates the environment (external and equipment) and supports scripted test scenarios similar to actual missions.

The computer-program test system covers both element computer-program integration and test and *multi-program integration,* where message interfaces are verified and total weapons system functional performance is evaluated. Builds of the individual element programs are informally demonstrated prior to delivery to multi-program integration and element integration, which is conducted at the system test site in parallel with multi-program integration.

After the computer programs are complete, they must be put into the overall system.

This brings us back to the system-development sequence. *Element integration* interfaces the computer system with the addition element equipment subsystems (for example, radar signal processor, receiver, arrays, transmitter) in a methodical stepwise fashion similar to the one used in the program integration.

Program *acceptance test* is performed on the total program in a stand-alone environment after the major portion of multi-program and element integration is complete to assure a stable baseline for program validation to the program performance requirements.

The final validation of the computer programs is part of total *system integration and test*. This covers functional performance testing, system load testing, and operational evaluation against real-life scenarios. In AEGIS, this takes place at a land-based test site.

Managing the process

Managing the development of large embedded computer systems and programs is both a system-development and a computer-program-development task.

Success in this undertaking depends on establishing a task structure and then building an organizational structure with appropriate business and technical skills to perform those tasks. In AEGIS, the tasks range from highly technical tactical-program design in critical, real-time radar control loops to maintenance and scheduling of programming production facilities. With a large, multi-disciplined team, major problems can arise in the areas of communication, visibility, and control. Techniques and practices to help the managers and developers meet these problems include both project management and the system engineering and programming disciplines. These aids apply in appropriate degree to system and program developments of all sizes and complexities.

As would be expected, the selection of qualified team members is a major contributor to success. A sound development approach and good tools will not make it with an unskilled or inexperienced team.

Organization

A large project such as AEGIS is first and last a system-development task, with equipment and program development supporting the rest of the system's performance requirements. System engineering is emphasized throughout the system and computer-program development process. In addition, a strong project-management organization is required to plan, task, monitor, and control the total team effort.

The matrix organization is an effective organizational structure for large system developments.

In the matrix organization, responsibility for each major element of the system is assigned to an individual project manager. Each element project manager carries responsibility for: cost; schedule and technical performance; tradeoff decisions among equipment, computer programs, and operator functional allocation; and system element integration and acceptance. He implements the tasks using specialists in skill areas, where a standardized development approach can be applied to all elements of the total system.

A central system engineering activity (under a system engineering manager) ties the total system design together.

Again, a central programming project manager assures that a standardized computer-program development approach is used throughout the project. The system test and evaluation activity acts as an independent test and evaluation agency for the project, to certify test completeness at the lower levels and to perform the final system test and evaluation.

The element programming team provides support functions such as the central computer-program library, the program generation center, documentation and publications activities, configuration management, product assurance, and project management. The technical programmer teams, which develop the programs, are structured into skill and task responsibilities. The element program design team acts as the interface with system engineering, produces the program design specification, and monitors the program-development and integration activities for technical integrity. Specially trained senior program-integration teams perform the multiprogram integrating element integration and support final system integration and test.

The tools and techniques

A number of management techniques and practices have proved successful over the more than seven years of AEGIS system development, including an increase in disciplined management of computer-program development. These tools and techniques can conveniently be organized into three groups (Table II): system engineering techniques; modern programming practices; and project management tools.

The AEGIS project uses standard system engineering techniques and some new ones developed specially for AEGIS.

The following system-engineering techniques are among the most important ones used in AEGIS. *Functional flow diagrams and descriptions* (F^2D^2) show the functional flow of the system at different levels or tiers of system functional allocation. For example, the tier-2 level shows the functional allocation and interfaces among the equipment, computer programs, and operators, and shows the message and signal flow through the system. *System activity timing diagrams* show the time sequence of operational scenarios through the system. *Error budgeting* allocates system errors to specific parts of the system so that error performance can be managed.

Two *computer models* of the AEGIS system have been set up for the evaluation and prediction of system performance. These systems (a high-accuracy, single-target simulation and a medium-accuracy multitarget simulation) allow verification of algorithm designs before they are implemented in tactical computer programs. *Interface definition* is achieved in a formal interface design specification; interfaces are controlled by requiring engineers responsible for each side of an interface to sign off all changes.

Finally, to support communication between system engineering and programmers, a *systems definition request/response system* has been set up so that if the programmer doesn't understand the performance requirement, he can state his problem and the system engineer can respond with a clarification or correction. *Design reviews,* principally by system engineering, verify that the program design and code meet the performance requirements and support the overall system design.

Table II
Tools of the trade. These management techniques are discussed in text.

System engineering techniques

Functional flow diagrams and descriptions
System activity timing diagrams
Error budgeting
System computer modeling
Interface definition
System definition requests
Design reviews

Modern programming practices

Computer-program development plan
Top-down/structured design
Program modularity
Programming standards
  Structured programming
  Documentation
  Testing methods
  Module and data structures
  Naming conventions
  Coding and commenting
Code verification
Formal problem/error reporting
Core/time resource management

Project management tools

Work-breakdown structure
Task work packages
Earned value system
Baseline/configuration controls

"Modern programming practices" have shown improving results as the programming community becomes experienced with the new disciplines.

The programming techniques listed below have been used successfully on a number of projects in addition to AEGIS. We have incorporated all of these practices in AEGIS, with especially effective results in some areas. The *programming plan* should include a description of what programs are being developed and the who, how, when, and where of the development process. *Top-down structured design* allows orderly development with sequential addition of functional capability and localization of impact caused by changes. *Program modularity* is a direct result of effective structured design. *Programming standards* support effective communication and a disciplined large team development—without standards, the programs would not interface properly.

Structured walkthroughs of the detailed design by system engineers and program top-level designers are a must prior to formal release to coding, with all corrective action spelled out in the written release to coding. After coding is complete, peer or immediate supervisor *code verification* assures that the program is as designed. A formal *problem/error reporting* and corrective action system is necessary, with the degree of formality and level of approval increasing at higher levels of integration and test.

Most programs get in trouble by overrunning their allocated computer resources in order to meet performance requirements. A critical management tool that is also a modern programming practice is *computer resource management*; that is, the budgeting and continued estimating of core and execution time use as the program matures.

Project-management tools are used to predict potential trouble spots.

Project management of computer-program development includes task allocation to formal statements of work per a project *work breakdown structure. Cost management systems* are used to provide monthly cost reporting, supported by schedule charting and an *earned value system* for measurement. *Work packages* define tasks several levels below the work-breakdown structure for high-resolution measurement of work-completion status and more accurate measurement of earned value. For example, completion status is evaluated for flowcharting by measuring procedures flowcharted versus the total estimated number of procedures required; code status is measured as the number of lines of error-free code compiled versus the estimated required code; and unit test is measured on number of functional threads tested versus the number in the module. Work measurement should not be used to generate historical records, but should predict trouble spots for corrective action.

Baseline and configuration control is critical on a large program development. Baselines under control should include the equipment configuration, computer resource allocations, interface design specifications, program documentation, all code, problem/error reports and corrective actions, and all test materials (test programs, test scripts, data sets, procedures, and test reports). System review and baseline control boards should be established at the working level to support the project Change Control Board.

Applying the tools

A good set of tools is not enough. New and even excellent tools, practices, or techniques have a cultural lag between their introduction and effective use.

Two approaches seem to help shorten this cultural lag: 1) involving key team members in establishing practices to be used and the timing and methodology of their use; and 2) investing in user manuals and training in their effective use. A most important management task in this area is to listen carefully to complaints about practices or tools, and then take timely corrective action.

People management, a major part of any management task, is even more important on a large development project. And since both systems engineering and computer programming are highly individualistic tasks, this aspect of management is the most difficult. Most seminars and conferences have touched only slightly on this major factor in team success, but Weinberg[9] provides a thorough-going coverage of the subject.

Reviews are necessary at all levels of design.

The management task is plan, task, monitor, and control. Accurate knowledge of technical and cost status and timely solution to problems are vital to good management results. Regular design and project status reviews with carefully planned agendas aid this process. These reviews should cover specific subjects to be effective; the general "cover anything that comes up" meeting may be fun, but doesn't contribute much to results. AEGIS has a series of technical reviews that run through the whole development sequence and include Navy project and user personnel, Navy technical laboratory personnel, RCA system engineers and computer system scientists, plus programmers and computer scientists from the program design activities. Project reviews range from executive sessions involving senior Navy officials down to weekly reviews of the programming activities by the responsible programming project engineer. Weekly project reviews are held by the RCA Project Manager, providing a review of each element of the Combat System approximately once each month. Formal followup of action items from all reviews increases the effectiveness of the review system.

Management information centers are valuable as a means of increasing visibility and improving communication.

AEGIS uses a number of information centers or work rooms. The AEGIS Computer Programs Development Control Center has posted on its walls current configuration, schedule and core and time management information, and problem action followup reporting. More detailed schedule and manpower planning is posted in rooms maintained by the programming teams. Special workrooms have posted the system engineering F^2D^2 diagrams, the Command and Decision data-base tables, and other subjects where high visibility and careful following are required.

Although much of the management process involves oral reviews, discussions and conversations, it is important to put management *direction* in writing. There should be written statements of work and task assignments as well as documented standards, methods, design analysis, and specifications. Programmers, systems engineers, and test engineers should have design documents for all programs, including flowcharts and well annotated structured listings. Problem/error reports and corrective actions should have a formal documentation process. Good distribution of these documents aids communication and makes future accurate reference to the material possible.

One of the most critical areas for decisions is the program-development facilities; that is, how many computers and peripherals are required to support the development tasks. Since this requires money up front, the wrong decision is often made, saving on computers at the front end of the job and driving the development costs up many times over the savings. AEGIS has set up four program-development centers using approximately twenty single- and multi-bay computers: the Program Generation Center; the Computer Program Test Site; the Data Reduction Center; and the Combat System Engineering Development Site.

Operating and maintaining these centers requires an experienced crew, which includes field engineers from the major equipment suppliers and computer-program systems specialists to support the operating systems.

Finally, management must take time to evaluate all of this and make timely decisions. Problems solved promptly always cost less. This is especially true on a large team where continuing open problems grow in confusion and misdirection. Managers must invest the time in the management process.

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VLSI—tools, technology, and trends

What to make? How to use? These questions have assumed equal importance with the traditional "How to make?" and have pushed the software technologies of design and applications to supplement the hardware technology of silicon.

I.H. Kalish

Very Large Scale Integration of tens of thousands components per package is showing a profound qualitative impact on the application of electronics to the needs of our society.

SSI to MSI to LSI to VLSI

During the past fifteen years, integration levels have progressed from a few gates per chip to thousands of gates and tens of thousands of components per device (Table I). This remarkable progress is the result of several technological advances: improved photolithographic processes are permitting finer geometries; refinements in the manufacturing process have resulted in fewer defects per wafer; and innovative circuit design and system organization have resulted in high functional density.

Processing perfection is a crucial element determining the practical level of device integration.

If we define D as being the density of fatal defects per unit area associated with a given process and A as the area of the device being fabricated, then the process-limited yield can be approximated by the expression:

$$Y = \frac{1}{1 + AD}$$

Table I
Increasing integrated circuit complexity has led to significant changes in the application of electronics to our society. Starting with the first small-scale integrated circuits in the early 1960s, we have witnessed an order of magnitude jump in device complexity about every five years.

Integration level	Complexity (gates)
Small scale (SSI)	1 - 10
Medium scale (MSI)	10 - 100
Large scale (LSI)	100 - 1000
Very large scale (VLSI)	>1000

This function is plotted in Fig. 1. Typical VLSI devices are between four and six millimeters on edge. Thus, to obtain practical yields on such devices, defect densities below twenty per square centimeter are required.

Design innovations have improved functional density.

Problems of packaging as well as those of defect density and chips-per-wafer economics have limited increased chip size as a prime approach to VLSI. The major efforts have focused on achieving maximum functional density within chip sizes of about sixteen to twenty square millimeters. Innovative circuit design and system organization have produced a high level of functional density without making major demands on the technology.

The one-transistor-per-cell dynamic memory is perhaps the best example of circuit innovation that improves functional density. The use of integral read-only-memories and programmable logic arrays have also been approaches for increasing functional complexity. After all these techniques have been applied, however, the basic approach to improving functional complexity is to put more—but smaller—transistors on a chip.

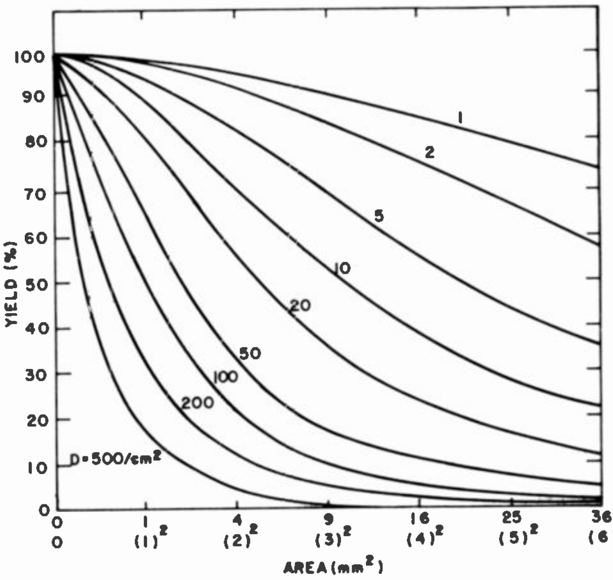
The push for smaller transistors

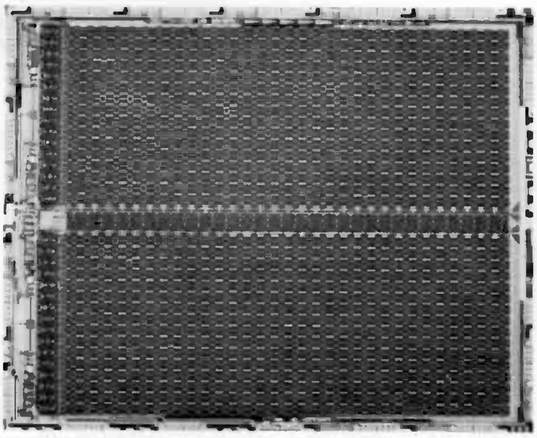
Current MOS production technologies are utilizing transistor channel lengths of four to seven microns. Intense effort is currently being applied to the fabrication and understanding of channel lengths in the one micron region for the next generation of VLSI. One of the new tools being applied to the achievement of this next generation of technology is the electron beam.

The RCA Solid State Technology Center recently acquired the Manufacturing Electron Beam Exposure System (MEBES) to support RCA's LSI and VLSI efforts.

This equipment makes high resolution photomasks for conventional processing, but it also has the capability of supporting engineering efforts on direct wafer ex-

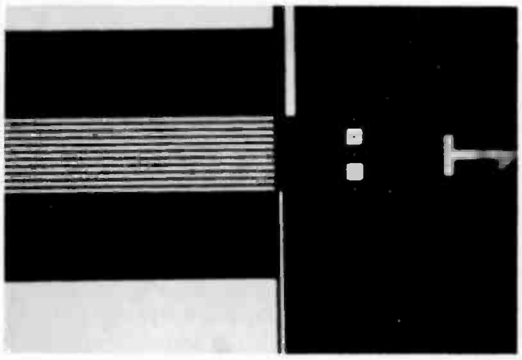
Fig. 1
Functional complexity and hence the economic value of an integrated circuit is related to its area. The defect density is determined by a combination of process complexity and processing environment. Thus the practical attainment of VLSI requires the application of refined technologies in controlled environments.



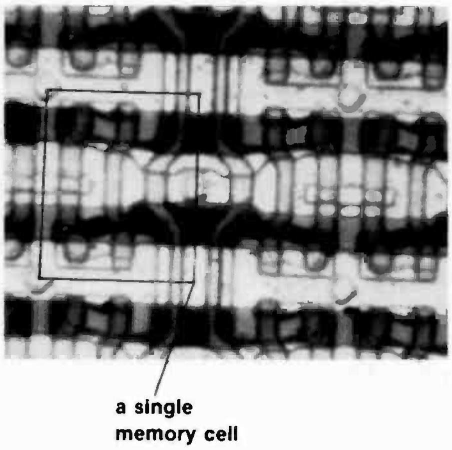


This VLSI device illustrates the state of the art of SOS manufacturing technology. This 20-square-millimeter SOS memory contains over 25,000 transisters and thus requires low defect density in both photomasks and processing environment. The high efficiency of this layout (over 60% of the chip area is memory) has been accomplished by innovative sensing techniques making the use of a five transistor memory cell feasible.

RCA's Manufacturing Electron Beam Exposure System (MEBES) is currently being used to generate high resolution photomasks in support of RCA's VLSI efforts. Complex data processing within the MEBES computer section permits the elimination of reticle and step-and-repeat operations to minimize defect density and pattern run out.



One-micron lines and spaces drawn from a MEBES test pattern. The VLSI technology of the next decade will be designed with micron and submicron physical features and thus be dependent upon such advanced approaches as the electron beam technology for device fabrication.



Buried-contact five-transistor memory cell made using MEBES-generated masks. A new generation of COS/MOS technology, the buried contact approach, will make a significant increase in circuit complexity practical. This 1000-square-micron memory is small enough to be the building block in RCA's 16k SOS static RAM program; it is less than one third the area of cells being fabricated with current production design rules.

posure. A one-quarter-micron resolution can be achieved by the MEBES electron beam, and its laser interferometer positioning controls ensure address repeatability to within one-eighth of a micron.

Competition—NMOS vs. SOS

The need for low defect density in VLSI processing has narrowed the choice of technologies available. Table II compares two of the leading contenders. The lower number of masks required to implement NMOS designs has always made it popular for LSI applications. As the industry moves to even higher levels of complexity, however, the low-power potential of the SOS technology becomes more and more important. Reliability and economic considerations make it advisable to keep the dissipation of complex devices below one watt per package and this will therefore be a limit on NMOS VLSI. The numbers in Table II anticipate that, by 1980, the advent of the buried contact SOS technology will close the gap on packing density and from then on the higher performance potential of the CMOS/SOS technology will dominate.

The evolution of the RCA CMOS technology into the region of VLSI applications is projected in Fig. 2. The original CMOS technology could not economically attack LSI applications and hence most of its original use was concentrated in MSI applications that required low power and wide power supply range. LOVAG (low voltage aluminum gate) was the first LSI technology to be applied to the timekeeping area while the high performance C^2L (closed CMOS logic) provided an entry into the microprocessor market. The projection now is for the buried-contact SOS technology to support RCA's entry into the VLSI marketplace.

The application of evolving technology trends to SOS product generation is summarized in Table III. The generation of 150,000 transistor chips using electron-beam technology and two-micron design rules is a straightforward extrapolation of present efforts.

Table II

Comparison of technologies. The introduction of the aggressive buried-contact design rules will make CMOS/SOS directly competitive with advanced NMOS techniques in function complexity. From that point, the system advantages of CMOS—low power and wide voltage range—should give it an advantage in new VLSI applications.

	NMOS		SOS	
	1978	1980	1978	1980
Density (gates/mm^2)	140	200	110	200
Gate delay (ns)	1	0.5	2	1
Power dissipation (mW/gate)	1	0.4	0.1	0.05
Speed/power (pj)	1	0.2	0.2	0.05
Mask levels (No.)	6	6	7	8
Critical dimensions (microns)	4	2	5	3.5
Static memory cell (μ^2)	2400	1100	3300	1000

Table III

Future SOS product direction. Memories and microprocessors are the most natural directions for CMOS VLSI product development. Beyond these, however, the advent of customer-programmable circuits with the EAROM (Electrically Alterable Random Access Memory) will result in another generation of user-determined system applications of VLSI.

	1980	1982
Process innovations	Buried-contact double poly	E-beam photolithography
Design rules	3½ micron	2 micron
Die sizes (typical)	5 mm^2	6 mm^2
Wafer sizes	4" squares	5" squares
Defect density (per level)	1/cm^2	½/cm^2
Die complexity (typical)	80k transistors	150k transistors
Potential products	16k RAM 8k EAROM 64k ROM 16-bit microprocessor	64k RAM 28k EAROM 126k ROM 32-bit microprocessor

The future

One aspect of VLSI can be predicted with confidence—VLSI devices will be low cost devices. It will take a lot of engineering effort and time to generate a new VLSI device, but once it has been made and debugged, all of semiconductor history indicates that it will be a low-cost mass-produced device. Custom VLSI will probably not be worth the economic risk since the enormous engineering expenses involved in the design, evaluation, and the development of testing procedures cannot be amortized by volume production.

The implications of this are quite significant for the evolution of new equipment design. In the MSI world of integrated circuits, the equipment designer had thousands of circuits to choose from with a variety of manufacturers and a variety of technologies. The VLSI world is more likely to be similar to the world of vacuum tubes where there were a relatively small number of multisourced well-understood and characterized designs that users learned to be comfortable with. The application of a given family of VLSI parts will require a major educational investment by the user—an investment he will be unwilling to cast away too soon. Thus it seems likely that the VLSI world will be made up of relatively standardized forms of memories and microprocessors with electrically programmable logic arrays and ROMs giving the user his potential for a creative contribution to his product.

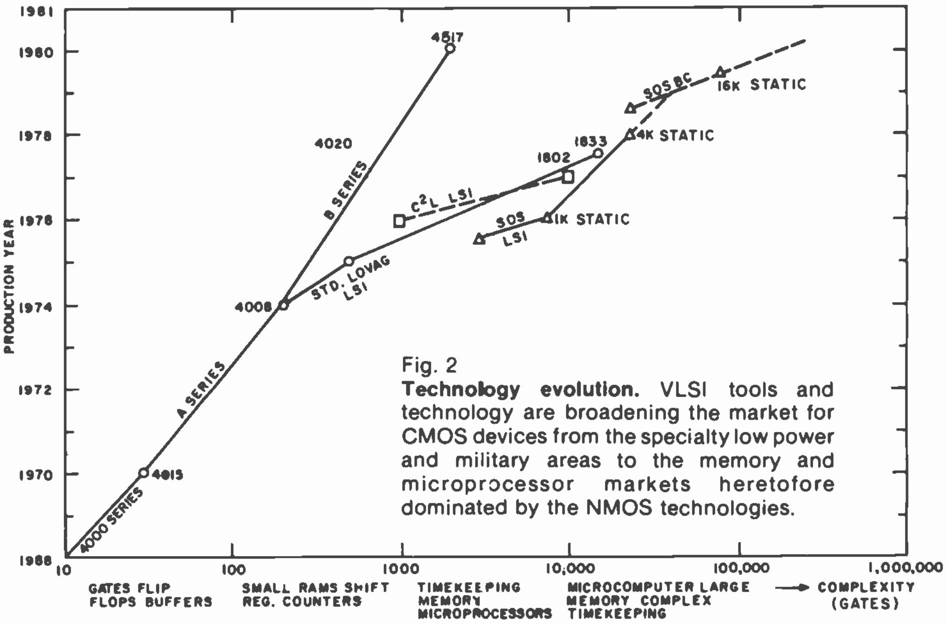


Fig. 2

Technology evolution. VLSI tools and technology are broadening the market for CMOS devices from the specialty low power and military areas to the memory and microprocessor markets heretofore dominated by the NMOS technologies.

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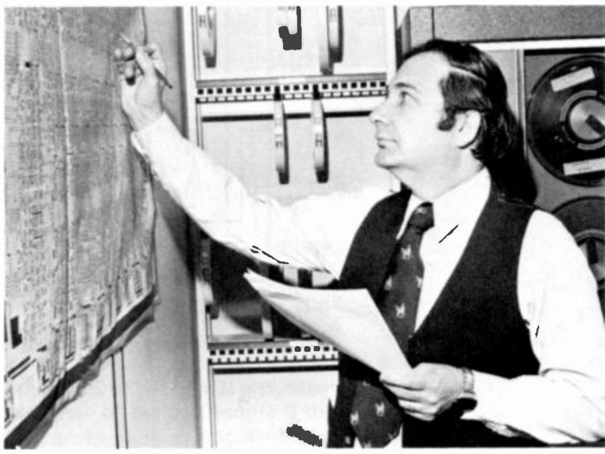

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Modern IC applications in communications systems

M.V. Hoover

ICs can provide relatively simple and economical solutions to complex communications design problems.

New generations of ICs are becoming available to aid communications systems designers in their work. The pervasiveness of these IC applications can be best illustrated by descriptions of specific examples taken from various IC product categories. The examples here use ICs for frequency division and fm-if systems.

A new IC for frequency division at vhf and uhf

A new IC[1] has been developed for use in frequency division ("prescaling") at vhf and uhf, with particular applicability in frequency-synthesized tuning systems. The IC divides by 256 in the uhf mode and by 64 in the vhf mode, and operates over the frequency band of 90 to 1000 MHz. The logic diagram and pin configuration (dual-in-line package) are shown in Fig. 1. Independent input terminals are provided for ac coupling of vhf and uhf input signals.

The mode of operation is band-switch selectable by means of a logic signal applied to terminal 3. In the uhf mode, which is activated by applying a logic 1 signal to terminal 3, all of the eight divider stages are operated, resulting in division by 256. In the vhf mode, with logic 0 at terminal 3, two divider stages are bypassed, resulting in division by 64.

Complementary output terminals (4 and 5) are provided, typically delivering a 1-V peak-to-peak signal with controlled slew rate for harmonic suppression. By maintaining a balanced load and by limiting output-signal rise and fall times (typically 70 ns), harmonic output is limited above about 40 MHz. Table I gives some typical electrical characteristics of the prescaling IC.

A new fm-if system IC

In 1970, the industry's first comprehensive fm-if system IC (CA3089) was introduced.[2] It contains an if amplifier, quadrature detector, af preamplifier, and specific circuits for agc, afc, muting (squelch), and tuning-meter control. This circuit has attracted a world-wide following of users. Recently, a generically similar new IC (the CA3189)[3] has been introduced, incorporating a number of additional features and improvements that permit the design of communications systems with enhanced performance. Following is a listing of additional features and advantages incorporated into the new IC:

1) typical $(S + N)/N > 70$ dB;

2) adjustable agc threshold voltage for the tuner's rf stage;

3) signal-strength-meter drive voltage depressed at low signal levels;

4) deviation-muting logic provides on-channel step control voltage, which simplifies design of signal-search type receivers and permits use of circuitry to minimize "audio thumping" when tuning onto or through a station; and

5) externally programmable audio output voltage.

Fig. 2 contains a block diagram of the new IC (CA3189) together with a schematic diagram of the comparatively few external parts the IC requires. Its 3-dB limiting sensitivity is typically 12 μV, and it typically delivers audio in excess of 500 mV at ±75 kHz deviation with the suggested quadrature-detector components. Fig. 3 depicts typical limiting and noise characteristics for three different receiver-if configurations.

The IC achieves typical (S + N)/N greater than 70 dB.

The input stage is a cascode circuit, which provides low input capacitance, an asset when the device is being driven by a

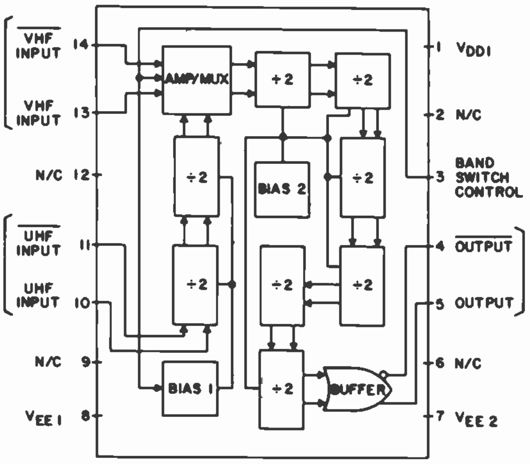

Fig. 1
Frequency-dividing IC divides by 256 in uhf mode and by 64 in the vhf mode. Logic 0 signal applied to terminal 3 bypasses two divider stages for vhf division.

Table I
Electrical characteristics of RCA's new frequency-division IC. Logic pulse changes operation from uhf to vhf.

UHF input signal	f_{in} = 450 to 950 MHz 80 mV (rms) (max)
VHF input signal	f_{in} = 90 to 275 MHz 40 mV (rms) (max)
Band-switch control voltage	logic 1 = 2.4V (min) logic 0 = 0.8V (max)
Power-supply voltage*	$(V_{DD} - V_{EE}) = 5.0$ V
Device current	60 mA

*Terminals 7 and 8 are normally tied together as the negative supply terminal.

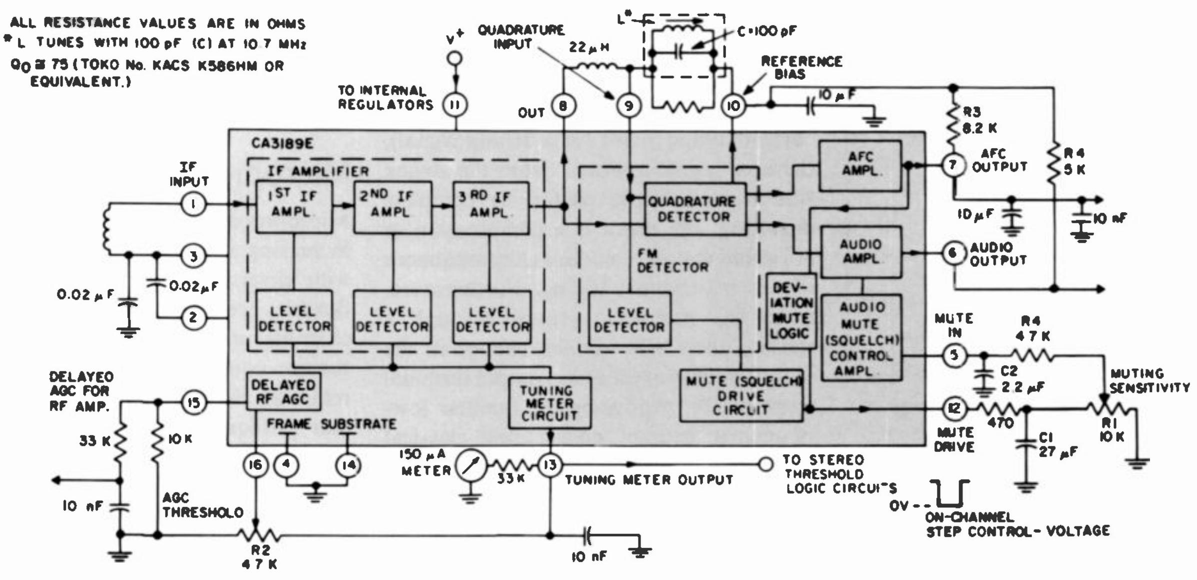

Fig. 2
Improved fm-if subsystem IC has special circuits for signal-strength-meter drive, adjustable agc threshold voltage, deviation-muting logic, and programmable audio output level.

ceramic filter element. The bandwidth of the amplifier has been set at 15 MHz. Since a majority of the broadcast-band fm-if circuits operate at 10.7 MHz, the bandwidth of the amplifier is not restrictive. This choice of bandwidth reduces wideband noise, as the amplifier does not employ interstage filter elements. Restricting the if bandwidth reduces the criticality of pc-board layout from the standpoint of the need to avoid parasitic instabilities.

The agc threshold voltage for the tuner's rf stage is adjustable.

Many modern fm receivers employ a dual-gate MOS field-effect transistor (MOSFET) in the rf stage. The circuit used in the new IC provides the user with flexibility in selecting the threshold voltage at which agc operation commences. It provides a dc output suitable for providing an agc range in the order of 40 dB when applied to G_2 of a dual-gate MOSFET. The point at which agc to the rf stage commences can be chosen by applying a suitable control voltage at terminal 16, the typical agc threshold voltage being 1.25 V. Potential to drive the agc threshold-adjusting potentiometer R2 can be taken from terminal 13. The characteristics of the agc dc voltage for the tuner as a function of input signal voltage can be determined by referring to Fig. 4.

With this IC, the signal-strength meter shows a true reading at zero and low signal strengths.

The on-chip tuning-meter circuit consists of three amplitude detectors (fed from the output of the three limiter stages), a current summer, and an output-level shifter. Under ideal zero-signal conditions, the current output should be essentially zero. In practical applications, however, noise from preceding stages (e.g., the rf and mixer stages) presents significant drive to the meter. To obviate this problem, a dc offset has been built into the meter drive circuit so that the meter will show a true zero reading under zero-signal conditions. Fig. 4 shows the voltage at meter-driving terminal 13 as a function of input signal.

The deviation-muting circuits eliminate annoying "thumps" that can otherwise occur while tuning through stations.

Two types of muting circuits may be used with the new IC. The first is a classical approach, i.e., noise-muting, which can be used to mute noise between stations. Fig. 4 shows the muting characteristics: muting is applied in accordance with this characteristic curve as the input signal decreases below about 40 μV. Potentiometer R1, in Fig. 2, is used to adjust the muting threshold. This type of circuitry is effective in combating interstation noise,

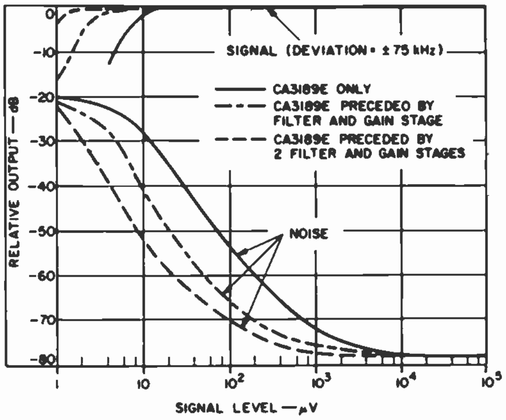

Fig. 3
Typical noise characteristics are very good—greater than 70 dB at normal signal levels. Limiting characteristics are also good.

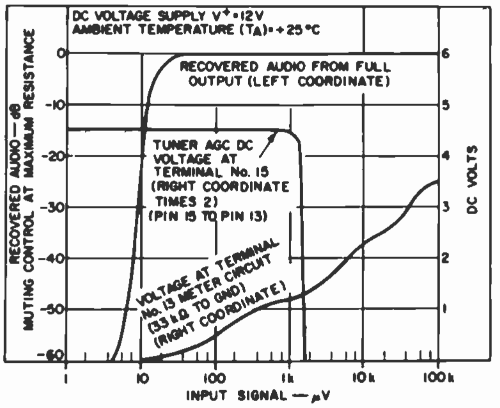

Fig. 4
Tuner agc has an adjustable threshold voltage. Figure also shows IC's low drive-signal output for signal-strength meter at low signal strength.

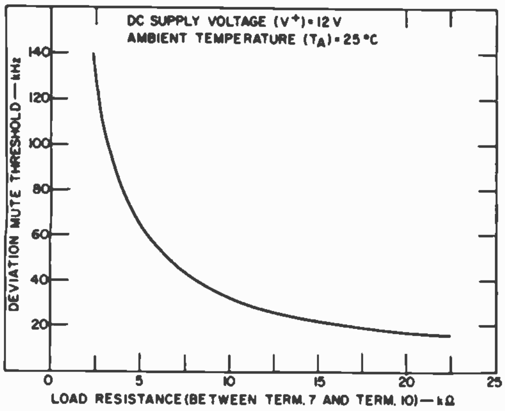

Fig. 5
Deviation-muting circuit gives sharper results than standard demuting circuits. Threshold value for demuting depends upon value of resistor R3, placed between terminals 7 and 10 in Fig. 2. With the value used in Fig. 2, graph shows that receiver must be tuned within 40 kHz of station's center frequency before demuting occurs. Other circuits can have partial demuting as far away as 300 kHz from a station's center frequency.

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but its performance leaves something to be desired when tuning toward or away from a strong signal. Under these conditions (e.g., within the order of 300 kHz from the correct tuning point for a strong signal), there is "signal splatter" from the strong station to produce partial or complete demuting; the result is a combination of noise and distorted audio as a consequence of the off-channel tuning. Furthermore, when the receiver is tuned through a station, there is a sudden change in the output dc level at the audio output terminal (terminal 6), producing the familiar low-frequency "thump" noise. These classical annoying imperfections are characteristic of noise-muted systems.

These annoying characteristics can be considerably diminished by using so-called "deviation-muting" circuitry, which has been incorporated in the new IC. Deviation-muting logic is connected between the afc and mute-drive output terminals. This circuitry consists of two accurately determined reference levels symmetrically placed about the correct-tuning afc reference; the result is a marked "sharpening" of the demuting action. For example, with this circuit in operation, the receiver must be tuned within about 40 kHz of the center frequency before demuting suddenly occurs. Furthermore, the deviation-muting threshold depends upon the value of the load resistor R3 connected between terminals 7 and 10; these characteristics are portrayed in Fig. 5. The use of this circuit permits the incorporation of an integrating circuit (C1, R4, C2 in Fig. 2) to greatly reduce the "thumping" noise mentioned above when tuning through a station. As shown in Fig. 2, the deviation-muting feature also provides a sharply-formed step control voltage (typically 5.6 V) whenever muting or demuting occcurs. This "on-channel" signal (zero volts) is useful in controlling receivers with channel-searching features.

The audio output voltage is externally programmable.

The audio output at terminal 6 is a current source, and requires the use of an external output load resistor; it is preferably referenced back to the 5- to 6-V reference voltage at terminal 10. In this manner, the magnitude of the recovered audio voltage may be programmed by selecting an appropriate load resistor, limited only by the maximum distortion-free voltage amplitude within the device capability. Since the load resistor R3 is returned to a voltage reference generated at terminal 10 by an internal zener diode, residual noise generated by the zener may be bypassed to ground by means of a capacitor.

Microprocessors

Microprocessor ICs are being used in an increasing abundance of applications in a wide diversity of fields because they are flexible, economical building blocks. For example, many communications systems require coordinated functioning between real-time clocks (used for systems timing) and frequency-measurement circuits. RCA's COSMAC CMOS IC microprocessor has been designed into a system to perform these functions; the design will be the subject of a future *RCA Engineer* article.

Conclusions

New-generation ICs are becoming available for a number of application categories. A new IC for frequency-division at vhf and uhf has been described, as have the features of a next-generation IC for fm-if systems. The fm-if IC provides an on-channel "stop-function" when used in search-mode receivers, as well as improved deviation muting. Perhaps these examples best illustrate the major reason for the modern IC's influence in communications systems—the IC offers the designer a comparatively simple and economical means of solving design problems formerly ranked as complex.

Acknowledgment

The writer acknowledges that his efforts in connection with this paper have been more editorial than authorial. The credit for the origination of the material contained here belongs to a great many more people than the few mentioned in the reference section below. It is hoped that the many will favor this rendition of their work.

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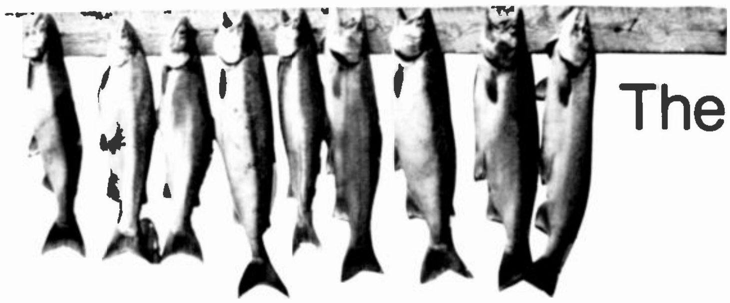

on the job/off the job

The lure of electronic fishing

N. Brooks

Fishing can be frustrating as well as fun. The catch to fishing is first finding the fish. Once you've found them, then you've got a fighting chance. The solid-state digital depth sounder described here gives you that break.

I grew up fishing the streams and rivers of southern Indiana and gradually expanded my range to cover many other states and quite a bit of Canada. My most "exotic" trips have been to Chantrey Inlet, N.W.T., approximately 100 miles north of the Arctic Circle where the Back River empties into the Arctic Ocean, and to Clearwater Fjord of Baffin Island where the Clearwater River empties into Cumberland Sound right on the Arctic Circle. These places have lake trout, arctic char, arctic grayling, and whitefish.

All of my fishing has been in fresh water, and I have enjoyed catching many species from bluegills to lake trout, salmon, and muskies. Being relatively close, I have done much fishing in Lake Michigan and the states of Michigan and Wisconsin. Both of these states have had very active fish conservation programs resulting in good fishing for several species such as bluegill, perch, crappie, bass, trout, salmon, pike, walleye, and musky.

Fishing techniques

Several methods are used to catch fish, such as fly fishing, spinning, bait casting, trolling, and jigging; any of them may be done with artificial or natural baits or lures. I have always believed the object of fishing is to catch fish, and I have used any or all legal methods in trying. Most of my fishing partners will verify that I get my share of fish. Having the proper equipment and learning how to use it is very important. Learning the habits and characteristics of the species of fish you are trying to catch also is a big help. Some are normally found near the surface, and some are normally near the bottom, with others in between. For example, wind and weather, especially temperature, will affect the depth of salmon in Lake Michigan.

Michigan has done a tremendous job in making Lake Michigan the best fishing hole in this part of North America. In recent years the other adjoining states have pitched in and fishing for coho and chinook salmon, rainbow trout, brown trout, and lake trout is very good in most all areas of the lake. Since salmon are not native to this area, we had to learn new fishing methods and even developed new equipment such as downriggers and baits. A downrigger is made up of a large diameter spool with strong (150 lb test) wire line used to lower a lead weight called a cannon ball (5 to 10 lb common) to depths of up to 200 (or more) feet. The bait and line from the fishing rod is connected to the cannon ball by means of a release system so that when a fish strikes the lure, the system releases the line from the cannon ball. Hence, there is no weight on the line for the fish to fight against. Many special baits, mostly odd shaped, and bent pieces of metal of all colors were tried, some with good success. Large flies trailed from doggers (bent pieces of metal which wobble) also work very well.

Why a fish finder?

A fish finder is a necessity if you are serious about catching fish in Lake Michigan or most other bodies of water because, for reasons known only to the fish, they are not in all areas of the water at the same time. You must first find the fish before you can catch them. The fish finder will also indicate the depth at which to run your lures and provide an indication of the number and size of the fish. After the fish have been located, it's up to the fisherman to determine the best lure, trolling speed, etc., to catch them.

In recent times fishing has evolved into basically two types; commercial and sport fishing, each with its associated types of equipment. Several years ago, electronics, in the

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form of sonar fish locators and depth sounders, began to play an important role in the taking of fish. These units were first used by commercial fishermen but later were adapted to use by sportfishermen. Beside being expensive, the early models were not without their problems. They were bulky and heavy with their tubes and vibrator-type power supplies. On most of them, the depth accuracy depended on the speed of a motor usually controlled by a "circuit breaker" type of governor, which caused reliability problems. Then, transistors came into practical use. This solved some of the size, weight, battery drain (especially on portable units), and reliability problems; but it left a basic problem area which is found today on most fish finders—the electric motors which determine the accuracy and reliability of the units.

All fish finders I know of work on the basic principle of transmitting a pulse of ultrasonic sound, then receiving and displaying any echoes from fish or the bottom in terms of time or depth. This is usually done by firing a neon bulb attached to a motor-driven disc with the motor speed controlled so that one revolution is equal to a given time or feet of depth. I know of two units recently placed on the market that have no moving parts. But one of these uses neon bulbs, and neither has the depth resolution required.

Searching for the ideal fish finder

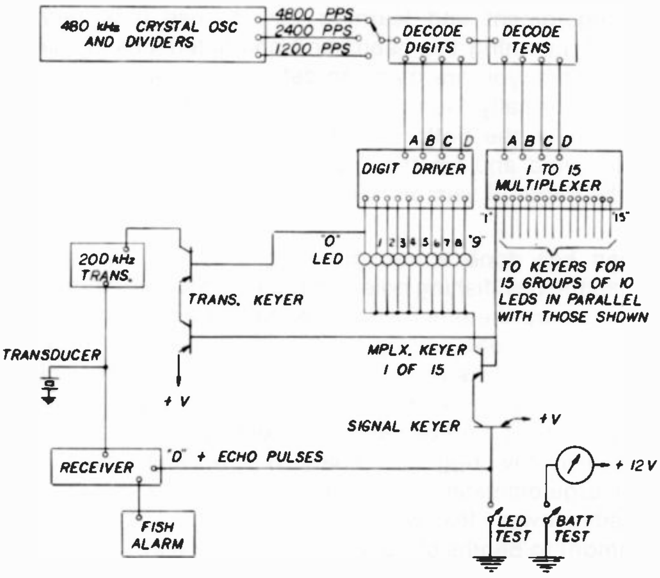
A few years ago, four of us were on a salmon fishing trip to Lake Michigan with three fish finders, one almost new, among us. Within three days none of the units was useable; one developed an open motor, another gave a 60-foot depth reading in water we knew to be at least 90 feet deep (the motor running slow), and the third one had a shorted output transformer. (The transformer is used to develop the high-voltage signal to operate the neon bulb depth-indicator light.) It was almost hopeless to go out without a finder, so we finally borrowed one from another group of fishermen and finished out our trip. This event started much discussion on what would constitute an ideal fish finder. As we also make fly-in trips to remote places in Canada, size, weight, and battery life were also important considerations besides reliability. If the indicated depth accuracy is not within about one percent, depending on the type of fishing, you will do more boat riding than fish catching. Another point is that in addition to having a good fish finder, you must learn its capabilities and how to use it. I have been with guides and charter boat operators who were missing some of the fundamentals.

After establishing the basic requirements, I started to look for parts and materials that would satisfy my objectives. About this time LEDs were coming into use, and I decided these should make a reliable readout because they required no high-voltage transformer or motor and offered significantly lower current drain on the batteries. The answer to accuracy was a crystal-controlled time base which triggers the sonar sounding pulse and controls the scanning time of the LED echo pulse displays. Low-power ICs were used for dividers in the time base and counters for the LEDs where possible. A system of multiplexing was worked out for the display LEDs to keep the number of ICs and the battery drain to a minimum.

Circuit design and operation

The depth sounder shown in Fig. 1 is of the type that excites a 200-kHz transmitter to generate an acoustical wave through a transducer. Reflected acoustical waves from objects such as fish and the bottom are received at the transducer and converted by the receiver into a single pulse or series of pulses. The transmitter frequency of 200 kHz is chosen to be compatible with conventional transducer characteristics.

Fig. 1
Digital depth sounder has three ranges: 0-75 ft, 0-150 ft, and 0-300 ft, corresponding to the time-base generator output of 4800, 2400, and 1200 pulses per second, respectively. Each time the "0" LED is scanned, the 200-kHz transmitter is keyed and the pulse is radiated by the transducer. The echo return is received and rectified to a single pulse which lights the LED corresponding to the depth of the fish.



As illustrated in Fig. 2, the time-base generator of the sounder is formed by a combination of a conventional crystal oscillator and frequency dividers. The generator provides three outputs of 4,800, 2,400, and 1,200 pulses per second, corresponding to the three depth ranges of 0-75, 0-150, and 0-300 feet, respectively. Using one digit driver, one 1-to-15 multiplexer, and fifteen multiplex keyers, the LEDs are scanned sequentially at the rate determined by the range switch. The LEDs are arranged in fifteen groups with ten LEDs in each group. In any one group, each LED has one terminal connected to the corresponding output of the digit driver. The other terminal is connected to the collector of the multiplex keyer transistor for that group.

The 150 LEDs are arranged in a 15-inch dial scale so that on the 150-foot range each LED equals one foot of depth.

Each time LED "0" is scanned, the output of the digit driver for LEDs "0" - "9" and the 1-to-15 multiplexer activates the transmitter keyer circuitry (see Fig. 1). A 200-kHz transmitter is then energized and transmits only for the time LED "0" is scanned. A receiver tuned to 200 kHz receives and rectifies the echo return so that the output is a single pulse. This echo return pulse closes the signal keyer transistor switch and places a voltage on the emitter of all fifteen multiplex keyer transistors, which in turn, lights the corresponding LED.

Bottom depth and fish depth are clearly distinguishable from each other by the pattern observed in the LEDs, as shown in Fig. 3. Normally, for constant depths for fish or the

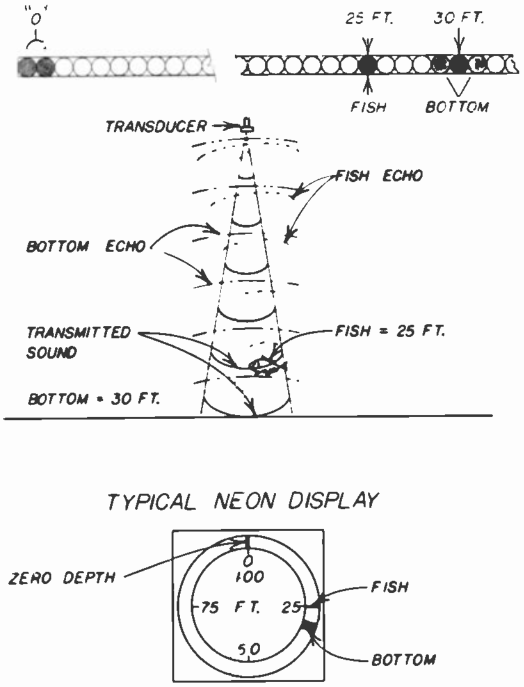


Fig. 3
The solid-state digital depth sounder (top) uses 150 LEDs in its display; each one indicates a segment of depth. This system provides for greater accuracy and reliability in determining depths of fish at various levels than the typical motor-driven neon display type (bottom) with its inherent instability. Middle diagram shows the cone-shaped sound-wave pattern produced by the transducer (used in both display systems).

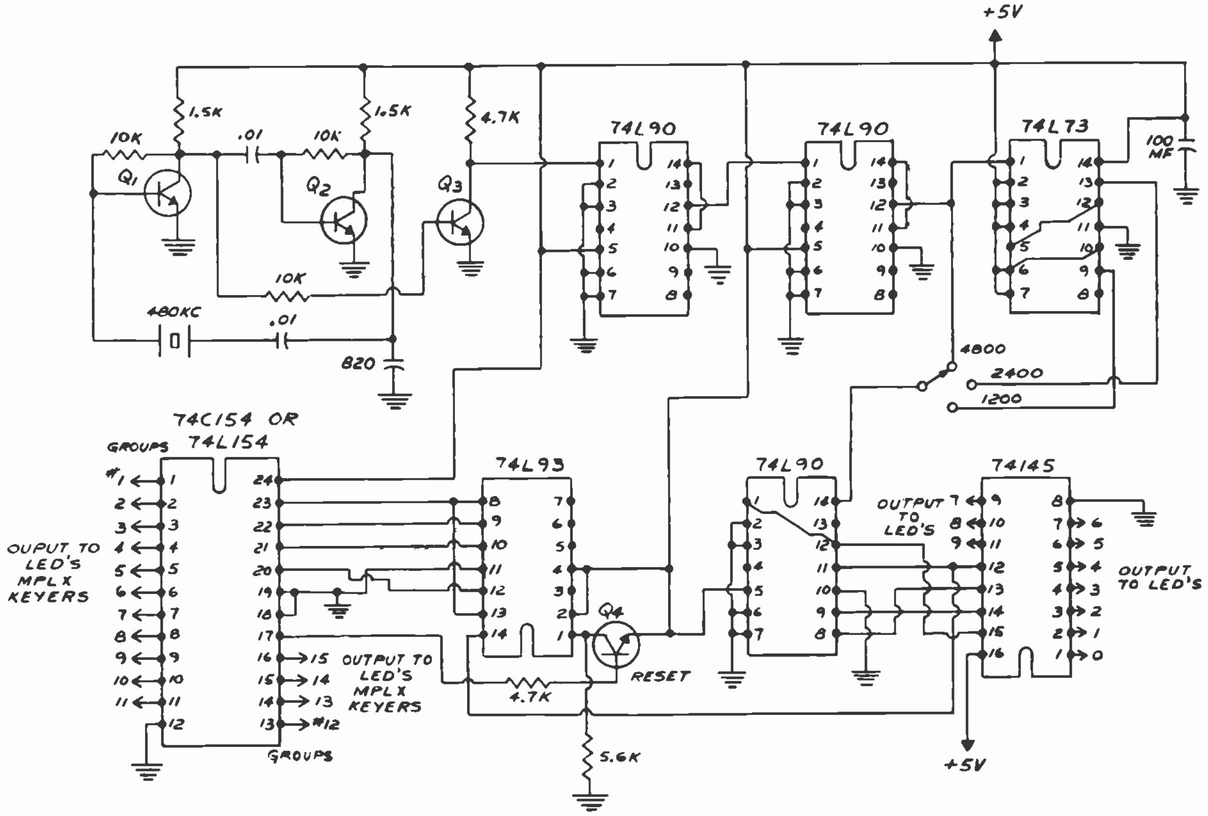


Fig. 2
Time-base generator circuit for the sounder combines a conventional crystal oscillator with frequency dividers. Sequential scanning of the LEDs is controlled by multiplexers and digit drivers.

bottom, one or two LEDs will be lighted depending upon the constancy of the depth. As rapid changes in depth occur, whether for fish or bottom soundings, the LEDs will light in sequence corresponding to changes in depth.

Why LEDs for display?

To my knowledge, LEDs had never been used for this application at the time I was considering the design. Some thought was given to numerical readouts, but because I wanted a constant indication of the bottom depth and often there are fish anywhere from the bottom to the surface which are to be displayed at the same time, I decided to use 150 one-tenth-inch diameter LEDs and let each one indicate a segment of depth. For the three depth ranges used, this meant that on the 75-foot depth range each LED represents 6 inches, on the 150-foot depth range, 12 inches, and on the 300-foot range, 24 inches. Depending on crystal accuracy these segments can be made to indicate within an inch or so at a hundred-foot depth as far as the unit is concerned. There are other things, temperature, type of water, etc., that affect readings, but these are not a factor in my fishing.

Interpreting the display

By gating the LEDs with the counters and the echo pulses, any number of fish at any depth and also the bottom depth are displayed in sequence, which appears as a continuous display to the eye. To properly interpret the display you must take into account the pattern of the transmitted "sound" and the received echo of this "sound." The depth indicated on the display is a measure of the time it takes the sound to travel (in water, approximately 4800 feet per second) from the transducer to the target and return to the transducer.

The transducer normally sends out a short pulse of sound waves in a conical pattern, which means that increasingly larger areas are covered as the depth increases. This pattern is shown in Fig. 3. Transducers vary widely in radiated patterns from a few degrees to several degrees. A typical one with a 25-degree cone will cover approximately a 4-foot diameter circle at a 10-foot depth, a 23-foot diameter at 50 feet, and 45-foot diameter at 100 feet. Thus, not all fish, or other targets, that show on the display are going to be directly under the boat and may appear at a depth slightly greater than the actual depth. As you approach a fish lying still in the water, his depth appears to become shallower and, as you leave, it will appear to go deeper when you are on a line directly over the fish. If the fish is at the edge of the cone on either side of the boat, the depth indication will not change noticeably but will be slightly greater than the actual depth.

Salmon, especially the chinook, run at depths of over 100 feet, and it has been my experience that you must get your lure within a foot or two of the actual depth of the fish but never below them. This narrows the range of effective lure depth and requires an accurate depth indicator, especially if you are using it for location and navigation by water depth. In addition, you must select a good lure and move it at the right speed with the proper action. In short, a fish finder may locate the fish but it's still up to the fisherman to make them open their mouths.

Preventing false alarms

On the days when you're not into large schools of fish, you lose interest in constantly watching for fish on the indicator. A fish alarm, an audible signal, was incorporated in the unit so an alert would sound in case of a potential strike. The fish alarm idea was not new, but after a few days of use in Lake Michigan, I decided it could be improved. The problem was that in some of the good fishing areas, as you might expect, there were many small fish near the surface covering large areas. So the alarm was on almost constantly, requiring careful watching of the display to see if there were good fish below, which there were many times. All fish alarm systems that I know of, even on units made today, have an adjustment to prevent alarm on a bottom echo but have no control over echoes near the surface.

To overcome this problem I added a circuit and a control (see Fig. 4) with which I can vary the triggering sensitivity of the alarm circuit down to about 30 feet without affecting the sensitivity at the greater depths. The sensitivity is decreased on a slope from the depth of the starting point, determined by the control setting, to the surface. To do this I used two transistors in series (a type of gate) so that if the combined echo pulse and alarm gating pulse equals a given value it will switch on the following stage, turning on the alarm. The control marked "top" in Fig. 4 shapes the leading edge of the

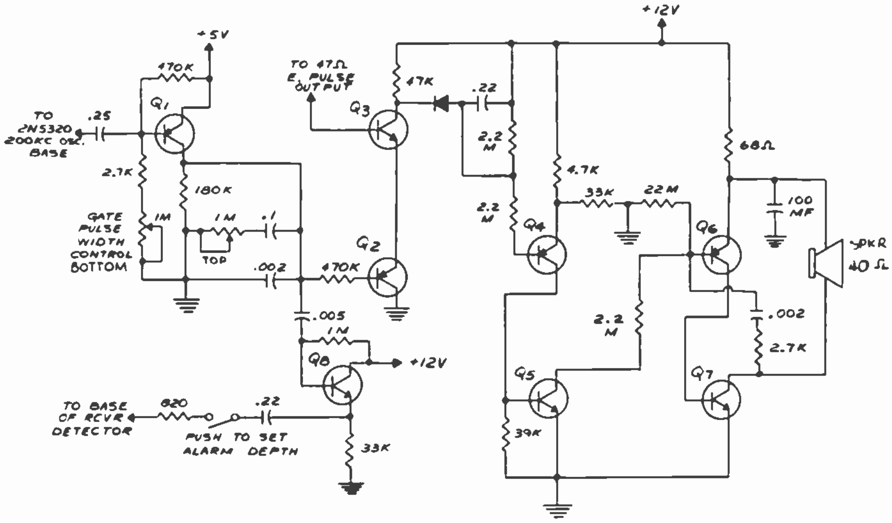


Fig. 4
Fish alarm circuit incorporates dual triggering sensitivity to prevent alarm sounding from small fish near the water's surface as well as from the bottom echo.

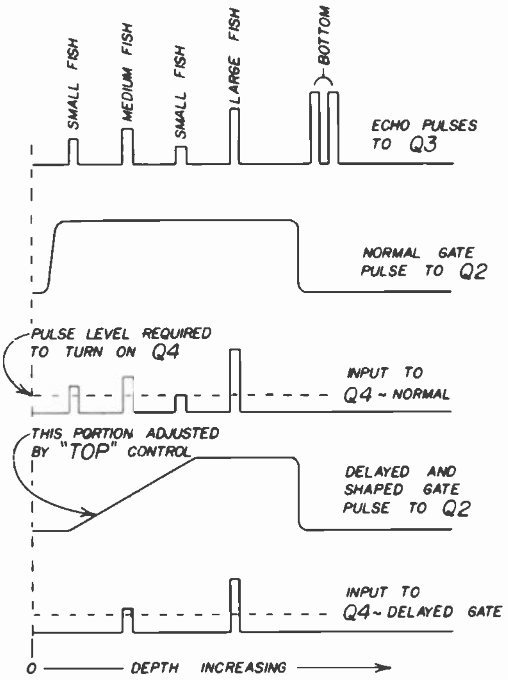


Fig. 5
The addition of a "TOP" control to the fish alarm circuit (Fig. 4) helps discriminate large fish from small fish near the water's surface. The TOP control shapes and delays the gate pulse so that small echos (from small fish) will not turn on the alarm.

alarm gating pulse into a sawtooth and varies the amplitude of it so that as it is reduced, it requires a larger echo (fish) pulse to turn on the alarm. Fig. 5 shows how the pulse shaping works. With proper adjustment the small fish are no bother but large fish near the surface are not missed.

Alarm circuit operation

In my alarm circuit, Q1 is driven by the keying pulse to the 200-kHz oscillator and generates a gate pulse of varying width depending on the setting of the control marked "bottom." This pulse is used to turn on Q2. The echo pulses turn on Q3. Both Q2 and Q3 must be on to drive Q4, turning on the multivibrator driving the speaker. This is the conventional alarm circuit. When the bottom control is adjusted so that the gate pulse to Q2 shuts off Q2 before the bottom echo pulse is received, the alarm will not sound on the bottom echo, but will sound on any echoes above the setting of the bottom control.

By adding the control marked "top" and a 0.1-microfarad capacitor, the leading edge of the gate pulse is shaped and delayed so that small echo pulses on Q3 will not turn on the alarm. In this mode of operation, Q2 receives an increasing amplitude (sawtooth) gate pulse and being only partially turned on, a correspondingly larger echo pulse must be received by Q3 to turn on Q4. Since the echo pulses are somewhat related to fish size, with proper adjustment of the "top" control small fish will not trigger the alarm but large ones will, as shown in Fig. 5.

Echoes from fish are not normally as strong as the bottom echoes, depending of course on the type of fish and the type of bottom and assuming the fish is near the bottom. To obtain good readings on small fish (those approximately 5 pounds in weight) I experimented with receiver sensitivity vs. transmitted power to the extent that I decided to run the transducer at the maximum rating for voltage input. The reason for maximum transducer drive vs. receiver sensitivity is that more sensitivity gives more problems with unwanted signals such as ignition, motor, and propeller noise. Because transducers resonate at a specific frequency, the output circuit driving them must be tuned to the exact frequency and, consequently, the receiver must be tuned to the same frequency with a reasonably narrow bandpass.

Toward perfection

I worked on this project, along with others, in my spare time for approximately a year. The unit was put into a box 3x4x6 inches (almost pocket size). The power source is a 12-volt lantern battery, and the unit has a current draw of 125 mA with both "0" and bottom signal displayed.

I have had much enjoyment from using this unit for the past three years. It is completely solid state, has no moving parts, and will maintain its accuracy for many years to come. But I expect to keep adding new developments to keep it ahead of anything on the market.

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Mandatory licensing of engineers: pros and cons

RCA Engineer Staff

Proposed state laws requiring mandatory licensing of engineers in "responsible charge" could affect every working engineer.

A controversy regarding regulating the practice of engineering is taking place across the nation. Up until now, most engineers employed by industrial companies have been exempt from mandatory state licensing. During the past few years, however, mounting pressure has been exerted on state legislatures to remove this "industrial exemption" for many engineers. Expanded licensing requirements would strongly affect engineers, companies, and the public. In this article, arguments of the controversy will be presented along with enough background to inform readers about the issues.

State laws governing the practice of engineering exist in all fifty states, the District of Columbia, the Canal Zone, Guam, and Puerto Rico. Generally, the intent of these laws is to safeguard life, health, and property, and to promote the public welfare. The laws pertain to engineering that is performed in a practitioner-client relation, generally referred to as consulting engineering.

The first engineering state licensing law was enacted by the state of Wyoming in 1907. Its impetus came from the State Engineer, who was determined to stop abuses in land surveys concerning water rights. Such surveys at the time were being prepared by lawyers, real estate brokers, notaries, insurance agents and even pawn brokers who had been posing as engineers or as surveyors.[19] Other states and territories followed suit in a slow but steady progression.

Throughout the development of licensing legislation, focus has remained on direct practitioner-client consulting applications. Legislation has not governed large numbers of engineers employed in other capacities. Exemptions from mandatory licensing include U.S. Government employees, employees and subordinates of licensed engineers, public utility employees, industrial employees, and individuals performing engineering services for other than public use. While engineering licensing has proliferated among states, there is no federal law on engineering licensing.

The authority to regulate engineering practice derives from the police power of the state. Each state exercises full autonomy in establishing and administering its licensing requirements. Some progress has been made in promoting uniform standards, but wide differences currently exist from state to state. Implementation of licensing regulations is administered by state boards that represent an official arm of state government and are created by legislatures. State boards are charged by legislatures to establish criteria for licensing, to set minimum levels of performance, to administer licensing statutes, and to propose changes needed to maintain currency. Individuals on various state boards have formed a voluntary association now called the National Council of Engineering Examiners (NCEE), which has participation by all U.S. states and territories.

NCEE has drafted proposed legislation which would revise existing statutes governing the licensing of engineers. This proposed legislation is known as the NCEE "Model Law."[2] The Model Law contains no provision for an industrial exemption *per se*. It defines the "practice of engineering" broadly, in a manner which would likely encompass all work in RCA that is typically referred to as engineering. It requires that anyone who is in "responsible charge" of such work be licensed. Responsible charge is defined as "... direct control and personal supervision of engineering work." The requirements for licensing include experience, examination, and graduation from an *engineering* curriculum. The only industrial employees practicing engineering who would be exempt from licensing are employees or subordinates of licensed engineers.

Lobby efforts have been organized to encourage the adoption of the NCEE Model Law. Spurred by the consumerism movement, recent lobby efforts have intensified. In 1976, NSPE, the National Society of Professional Engineers (the professional association of licensed engineers) issued a policy statement in support of the NCEE Model Law. NSPE Policy No. 36-B reads as follows:[1]

> "NSPE believes that the state engineering registration laws should apply to all engineers responsible for engineering design of products, machines, buildings, structures, processes, or systems that will be used by the public; and urges management to engage only registered professional engineers for responsible engineering positions. Management is also urged to promote registration among all of its engineering staff. The Society is opposed to proposals to exempt engineers in industry from the state registration laws and recommends the phasing out of existing state exemptions in state registration laws."

Recently, the United States Activities Board, the political-action arm of IEEE, proposed to the IEEE Board of Directors that IEEE should support removal of the industrial exemption. By its action of Feb. 19-20, 1977, the IEEE Board adopted the USAB policy statement (IEEE Policy Statement 7.3).[22] However, this IEEE policy has not yet been implemented. Member preference is not clear. For example, response to the IEEE 1977 U.S. Member Opinion Survey[26] appeared somewhat contradictory:

16. Do you agree with the IEEE Board of Directors' recommendation to establish mandatory licensing by the states for practitioners who are responsible for their activities or for the activities of their subordinates?
Agree 55.8%
Disagree 34.0%
Not Sure 10.1%

19. Would you favor eliminating all exemptions which allow engineers working for industry to practice without a license?
Yes 29.4%
No 57.5%
Not Sure 13.1%

18. Should use of the title "Engineer" be restricted to those persons who are registered or licensed?
Yes 50.2%
No. 44.0%
Not Sure 5.8%

21. Should IEEE require either a degree or a P.E. license for all grades of membership above student grade? grade?
Yes 45.5%
No 48.6%
Not Sure 5.8%

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Arguments favoring and opposing expanded licensing are numerous, often heated and emotional, sometimes based on fact and sometimes based on opinion. A sample of these arguments follows. In order to convey their intensity, the language chosen is similar to that actually used, including quotes. Therefore, what is stated as fact may or may not be verifiable.

Pro—arguments for expanded licensing

"There is a public need."

The news of the day is replete with instances of actual, near, or potential injury or death resulting from actual or potential malfunction or inadequate protection of manufactured products. The consumerism movement and the increasing number and size of product liability suits establish beyond any doubt that product safety is inadequate. Neither the "conscience" of industry nor product liability legislation have proven sufficient. It is not sufficient to "pay" if someone sues you, which has been industry's stand. "... we need the engineer to assume responsibility for doing it right in the first place... and registration puts that responsibility on him."[6] Manufactured articles such as autos, refrigerators, tvs, gas furnaces, and microwave ovens impinge directly on the daily lives of citizens. Faulty engineering in their design or fabrication may be just as dangerous as faults in bridges or buildings.

Expanded licensing might reduce the current cost of product liability agencies. "Has the industrial exemption of engineers and their engineering activity been in the public's best interest over the years? Two answers to the negative can be seen in the recent enactment into Federal law of the Occupational Safety and Health Act (OSHA) and the U.S. Consumer Product Safety Act (CPSA). The public's elected legislative representatives in Washington, D.C., deemed it to be in the public's safety interest to create these two very large agencies, provide millions of dollars in budgets, and place thousands of government people to work in enforcing what industry through the years failed to do voluntarily—that is, to take steps necessary to provide safe working conditions (OSHA) and to prevent unreasonably unsafe products from getting into the hands of consumers (CPSA). It appears now, using hindsight, that had industry's engineers and their engineering activity not been exempted from registration laws but rather had been legally bound and permitted to practice professional responsibility, the need for OSHA and CPSA might well have been avoided."[4]

Con—arguments against expanded licensing

"Expanded licensing would not increase public protection."

Within industry, engineering competency is *demonstrated* daily on specific tasks. Business success *depends* on competent performance. It is inconceivable that licensing criteria (education, experience, exam) will be able to *predict* competence in generalized tasks adequately.

In the case of manufactured products, an abundance of regulations, state and federal, already apply to the products, to the manufacturers, and to manufacturing processes. Corporations bear full legal responsibility for, and their survival depends on, the performance of their products. Products are shaped by an extensive variety of influences from many occupations. Licensing engineers would not be beneficial; a survey conducted by NSPE indicated that its members believe the expanded licensing would not improve the designs of consumer products.[27] There is no significant and discernible threat to the public posed by engineers in industry that is not far more effectively handled by product safety regulations.

"Expanded licensing would create dysfunction and increased costs."

Holding certain individual engineers legally responsible would result in their taking a protective-defensive posture, based on the potential of having to defend their judgment and actions from a witness stand. Such a posture would reduce the efficiency of multi-discipline teamwork, which is essential to modern design.

With expanded registration requirements, assignment to certain tasks could not be made solely on the basis of competency, career development, reward, efficiency, availability, etc. Who is licensed and who is not always would be an overriding concern.

Individuals and organizations would face increased administrative burdens, increased bureaucracy, and in-

Pro (continued)

"Expanded licensing of engineers in industry would be responsive to the public need."

Licensing is an assurance for the public that engineers responsible for designing equipment and providing engineering services that have potential public effect have met at least minimum standards of competence. With the industrial exemption, the public has no such assurance. Licensing is not a guarantee of the competence of engineers any more than it is for medical practitioners. It does, however, assure a minimum standard and provide for disciplining offenses. Also, licensing creates a climate conducive to responsible actions. Licensed engineers have sworn oaths to be morally responsible in protecting the public's interest. They are very much aware that they are legally and morally responsible to the public.

Licensing engineers in industry is entirely consistent with their expanding social consciousness. Today's engineer is vitally concerned and involved with consumerism, environmentalism, product safety litigation, and other social and legal forces. Engineers want to design products and provide services that are inherently safe, but they are sometimes pressured by their employers to cut corners. "The engineer attempting to practice ethically in industry today, whether a registered PE or an engineer professional, has virtually no legal or professional backing in the real world when faced with taking responsible action to protect the public, when this action is in disagreement with his employer. In effect, the so-called industrial exemption is denying 82 percent of all engineers equal protection under the same law that provides protection to a PE who practices as a consultant."[4] Since the Model Law would require that the engineer not approve anything which, in his or her experienced judgment, would be inconsistent with the public well-being, it would protect engineers in such situations. Given such backing, engineers would act in instances where they cannot now act to provide additional public protection.

Note that the "Model Law" requires licensing for only those engineers in "responsible charge." The objective is for the design process and final designs and decisions to be approved by the judgment of licensed professionals.

"Expanded licensing will enhance the engineering profession."

"In the final analysis, whether engineering is to be fully recognized as a leading force in the nation's growth and progress turns upon the status of engineering in the industrial economy. Engineering as a whole cannot obtain its rightful place in the hierarchy of the professions until it is defined and recognized on a legal basis, and that means the registration of all qualified engineers in industry, where most of them are to be found."[1] Licensing carries with it a social value and esteem. It enables an occupation to limit access to only those prescribed.

Con (continued)

creased costs. The state would have to administer licensing boards and disciplinary activities. Engineers would have to undergo additional educational and examination processes and pay license fees. Industry would have to deal with additional record keeping and administrative reporting, plus reduced efficiency through lost flexibility. Ultimately, these costs would be borne by the public and by engineers. Costs for license fees to U.S. engineers could amount to almost $200 million per year.[22]

"Many engineers and other technical professionals would be put at a disadvantage."

Graduates of non-engineering curricula would not be eligible for licensing. Many engineering graduates may not wish to obtain a license or may be unable to do so for many reasons other than job competence. These individuals would never be in "responsible charge." Therefore, promotions, transfers, employment, and task assignments would be limited for them. Simply put, if you're content to be a subordinate engineer all your life, you won't need a license. But if you aspire to responsibility and promotion, you would have to be licensed. Or, as put by Morton S. Fine, Executive Director, NCEE, "If the industrial exemption is removed broadly, as is being proposed, then registration will be necessary to insure advancement, security, and mobility. . . ."[19]

Modern products are engineered by teams of professionals from many disciplines for which licensing is not proposed (physics, chemistry, software, etc.). To arbitrarily subjugate such individuals to the direction and approval of a licensed engineer destroys the essence of effective teamwork, which allocates influence to competence.

Older engineers would be forced to participate in a process designed primarily to screen new engineers wanting to enter the profession. "Grandfathering" may enable some engineers to obtain licenses who would not otherwise do so. But movement toward periodic recertification and relicensing would eliminate this advantage. It is unlikely that non-engineer professionals would be permitted to "grandfather."[10]

"Government regulation should be limited to necessity."

Legislative regulation of a profession should be used only when no other satisfactory method exists for solving a significant problem. Proponents have not established evidence for the following with regard to engineers in industry: Have there been complaints of abuse? How serious? How widespread? How many people involved? What harm is the public now suffering because engineers in industry are not presently regulated? Would licensing have prevented instances where abuse has been demonstrated? Would other remedies have worked as well?

Regulation of occupations has always been limited to direct practitioner-to-client or -public relationships. For example, regulation does not encompass physicians engaged in

Pro (continued)

A part of the licensing regulations prohibits others not licensed from using the title of the occupation. Those now using the title *engineer* inappropriately would be prevented from doing so (e.g., stationary engineer, railroad engineer, service engineer).

"The industrial exemption is a mere political expediency."

There are many exemptions from required licensing in the various state laws. Some are legal (engineers in the Federal government), and some are policy (public utility engineers). Industrial exemptions, however, were originally granted because state legislatures made political tradeoffs to industry pressure in order to be able to enact engineering registration laws.[7] Therefore, industry exemptions never were based on nonpolitical reasoning.

It is inconsistent and illogical to require engineers to be licensed in order to design roads, bridges, tunnels, airport runways and facilities, and radio and tv broadcasting buildings and at the same time exempt from license requirements engineers who design the automobiles, trucks, trains, airplanes, and electrical and mechanical equipment used by and in these facilities. When politics is set aside, the rational solution is the licensing of *all* engineers in responsible charge.

There is no expectation that universal registration of engineers will be accomplished "overnight." The Model Law is proposed as a starting point on a state-to-state basis. Many clarifications and adjustments will have to be worked out through a trial-and-error process. However, it is a rational process and it is important to start. Many companies encourage voluntary registration and thus admit to its having value.

Con (continued)

medical research, lawyers devoted to within-company legal activity, or industrial accountants. Nor does it encompass plumbers and electricians employed for piping or wiring on products. Regulation of direct-to-public relationships is legitimate because the public has no intermediate or intervening agency to protect its interests and governmental regulation can be of significant, and perhaps the only, protection.

Proponents are advocating the expansion of regulatory laws into nontraditional coverage. Focus on the phrase "removing the industrial exemption" conveys the impression that the industrial exemption is some sort of "loophole." It isn't. It is a needed and legitimate limitation that brings engineering regulation into the same coverage found with other regulated occupations—namely, direct-to-client relationships.

"Expanded licensing is self-serving."

There are almost one million engineers in the U.S.; approximately 30% are registered. Less than 7% are members of NSPE.[9] Thus, a very small minority is pressing strongly for states to impose legal restrictions on the majority.

It is typical for the biggest promoters of licensing to be those who are licensed.[16] Their interests are very likely self-serving. NSPE's Position Paper openly admits to "... a dual purpose and motivation..to protect the public health, safety, and welfare..." and "...there is no denying that much of the impetus for universal registration of engineers derives from the true faith that engineering will not achieve its rightful place as a recognized profession unless and until all of its practitioners and title holders have qualified under the legal standard of the law."[1]

Enhancing the status and prestige of an occupation is not an appropriate use of the police powers of a state. Arguments appealing to status so derived are improper.

Conclusion

Expanded licensing would affect every working engineer either directly or indirectly. Some have classified the proposed legislation as the most important ever for engineers. At this point it is not predictable whether such legislation will be adopted.

In the article starting on the next page, RCA's official position on the issue is stated and explained.

Bibliography

This bibliography is arranged in three categories: articles favoring expanded licensing, articles opposing expanded licensing, and articles that present information or description without taking a strong position pro or con.

Favoring expanded licensing

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Ed. Note: The terms "licensing" and "registration" are both used in referring to state regulation. While there may be technical differences, the two terms are usually used interchangeably in most places.

Opposing expanded licensing

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What is it and how did we arrive at it?

RCA's position on licensing engineers

W.J. Underwood

Faced with legislation that may remove the industry exemption from state engineering licensing laws, the Corporation has taken an official position.

The accompanying article described the issue and controversy concerning expanded mandatory licensing of engineers. As indicated, large numbers of technical professionals, both engineers and non-engineers, would be significantly affected by enactment of NCEE's "Model Law." Also significantly affected would be the companies who employ those technical professionals and the public, who would ultimately pay the increased cost. Because of its importance, RCA Corporate Engineering management considers it desirable to adopt an official company position on the issue and to work from this position in the controversy. That policy is given in the "box" on the next page.

We believe our Corporate position reflects the interests of the majority of RCA's technical staff. In the spring of 1977, as a part of the Corporate Engineering Information Survey, we asked RCA's professional technical staff, "How important do you think it will be in the future for RCA engineers to obtain a professional license?" The 2,290 responses received to the question reflected a 75% cross-section of RCA's engineering population. Results:

18% — Very Important or a Necessity
82% — Slightly Important or Not Important

Those who already had state licenses (307) answered:

30% — Very Important or a Necessity
70% — Slightly Important or Not Important

Those who planned to become licensed (251) answered:

30% — Very Important or a Necessity
70% — Slightly Important or Not Important

Any controversy usually has some merit on both sides. We respect the interest in improving the professional status of engineers and of improving the engineering profession. We suspect this goal accounts for most of the motivation to expand licensing. We regard this position as the use of a wrong method to attain a very desirable goal. We cannot subscribe to "using" government regulation as a means of status improvement.

RCA is justly proud of its technical staff, professional and sub-professional alike. RCA's professional technical non-engineers (chemists, physicists, mathematicians, computer scientists, etc.) have made major contributions to both science *and* engineering, many of world-wide repute. They have held and continue to hold positions of significant and major responsibility. We would not subscribe to any action which would diminish their status in any way.

RCA regards its technical staff as mature, responsible persons who *do* exercise integrity in their work. We regard our company in a similar manner. Therefore, we cannot subscribe to a position that is based on an assumption of irresponsibility. We believe that a careful study of product failures would indicate an insignificant percentage caused by faulty engineering design that could be cured by licensing. We regard arguments linking product failure to lack of licensing so overdrawn as to be unworthy of serious consideration.

RCA will continue supporting individuals who voluntarily seek state licensing as a matter of their personal interest. We willingly conform to licensing requirements in any direct client-practitioner relationship. We will, however, oppose attempts to force licensing on those engineers now practicing under the very legitimate industrial exemption.

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Mandatory registration of engineers— RCA Corporation position

RCA Corporation supports the licensing of engineers who offer their services on a direct client-practitioner relationship, and it supports the voluntary registration of engineers employed by others where the engineers believe this would serve their personal interests. However, RCA opposes proposed revisions to state statutes that would require all "responsible" practitioners of engineering to be licensed. It believes such mandatory registration is not in the best interests of the engineering profession, the public, or technological progress.

The proposed revision to the statutes governing registration of engineers is based on a "model law" drafted by the National Council of Engineering Examiners. As broadly defined in the "model law," the "practice of engineering," for a technologically-based company, would likely include work performed by chemists, physicists, computer scientists, mathematicians, and others who are not graduate engineers. However, the proposed requirements would restrict licenses to graduates of an engineering curriculum and to those who pass an extensive engineering examination under state auspices. In addition, the "model law" would require licensing all those in "responsible charge" of engineering work.

For engineers in industry, the revised law would impose an unnecessary burden of time and money to obtain licenses and renewals to continue the work they have been doing for years. For many it would require a reeducation process. It would also limit leadership opportunities to the licensed engineers.

According to the "model law," the purpose of mandatory legislation is "...to safeguard life, health and property and to promote the public welfare." There is no convincing evidence that licensing engineers in industry would accomplish this. Industry is responsible for its products and services. Its professional technical people, regardless of whether they are licensed, are generally unknown to the public. It would be difficult, if not impossible, to pinpoint individual responsibility in what is generally today a team effort combining many specialized talents in many fields.

For industry, the proposed revisions would substantially restrict flexibility in work assignments and responsibilities, and reduce internal efficiency without any compensating benefits. Additional administrative burdens would have to be imposed to maintain control over who is licensed, in which disciplines and in which states, and personnel would have to be asssigned accordingly. Given the complexity of modern technology, it would require artificial sign-off on designs even where it is impossible for any one person to determine where his work began and left off.

Expanded licensing requirements would increase taxpayer costs for licensing and enforcement. They would introduce complex bureaucratic procedures in industry; these costs would also ultimately have to be borne by the public. Because they are neither necessary nor in the public interest, RCA, therefore, opposes the proposed revisions.

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.

AUG 28-31, 1978—**Laser Applications and Optical Communication** (Soc. of Photo-Optical Instrumentation Engineers) Town and Country, San Diego, CA **Prog Info:** SPIE, PO Box 10, Bellingham, WA 98225

SEP 5-8, 1978—**COMPCON FALL** (IEEE) Washington, DC **Prog Info:** COMPCON FALL, P.O. Box 639, Silver Spring, MD 20901

SEP 5-7, 1978—**Intl. Optical Computing Conf.** (IEEE) Imperial College, London, Eng. **Prog Info:** S. Horvitz, Box 274, Waterford, CT 06385

SEP 6-8, 1978—**Fiberoptic Communication Conf. & Exhibit** (Info. Gatekeepers Inc.) Hyatt Regency O'Hare, Chicago, IL **Prog Info:** Information Gatekeepers, 167 Corey Rd., Suite 212, Brookline, MA 02146

SEP 6-8, 1978—**OCEANS '78** (IEEE, OEC, MTS) Sheraton Park, Washington, DC **Prog Info:** Myra Binns, Marine Tech. Society, 1730 "M" Street NW, Washington, DC 20036

SEP 12-14, 1978—**Western Electronic Show & Conv.—WESCON** (IEEE) Los Angeles Convention Ctr., Los Angeles, CA **Prog Info:** W.C. Weber, Jr., 999 N. Sepulveda Blvd., El Segundo, CA 90245

SEP 12-14, 1978—**Automatic Support Systems for Advanced Maintainability (AUTOTESTCON)** (IEEE) San Diego, CA **Prog Info:** Bob Aquais, General Dynamics Electronic Div., Mail Stop 7-98, PO Box 81127, San Diego, CA 92138

SEP 17-20, 1978—**Joint Fall Mtg. American Ceramic Soc. and IEEE Subcommittee on Ferroelectricity** (Am. Cer. Soc., IEEE) Dallas Hilton Inn, Dallas, TX **Prog Info:** Relva C. Buchanan, Dept. of Ceramic Engrg., 208 Ceramics Bldg., U. of Illinois, Urbana, IL 61801

SEP 21-23, 1978—**Interactive Techniques in Computer Aided Design** (IEEE) Palazzo dei Congressi, Fiera di Bologna, Italy **Prog Info:** Dr. Bertram Herzog, Computer Ctr., U. of Colorado, Boulder, CO 80303

SEP 24-27, 1978—**Electronic and Aerospace Systems Conv. (EASCON)** (IEEE) Sheraton Intl., Arlington, VA **Prog Info:** Bette English, At-Your Service, Inc., 821 15th Street NW, Washington, DC 20005

SEP 25-27, 1978—**Ultrasonics Symp.** (IEEE) Cherry Hill Hyatt House, Cherry Hill, NJ **Prog Info:** F.S. Welsh, Bell Telephone Labs, 555 Union Blvd., Allentown, PA 18103

OCT 1-4, 1978—**Design Engineering Technical Conf.** (ASME) Radisson Hotel, Minneapolis, MN **Prog Info:** Technical Affairs Dept., ASME, 345 E. 47th St., New York, NY 10017

OCT 1-5, 1978—**Industry Application Society Annual Meeting** (IEEE) Royal York Hotel, Toronto, Ont. **Prog Info:** W. Harry Prevey, 4141 Yonge Street, Willowdale, Ont., MSP 1N6

OCT 15-19, 1978—**ISA Intl. Conf. and Exhibit** (ISA) Philadelphia, PA **Prog Info:** Instrument Society of America, 400 Stanwix St., Pittsburgh, PA 15222

OCT 16-17, 1978—**Joint Engineering Management Conf.** (IEEE) Regency, Denver, CO **Prog Info:** Henry Bachman, Hazeltine Corp., Greenlawn, NY 11740

OCT 16-18, 1978—**Electronics Conference and Natl. Communications Forum** Chicago, IL **Prog Info:** National Electronics Conf., Oak Brook Executive Plaza #2, 1211 W. 22 St., Oak Brook, IL 60521

OCT 18-20, 1978—**Joint Automatic Control Conf.**, (IEEE) Civic Center, Philadelphia, PA **Prog Info:** Dr. Harlan J. Perlis, New Jersey Institute of Tech., 323 High Street, Newark, NJ 07102

OCT 18-20, 1978—**Canadian Communications and Power Conf.** (IEEE) Queen Elizabeth Hotel, Montreal, P.Q. **Prog Info:** Jean Jacques Archambault, CP/PO 757, Montreal, Quebec H2L 4L6

OCT 21-25, 1978—**Engineering in Medicine and Biology** (IEEE) Marriott Hotel, Atlanta, GA **Prog Info:** Walter L. Bloom, M.D., Georgia Institute of Tech., Atlanta, GA 30302

OCT 23-25, 1978—**Digital Satellite Communications** (IEEE) Hotel Reine Elizabeth, Montreal, Que. **Prog Info:** Marcel Perras, Teleglobe Canada, 680 Sherbrooke Street W., Montreal, Que. H3A 2S4

OCT 23-25, 1978—**Fourth Intl. Conf. on Digital Satellite Communications,** Montreal, Que. **Prog Info:** Mrs. Sara Bairn, Teleglobe, 680 Sherbrooke St. West, Montreal, Que. H3A 2S4

OCT 24-26, 1978—**Biennial Display Research Conf.** (IEEE,SID) Cherry Hill Inn, Cherry Hill, NJ **Prog Info:** Lawrence Goodman, RCA Laboratories, Princeton, NJ 08540

OCT 25-27, 1978—**Intelec (Intl. Telephone Energy Conf.)** Sheraton Park, Washington, DC **Prog Info:** J.J. Suizzi, Bell Laboratories, Room 5D-178, Whippany, NJ 07981

OCT 29-NOV 3, 1978—**SMPTE Technical Conf. and Equipment Exhibit,** Americana Hotel, New York, NY **Prog Info:** SMPTE, 862 Scarsdale Ave, Scarsdale, NY 10583

OCT 30-NOV 1, 1978—**Semiconductor Laser Conference** (IEEE, QEA) Sheraton at Fisherman's Wharf, San Francisco, CA **Prog Info:** T.L. Paoli, Bell Laboratories, 600 Mountain Ave., Murray Hill, NJ 07974

NOV 3-6, 1978—**Audio Engrg. Soc. Conf.** (AES) New York, NY **Prog Info:** Almon H. Clegg, Panasonic Corp., One Panasonic Way, Secaucus, NJ 07094

NOV 6-9, 1978—**Advanced Techniques in Failure Analysis** (IEEE) Marriott Hotel, Los Angeles, CA **Prog Info:** Robert J. Kolb, TRW Defense & Space Systems, 1 Space Park R6/2184, Redondo Beach, CA 90278

DEC 4-6, 1978—**Intl. Electron Devices Meeting** (IEEE) Washington Hilton, Washington, DC **Prog Info:** Susan Henman, Courtesy Associates, 1629 "K" Street, NW, Washington, DC 20006

DEC 4-6, 1978—**National Telecommunications Conf.** (IEEE) Hyatt Hotel, Birmingham, AL **Prog Info:** H.T. Uthlaut, Jr., South Central Bell., P.O. Box 771, Birmingham, AL 35201

DEC 12-14, 1978—**MIDCON** (IEEE) Dallas Convention Ctr., Dallas, TX **Prog Info:** W.C. Weber, Jr., EEEI, 999 N. Sepulveda Blvd., El Segundo, CA 90245

JAN 23-25, 1979—**Reliability and Maintainability** (IEEE) Shoreham Americana, Washington, DC **Prog Info:** D.F. Barber, POB 1401, Branch PO, Griffiss AFB, NY 13441

Calls for papers

JAN 23-25, 1979—**ATE Seminar/Exhibit: Automated Testing for Electronics Manufacturing** Marriott, Los Angeles, CA **Deadline Info: 9/1/78 250-word abs. to** Sheila Goggin, ATE Seminar/Exhibit, 1050 Commonwealth Ave., Boston, MA 02215

SEP 23-26, 1979—**3rd World Telecommunication Forum** (ITU) Geneva, Switzerland **Deadline Info: 9/30/78 100-200 word abs. to** A.E. Joel, Jr. Bell Telephone Laboratories, Room 2C-632, Holmdel, NJ 07733

Pen and Podium

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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.

Automated Systems

J.E. Fay
ATE operating systems, high order language and standardization—Industry/Joint Services Automatic Test Conf. and Workshop, San Diego, CA (4/6/78)

J.C. Haggis
ATE test program development—ATE Symp., U. of Alabama, Huntsville, AL (6/15/78)

R.E. Hartwell
ATE for maintenance of non-electronic systems—ATE Symp., U. of Alabama, Huntsville, AL (6/15/78)

R.J. Monis
Automated test system—ATE Symp., U. of Alabama, Huntsville, AL (6/15/78)

J.A. Murnane
Observations and examples of ATE acquisition—Industry/Joint Services Automatic Test Conf. and Workshop, San Diego, CA (4/6/78)

S.P. Patrakis
PRICE for design to unit product cost—PRICE Users' Meeting, San Francisco, CA (4/17/78)

E.W. Richter
Broadband discriminators for ATE measurement of sideband noise—*IEEE Trans. on Instrumentation and Measurements* (6/78)

Advanced Technology Laboratories

M. Corrington
Implementation of fast cosine transforms using real arithmetic—Natl. Aerospace & Electronics Conf., Dayton, OH (5/16-18/78)

A. Feller
A fully automatic layout program for LSI devices that optimizes speed performance—Lehigh Valley Semiconductor Symp., Bethlehem, PA (5/12-13/78)

A. Feller
A speed oriented fully automatic layout program for random logic VLSI devices—Natl. Computer Conf., Anaheim, CA (6/5-8/78)

D. Gandolfo|J. Tower
L. Elliott|E. Herrmann
Progress in programmable CCD correlators—IEEE Workshop on CCD Signal Processing, New York, NY (5/15-16/78)

Government Communications Systems

C.D. Fisher
From ASPRs to DARs: a change or more of the same?—American Defense Preparedness Assoc., Technical Documentation Division, 20th Annual Meeting, New Orleans, LA (6/7-9/78)

S. Klurman
A predictive analysis for optimum contour-after-wear for magnetic heads—IEEE Intermagnetic Conf., Florence, Italy (5/10/78)

B. Tyree
Ground mobile forces tactical satellite SHF ground terminals—Conf. *Record*, Intl. Conf. on Communications, Toronto, Canada (6/4-7/78)

Government Systems Division Staff

J. Hillibrand
Design tools for custom LSI—Industry/SAMSO Conf. and Workshop on Mission Assurance, Los Angeles, CA (4/25-27/78)

Laboratories

J.J. Hanak|V. Korsun
Granular metal barrier contacts in amorphous silicon solar cells—*Proc.*, 13th IEEE Photovoltaic Specialists Conf., Washington, DC (6/5-8/78)

P.H. Robinson|R.V. D'Aiello
D. Richman|B.W. Faughnan
Epitaxial solar cells on low-cost silicon substrates—*Proc.*, 13th IEEE Photovoltaic Specialists Conf., Washington, DC (6/5-8/78)

Missile and Surface Radar

J.A. Bauer
State of the art leadless chip carrier applications for avionics packaging—IEEE Computer Packaging Symp., Skytop, PA (5/18/78)

M.W. Buckley
Project/program management—Course Director, Berkeley, CA (6/14-16/78)

M.W. Buckley
Decision making techniques for engineering managers—Conf. *Record*, Electro (IEEE Electronic Show and Convention), Boston, MA (5/78)

C. Gumacos
Weighting coefficients for certain maximally flat nonrecursive digital filters—Letter, *IEEE Trans. on Circuits and Systems* (4/78)

D.L. Pruitt
Hybrid SCR switch—*Proc.*, Thirteenth Pulse Power Modulator Symp., Buffalo, NY (6/20-22/78)

D.L. Pruitt
High voltage dc power conditioner—*Proc.*, Thirteenth Pulse Power Modulator Symp., Buffalo, NY (6/20-22/78)

A. Schwarzmann
The high power performance of a 5 kW MIC diode phase shifter—*Digest*, GMTT Symp., Ottawa, Ont. (6/29/78)

R.J. Smith
Distributed microprocessing in radar systems—*Proc.*, 1978 IEEE Intl. Symp. on Circuits and Systems, New York, NY (5/78)

G.W. Suhy
Real-time simulation as a tool for system development—*Proc.*, Ninth Annual Modeling and Simulation Conf., Pittsburgh, PA (4/78)

Patents

Advanced Technology Laboratories

M.L. Levene
Creating a closed image from segments—4088867

Astro Electronics

C.A. Berard
Guard circuit for high impedance signal circuits—4091430

Automated Systems

W.J. Hannan
Format for color diffractive subtractive filters—4094584

Broadcast Systems

B.M. Pradal|P.L. Buess
Frequency linearization and sensitivity equalization of a frequency modulated crystal oscillator—4088968

Consumer Electronics

S. Miko
Ferroresonant transformer structure—4088942

Government Communications Systems

L.V. Hedlund
Chrominance signal transcoding apparatus—4093959

K.R. Keller
Forming patterned polycrystalline silicon—4090915

Laboratories

F. Aschwanden
Master oscillator synchronizing system—4092672

P.K. Baltzer
Parallel access memory system—4092728

S. Berkman|K.M. Kim|H.E. Temple
Si_3N_4 coated crucible and die means for growing single crystalline silicon sheets—4090851

G. Denes
Random access-erasable read only memory cell—4095281

J. Dresner|B. Goldstein
Magnesium oxide dynode and method of preparation—4088510

J. Dresner|K.W. Hang
Article with electrically-resistive glaze for use in high-electric fields and method of making same—4091144

M. Ettenberg
Multi-layer reflector for electroluminescent device—4092659 (assigned to U.S. Government)

A.M. Goodman|C.E. Weitzel
Method of adjusting the leakage current of silicon-on-sapphire insulated-gate field-effect transistors—4091527

L.A. Goodman
Liquid crystal matrix display device with transistors—4094582

W.H. Groeneweg|A.V. Tuma|L.A. Harwood
Controlled oscillator with increased immunity to parasitic capacitance—4095255

P.E. Haferl
Pincushion correction circuit—4088931

F.Z. Hawrylo|H. Kressel
Electroluminescent semiconductor device with passivation layer—4095011

E.P. Herrmann
Charge coupled device with diode reset for floating gate output—4090095

A.C. Ipri
Silicon implanted and bombarded with phosphorus ions—4092209

H.F. Lockwood|H. Kressel
Stripe contact providing a uniform current density—4092561

K.D. Peters
Disc caddy and disc player system therefor—4093152

P.M. Russo
Priority vectored interrupt using direct memory access—4090238

F.N. Sechi
Connection of a plurality of devices to a circular waveguide—4091334

W.W. Siekanowicz|C.H. Anderson
T.L. Credelle
Flat display device with beam guide—4088920

M. Toda|S. Osaka
Surface acoustic wave absorber—4090153

C.C. Wang|T.C. Lausman|R.F. Bates
Method of regenerating a lead monoxide target layer of a camera tube—4090758

C.F. Wheatley, Jr.
Semiconductor device having symmetrical current distribution—4091409

C.F. Wheatley, Jr.
Voltage reference circuits—4088941

J.P. Wittke
Method of aligning optical fibers with light emitting optical devices—4090777 (assigned to U.S. Government)

P.N. Yocom
Rare earth activated lanthanum and lutetium oxy-chalcogenide—RE29662

Missile and Surface Radar

M.L. Bardash|C.P. Clasen|R.M. Scudder
L.H. Simon|C.S. Sorkin|R.O. Yavne
R.W. Ekis|A.I. Mintzer
Ground-controlled guided missile system—4093153 (assigned to U.S. Government)

C.E. Profera
Beam forming network—4091387

Picture Tube Division

F.C. Farmer, Jr.
Electrical continuity test apparatus having a forward biased diode across the test terminals—4088947

R.L. Barbin
Convergence apparatus for in-line beams—4091347

S.A. Harper
Photographic method for printing particle pattern with improved adherence utilizing vanadates—4089687

Solid State Division

A.A. Ahmed
Voltage supply regulated in proportion to sum of positive- and negative-temperature-coefficient offset voltages—4095164

R.R. Brooks|J.E. Wojslawowicz
Direction reversing direct current motors and their control—4095155

L.F. Heckman, Jr.
Coaxial cavity microwave oscillator with manually adjustable capacitive feedback element—4091337

M.V. Hoover
Complementary symmetry FET mixer circuits—4090139

L.A. Kaplan
Circuit for reducing ripple voltage—4092609

W.N. Lewis
Combination glass/low temperature deposited $Si_wN_xH_yO_z$ passivating overcoat with improved crack and corrosion resistance for semiconductor devices—4091406 (assigned to U.S. Government)

J. Ollendorf|F.J. Cestone
Method of performing contactless photolithography—4088406

O.H. Schade, Jr.
Amplifier circuits—4092612

H. Sorkin
Process for filling dynamic scattering liquid crystal cells—4091847

Engineering News and Highlights

Race is new EdRep at Consumer Electronics

Steve Race has been appointed an Editorial Representative for Consumer Electronics in Indianapolis. He is Manager, Manufacturing Projects, in Manufacturing Technology, and has held test design and quality control engineering and management positions in the Bloomington and Juarez plants.

As EdRep, Steve will assist CE manufacturing engineers with papers for the *RCA Engineer* and inform the editors of new developments, professional activities, awards, publications and promotions in his area.

Martin appointed to GSD post

Thomas A. Martin has been appointed a Staff Technical Advisor, Engineering, for the Government Systems Division. He will advise on the design of hardware and software systems being produced for government agencies. GSD's four business organizations are Missile and Surface Radar, Moorestown; Astro-Electronics, Princeton; Goverment Communications Systems, Camden; and Automated Systems, Burlington. Since joining RCA in 1970 he has held several positions in systems management.

Promotions

Alascom

Ronald G. Weber from Senior Engineer to Manager, Systems Engineering.

Government Communications Systems

Ray H. Brader from Senior Member, Engineering Staff, to Unit Manager, Communication Systems Engineering.

Kenneth J. Prost from Member, Technical Staff, to Unit Manager, Defense Communications Laboratory.

Edward Van Keuren from Unit Manager to Manager, Command and Control Systems.

Astro-Electronics

R. Mancuso from Engineer to Manager (Specialty) Engineering.

Advanced Technology Laboratories

Alba F. Cornish from Senior Member, Engineering Staff, to Unit Manager, Processor Design Group, Digital Systems Laboratory.

Stanley E. Ozga from Senior Member, Engineering Staff, to Unit Manager, Processor Design Group, Digital Systems Laboratory.

James E. Saultz from Manager, Marketing Development, to Manager, Digital Systems Laboratory.

Degrees granted

Government Communications Systems

David Sheby—PhD, Engineering Science; California Institute of Technology, Pasadena, CA.

Staff announcements

RCA Laboratories

David D. Holmes, Director, Television Research Laboratory, appointed **Robert H. Dawson,** Manager, New Technology Applications Research.

Service Company

Edward B. Campbell was appointed Manager of Industrial Electronic Services Marketing.

Picture Tube Division

Donald R. Bronson, Division Vice President, International, appointed **Gene W. Duckworth,** Director, Operations, Soviet Equipment Contract.

Charles W. Thierfelder, Division Vice President, Product Safety, Quality and Reliability, appointed **J. Paul Sasso,** Administrator, Field Quality Program Coordination.

National Broadcasting Company, Inc.

Julian Goodman, Chairman of the Board, announced the election of **Fred Silverman** as President and Chief Executive Officer and a Member of the Board.

President and Chief Executive Officer

Edgar H. Griffiths, President and Chief Executive Officer, announced the election of **Herbert S. Schlosser,** Executive Vice President, to the Board of Directors.

Edgar H. Griffiths, President and Chief Executive Officer, announced the election of **Richard W. Sonnenfeldt** to Vice President, "SelectaVision" VideoDisc Project.

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

Picture Tube Division

Lyons, K.C., Midland, Ont.; ONT-

Professional activities

Hampel on Critical Technology Committee

Dan Hampel, Manager, Defense Communication Laboratory, Government Systems Division, recently served as one of ten members of the Critical Technology Expert Group on Array Processors. This group of experts was formed at the suggestion of industrial leaders to aid the government in defining export controls on array processors.

University of Toronto honors Hillier

Dr. James Hillier, retired Executive Vice President and Senior Scientist, will be awarded an honorary Doctor of Science degree by the University of Toronto. He is being recognized for his pioneering work on the electron microscope.

Kaye on IEEE committee

Leo Kaye, who is an engineer and scientist on the technical staff of Data Systems Engineering, Automated Systems, Burlington, has been appointed to fill the Standards Affairs Seat of the Systems Technology Technical Interest Council (TIC), IEEE Computer Society. In this function he will represent the TIC at Standards Committee meetings, ensure that each Technical Committee has appropriate representation on the Standards Committee, identify those areas within each TC that requires standards activity, assist the TC Chairman as needed, and in general promote all TIC standards related activities.

Good things happen . . .

Two artists who were responsible for designing *RCA Engineer* covers have recently received professional recognition.

Andy Whiting received a third-place ribbon in the annual Society of Commercial Photographers of Delaware Valley print competition for his photo of an ear of corn with two hybrid circuits (our Aug/Sep 1977 cover.) Andy is the Leader at Photographic Services of Missile and Surface Radar, Moorestown.

Bob Canary, who designed the cover for the communications issues (Oct/Nov, 1977 and Dec/Jan, 1977-78) was recently promoted from Illustrating Leader of the ATL Engineering Communications group to Administrator, Proposal and Presentation Graphics, Government Systems Division, Marketing.

Burlington has Technical Recognition Dinner

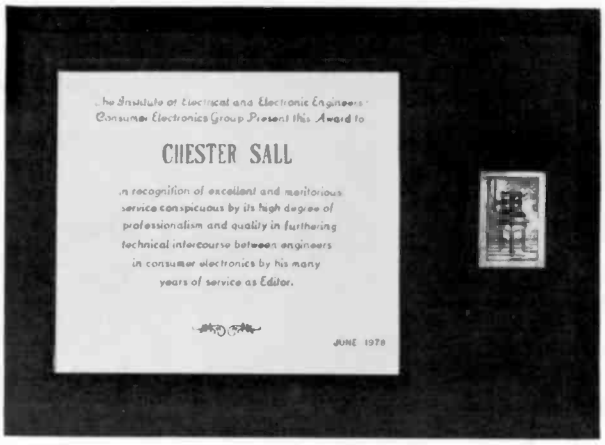
Forty-one engineers and scientists and their spouses from Automated Systems, Burlington, were recently honored at that activity's annual Authors' and Patent Awards Dinner. Of the forty-one people, ten had published papers in the *RCA Engineer* in 1977.

At the Technical Recognition Dinner, **Dick Hanson,** the Manager of Design Engineering, Non-Electronic Test Engineering got his ten-patent-award; **Steve Hadden,** a Senior Member of the Technical Staff of the same group, got his five-patent-award. Shown are (l. to r.) **Harry J. Woll,** Div. V.P. and General Manager; **Dick Hanson; Steve Hadden;** and **John Regan,** Vice President, Patent Operations.

GCS honors authors/inventors

Government Communications Systems recently held its annual Authors and Inventors reception in Camden. Of the 85 who attended, fifty-five were people who wrote or presented papers or filed patent disclosures in 1977.

Communication Award—Chet Sall, an Editorial Representative for the *RCA Engineer*, who recently retired after 35 years with RCA, was awarded this plaque by the IEEE. He is a charter member of that organization's Group on Professional Communications.



The Institute of Electrical and Electronic Engineers
Consumer Electronics Group Present this Award to

CHESTER SALL

in recognition of excellent and meritorious
service conspicuous by its high degree of
professionalism and quality in furthering
technical intercourse between engineers
in consumer electronics by his many
years of service as Editor.

JUNE 1978

Editorial Representatives

Contact your Editorial Representative, at the extensions listed here, to schedule technical papers and announce your professional activities.

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KRISHNA PRABA Gibbsboro, N.J. Ext. 3605
ANDREW BILLIE Meadow Lands, Pa. Ext. 6231

Mobile Communications Systems

FRED BARTON* Meadow Lands, Pa. Ext. 6428

Avionics Systems

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JOHN McDONOUGH Van Nuys, Cal. Ext. 3353

Cablevision Systems

JOHN OVNICK* N. Hollywood, Cal. Ext. 241

Government Systems Division

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AL SKAVICUS Burlington, Mass. Ext. 2582
LARRY SMITH Burlington, Mass. Ext. 2010

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