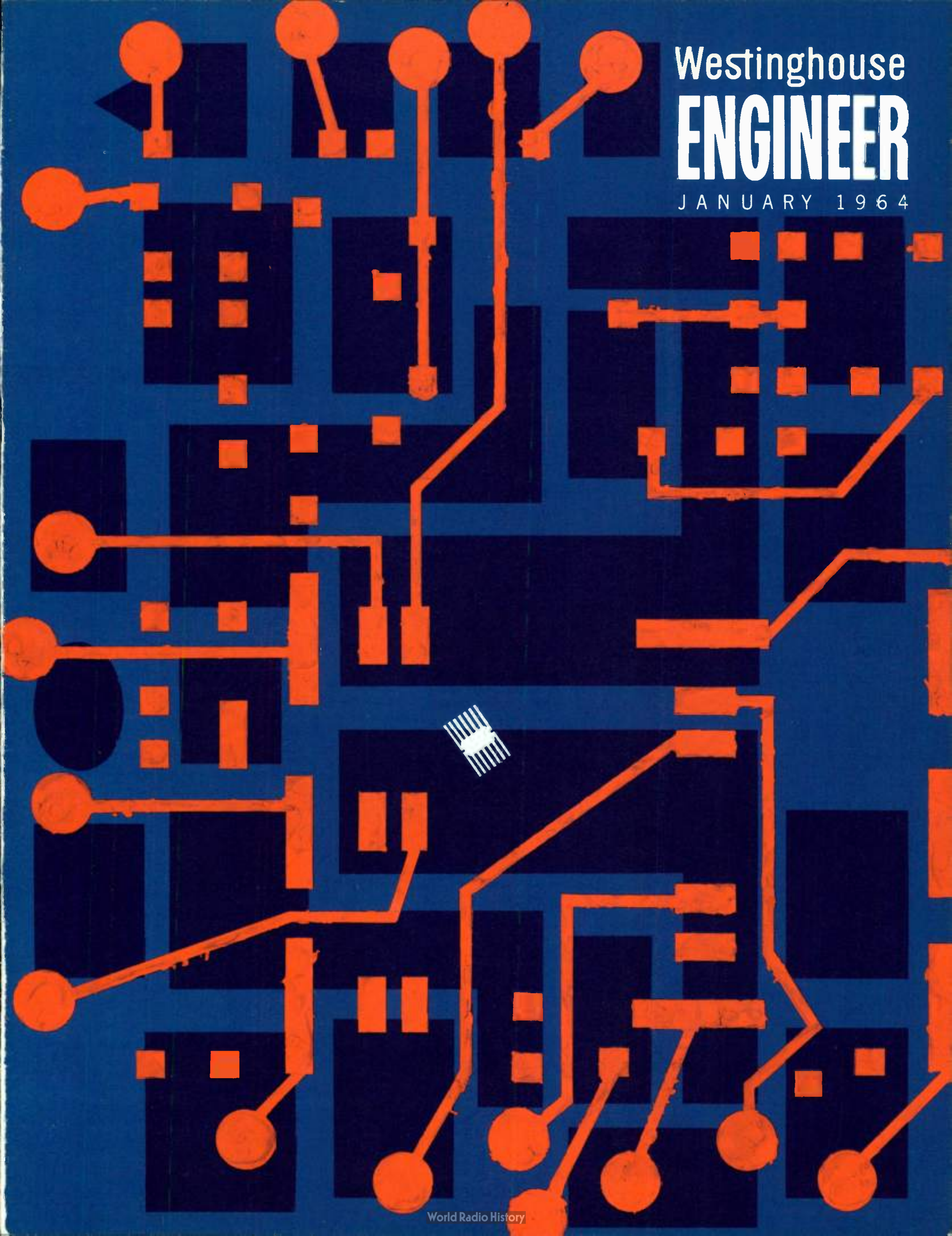

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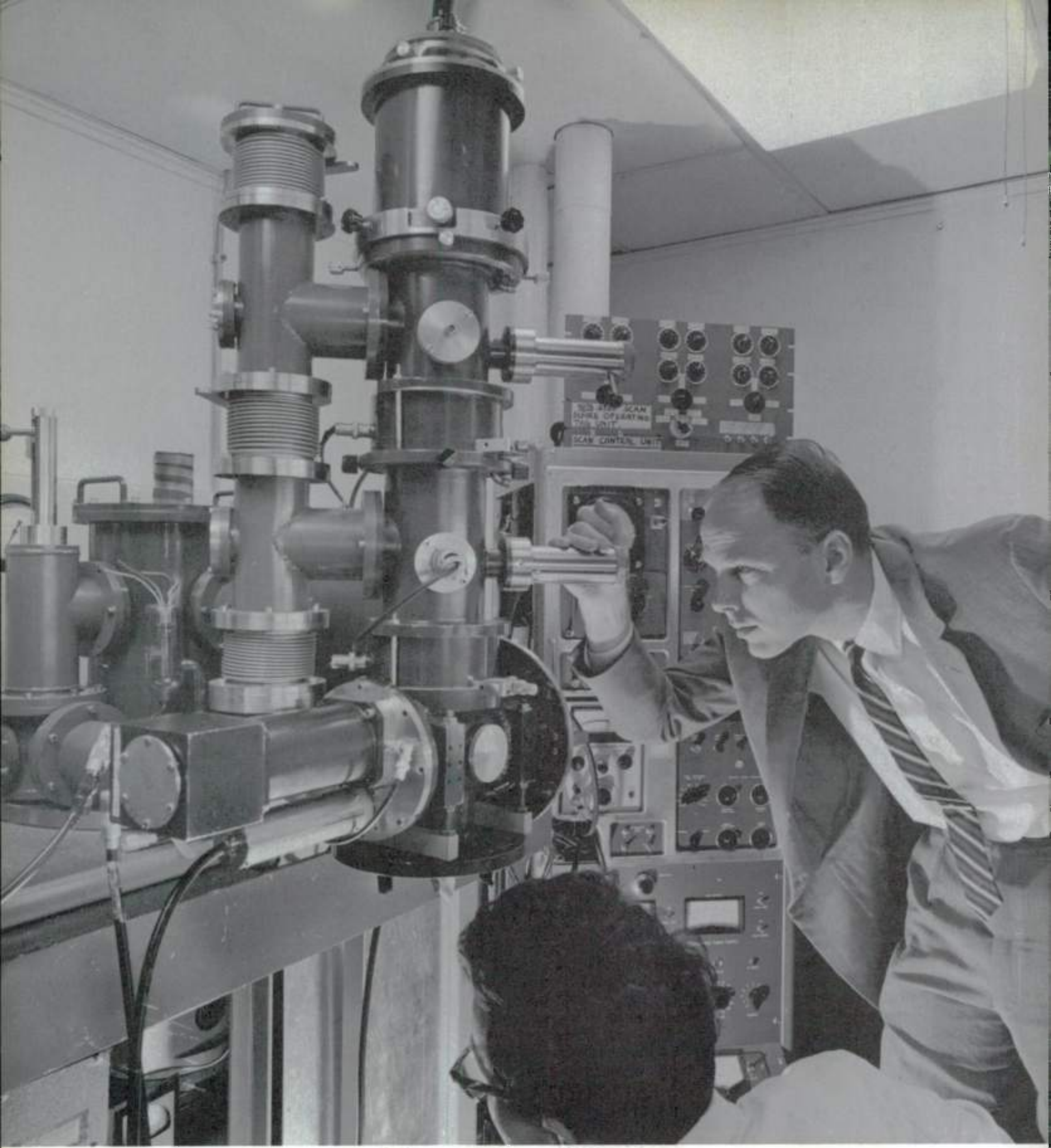
JANUARY 1964



Scanning electron microscope, a new type of electron microscope, forms detailed images of tiny surface areas by scanning them with a fine electron beam. The beam causes the specimen to emit secondary electrons in numbers determined by the shape and nature of the surface. These electrons are collected and converted to an image. Resolution and depth of focus are better than can be achieved with optical microscopes, and magnification is about 10 times greater. One of the initial uses of the instrument is in studying molecular electronic devices. It reveals the intricate surface structures of these devices and also shows the electric fields on them as they operate. (See page 31.)

Westinghouse ENGINEER

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Cover Design: The integrated circuit is the first form of molecular electronics to reach the initial stages of mass production. The elements chosen for this month's cover design are masking art for the circuit, an interconnection pattern, and an integrated-circuit package.

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Molecular Electronics and the Circuit Engineer

E. A. Sack, Engineering Manager, Molecular Electronics Division,
Westinghouse Electric Corporation, Baltimore, Maryland.

Practical application of molecular-electronic techniques depends on knowledgeable design of the equivalent circuit, from which the integrated circuit can be developed.

The techniques of molecular electronics make possible the integration of functions ordinarily performed by an entire assembly of electronic components into a tiny block of material. Circuit functions of as many as 50 components—resistors, capacitors, transistors, and diodes—can now be assembled into a silicon block only 60 by 60 by 8 mils. Molecular electronics, in the form of the *integrated circuit*, has reached the initial stages of mass production.

Integrated Network Design

During the early development of molecular electronics, the role of the circuit engineer in a technology where, supposedly, networks would no longer be assembled from discernible components, was somewhat in doubt. It is now clear that knowledgeable circuit design is a key step in the application of integrated circuitry; successful "molecularization" of a system often depends on decisions made by the circuit engineer long before the molecular-device designer enters the picture.

If a circuit engineer seeks to synthesize a subsystem function by interconnection of "off-the-shelf" integrated-circuit networks, he will find them increasingly well characterized in reasonably familiar terms, and generally amenable to the techniques of synthesis, analysis, and worst-case design—all familiar techniques for applying conventional components. If, on the other hand, the circuit engineer wishes to determine whether a circuit he is already using can be translated into integrated form (and this is the more frequent circumstance today), he must have adequate knowledge of the present capabilities and limitations of the technology. Some basic guidelines can be established for judging whether a given subsystem or circuit can be economically fabricated in silicon. By observing these rules, the circuit engineer can avoid enticing the device engineer into overambitious objectives; but he can also realize the cost, reliability, and performance advantages inherent in silicon networks.

The lumped-component equivalent circuit will remain a principal means of communication between the circuit engineer and the integrated-device designer for some time to come. This does not mean that the overall function to be performed is not the dominant specification, or that the device designer simply copies the lumped equivalent circuit "piece-by-piece" into the silicon chip. It does mean, however, that the equivalent circuit is a familiar and powerful medium of communication between the circuit engineer and the device designer.

The capabilities of the integrated circuit technology are depicted symbolically in Fig. 1. The number of equivalent lumped components to be integrated into a single silicon chip is plotted along the x-axis; various types of components are listed on the y-axis in order of increasing difficulty of integrating them into silicon. The z-axis contains a rating of the ease with which different mixes can be fabricated simultaneously by a given set of semiconductor processes. Except for the limitations of graphic display, a fourth axis for tolerance would be included to account for the most difficult tolerance encountered; in Fig. 1, this variable is considered along with the type of component.

Both engineering and production costs tend to rise as the network to be integrated increases in equivalent number of lumped components, difficulty of component type, and incompatibility of the component mix. The fact that the area of silicon required to integrate a network tends to increase with the number of components per network has led some to suggest that area alone is a good criterion of the cost (or practicality) of integrating a given network. However, a simple component to produce and a difficult one can occupy the same silicon area. Recognizing this, others have assigned weighting factors to the various component types in arriving at a cost formula. But this modification fails to account for possible processing incompatibilities of the mix. A quasi-empirical relationship that accounts for number, type, tolerance, and compatibility in proper relationship can be derived; the general characteristics of this relationship are indicated in Fig. 1.

Over the past year, one to ten components per chip have become fairly routine, and ten to twenty-five have become practical. Silicon networks have been made with 50 or more components per chip, but, until recently, the yield has not been good enough to make them feasible on a cost basis. Intensive work on process control has made networks with up to 50 components per chip practical, and the yield of networks in the 50 to 100 range, in experimental processing, is encouraging. Continuing process improvement could result in networks with several hundred components per chip in the next year or so.

At present, an absolute figure of difficulty cannot be assigned to each lumped component that might be proposed for integration into silicon. The ease with which a

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The writer wishes to acknowledge the contributions of Dr. H. C. Lin, J. Husher, and L. Morgenstern to various phases of this paper.

given lumped component function is incorporated into a silicon structure depends upon the processing method adopted by the fabricator and the particular ingenuity and experience of the device designer.

A ranking of difficulty arrived at by averaging difficulty ratings assigned to various components by a number of integrated device designers is shown in Fig. 1. The exact structure of the list has little significance, particularly in the difficult end of the spectrum where experience is limited and new developments frequently upset the ranking. However, the overall pattern of the list is significant and the spread from easy to difficult, when translated into production cost of integrated networks, can be an order of magnitude or more.

Conventional processes for fabricating silicon networks permit simultaneous fabrication of resistors, capacitors, diodes, and signal-level transistors. These component types constitute a highly compatible mix. On the other hand, semiconductor components such as field-effect transistors, high-voltage or high-current transistors, complementary pairs and other npn-pnp structures tend to require processing that must be somewhat tailored for optimum results.

Integrated Circuit Components

To date, there has been little standardization of the characteristic parameters of components commonly incorporated into integrated networks. Device designers tend to use their ingenuity in varying component configurations and ratings to best satisfy the job at hand. It is helpful to the circuit engineer, however, to be aware of typical characteristic values that are regularly achieved in practical silicon structures.

Diodes—Characteristics of typical diodes formed in integrated networks are shown in Fig. 2. One device (FO2S) is a fast recovery type for digital gates, two (FO2 and FO1) have slow recovery characteristics for charge storage compensation, and one (GP) is a general purpose diode for voltage-level-setting or clamping applications.

Transistors—Typical switching and medium-high-frequency npn transistors, which can be fabricated in integrated circuits, are shown in Fig. 3. Although parasitic capacitance can cause some decrease in the maximum performance of a given transistor design when it is buried in a silicon network, device designers are discovering structural variations that generally restore some, if not all, of the performance of the device.

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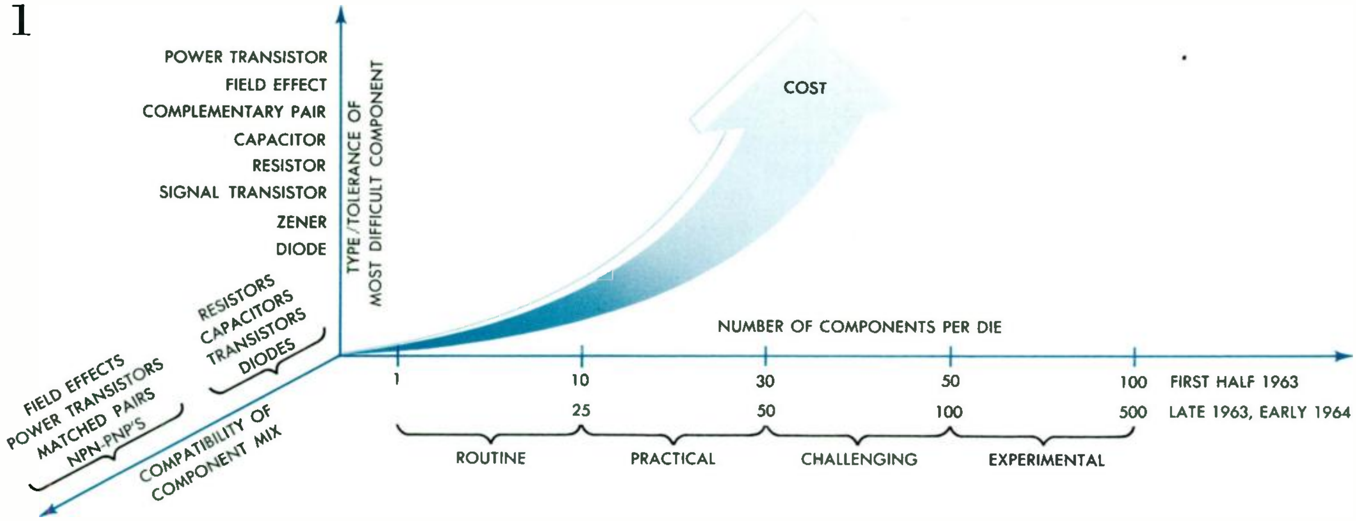


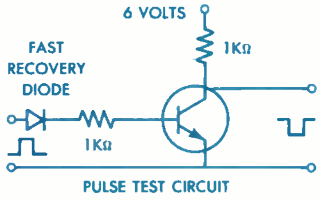
COST OF AN INTEGRATED CIRCUIT is a function of the number of components per chip, the type and tolerance of the most difficult component, and the compatibility of the component mix. This relationship is shown graphically above.

2 DIODES FOR INTEGRATED CIRCUITS

Design Identification	Performance in a Functional Electronic Block			
	Inverse Breakdown (volts)	Forward Drop (volts)	Recovery Time (ns)	Reverse Capacitance (pfd)
Logic and Switching Types				
FO2S	40	1 V @ 40 ma	2	1
FO2	10	1.0 V @ 100 ma	300	—
FO1	10	1.0 V @ 100 ma	400	—
General Purpose				
GP	25	0.65 V @ 10 ma	$I_R < 1 \mu a$ @ 10 V	

3 TRANSISTORS FOR INTEGRATED CIRCUITS (switching and high-frequency types)

Design Identification	Performance in a Functional Electronic Block							
	Collector-to-Base Breakdown with Emitter Open (volts)	Collector-to-Emitter Breakdown with Base Open (volts)	Collector-to-Emitter Saturation (volts)	Current Gain	Storage Time (ns)	Rise Time (ns)	Fall Time (ns)	High-Frequency Cutoff (mc)
TV1	40	15	0.2 V @ I_c = 25 ma	70	—	—	—	300
TV2	40	15	0.12 V @ I_c = 15 ma	50	—	—	—	700
FOUT2	40	16	0.15 V @ I_c = 20 ma	50 @ I_c = 1 ma	5	10	20	—
T34	40	17	1 V @ I_c = 200 ma	50	—	—	—	500
DD2	45	18	0.4 V @ I_c = 50 ma	50 @ I_c = 50 ma	10	15	20	—
DR0	45	18	0.7 V @ I_c = 100 ma	40 @ I_c = 100 ma	15	15	30	—
T316	50	22	0.08 V @ I_c = 20 ma	40	—	15	70	—

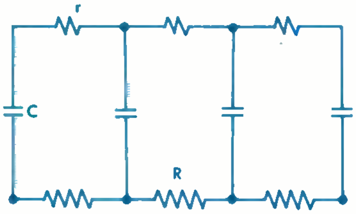
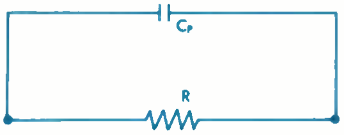


PULSE TEST CIRCUIT

4 TRANSISTORS FOR INTEGRATED CIRCUITS (power and audio-frequency types)

Design Identification	Performance in a Functional Electronic Block				
	Collector-to-Base Breakdown with Emitter Open (volts)	Collector-to-Emitter Breakdown with Base Open (volts)	Collector-to-Emitter Saturation (volts)	Current Gain	Special Note (f_T—high-frequency cutoff)
30	75	50	1.5 V @ I_c = 3 amp	30 @ I_c = 3 amp	f_T = 15 mc
58	75	50	0.8 V @ I_c = 1 amp	40 @ I_c = 1 amp	f_T = 30 mc
05	55	40	0.5 V @ I_c = 500 ma	40 @ I_c = 500 ma	f_T = 50 mc
10	30	15	0.2 V @ I_c = 25 ma	80 @ I_c = 25 ma	f_T = 100 mc
54	40	24	0.9 V @ I_c = 10 ma	30 @ I_c = 10 ma	pnp for complementary npn-pnp structures

5 RESISTORS FOR INTEGRATED CIRCUITS

	Equivalent Circuit		Major Range of Values			
			Sheet Resistance (ohms/mil²)	Resistance (ohms)	Mfg Tolerance	Temperature Coefficient of Resistance (ppm/°C)
Diffused Silicon		SILICON RESISTOR Formed by the diffusion of impurities into silicon r = Distributed resistance of the bulk semiconductor C = Distributed capacitance of a reverse-biased pn junction R = Resistance of diffused layer	100 ↓ 400	100Ω ↓ 50 KΩ	± 5% ↓ ± 20%	50 ↓ 5000
Thin Films		THIN FILM RESISTOR Formed by deposition of resistive material R = Resistance C_P = Parallel capacitance	5 ↓ 5000 +	10 ↓ 10 megΩ	± 0.01% ↓ ± 10%	− 25→ + 150 ↓ − 300→ + 300

Some low-frequency and power transistors that have been fabricated in silicon networks are shown in Fig. 4. The ratings of these devices are generally equivalent to the performance of separate silicon components.

Resistors—The resistance and tolerance ranges for typical diffused resistors in silicon networks are shown in Fig. 5. Resistance values in the 100- to 50 000-ohm range are typical, and tolerances of ±10 percent are commonly achieved by controlled processes.

Silicon diffused resistors often fall short of requirements on temperature stability. Resistors are best applied in divider arrangements, where ratios rather than absolute resistances are important. If the lumped equivalent network is properly designed, the integrated circuit can usually meet or exceed popular thermal stability specifications.

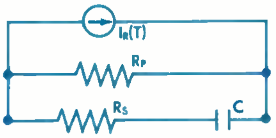
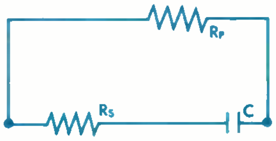
Diffused resistors are also somewhat more restricted than the circuit designer would like in fabrication tolerance, resistance range, and distributed capacitance. Because of the need for improvement in these areas, and in thermal stability, the device designer is moving rapidly to incorporate thin films of materials other than silicon into the integrated network. As shown in Fig. 5, successful incorporation of thin-film resistors will give the circuit designer considerably more freedom in the type of network that he can expect to economically integrate.

Capacitors—Typical parameter ranges for silicon-diffused and silicon-oxide capacitors are shown in Fig. 6. In both cases, the fundamental trade-off between working voltage and capacitance per unit area is evident. With diffused capacitors, the nonlinear charge-voltage relationship of the junction may lead to an objectionable voltage sensitivity of capacitance in certain applications.

Loose tolerance, voltage sensitivity, and moderately high dissipation factors of diffused-junction capacitors have led to considerable investigation of capacitors formed from dielectric layers on the surface of the chip. Oxides of silicon are convenient to fabricate but are less than ideal as dielectrics; this is particularly true of the oxide-glasses, which appear on the surface as a result of the diffusion processes. Oxides of other materials, such as tantalum and titanium, are receiving considerable attention and will be frequently incorporated in future networks.

Zener diodes—Device designers have found it relatively easy to build Zener diodes into integrated circuits when the breakdown requirements are in the 6- to 10-volt range. A tolerance of ±10 percent on the breakdown voltage is

6 CAPACITORS FOR INTEGRATED CIRCUITS

	Equivalent Circuit	Value Range of Parasitic Components			Major Range of Values				
Diffused Silicon	 Capacitance of a reverse-biased junction R_S = Equivalent series-loss resistance R_P = Leakage resistance C = Capacitance of reverse-biased pn junction $I_R(T)$ = Diode saturation current	$I_R(T)$ increases by a factor of 2 every 10°C			Breakdown Voltage (volts)	Bias (volts)	Capacitance (pfd per mil²)	Mfg Tolerance	Temperature Coefficient of Capacitance (ppm/°C)
					10	2	1.29	± 15%	200
			Min	Max	10	4	0.45	↓	↓
		I_R Diode Sat Current	< 1 nano-amp	10 μa @ 125°C	10	8	0.37		
					30	2	0.51		
		R_P Leakage Res	~ 10 megohms	~ 1000 megohms	30	16	0.30		
					70	2	0.20		
					70	50	0.04	+ 50%	
Thin Films	 Capacitor formed from a dielectric material R_S = Equivalent series loss resistance R_P = Leakage resistance C = Capacitance				Material	Working Voltage (volts)	Capacitance (pfd per mil²)	Mfg Tolerance	Temperature Coefficient of Capacitance (ppm/°C)
					SiO	6	3.2	± 10%	
			Min	Max	SiO	~ 80	0.045	± 10%	
		R_P Leakage Res	~ 10 megohms	> 2 × 10^4 megohms	SiO_2	50–100	0.026	± 10%	< 100
					Ta_2O_5	~ 100	0.65	± 3%	< 250
					TiO_2	50	1.65	± 2%	~ 800
					TiO_2	22	3.5		~ 300
					TiO_2	112	0.77		~ 300
					WO_3	~ 100	3.0		

7 TYPICAL INTEGRATED CIRCUIT DISSIPATION RATINGS FOR POPULAR PACKAGES

Package	Chip Power Dissipation (per unit area of chip mounting contact—°C chip temperature rise)
¼- × ¼-inch Flat Pack with Chip Brazed to Kovar Base	0.005 mw/mil² — °C
¼- × ⅛-inch Flat Pack with Chip "Fritted" to Ceramic Base	0.0027 mw/mil² — °C
TO-5 Braze Mount	0.005 to 0.02 mw/mil² — °C
Special Package for Integrated Circuits Containing Power Transistors	0.1 to 0.4 mw/mil² — °C

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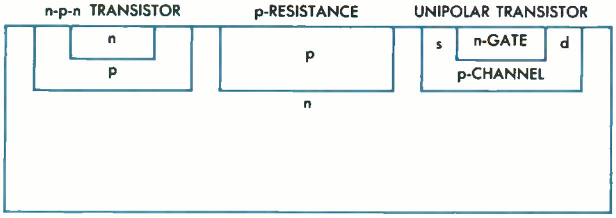

SIMULTANEOUS FORMATION of different regions speeds production of integrated circuits. Here, three p-regions are diffused simultaneously into an n-block, and n-regions are next diffused to complete the n-p-n and unipolar transistors.

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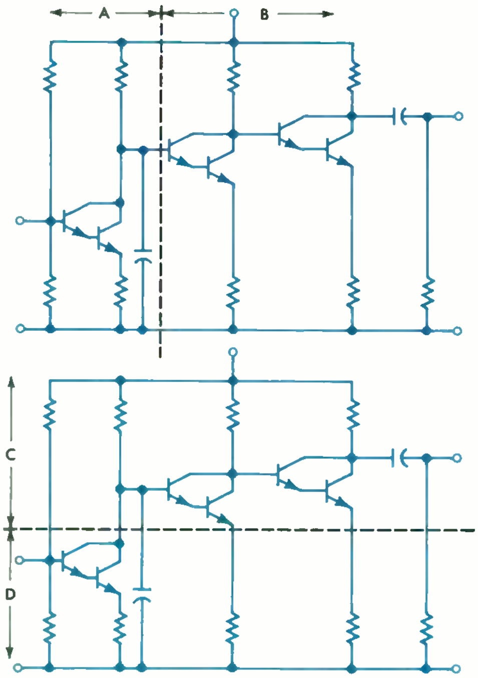

SUBNETWORKS should be chosen to perform logical electronic subfunctions; interconnections between subnetworks should also be minimized. The *A* and *B* networks are better than *C* and *D* on both counts.

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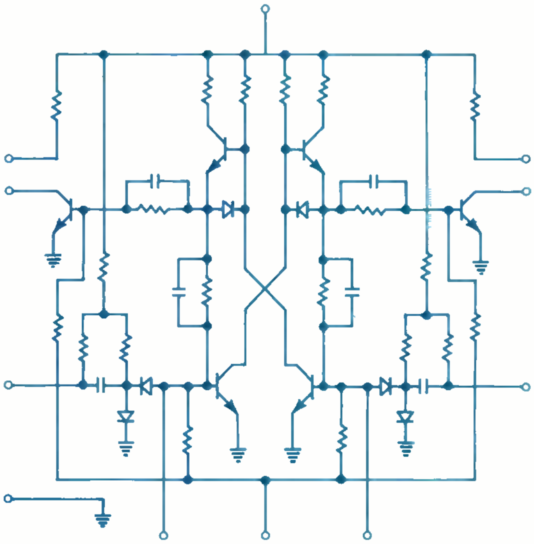

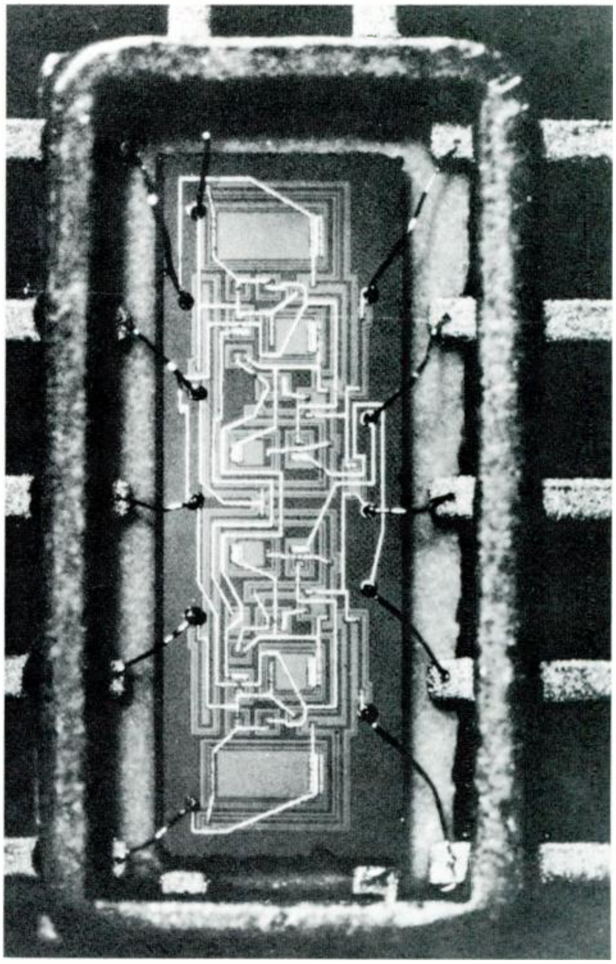

MOLECULAR FLIP-FLOP CIRCUIT on a 60 by 120-mil block (see enlarged photo) is equivalent to 40 discrete active and passive components.

not difficult to achieve. Higher voltage Zener diodes are generally made through series interconnection of several low-voltage units.

Matching—Key characteristics of certain active components in a network must often be closely matched to achieve a desired function. For example, it may be necessary that the current gains of a pair of transistors be within ±5 percent under specified bias conditions.

In conventional lumped-component circuits, matching is usually achieved by selecting parts from a large inventory. For integrated circuits, components are fabricated on a single chip, and must be matched by holding close geometrical and processing tolerances. In the present state of the art, it is reasonable to expect the current gains of neighboring transistors in a silicon block to be matched to ±10 percent. Improvements in process control should bring matching within ±5 percent on a routine basis.

Power dissipation—Because the component regions in the silicon integrated circuit are in intimate thermal association, it is generally desirable to consider the dissipation of the network as a whole rather than examining limits region by region. As in transistor technology, the power capabilities of the silicon chip are largely dictated by the encapsulation and die-mount technology. Typical operating conditions for some of the more popular integrated circuit packages are shown in Fig. 7. Allowable temperature rise at the silicon chip is, of course, dependent on the detailed environmental limits of the specific application. However, a rise of 100 degrees C may be used for approximate feasibility calculations.

Interconnections—The detailed interconnection pattern is usually determined by the integrated-device designer, so that the circuit engineer can make only approximate allowances for parasitic capacitance of interconnections in his initial calculations.

Useful design values for aluminum evaporated interconnections over silicon oxide are: sheet resistance, 0.02 ohms per square mil, and capacitance to silicon, 0.05 picofarads per square mil. Since the average interconnection is 3 mils long and 1.5 mils wide, the parasitic resistance and capacitance are approximately 0.06 ohms and 0.4 pfd per connection.

Rules for Subnetwork Selection

Frequently, the circuit engineer is confronted with a circuit that is best approached by subdivision into integrated subnetworks. The selection of subnetwork boundaries can influence the success of the application. The following guidelines will aid the process of subdivision:

Minimize interconnections—A prime objective of integrated-circuit electronics is to increase reliability by reducing external interconnections. A number of studies of digital systems have shown that proper selection of subnetwork boundaries can markedly reduce interconnections. Of course, the lead limitations of practical encapsulations place boundary conditions on the optimization; at present, fourteen-pin packages represent a practical maximum, although configurations with up to twice this number are under consideration.

Seek maximum use of chip design—A characteristic of the photomasking process for integrated circuit fabrication is that a variety of interconnect patterns for a given silicon chip layout is less expensive to provide than a variety of chip designs. This has led to consideration of so-called "universal" silicon chip designs, where the circuit designer can "shop" from a selection of components on a master chip and have them interconnected.

Unfortunately, excessive use of the universal chip concept is impractical because it requires that all components on the chip be tested and operational even though they may not be used in every interconnection; the fixed component arrangement may force the use of an unreliable and highly parasitic interconnection pattern. However, intelligent use of the concept is recommended, particularly in digital systems where the optimum subnetworks may differ only in minor details. Typically, a digital system requiring twenty subnetworks might be best satisfied by five basic chip designs and twenty interconnect patterns.

Choose a subnetwork that performs a familiar subfunction—Communication between the circuit engineer and the device designer will be improved if the subnetworks chosen for integration perform familiar electronic subfunctions. For example, if the problem is to select a cascade of amplifiers (such as shown in Fig. 9) the terminal performance of subnetworks *A* and *B* is more logical than networks *C* and *D*. The problem of providing instrumentation to test the resulting circuits is also eased by care in the selection of the subfunctions.

Group components with regard for compatibility—The silicon substrate resistivities and profiles that are optimized for one set of components in silicon may be quite antagonistic to others. Hence, it is necessary to consider compatibility as an important variable when selecting components for a subnetwork. Nothing can be gained by insisting that a difficult component be integrated with an otherwise practical network of compatible components, if the combination is a severe detriment to yield and, possibly, to overall reliability. The difficult or incompatible component is best included in the system as a separate package until technology is really prepared to handle it.

Conclusions

Integrated network technology is a powerful tool for increasing reliability and reducing cost of equipment. As with any new technology, certain design guidelines and restrictions must be observed.

The design and production costs of a network design increase with the number of equivalent lumped components per chip and are greatly influenced by the type and compatibility of the component mix. At present, networks consisting of resistors, capacitors, diodes, and transistors with 10 to 30 components per chip are economically advantageous in many systems; for these networks, design costs of a few thousand dollars and production costs of $10–20 per unit are often cited. Networks with significantly more components, difficult components or a less compatible mix, or both, cost more and may or may not be economically feasible at a given point in time.

In subdividing a system into subnetworks for integration, the circuit engineer should minimize interconnections, maximize the use of a given chip design, and select subnetworks that perform familiar subfunctions. Recognition of these guidelines can greatly facilitate full use of today's molecular circuit technology.

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Jan. 1964

Financial Concepts for Economic Studies

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An economic comparison of engineering alternatives can be accomplished most effectively by comparing the revenue requirements of competing options. The distinguishing feature of revenue-requirements analysis is the use of estimated minimum acceptable return on investors' committed capital as a component of revenue requirements. The financial concepts necessary to the understanding of revenue requirements and minimum acceptable return are discussed in this first article of a series.

Engineering economics is a special branch of industrial management concerned with selecting the most economic choice from among several engineering alternatives. It does not inquire into the absolute profitability of projects, but into *differences* in the financial desirability of the possibilities investigated. Thus, it differs sharply from either cost accounting or rate making, in that costs common to both alternatives may be deliberately ignored.

Practically all problems in engineering economics are best solved by comparing *revenue requirements* of the competing proposals. Revenue requirements are not estimates of actually expected revenues; nor are they just another name for annual costs, or fixed charges—phrases that are sometimes inaccurately used when revenue requirements is intended. The term revenue requirements has a very exact and different meaning and implies the use of special arithmetic.

Revenue Requirements

Revenue requirements are strictly defined as the hypothetical revenues that would have to be obtained to cover all expenses incurred, associated with and including *minimum acceptable return* on investors' committed capital in the enterprise, no more and no less.

At this point, minimum acceptable return can be defined briefly as the dividends and interest (paid on invested capital) that is barely good enough to satisfy investors. The distinguishing feature of the revenue requirements approach is the inclusion of this particular form of return, which differs from the variety of returns included in estimates of annual costs or fixed charges, as they are commonly evaluated and used.

In these other procedures, return is sometimes taken to mean the company's actually anticipated earnings over a period of years. Or it may represent expected return for the particular project under study. Again, the proposed percentage return may be a "cut-off" percentage arbitrarily selected by management as the lowest attractive rate the project must earn in view of the special risks involved. Or it may be the "fair return" percentage of rate base, established by the regulatory commission. On occasion, the percentage return is set at the going rate of interest on conservative investments, regardless of the risk status of the company on the project concerned. But none of these concepts represent the *minimum acceptable return* that identifies the revenue requirements discipline. The exact nature of this return, and a statistical procedure for its estimation, will be described later in this article.

The basis for identifying economic choice by revenue requirements analysis is illustrated graphically in Fig. 1. The difference between revenue requirements and total revenues on sales is profit margin (and the taxes associated with this profit margin). Thus, by minimizing revenue requirements, profit is maximized.

As indicated in Fig. 1, minimum acceptable return is one of three major components of revenue requirements. When this component has been estimated, the second component—income tax on minimum acceptable return—is known. The third major component includes all other revenue expenses, such as depreciation, operations expense, maintenance expense, etc.

Many of the parts that make up revenue requirements are direct functions of capital investment—for example, return, depreciation, taxes, and insurance. In many economic studies, future revenue requirements are arbitrarily estimated as a percentage of capital investment currently in service. This procedure usually assumes that capital investment is kept intact by making replacements immediately when retirements occur, so that investment in

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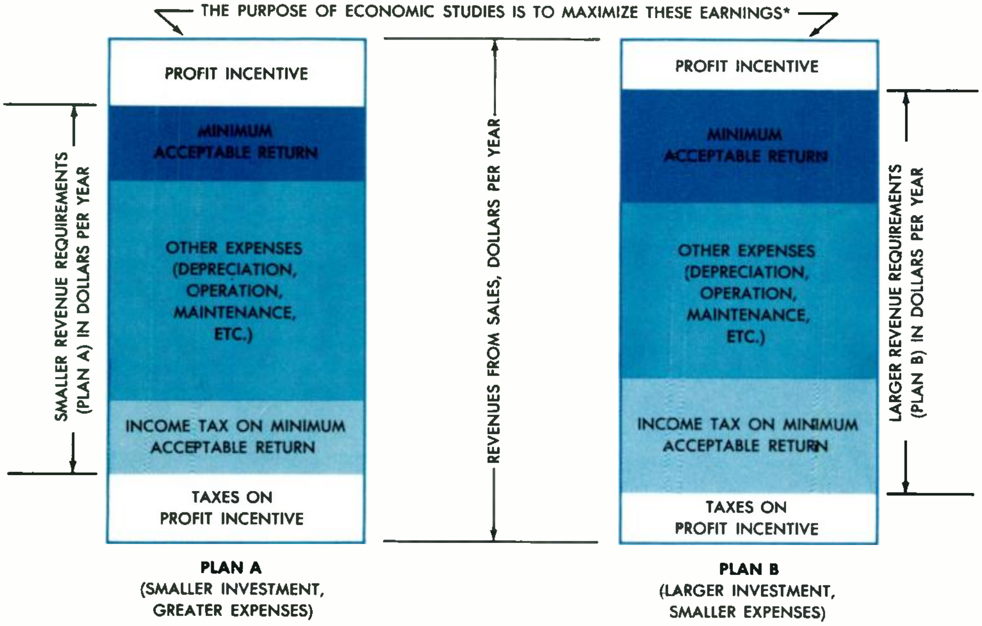
*Until his recent retirement, Mr. Jeynes was Engineering Economist with Public Service.

1 DIAGRAM OF INTENT AND BASIS FOR IDENTIFYING THE ECONOMIC CHOICE



**"Profit incentive" is the margin of actual earnings over and above the minimum acceptable return. Maximizing this margin, as by selecting Plan A in this example, maximizes earnings for existing owners (pre-project investors). Out of the same revenues, the profit margin is maximized by minimizing revenue requirements.*

Calculated revenue requirements include minimum acceptable return at the same percentage for both alternatives. But the superior plan, by increasing profit margin, tends to reduce minimum acceptable return, thus reassuring its superiority.

About this series . . . *The September 1960 issue of the Westinghouse ENGINEER carried an article, "System Simulation . . . For Aiding Utility Planning and Operation." In the introductory paragraphs of this article, the authors stated:*

". . . Expanding a power system economically depends in large part on utility management's ability to choose between alternate plans. To make economical choices, utility management needs to know what is likely to happen on the average, and also, what the odds are for unusual events. These unusual events also need a dollar evaluation.

"Expansion planning has been difficult because of the many complex interrelated factors that must be considered before making each expansion decision. What will load growth be? What will operating expenses be? What effect has inflation? Will an interconnection postpone a needed unit? How are future choices affected by present ones? Many more questions need answers."

The simulation techniques described in this article on System Simulation were developed by an operations research team consisting of personnel from Public Service Electric and Gas Company of New Jersey and Westinghouse. In this comprehensive study, dollar evaluations required that economics become an integral part of the calculations. ***Paul H. Jeynes****, the Engineering Economist for Public Service, provided the economic theory, and a new dimension was added to utility system simulation by computer.* ***C. J. Baldwin*** *directed the application of this theory for Westinghouse.*

The importance of economics in system engineering studies led Westinghouse to develop a course on engineering economics, which was offered to utility customers in its Advanced School in Electric Utility Engineering. The background material for this course was provided by Paul Jeynes.

This article is the first of a series on engineering economics by Jeynes and Baldwin that will appear in the ENGINEER. These articles will summarize the material covered in the engineering economics course.

The first article, "Financial Concepts for Economic Studies," defines revenue requirements analysis, the method for making economic comparisons of competing alternatives. The next article, "Financial Mathematics for Economic Studies," will describe the arithmetic techniques needed to convert revenue requirements for a series of years to present-worth equivalents for making economic comparisons.

Future articles in the series will discuss other methods of making economic comparisons and contrast them to revenue requirements analysis. Concepts of economy and profitability will be discussed. Problems in engineering economic studies and some of the techniques used to make long-range studies will be described.

The series will attempt to provide for the reader a background for the economic considerations that are becoming an integral part of system engineering studies. While the material has been drawn largely from the electric utility field, the economic principles discussed are applicable to any industry.

2 PERCENTAGE REVENUE REQUIREMENTS FOR STEAM GENERATING PLANTS

	Land	Structures	Boiler Plant	Turbine Generator	Accessory Electric Equipment	Miscellaneous	Weighted Average*
Return (Note 1)	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.0%
Depreciation (Note 2)	—	.69	1.46	.77	2.01	2.67	1.2
Federal Income Tax (Note 3)	4.53	2.48	2.49	2.24	2.84	2.58	2.5
Real Estate Tax (Note 4)	5.21	2.41	—	—	—	—	.6
Insurance	—	.50	.50	.50	—	—	.4
Subtotal	15.74%	12.08%	10.45%	9.51%	10.85%	11.25%	10.7%
State Taxes (Note 5)	1.89	1.45	1.25	1.04	1.30	1.35	1.3
Total of Above Items	17.63%	13.53%	11.70%	10.55%	12.15%	12.60%	12.0%

**The revenue requirement for steam generating plant is weighted in proportion to the total plant investment by accounts. This differs for different stations.*

Note 1. This is the estimated minimum acceptable percentage return on the pool of investors' committed capital.

Note 2. Depreciation is based on estimates of average life, type of dispersion, and net salvage value for each account. If the economic study involves particular items in an account, a different annuity should be calculated for the items' unique life, dispersion and salvage.

Note 3. Federal taxes are based on the 52% statutory rate, 55% debt at 3.75% interest, "Straight-line" depreciation for books, and sum-of-the-years digits for taxes; normalized. Older plant not subject to liberalized depreciation has higher taxes, and plant certified as emergency facilities has smaller percentages.

Note 4. Real estate taxes vary widely between municipalities. These are typical average values.

Note 5. This represents gross receipts and franchise taxes, in the present case.

3 TYPICAL UTILITY BALANCE SHEET ASSETS AND LIABILITIES

Assets

Utility Plant (land, buildings, equipment)
Cash (including bank deposits)
Accounts Receivable (bills sent out, not yet paid)
Materials and Supplies (not yet processed into plant or product)

Liabilities

Capital Stock (preferred and common)
Surplus (usually representing retained earnings, or earned surplus)
Long-term Debt (mortgage bonds, debentures)
Current and Accrued Liabilities:
  Bonds and notes due within one year
  Accounts payable (bills received, not yet paid)
  Customer deposits
  Taxes accrued (amounts accumulated, not yet paid)
Deferred Credits (such as unamortized premium on debt)
Reserves (usually excluding the depreciation reserve, nowadays appearing as a negative figure among assets)
Contributions in Aid of Construction (donations from government or individuals for construction purposes)

4 OUTLINE OF INVESTORS' COMMITTED CAPITAL

Sources of Capital on Which a Return is Paid

Debt

1. Long-term debt
   a. Amounts due within one year
   b. Amounts due after one year
2. Unamortized premium on debt
3. Notes payable
4. Customers' deposits on which interest is paid
5. Less amortized debt discount and expense*

Equity

6. Preferred stock, including premiums
7. Common stock
8. Capital surplus
9. Earned surplus

The term *capitalization* includes items 1b, 6, 7, 8, and 9. Note that *depreciation reserves* are not a part of investors' committed capital, since these funds come from customers.

**This adjusts the overstatement of items 1 and 2 to correctly represent the true amount of investors' committed capital in debt.*

The Accountant's Word for it . . . The vocabulary used by the financial community has a technical connotation not usually attached to it by others. Some of these distinctions may aid the reader:

Acceptable return—the minimum acceptable return to the investors in percentage of the investors' committed capital. See text.

Cost and *Value*—a sharp distinction exists in the meaning of these two words: Cost is a purchase price actually paid, while there are many kinds of value—book value, market value, depreciation value, firm value, value in use, value of exchange, etc. There is no such thing as absolute value.

Earnings and *Return*—synonymous, although earnings more often means dollars while return more often is expressed as a percentage. Both earnings and return are gross income.

Expenses—charges that accountants make to the expense accounts. The same expenditures—for example, money spent to keep equipment in operating condition—are not expenses if the accountant charges them to a capital account. Expenses are also known as *revenue deductions*.

Income—a net figure, the difference between revenues, or gross receipts, and expenses.

Gross Income—operating income from a company's main business plus other income, net, from incidental sources. Other income, net, is not net income.

Net Income—gross income less income deductions. Income deductions consist mainly of interest on long-term debt.

Revenue—receipts from sales of a company's product.

Yield—the yield of a security is the amount of earnings actually paid to the owner of the security. *Percentage yield* is the ratio of the yield to the market price the owner paid for the security. Ordinarily, less than 100 percent of earnings available for common stock dividends is paid out to stockholders. The ratio of dividends paid to the earnings payable is the *payout ratio*. The remainder is retained in the business and called *retained earnings* or *earned surplus*.

service remains equal indefinitely to the initial capital outlay (neglecting effects of inflation). Components of annual revenue requirements that are functions of capital investment can thus be readily calculated as a simple percentage of the initial capital outlay. Many companies prepare tables of typical revenue requirements for various classes of plant, expressed as a levelized percentage of initial investment on this basis. An example for steam generating plants is shown in Fig. 2. Similar tables can be developed for transmission, distribution, or other types of facilities.

Several items of cost are excluded from these tables because they do not affect differences between alternatives. Certain other costs, which may affect differences, are not shown in the tables because they are not a direct function of capital investment—for example, fuel cost, and operation and maintenance expenses. These costs may be related to the use made of the facilities, regardless of the capital investment; or, such expense may be reduced by making a larger investment in more efficient equipment.

Sometimes compilations like Fig. 2 are called *fixed charges;* or, if operation and maintanance expense are treated as a percentage of investment, they may be called *carrying charges.* But neither expression conveys the essential feature implied by the term *revenue requirements*—the inclusion of the minimum acceptable percentage return on the company pool of investors' committed capital, and income taxes on that particular return only.

Depreciation and Amortization

If a company is to offer an attractive opportunity to investors, it must obtain funds, via its revenues from sales, sufficient to recover the initial cost of assets by the time their productive life ends. Therefore, depreciation expense is a major item of revenue requirements. Regular periodic charges are made to recover initial capital commitment exactly (less scrap value) by the date of retirement. These funds are used continuously in the business as they accumulate—the same as any other capital funds—without waiting for the retirement date. By this procedure, investors' capital commitments are kept productively employed indefinitely, and the integrity of the investment is maintained at all times, so long as there is opportunity to make the productive reinvestment.

When retirement-expense charges are made in this manner, related to the life of facilities rather than in proportion to any loss in value, the process is called *amortization.* While these charges are commonly called depreciation expense, they do not in fact reflect loss in value at all. They are, strictly speaking, amortization of retirement cost. As such, they are independent of price-level changes, which only affect cost of the replacement. But, in deference to current usage, revenue requirement analysis uses the loose term depreciation expense to describe the more exact concept, amortization of retirement cost.

The Company Pool of Capital

The financial structure of a corporation provides a background for a discussion of minimum acceptable return. From a financial standpoint, a corporation has two basic characteristics:

(1) A corporation owes somebody for everything it owns—assets are offset by liabilities. For example, a public utility owns its generating stations only because it has persuaded someone to invest money; investors provide this capital.

(2) Corporations exist to make productive use of this borrowed capital—to produce satisfactory earnings in the form of interest and dividends for the investors.

A listing of typical utility assets and liabilities that appear on the balance sheet is shown in Fig. 3. Because there are many concepts of value, accountants long ago decided that the balance sheet should state assets and liabilities in terms of actual cost, so far as possible. Thus, all assets in the form of plant appear at their original cost until they are retired. Depreciation of these assets is usually listed separately as reserves for depreciation.

Comparison of a company's assets against its liabilities will reveal that a substantial part of its assets must have been purchased with funds accumulated in the depreciation reserve, by way of charges for depreciation expense. For a typical public utility, some 25 percent of investment in gross plant may have come from depreciation reserves. Because these funds come from customers and not from investors in the company, there is no return to be paid to investors as compensation for their use. Confusion on this point is one of the most troublesome concepts in engineering economics.

The liabilities that offset assets on the balance sheet (Fig. 3) are sometimes described more specifically as *liabilities, capital stock,* and *surplus.* The issuance of a bond is clearly a liability, but issuance of capital stock involves no similar formal agreement to pay back the money obtained. However, since sale of stock is an important source of capital funds for purchase of assets, capital stock is logically associated with other liability items. Surplus comes from earnings that have been retained in the business, rather than paid out to investors as dividends, so that it is also a source of capital funds.

Before an enterprise can go into business, it must raise money to start. These essential capital funds are the *investors' committed capital,* and are defined in Fig. 4. Investors' committed capital can be grouped into two categories: *debt,* which is that portion of liabilities owed to nonowners of the business, and *equity,* which represents the stockholders' (owners') share of the business.

Each type of investment, be it debt or equity, has its own particular rate of return dependent on its characteristic risk—on the degree of assurance that expected interest or dividends will actually be paid. Short-term lenders take the least risk and are normally willing to accept the smallest percentage return. Stockholders are entitled to residual earnings after all other claims have been satisfied; accordingly, they demand the largest percentage return. However, stockholders customarily modify their demands in view of the fact that if the company is prosperous, earnings and dividends per common share can be expected to increase, even though percentage earnings on the total pool of capital remains constant.

Because of this anticipated increase in earnings per share, buyers of new common-stock issues are willing to pay a price per share that results in a relatively low initial percentage yield on the purchase price. This makes available to the company a source of low-cost incremental capital, at a rate less than the current and anticipated percentage actual earnings. The spread between minimum acceptable return on incremental funds and the higher "internal" rate of actual average earnings on already-committed capital further enhances the return to existing stockholders (the lower price per share of earlier issues of the same stocks earns the same dividends per share as the new issues, for which newcomers are willing to pay a higher price). This process repeats itself with each new issue of stock at a higher price per share.

The financial success of a corporation can be measured by the margin of average earnings in excess of the lower initial return on available incremental capital funds. It is also reflected in the margin of market price per common share over and above book value per share of common equity, i.e., the paid-in value plus retained earnings per common share outstanding. The recognition of this highly desirable state of affairs distinguishes revenue requirements analysis from all other methods.

Debt Ratio and Leverage

One method of increasing the stockholders' rate of return for a given rate of company earnings is to borrow part of the capital required at a low interest rate. This is known as *trading on the equity*, or *leverage*. It is best demonstrated by a simple example:

Consider a capital investment of $1000 which earns 6 percent or $60 per year. If 20 percent of the capital is represented by debt at 4 percent interest, the yield on the equity is 6.5 percent, calculated as follows:

Debt	$ 200	@ 4%	= $ 8.00 per year
Equity	800	@ r%	= 52.00 (by difference)
Total	$1,000	@ 6%	= $60.00 per year

r = 52/800 = 6.5%

But suppose total earnings remain at 6 percent while 60 per cent of the capital is represented by debt at 4 percent interest. Now the yield on the equity is 9 percent:

Debt	$ 600	@ 4%	= $24.00 per year
Equity	400	@ r%	= 36.00 (by difference)
Total	$1,000	@ 6%	= $60.00 per year

r = 36/400 = 9.0%

These two examples illustrate that trading on the equity can benefit stockholders, and one might be inclined to increase debt even further to improve the stockholders' yield. However, consider what happens in a poor year when earnings are cut in half, say to $30:

Debt	$ 200	@ 4%	= $ 8.00 per year
Equity	800	@ r%	= 22.00 (by difference)
Total	$1,000	@ 3%	= $30.00 per year

r = 22/800 = 2.75%

5 ESTIMATE OF MINIMUM ACCEPTABLE RETURN

Assumptions

1. Common equity before the new issue = $110,000,000. This is the book value of retained earnings to date, plus paid-in value of common stock outstanding at date new issue is to be offered.
2. Additional common equity desired = $8,000,000. That is, mean common equity during the ensuing year is to be $110,000,000 + 8,000,000 = $118,000,000.
3. Assumed amount realized, after expenses, per share sold = $25.00.
4. Estimated earnings to support that price = $1.75 per share.
5. Anticipated payout ratio = 60%. This means that 40% of net earnings will be retained.
6. Shares of common stock outstanding, before new issue = 6,000,000.
7. Debt and preferred stock outstanding, after new issue, as below.

Estimate of Acceptable Return

The calculation consists of determining the number of new shares that would have to be issued to obtain the desired incremental equity at the estimated best price obtainable per share, and the percentage earnings on the firm's pool of capital necessary to support that price.

New equity = new shares × price/share plus earnings retained during ensuing year. (Retained earnings are assumed to increase linearly throughout the year.)

8,000,000 = New Shares × 25 + ½ × 0.40 × 1.75 × (6,000,000 + New Shares)
Solving this expression:
(New Shares) (25 + 0.350) = 8,000,000 − 0.350 (6,000,000,000)
New Shares = 232,742
Thus, total shares after the new issue = 6,232,742

If the company were to earn exactly the minimum acceptable percentage on the resultant mean capitalization during the ensuing year, return would be as follows:

Debt	$ 50,000,000 at	3.8%	= $ 1,900,000 per year
Preferred Stock	10,000,000 at	5.0%	= 500,000
Common Equity	118,000,000 at	1.75 × 6,232,742	= 10,907,299
Totals	$178,000,000	118,000,000	$13,307,299 per year

Estimated minimum acceptable return = $\frac{13,307,299}{178,000,000} = 7.48\%$.

This is a reduction of 58 percent in stockholders' yield. The situation is even worse if 60 percent of the capital is represented by debt:

Debt $ 600 @ 4% = $24.00 per year
Equity 400 @ r% = 6.00 (by difference)
Total $1,000 @ 3% = $30.00 per year
r = 6/400 = 1.5%

This is a reduction of 83 percent in stockholders' yield. In hard times, a company with a high percentage of debt is likely to go bankrupt if earnings are not sufficient to meet obligations.

Another important consideration is that the lenders' risk increases when the percentage debt is increased. The examples assume the interest rate on the debt remains at 4 percent, as would be the case for existing debt. However, if debt must be refinanced, investors certainly will demand a higher interest rate if the prospect of earnings are poorer.

However, so far as economic studies are concerned, the inherent riskiness of the business (the assurance that company earnings will be maintained) is not affected by the relative amount of debt nor the interest rate on the debt. And since the company's minimum acceptable return percentage on the pool of investors' committed capital is a quantitative measure of the risk, one would not expect it to be affected. The lenders' risk may increase as percentage debt increases, and the risk associated with earnings on equity may increase, but the increase in percentage debt does not affect revenues, nor the ability of the company to maintain earnings on the pool of capital. Consequently, the minimum acceptable rate of return on the pool of capital is not ordinarily affected, although this is a matter of investor reaction and not an arithmetical certainty. Adoption of the superior plan can logically be expected to reduce minimum acceptable return, if it affects it at all, thus reinforcing the advantages of the plan selected on the basis of minimum revenue requirements.

Minimum Acceptable Return

A great deal has been said about minimum acceptable return on the pool of investors' committed capital. This figure is the break-even point between barely good enough and just not good enough return. If actual earnings are greater than the minimum acceptable return, the venture is profitable; if actual earnings are less than the minimum acceptable bench-mark, the venture is unprofitable. This is just a matter of definition of terms.

Utility regulation undertakes to place a fair ceiling on profits, or allow a fair margin of actual earnings in excess of the minimum acceptable floor. But commissions cannot dictate the minimum acceptable return percentage—only the investors can do this. When a company's actual or

6 PREFERRED METHOD OF ESTIMATING MINIMUM ACCEPTABLE RETURN

(Based on investors' prediction of dividends and market price three years hence.)

Suppose market opinion of a company's stock is believed to be as follows:

Year	Earnings/Share (During Year)	Dividends/Share (End of Year)	Price/Earnings Ratio	Market Price (First of Year)
1963	$1.80	$1.35	20	$36.00
1964	1.90	1.40	20	38.00
1965	2.00	1.45	20	40.00
1966	2.10	1.50	20	42.00

The market's minimum acceptable return on common equity may be calculated as the percentage which reproduces current market price of $36, when applied to the anticipated receipts of dividends and resale market price of $42. The following successive trials at three discount rates (8%, 8.5%, and 9%) indicate a minimum acceptable return (MAR) on common equity of very nearly 9.0%.

Multipliers are present-worth factors*, $\frac{1}{(1+i)^n}$, where i is the discount rate and n is the number of years.

Future Receipts	Assumed Discount Rates (Trial Values of MAR on Common Equity)		
	8.0%	8.5%	9.0%
$ 1.35	× 0.9259 = $ 1.2500	× 0.9217 = $ 1.2443	× 0.9174 = $ 1.2385
1.40	× 0.8573 = 1.2002	× 0.8495 = 1.1893	× 0.8417 = 1.1784
1.45	× 0.7938 = 1.1510	× 0.7829 = 1.1352	× 0.7722 = 1.1197
42.00	× 0.7938 = 33.3396	× 0.7829 = 32.8818	× 0.7722 = 32.4324
	$36.9408	$36.4506	$35.9690

Further assuming 55% debt at 5% interest, 10% preferred stock at 5.5%, and 35% equity at 9% return as above, then the minimum acceptable return on the company pool of investors' committed capital is 6.45%, as follows:

55% debt at 5.0% = 2.75%
10% preferred at 5.5% = 0.55
35% common at 9.0% = 3.15
Minimum Acceptable Return on company pool of investors' capital = 6.45%

**Present-worth arithmetic will be discussed in the next article in this series. In this example, $1.25* now *is financially equivalent to $1.35 a year from now if minimum acceptable return is 8 percent; hence, the present worth factor for this condition is 0.9259.*

anticipated earnings fall below a level acceptable to investors, whether by reason of regulation or any other cause, investors simply bid a lower price for the company's stock, which in effect, increases its minimum acceptable return. The important fact is that the minimum acceptable return *rises* when actual earnings fall; minimum acceptable return *falls* as actual earnings increase.

Estimating Minimum Acceptable Return

Minimum acceptable return on the investors' pool of committed capital can be estimated by reproducing investors' anticipation of stock earnings and market price for its common equity, and combining this component of return with that on senior securities (preferred stock and debt) in proper proportion. If annual growth rate is relatively small, and price-to-earnings ratios are fairly low and stable, it may be possible to predict the earnings that will be just sufficient to maintain a fixed market price per share, year after year. In such case, the method shown in Fig. 5 will produce dependable one-shot estimates of minimum acceptable return.

Under conditions more typical of recent years, anticipated growth and a high price-to-earnings ratio make anticipated capital gains the factor of major importance to market price. Accordingly, the estimating procedure shown in Fig. 6 places the emphasis on this consideration.

The process shown in Fig. 6 is prospective. The essential requisite is not its accuracy of prediction, in the light of events as they later transpire, but the accuracy with which current expectations of investors are reproduced, whether those expectations are substantiated by events or not. Since the sophisticated large-scale investors in public-utility securities provide the primary influence on market price, the minimum acceptable return for this industry can be estimated with a high degree of confidence. The procedure is identical for nonregulated industry, but perhaps it has a degree less assurance.

Normally, minimum acceptable return is expected to be above the maximum rate on senior securities (bonds, debentures, or preferred stock), and below the company's average of actual earnings. An arithmetical average of these boundary values will approximate the more meticulous solutions illustrated in Figs. 5 and 6. This short cut may be adequate for routine studies.

All of these approaches are one-shot inquiries into the immediate situation. Since revenue requirements are by nature lifetime projections, the appropriate minimum acceptable return percentage is also a lifetime projection of successive annual one-shot estimates. Despite the variability of many of the factors involved in estimates, such as investor opinion, percentage debt and interest rates, payout policy, etc., minimum acceptable return is a remarkably stable figure, year after year. Any contrary finding casts doubt on the estimate. For a prosperous company, minimum acceptable return is always less than actual earnings; it is ordinarily greater than the dividend rate on preferred stock. It varies in an inverse direction with actual earnings, current and anticipated, but the extreme limits of possible variability are quite narrow. Unlike actual earnings, it cannot fall to zero; and it cannot exceed actual earnings so long as incremental investment is economically justified.

This concept reflects the practical situation with respect to new issues of common stock. A going business is most reluctant to accept a price below book value of common equity, since on any earnings whatever, this would mean a larger percentage yield to newcomers than to existing proprietors who are offering their stock. This places a top limit on minimum acceptable return on equity, below actual earnings on equity. At the other extreme is the maximum price that new equity investors will offer, per share; this fixes the lower limit on minimum acceptable return on equity.

Objective of Economic Studies

Obviously, the first objective of a business is to maximize earnings; more specifically, the goal is maximized per-unit earnings, a sensitive and convenient index expressed as earnings per share of common stock. But this, too, is an incomplete statement of exact intent, because leverage permits maximizing return per share simply by increasing debt, with no increase in total earnings. Another paradoxical factor is that, as mentioned before, corporations attempt to sell new issues of stock at the highest price per share obtainable, thus minimizing the rate of return to the new investor. What, then, is an exact and comprehensive statement of a corporation's financial objectives?

The answer is that there are really two parts to a company's financial objectives regarding return on its capital investment: (1) *Minimize percentage return to new investors who supply incremental capital; and* (2) *maximize return to existing stockholders.*

This financial objective for return on capital investment is an essential consideration in the problem of economic choice, which undertakes to select the alternative that will simultaneously: (1) Maximize the margin of earnings in excess of minimum acceptable return on investors' committed capital; and (2) permit minimizing selling price of product while earning the same margin in excess of minimum acceptable return on investors' committed capital. A comparison of revenue requirements permits the utility to choose the alternative that will optimize the company's financial objectives with respect to its investor-owners, and with respect to its customers and competitive position.

Comparing Revenue Requirements

Once the various components of annual revenue requirements have been determined—minimum acceptable return, depreciation, taxes, etc.—the annual revenue requirements for the alternatives to be investigated can be compared. The comparison would be a simple matter if annual values were a constant figure each year; unfortunately, this is not usually the case. Therefore, two further concepts are necessary: the single-payment, hard-cash present worth, and the life-time-levelized annual payment, both of which are financially equivalent to the typically variable annual revenue requirements. These equivalencies make economic comparisons a matter of simple arithmetic, and avoid the pitfalls and self-contradictions that are inherent in other methods of analysis. These concepts will be discussed in the next article in this series, "Financial Mathematics for Economic Studies," scheduled for the March issue.

Westinghouse
ENGINEER
Jan. 1964

Increasing the Ratings of Single-Shaft Steam Turbines

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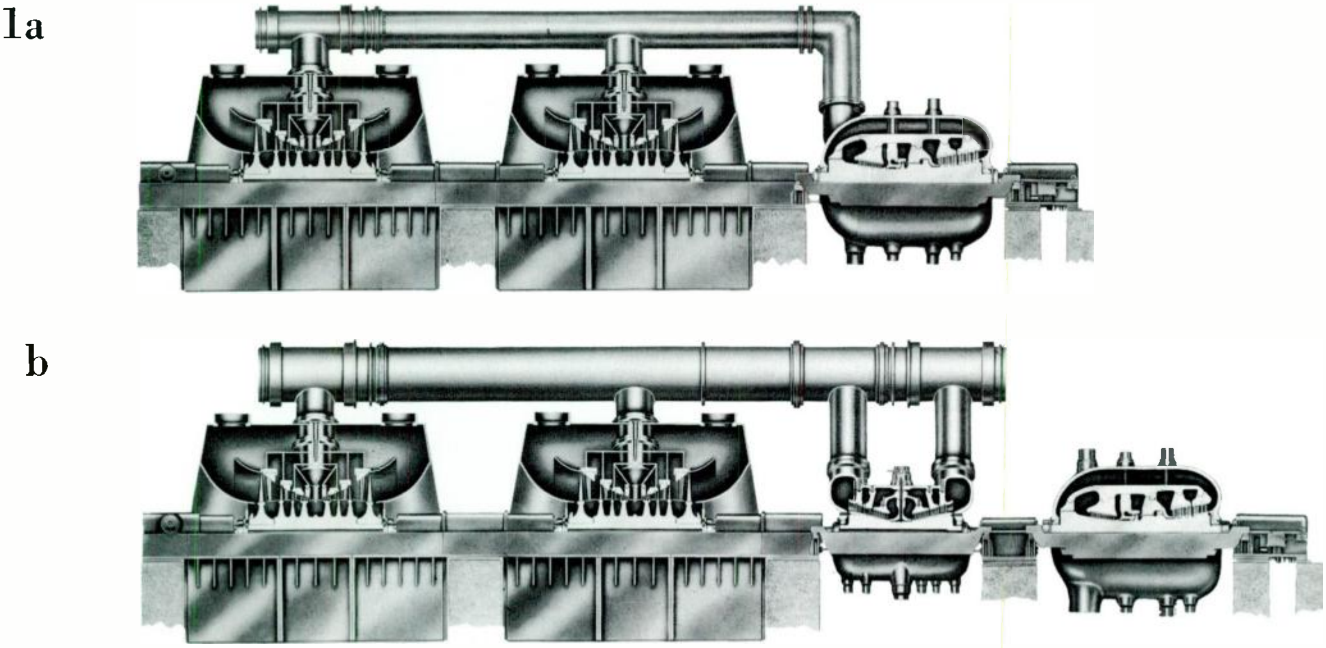
Advance design incorporates current technology into larger and more efficient tandem-compound turbines. Power capabilities of these machines now range up to 700 mw.

The designing and developing of an array of pre-engineered steam-turbine elements and components that can be used to fill future orders is known as *advance* design and development. It is a technique for continuous application of design and operation experience, technological advances, and knowledge of trends in the electric-utility industry.* Its benefits include greater flexibility of turbine arrangement, greater manufacturing standardization, and availability of improved components when they are needed. The end result of advance design and development is more economical electric power generation.

Development of tandem-compound turbine-generator units of larger capacity has been one of the major objectives of the advance design studies. Such units provide better thermal performance, lower capital cost, and greater reliability than smaller units of equivalent total capacity.

The programs have progressed to the point where 3600-rpm single-reheat turbine-generator units in the 500- to 600-mw range can be designed. These have three turbine elements in tandem (Fig. 1a). Permissible inlet steam conditions are 2400 or 3500 psi and 1000 degrees F, with reheat to 1000 degrees. (For comparison, the present largest tandem-compound unit with a combined high-pressure and intermediate-pressure element is rated at 250 mw. The largest with separate high- and intermediate-pressure



THREE TURBINE ELEMENTS IN TANDEM (*a*) make up a single-reheat turbine unit in the 500- to 600-mw range. The first element is a combination of high-pressure and intermediate-pressure blading. Combining these blade groups reduces the overall turbine length. The other two elements are low-pressure elements. (*b*) Adding a second reheat element and modifying the first combined element somewhat produces a single-shaft machine rated in the 600- to 700-mw range.

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*"Advance Development in Component Design for Large Steam Turbines," H. R. Reese, *Westinghouse ENGINEER*, vol. 19, July 1959, p. 98.

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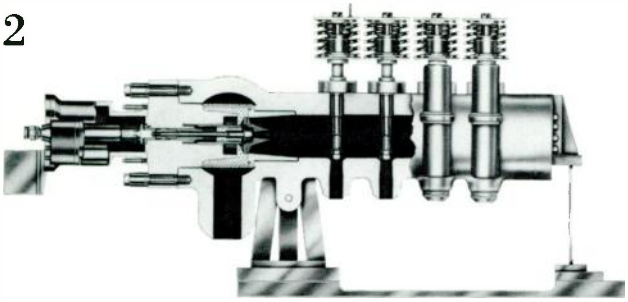

STEAM CHEST AND THROTTLE VALVE are combined, and two such units provide steam connections for the turbine. They are anchored to the station foundation to isolate piping reactions from the turbine casing.

elements is rated at 350 mw, although that design type is capable of operating at 500 mw.)

Minor modification of the first combined element and addition of a second reheat element extend the rating of the tandem-compound design to the 600- to 700-mw range. These units have four turbine elements in tandem (Fig. 1b). Permissible steam inlet conditions are 3500 psi and 1000 degrees F, with two reheats to 1000 degrees or to 1025 and 1050 degrees.

Design Improvements

HP-IP Element—The high-pressure and intermediate-pressure blade groups are incorporated in one combined turbine element called the HP-IP element. It is an extremely compact power package. Since it replaces the separate high-pressure and intermediate-pressure elements required in earlier designs, it decreases unit length about 18½ feet. This combining of elements is made possible by developments in metallurgy and mechanical design.

Metallurgical developments have produced a blade material (NIVCO) that has much better damping properties and high-temperature strength than other materials. NIVCO is used in the high-pressure control stage (first rotating row of blades). This material and a wider blade make it possible to use a single-flow control stage in machines of up to 700-mw capability with safe stress levels. The superior damping qualities of NIVCO permit admission of steam in a partial arc, so multivalve load-point control can be used. This improves part-load heat rate because there is no throttling loss as there is in single-valve control.

Mechanical design of the rotor has been improved by using blades with side-entry roots in the control stage and in all stages of the IP part of the HP-IP element. This allows the use of a full row of blades in every row, eliminating the excitation losses and resulting additional blade loading incurred when the closing blade of a row must be omitted.

The design of the high-pressure and intermediate-pressure blade groups and their arrangement in the turbine were studied closely to determine their effects on performance, maintenance of performance, and reliability. These studies indicated at the outset that a classical im-

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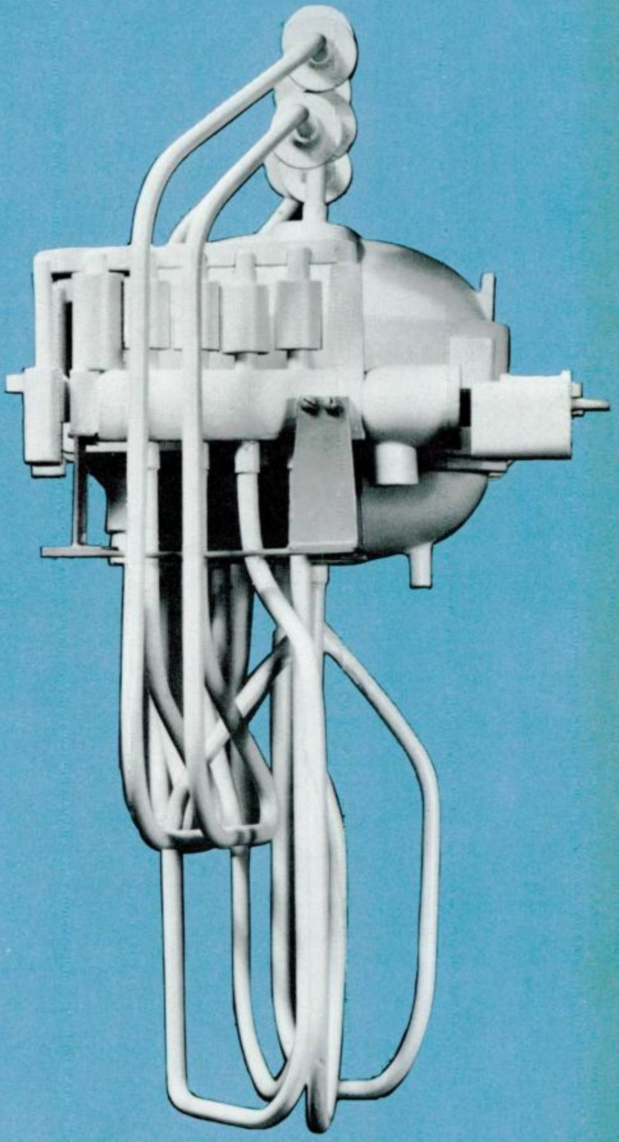

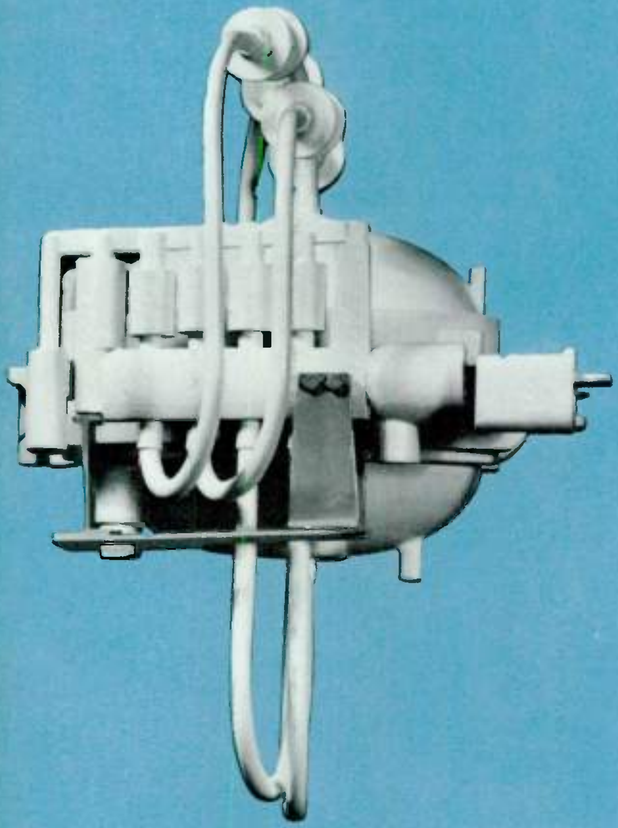

REQUIRED BASEMENT HEIGHT IS REDUCED by a new assembly of steam-inlet elements that includes two of the combination units illustrated in Fig. 2. The model at left shows a former inlet piping arrangement; the one at right illustrates the new arrangement.

4

INTERMEDIATE-PRESSURE INLET VALVE is also a combination type, containing a reheat stop valve and two interceptor valves. It is anchored to isolate thermal reactions.

pulse design was impractical and that some pressure drop had to be assigned to the rotating blade rows for optimum blading efficiency. The minimum degree of reaction required in the latter stages of the intermediate-pressure turbine, for instance, is about 35 to 40 percent, close to the nominal 50 percent of conventional reaction blading.

Studies of the relative work level and performance level of the impulse and reaction designs showed that the large volumetric flow involved favored the reaction design from an efficiency standpoint. With regard to work level, it was found that the decrease in the number of stages in the impulse approach caused much higher kw loading per stage, and unnecessarily complicated the mechanical design of the blading. These considerations led to the choice of a reaction design for the HP-IP element.

Because there is an appreciable pressure drop across the rotating blade rows, both blade groups are individually thrust balanced with separate balance pistons that sense the same pressures as their respective blade groups. Thus, a change in blading thrust is automatically compensated by an equivalent change in the opposing balance-piston thrust. This contributes to the reliability of the unit.

Main steam enters the HP-IP element through eight inlet pipes, four in the cover and four in the base (Fig. 1). It flows through the single-row control stage, reverses direction, and then flows through the high-pressure reaction blading and exhausts to the reheater. The reheated steam enters the intermediate-pressure section through four inlets, two in the cover and two in the base. After leaving the blading, it flows between the inner and outer casings to the opposite end of the element and exhausts to the low-pressure elements through two crossover pipes.

All blade rings and balance rings are separately mounted in the inner cylinder to give each component freedom to expand independently. This maintains running clearance and efficiency.

High-speed electronic digital computer studies and analog studies aided in performing the many detailed design calculations that were required. In fact, a design effort of this magnitude would be next to impossible without such aids. Typical calculations performed with the digital computer include: Blading performance and thrust; blading mechanical checks; rotor temperature distribution; stationary parts temperature distribution; three-dimensional blade-root temperature distribution; effects of various rotor and blade-root cooling methods; pressure-vessel stress distribution; rotor deflections and critical speeds; rotor stress distribution, including thermal effects; and three-dimensional blade-root stress distribution, including three-dimensional thermal effects.

Steam Connections—Several unusual features in the HP-IP turbine element should lower the initial cost of the overall power plant. First, the purchaser's connections for the main steam piping are to a pair of combined horizontal throttle valves and steam chests. Each chest has a throttle valve and four governor valves in a single unit (Fig. 2). The unit is anchored to the foundation, isolating the reactions of the main steam-station piping so they are not imposed on the main turbine casing. Anchoring permits reactions from the station piping many times larger than would be allowed in nonanchored sytems, and this reduces the amount of station piping required.

These combined throttle valves and steam chests can be assembled in the factory, shipped complete to the plant site, and placed on the foundation as a unit. The horizontal throttle valves are back-seated in both the open and closed positions to prevent steam leakage around the stems. Each governor valve has its own operating mechanism, and each back-seats in the open position.

The throttle valves, governor valves, turbine inlet pipes, inlet sleeves, and nozzle chambers are all designed as components of one inlet package. This improves the control of the pressure and temperature levels in the inlet areas of the turbine. It also has reduced the size of the turbine-inlet piping loops; they now occupy less space than that formerly occupied by the inlet piping for a 325-mw unit. This has reduced the required basement height (Fig. 3).

The same design principles have been applied to the intermediate-pressure inlet. The reheat stop valve is anchored and piping pressure drop is minimized. The combination valve contains one reheat stop valve and two interceptor valves (Fig. 4). Each turbine unit has two of these assemblies, one mounted on each side of the turbine in a manner similar to the combined throttle valve and steam chest arrangement. Accessibility is improved because all operating parts are above the turbine floor line.

The reheat stop valve is of the familiar swing-check type, redesigned to minimize impact loading during closing. The new interceptor valve is of partially balanced design and has a spherical seat similar to that used in the throttle valve. It is a diffuser-type valve, which improves flow properties. The valve assembly, including servomechanisms, switches, and supporting structure, is mounted on a bedplate for ease of installation and to facilitate shipment. This factory assembly makes it possible to cold-spring the supports. (Cold-springing is deforming the supports to the shape they will assume when heated.)

Anchoring the reheat stop valve assembly results in great improvement in the hot-reheat station piping. Pipe reactions on the turbine casing at the hot-reheat connections have been a problem in the industry for many years. Piping expansion loops take up space in the power station, and they are expensive. Also, with the decreasing ratio of building volume to kilowatt capacity in power stations, it is becoming more and more difficult to obtain the necessary pipe flexibility. Anchored reheat valves in the 400- to 900-mw range now permit piping moments at the turbine connections up to 15 times the values presently allowed with nonanchored valves. The amount of hot-reheat piping required, and thus the station cost, can be reduced considerably by taking full advantage of these large allowable moments at the turbine connections.

The anchored reheat design is greatly facilitated by use of the Westinghouse-developed Kromarc-58 steel for reheat piping. This material is about 50 percent stronger than other steels used for piping, so the reheat piping can have thinner walls. Reduced wall thickness and the consequent smaller pipe diameter reduce thermal reactions.

Low-Pressure Elements

These elements have double-flow casings, making a quadruple-exhaust design. This arrangement provides maximum reliability from a thrust standpoint; the inherent symmetry of the design also contributes to mechanical reliability. The blading in the inlet end is mounted in separate blade rings to minimize the effects of thermal distortion on seal clearances and thereby maintain efficiency. To keep distortion to a minimum, the large temperature drop (from approximately 700 degrees F crossover steam temperature to about 100 degrees exhaust temperature) is taken across three walls—an inner cylinder number one, a thermal shield, and an inner cylinder number two.

The size of the exhaust is determined by selection of last-row blades 28½ or 31 inches long. The larger ends cost more but are more efficient. The magnitude of the efficiency difference depends on load and vacuum, and its value depends on fuel cost. Consequently, the most economical exhaust annulus area is selected on the basis of capital cost and fuel cost.

These low-pressure turbine elements have also evolved from intensive development studies. The studies, and evaluations of design changes, have been aided by a low-pressure test facility in the development laboratories. Designers measured overall low-pressure turbine performance and made detailed traverse tests on turbine elements operating under actual loading conditions. The tests were then confirmed with similar tests on many full-size units in the field under actual loading conditions. These measurements led to improvements in steam velocity, flow direction, flow distribution, and steamline pattern in the exhaust stages.

Elimination of high-loss regions through improved blading designs contributed to a substantial improvement in efficiency. The resulting decrease in blading excitation loading increased the reliability and allowed application at higher mass flow rates. Studies in the air-flow laboratories also produced significant improvement in the design of exhaust hoods. The result is a diffusing type exhaust hood that is applicable to multiexhaust units.

Conclusion

The new high-rating tandem-compound turbine designs take full advantage of recent thermal, mechanical, and metallurgical advances. Their successful development is another step in the continued economic and technological progress that characterizes electric power generation.

Westinghouse
ENGINEER
Jan. 1964

Gemini Rendezvous Radar

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A primary objective of Project Gemini is the investigation of problems and techniques of manned vehicle rendezvous in space. This scientific and technological program of manned space flight is under the technical direction of the NASA Manned Spacecraft Center in Houston, Texas. Prime contractor of the Project Gemini spacecraft is the McDonnell Aircraft Corporation. The very light radar equipment that will help guide the two-man spacecraft into rendezvous with the orbiting target satellite is being developed by Westinghouse.

An intriguing operation in the coming Gemini series of orbital space flights is the rendezvous in space between two satellites. An unmanned Agena target vehicle will be placed in orbit; the two-man Gemini spacecraft will be launched into an approximately co-planar orbit with the Agena; the spacecraft will seek out the Agena, determine its range and bearing, and make the necessary changes in orbital velocity to allow mating with the Agena.

The radar being developed to assist in this operation has a number of distinguishing features brought about by the space environment and the unusual operational situation. Since the rendezvous is with a friendly vehicle, an interrogator radar can be used in the spacecraft to trigger a transponder radar return from the target. This arrangement permits long-range performance with low transmitting power. Also, even though the absolute velocity of both vehicles is large, there is no need for rapid closure between them, but rather, a desire to bring them into contact at a minimal differential speed.[1] These operating conditions differ considerably from conventional radar applications for missile or fire-control guidance, where the intercept takes place at high relative speeds and target radar return is weak.

These different boundary conditions for radar tracking open up a wide range of mechanization possibilities. When a transponder can be used to enhance the signal coming from the target, a 200- to 300-mile range can be obtained with low transmitter power levels; so small, in fact, that most of the usual signal-aiding techniques are unnecessary.

Target Enhancement

In conventional search-track radars, conservation of available signal power is usually the overriding design consideration, and in most cases, the largest area, narrowest beam antenna possible is used. Since antenna beamwidth will not cover the area of possible initial target locations, more hardware (gimbals, drive motors, etc.) is required to slew the antenna over an angular search region to find the target. But, with transponder target signal enhancement, no such complex antenna system is required. Wide-angle, low-gain antennas that require no gimbals can be used, eliminating the acquisition problem. This simplification provides a large weight advantage, since the antenna is the weight-pacing item in most radar systems.

Another advantage of target enhancement is that the transponder signal, unlike a normal reflected radar signal, will be steady, without the wide fluctuations common to radar reflections from a complex-shaped target. The transponder signal emanates from a single point, rather than appearing to wander over the target with aspect changes. These advantages eliminate two major sources of potential tracking error.

As will be shown later, signal enhancement also permits a lighter and simpler mechanical design.

System Accuracy

The slow relative closing velocities and long-distance acquisition make the guidance problem quite different from the usual missile intercept case. Since the target is nonmaneuvering, the precision with which the rendezvous can be made is limited only by the accuracy of guidance sensors and thrust rockets. Fuel required for terminal guidance maneuvers is, of course, highly critical and depends directly on the accuracy tolerances of the guidance sensors. In fact, many early studies of space rendezvous concluded that radar accuracies would have to be improved beyond the present state of the art to be suitable.

In the Gemini system, digital techniques have been used to provide accuracies that are not normally available with analog systems. Range and angle information is periodically read out in digital form to a spacecraft computer, where sophisticated orbital calculations can be performed rapidly and the results averaged over many sets of read-

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[1] "Space Rendezvous Guidance and Docking Techniques," C. I. Denton, R. M. Sando, A. T. Monheit, *Westinghouse ENGINEER*, July-September 1962, pp. 98–102.

ings, this averaging giving more accuracy than could be obtained from any single reading. The digital computer also complements the radar by combining radar angle outputs with signals from the spacecraft inertial platform. Thus, angular rates of the line-of-sight to the target can be computed digitally in inertial coordinates, and the need for high-accuracy rate gyros in the radar is eliminated.

System Characteristics

The spacecraft interrogator radar transmits a pulse-type signal, radiated over a continuous 70-degree solid angle. The transponder, upon receipt of the interrogating pulse, transmits a reply signal that is both delayed in time and shifted in frequency. The frequency offset permits the spacecraft receiver to discriminate readily between the transponder reply and any other reflected signals at the transmitter radar frequency. Such undesired reflections can come from the ground or, at close ranges, from the target vehicle.

The time delay between transponder reception and transmission allows the radar receiver to track the target to essentially zero range. Such close tracking is not possible with conventional pulse radar because the reflected signal return overlaps the transmitted signal, so that the reflected signal arrives at a time when the receiver is blocked out by the transmitter pulse. The transponder delays the return signal long enough so that, even at zero range, it arrives after receiver blocking has cleared.

The interrogator radar, upon receiving the transponder reply, measures the round-trip time with both analog and digital readouts, to provide target range. At long ranges, where the major expenditure of maneuvering fuel occurs, digital measurements are used to maintain maximum precision. Closer in, analog information is used directly by the astronaut for final spacecraft slowdown.

The analog measurement is made with conventional circuitry, in which a voltage proportional to time delay is generated by a linear voltage sweep circuit that begins at pulse transmission time and terminates upon receipt of the reply pulse. The much more precise digital readout is generated with a high-speed digital counter and a 10-mc crystal oscillator time standard. Target range is determined by counting the number of oscillator cycles between pulse transmission and reception at the interrogator.

Angle Measurements

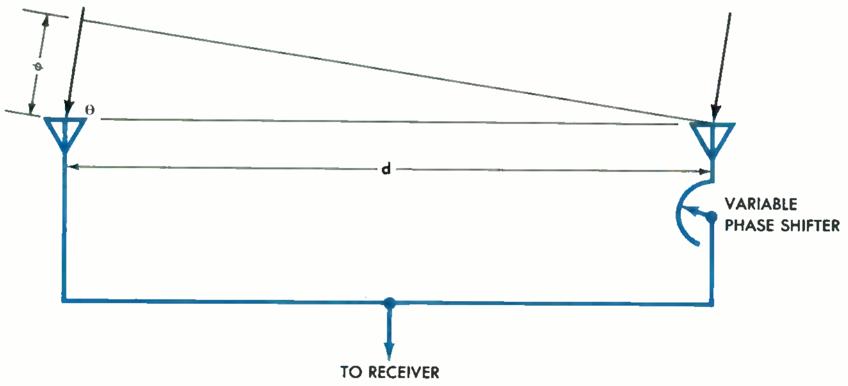
The most unique feature of the Gemini rendezvous radar is the mechanization for angle measurement. It is based on the well-known interferometer principle, where the difference in the time of arrival of the received signal is compared in two antennas. This principle is illustrated in Fig. 1. If the difference in arrival is equal to ϕ (usually expressed in terms of phase angle), and the distance between antennas is d, then the target angle θ, can be determined:

$$\cos\theta = \phi/d.$$

In the usual interferometer tracking system, an r-f phase shifter is inserted in one antenna arm and is servo driven to null the phase difference, ϕ. The position of the phase shifter is then proportional to the direction cosine of the received signal. The key problem is the accuracy with which this phase-shift measurement can be made. Since the ratio of angular error to phase measurement error decreases linearly with an increase in antenna spacing (Fig. 1), the typical solution to this problem is to use multiple wavelength spacing between antennas. However, when distance ϕ becomes equal to or greater than a half wave length for small angles of boresight (θ), ambiguous measurements arise—i.e., the same apparent phase delay occurs for several angles. Relatively complicated schemes are required to resolve these ambiguities.

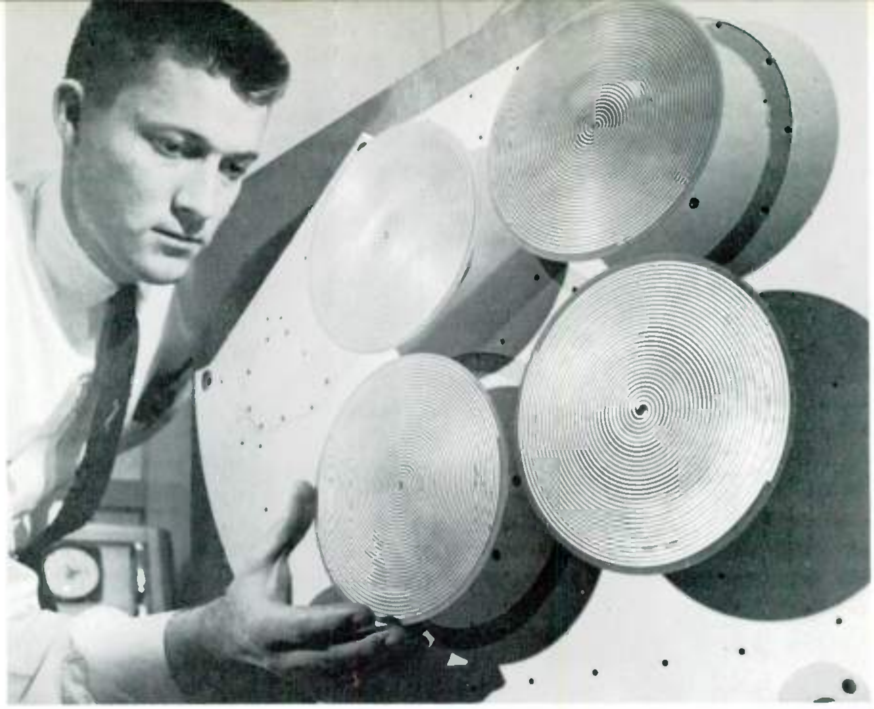
Circular Polarization—The Westinghouse approach avoids the ambiguity problem by using close antenna spacing in conjunction with an extremely linear phase shifter—a phase shifter that is an integral part of the antenna. This new approach is accomplished with antennas that are circularly polarized. The field pattern obtained with this type of antenna is illustrated in Fig. 2. The locus of the voltage vector at any instant of time along a line in the direction of the wave front describes a helix in space. Therefore, rotating the antenna emitting (or receiving) the r-f wave rotates this helix and is equivalent to physically moving the antenna forward (much like a screw thread). Thus, if antenna polarization is perfectly circular, a linear

1

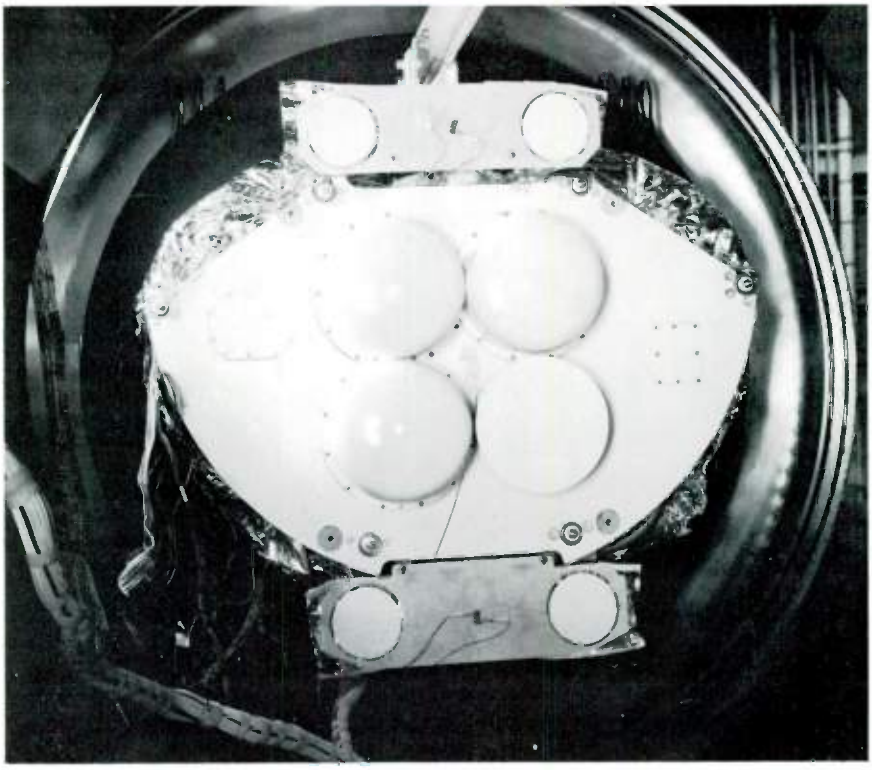


INTERFEROMETER PRINCIPLE is used by Gemini radar for angle measurement. Phase shifter is adjusted to nullify phase difference between received signals. Position of the phase shifter is proportional to the direction cosine of the received signal.

TRANSMITTING AND RECEIVING ANTENNAS for the Gemini radar will be located on the front of the spacecraft. With spiral antennas, angles can be measured by means of antenna rotation, rather than direct pointing at the target.



EXHAUSTIVE TESTING of the radar in a thermal-vacuum environment is necessary to assure proper operation in orbit. All heat generated by the radar must be radiated from the front surface shown in this photograph.



RADAR SIGNAL PATTERN, as received from the Gemini radar antenna, is measured in this radio-frequency anechoic chamber. The plastic material that lines the chamber prevents signal reflection to simulate a free space environment.

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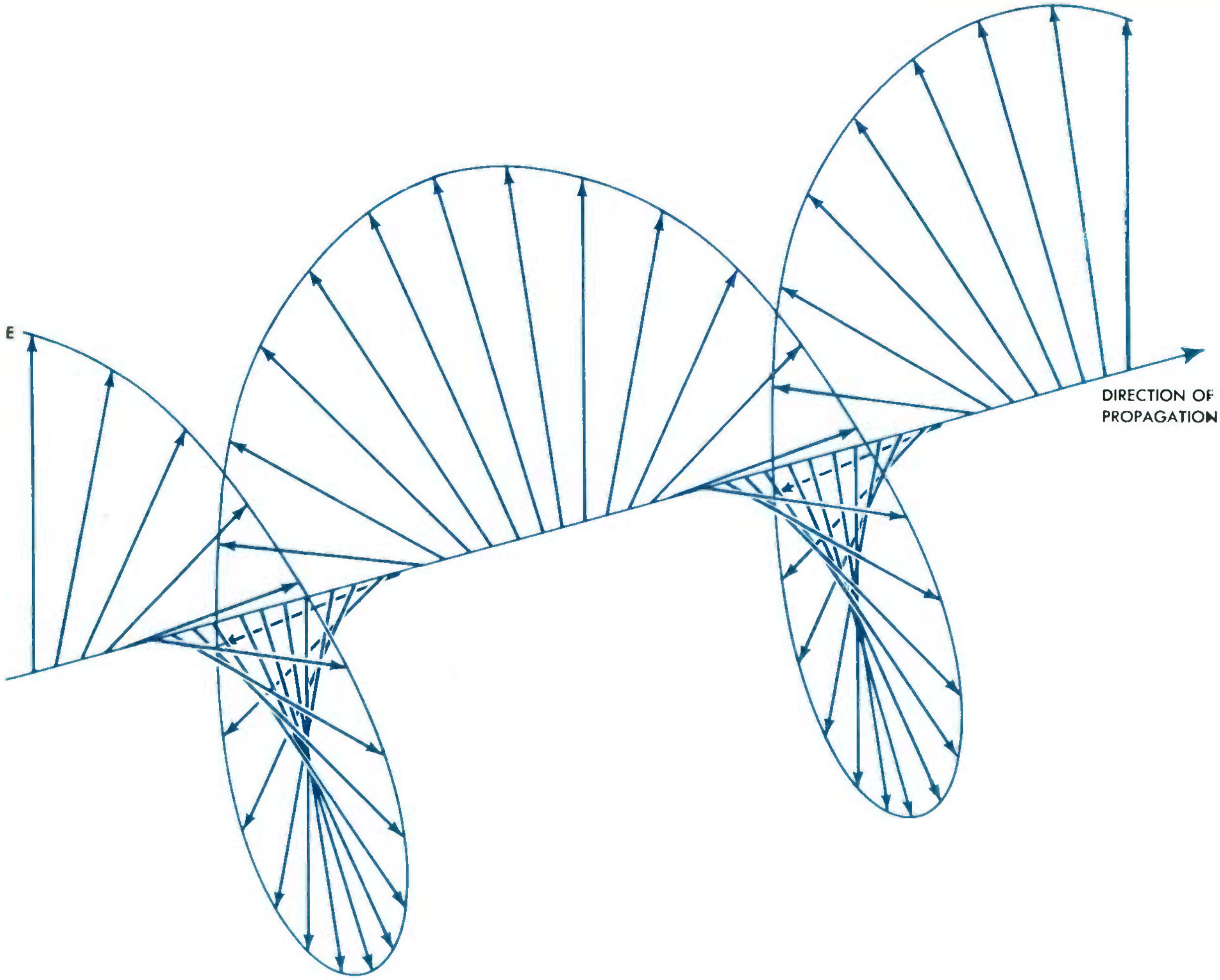

FIELD PATTERN of circular polarized antenna is helix advancing in the direction of wave propagation.

relation between wave front phase advance and antenna rotation is obtained, and the antenna can be rotated to serve as its own phase shifter.

Control of antenna pattern circularity is a key factor in obtaining accuracy. Design techniques have been evolved to obtain on-axis ellipticity ratios of 0.2 db, making the angular error due to ellipticity less than a milliradian.

Circular polarized antennas are built as Archimedian spirals, which are printed directly on an epoxy board. Since the antenna is very light, a direct-drive servo torque motor with no gear train can drive the antenna. This arrangement minimizes the usual servo nonlinearity problems caused by friction and backlash in gear trains.

To further simplify the mechanization and avoid the use of separate phase-matched receivers for the two antennas, the phase null error is converted into an amplitude-modulated error signal. This is done by synchronously switching in and out an extra length of line in one arm of the antenna pair. This allows one receiver to be used for a one-axis measurement and removes all phase stability requirements on the receiver.

Angles in two orthogonal axes are measured with three receiving antennas, one of which is common to both channels. The antennas are placed on the spacecraft so that the boresight axis is parallel to the roll axis; one pair of antennas lies in the pitch plane and the other pair in the yaw plane. Thus, one pair of antennas establish azimuth and the other pair establish elevation. A separate spiral antenna is used for transmission to avoid the use of a transmit-receive duplexer for the radar.

To permit measurement of both azimuth and elevation with a single receiver, the transponder reply pulse is made long enough to be time-shared between both axes (Fig. 3). The leading edge of the transponder reply pulse is used for range measurement. Receipt of the leading edge of the pulse triggers the angle-switching sequence; the receiver input is switched to monitor the azimuth pair of antennas, and receiver output is switched to feed the azimuth antenna servo drive. The switches then open to allow the receiver to clear and switch to connect the elevation channel. Thus, two-axis tracking information is obtained from each pulse. Special solid-state microwave switches with a

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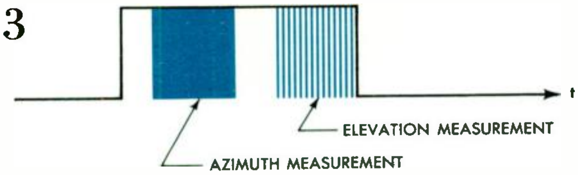
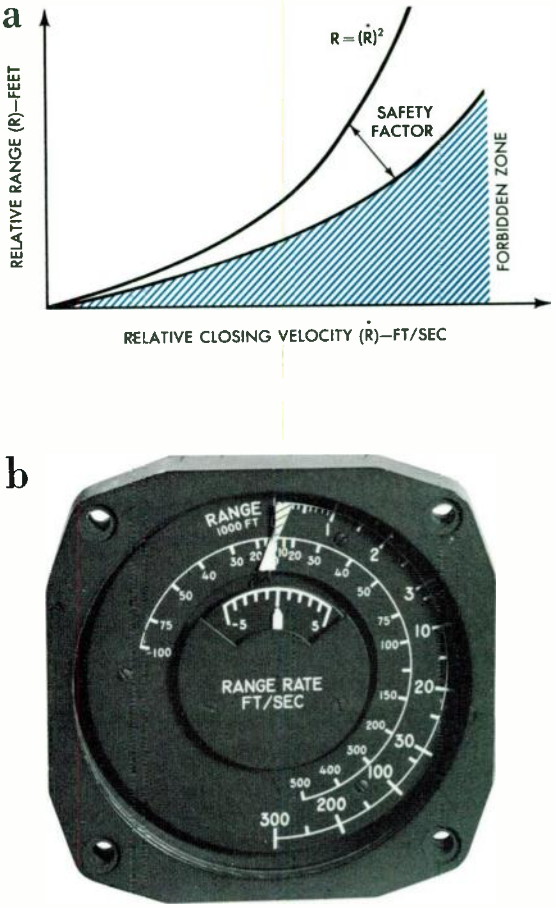


TRANSPONDER REPLY PULSE is time shared by the spacecraft radar receiver so that both azimuth and elevation can be measured with a single receiver.

4

TRANSPONDER that will be installed on the target Agena rocket contains another receiver-transmitter, which answers the Gemini radar's interrogating signal with a delayed signal of different frequency.

5a



DECELERATION PROFILES (*a*) show the safe relationship between relative range and relative closing velocity for the Gemini spacecraft and Agena target. This relationship $R = (\dot{R})^2$ is displayed (*b*) for the astronauts on adjoining scales.

high order of phase stability have been developed to accomplish the required r-f switching with switching times of small fractions of a microsecond.

Astronaut Display

The precision digital readouts supplied by the radar are used by the computer for calculating major velocity changes at long range. As the spacecraft nears the target, an analog information display guides the astronaut in making the final slowdown.

As described in a previous article[1] in the *ENGINEER*, there is an optimum flight profile between range (R) and range rate ($\dot{R}$), which is limited by the safety margins on thrust capability. This is shown in Fig. 4, where the forbidden zone is determined by the $R = f(\dot{R})$ relationship, where f is a function of maximum thrust available from the retarding engine. A safe profile for the Gemini mission was determined to be one where $R = (\dot{R})^2$. To assist the astronaut in determining quickly that he is on the safe side of this curve, both range and range-rate signals are derived in a semilogarithmic form and displayed on adjoining scales with all points on the range scale located opposite range-rate points that satisfy the relationship, $R = (\dot{R})^2$ as shown in Fig. 4b. By keeping the range-rate needle below the range needle, the astronaut maintains a safe rate of deceleration.

Logarithmic scale compression is used to allow long distances and high-closure rates to be displayed along with adequate resolution at the low end of the scales. An additional low-speed range-rate scale is included to provide more reading resolution at the low speeds to be used when the vehicles dock.

In summary, the interrogator-transponder technique has made possible a very light radar system that provides accuracy and reliability with low power demands. The interferometer system, with circular polarized antennas, has minimized angle-measuring complexity, yet provided angular measurement accuracies comparable to much larger antenna systems used with conventional radar systems.

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[1] *Ibid, page 19.*

Mechanized and Automated Warehousing

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What mechanizing and automating can do for warehousing, how the problems are solved, and the characteristics of the control systems used.

New tactics are required to reduce warehousing and distribution costs and, at the same time, improve service. Among the most effective tactics are mechanizing and automating as many of the warehouse functions as practical.

Mechanizing, as the term is used in this article, means applying a considerable amount of powered mechanical equipment in warehouse functions to augment the effectiveness of the labor force. *Automating* means applying and coordinating control equipment to operate the mechanical equipment, and part or all of the system served by the equipment, with little or no detailed attention. The techniques reduce costs and improve service, when properly applied, primarily by increasing plant efficiency and providing consistent high productivity per man-hour even with varying inputs and outputs. They can also keep management better informed of the functioning of the warehousing operation.

A fully automated warehouse fills its orders and replenishes its stock automatically, with all the detailed functions involved in those two major operations. There are perhaps four such warehouses operating in this country now, though others are being built and more could be justified. However, there is a broad spectrum between full automation and no mechanization at all. Between the two extremes are many types and degrees of mechanization and automation. The problem is finding the right type and degree for a particular operation. Fortunately, the possibilities are flexible enough to permit improvement of any kind of warehousing operation, either in a new facility or through modernization of existing space.

The *type* of mechanizing or automating required often is not at all obvious. Many years of experience in handling materials and information have shown that each warehousing problem must be studied and analyzed carefully if the treatment is to be effective. The solution usually consists of treating specific problems that are causing high costs or poor service. For example, mechanizing a congested area can double or triple warehouse production even though there just isn't physical room to double or triple the work force in the area.

Determining the *degree* of mechanizing or automating required also involves detailed analysis. Too little doesn't solve the problems and only wastes money. Too much wastes money also by provision of superfluous equipment. Even worse, it creates a system that is too inflexible to meet changing conditions. An overdone warehouse system might be compared to a completely unmanned pushbutton supermarket; it can be built, but it requires a tremendous investment and cannot adapt readily to changing products and changing buying patterns.

Although productivity per man-hour is the cost-reduction factor that usually comes to mind first, other factors are just as real even if some are less tangible. They include better scheduling, error reduction, better use of storage space, less theft, less handling damage, fewer accidents, and better stock control. Warehousing and distribution costs can be reduced an estimated 10 percent on the average, and much more in certain cases. One automated order-picking installation was initially justified on the basis of a four-year write-off, but it paid for itself in less than three years even without considering beneficial intangible improvements. This is typical of the reports from companies that have applied the techniques after carefully studying their operations and their needs.

Warehousing problems are attacked by separating them into small problems. The most effective way to divide the problems is to break a warehouse operation down into its basic functions. Then previous experience with those functions can be applied to the new problems. For example, the sorting of coils of steel, rolls of paper, or appliances may have the same functional solution, requiring only different conveyances.

Before the method is discussed further, consider the basic functions themselves.

Warehouse Functions

Receiving is the unloading of products at the incoming end of the warehouse, checking for damage and compliance with the purchase order, and recording the products. Many warehouses can omit portions of the receiving function. For example, a warehouse located at a factory uses the factory's inspectors and has no purchase order as

APPLIANCES ARE SORTED in this warehouse, and groups of similar products are accumulated, by an operator who diverts incoming products into temporary storage lanes. Similar products are then conveyed as a group into storage.

such; it will store every product the factory produces. The only portion of the receiving function common to all warehouses is the recording of products. Additional identification may be added to facilitate another warehouse function.

Sorting is the selecting of like products by any means. A hand truck or fork truck may do sorting as the product is being stored. A more mechanized warehouse takes the items as they come along a conveying means in random order, recognizes them by visual means or by predetermined code, and then uses this information to divert each item into its proper lane so that all of one type of product or a specified limited range of products will be together. A memory system is needed to accomplish this, and it can be one of two basic types. Mimic memory reproduces in miniature, either electrically or mechanically, the movement of the product. When the product passes an identifying point, its destination is put into the memory system, and this destination information travels in synchronism with the main conveying system. Only when the destination intelligence is opposite the correct destination is an output given to divert the object into the proper location. The other general form of memory consists of putting the intelligence on the product or on the product support piece and then reading each "label" at every diverter station until the proper lane is found.

Storage is the transmitting of products to locations in the warehouse and leaving them there until they are needed to fill orders. The two general types of storage are assigned-space and random storage.

Assigned-space storage minimizes record keeping and makes it easy to find the product for order filling. It has the disadvantage of requiring more warehouse space due to fluctuation in quantity of each item.

Random storage permits storing diverse products in any location in the warehouse. The product type and location are recorded in such a way that a person or a device can be instructed where to go in the warehouse to place or retrieve the product.

Assigned-space storage has been used much more than random storage, but improved control and mechanical devices are making the latter more and more attractive.

Order picking must be divided into three areas for definition: manual, semiautomatic, and automatic.

In manual order picking, the products are located within the reach of workers who walk or ride to the area, retrieve the required products, and convey them to a central location for subsequent operations.

Semiautomatic order picking employs mechanical equipment such as conveyors and stacker cranes, but has an operator to set up quantity and product identification by selector switches or pushbuttons for each product or group of products to be contained in an order. The order is then collected on a conveyance or at a central location before it is sent to the destination.

Automatic order picking is the use of cards, punched tape, or computer input to tell the order-picking control the quantity of each type of product required from the storage lanes or bins. The control then releases or retrieves the products and routes them on a common collecting conveyance to an operator or directly to a shipping dock.

Routing is determining where a device or product is to arrive and how it is to get there. In automated routing, information is given to the product or system so that it can follow a predetermined course or, in the event of overloading in one section of the system, take another course to the end location or continue around the system and try again. Such routing systems generally have a traveling memory system that makes a decision at every switch. Routing systems are usually applied in combinations with sorting systems.

Accumulation is the temporary holding of products to enhance the efficiency of the overall warehouse system. It can be used at the receiving end of the warehouse, the output end, or in between.

Inventory, for purposes of this article, is the keeping of records that show at least the quantity of each item in the warehouse. Inventory is a management control item, and it is often thought of as intangible in dollar value. This is not exactly true. With up-to-date inventory information, an order can be quickly checked against the availability of the product to eliminate shipping shortages or waiting for late items at the shipping dock. Many inventory systems are not now adequate to provide this function, and poor productivity can often be directly related to poor inventory information.

Paper work is material that informs the customer, the shipping department, the inventory records, the warehouse workmen, and the accounting department of transactions concerning an order.

Mechanizing and Automating Individual Functions

As stated earlier, warehousing problems are more easily solved if the overall operation is broken down by functions. Individual solutions can then be found and integrated into systems of the required degree of mechanization and automation. Some examples of ways of mechanizing and automating the individual functions follow.

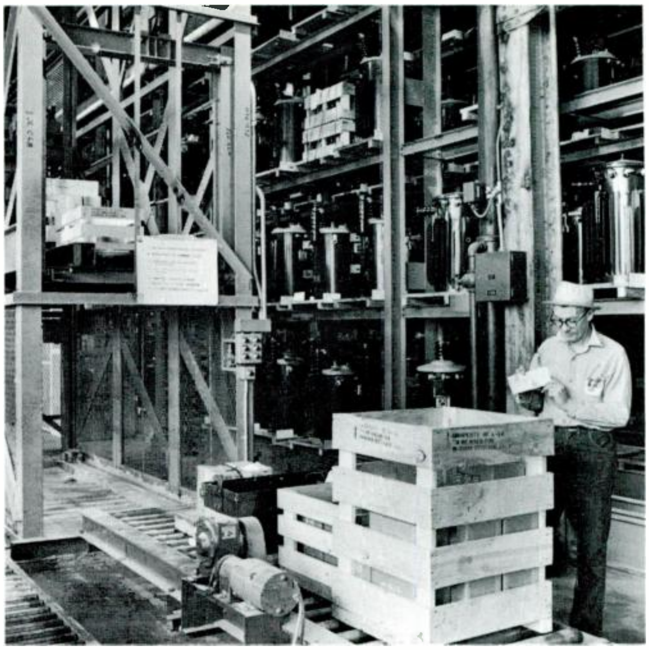
Receiving—This can usually be facilitated by mechanical unloading and handling equipment. The product also has to be identified, and it often is possible to include further information to facilitate some of the subsequent warehousing functions.

For example, incoming raw materials and outgoing finished products at the Westinghouse transformer plant in Sharon, Pennsylvania, are stored in a single random-storage warehouse. The items are placed on pallets as they are received at the warehouse, and an operator staples a business-machine card to the pallet. This card is punched with information on the quantity and style number of the item and its storage destination. The card travels with the item in subsequent operations (described in the *Storage* section that follows). When the card is punched, a paper tape is also punched with the same information to transmit the information to the receiving department. There, another card is produced from the tape to identify and locate the item when it is needed for shipment or for plant use.

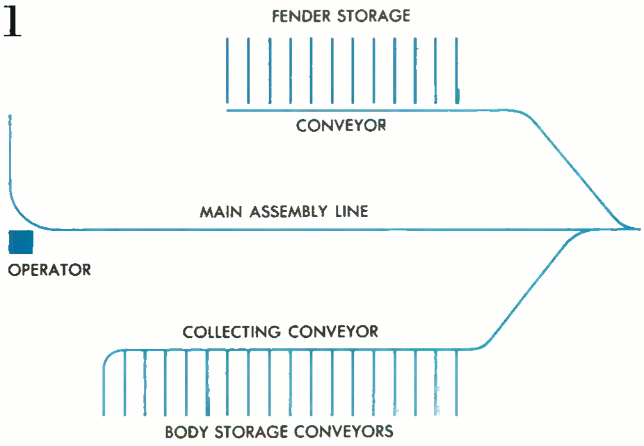
Sorting—Cartoned appliances are merged from all of the plant production lines onto one of two conveyors leading into the warehouse at the Westinghouse Major Appliance Division in Columbus, Ohio. (See photograph on page 25.) An operator at a control console sees each appliance and presses a pushbutton associated with one of the diverters and temporary storage lanes. This intelligence is recorded in the control's mimic memory, follows the appliance until it is opposite the correct lane, and then diverts the appliance automatically into the lane. This may be 60 seconds after the operator initially pressed the pushbutton and, in the meantime, he has been recognizing other products and pressing other buttons.

Storage—The transformer-plant warehouse mentioned under *Receiving* is a large random-storage facility with 22 000 locations for consolidated storage of raw materials and finished products. Automatic sorting equipment reads the punched card attached to each pallet and instructs a conveyor system to move the pallet to one of eight stacker cranes. The crane places the item in an empty storage location of the proper size. Storage locations are arranged in 400-foot aisles from floor level to 30 feet high. (See photograph on this page.)

Raw materials and finished products had previously been stored in several different locations at this plant, some of them requiring substantial hauling. Automatic sorting, random storage, and use of stacker cranes centralized all warehousing in one location and reduced the required warehouse area from 310 000 square feet to 110 000 square feet. The new warehouse saved the company about half a million dollars the first year it was operated.



PUNCHED CARD IS STAPLED TO PALLET to identify a product as it is received at an automated warehouse with random-access storage. Information on the card actuates sorting equipment that directs the item through a conveyor system to stacker cranes that place it in the proper storage location. Similar information on a card filed in the receiving department actuates the system to retrieve the item when it is wanted.



BODIES ARE STORED in conveyors in the assembly area of an automobile plant. An operator chooses the proper type and color by pushbutton as a chassis enters the area, and the bodies meet the chassis at the proper time and place for assembly. The proper fenders then enter the assembly line.

Order Picking—Semiautomatic order picking is used in the automobile assembly area diagrammed in Fig. 1. Bodies are stored on 24 flow-through conveyors, each holding only one type and one color. Fenders are also stored by type and color, and put on an overhead conveyor manually. As the chassis travels down the main assembly line, an operator presses one of 24 pushbuttons to choose a body. The control automatically releases the body at the correct time, and it travels along a collecting conveyor running in synchronism with the main assembly line and the fender conveyor. Each chassis arrives with the proper body, and then the fenders, for final assembly.

Automatic order picking is illustrated by a new installation in which nine stacker cranes are directed by static logic control to place and retrieve pallets of products (Fig. 2). When an order is received, it is entered into a computer. The computer decides which crane will retrieve which product, on the basis of crane availability. It then transmits the decision to the central logic control and tells it which bins the products are in. This control checks and decodes the information and retransmits it to logic controls on the individual stacker crane. (Static intelligence-transfer heads transfer the location information to the crane in its home position. This eliminates collector rails or cable reels.) The crane logic control checks the location information again. If the check is positive, the control starts both hoist and travel motions to retrieve the product as soon as possible. The product is deposited on a stub conveyor at the crane's home position, from which it travels onto the main collecting conveyor.

A computer was used in this order-picking system because it was required for another part of the total project. Its function could have been performed by logic control operating from punched cards or punched tape made up from the orders.

Routing—An easily visualized routing system is diagrammed in Fig. 3. A towline pulls carts past storage locations and loading docks. An operator inserts information into a control system to start a cart and stop it at the required locations.

Assume that an order requires stops at storage sections *A*, *C*, *D*, and *G* and delivery to dock 3. This information would be read into a memory system. As the cart came to switch *A*, it would automatically be switched off, and the personnel in area *A* would put their part of the order on the cart. They would then put the cart back on the tow line. It would go through switch *B* and on to switch *C*, where it would be automatically pulled off again by the system. The procedure would continue until the last part of the order had been assembled (at area *G*). After it was put on the tow line again at *G*, the cart would pass through *L* and continue on until switched off at loading dock 3. If one of the spur tracks had been full of carts (say at area *C*), the switch there would not open and the cart would continue around the loop to be switched off at *C* the next time around. A track could be provided beyond *H* on the storage loop to save traveling past the loading dock in this event. Such a routing system would be low in initial cost and flexible in operation.

Accumulation—When products are being sorted, it is often most efficient to accumulate a quantity of like products and convey them into storage as a unit. This can be done with temporary storage lanes such as those shown on page 25, from which units are conveyed as a train of like products. It also can be done ahead of a palletizing machine to consolidate many like products into one large pallet load. If considerable time is required to assemble an order, an output accumulation area is used to avoid tying up the shipping dock.

Inventory—Inventory records often go beyond the quantity of each product and include the location of the product. This allows use of random storage (such as that described under *Receiving* and *Storage*) and thereby increases the volumetric use of the warehouse. Computers with high memory capacity can greatly improve inventory information. With this information, management can better control the quantities of each product to assure that it is available but that no more is being stored than is necessary. The computer that does this work usually can perform other functions also, especially paper work.

Paper Work—Data-processing computers are used to speed the preparation of shipping papers, invoices, and stock ledgers for the warehoused products. Teletyped orders from the sales offices often serve directly as computer inputs. Westinghouse uses such an electronic order-processing system to speed the handling of orders for finished products delivered through a national warehouse system.

As with material-handling systems, paper-work systems can be tailored to many different needs. They can be used economically in most distribution systems, whether products are distributed from one warehouse or from many warehouses spread across the country.

Combining such systems with mechanized or automated material handling minimizes the time that elapses between the placing of an order by a customer and his receipt of the product. The warehouser is benefited through faster and more current sales and inventory records and consequent improved stock control and ability to fill orders.

Most Promising Areas for Systems Improvement

All of the warehouse functions can be improved in certain warehouses to reduce cost by removing bottlenecks, eliminating delay time, or increasing productivity per worker. Sorting, storage, order picking, and routing are the materials-handling functions that have the greatest potential for mechanization and automation, because they are best suited for mechanical and electrical solutions such as those described in the preceding examples.

Inventory and paper work also have much potential for cost reduction and better service. Systems suppliers and business-machine manufacturers are making great strides in their improvement.

The degree of mechanization and automation in these areas determine the electrical content of the system, since both are basically electrical techniques. This tends to place the responsibility for a system's success on the electrical equipment. For this reason, some electrical suppliers have taken total responsibility for warehouse *systems*—both the mechanical and the electrical equipment. This fresh approach has opened some problems to new solutions.

How Problems are Solved

When a warehouse owner realizes that he has problems, or wants to lower his costs per item handled, his first step should be to define his problems. A thorough self-analysis reduces the time that the system supplier has to spend on problem definition, and it increases the probability of finding the best solutions.

This self-analysis consists of a word description of the facility and the general problems, and records of the warehouse operation. The records include such things as volume handled, number of types of products handled, packaging and dimensions, warehouse size and configuration, and present method of handling products. The warehouser's own materials-handling engineer is the best person to do this work. If he has none, the warehouser probably should employ a consultant to define the problems and locate high-cost areas.

Even if the studies point toward full automation, the warehouser should not necessarily go directly to that goal. One who is presently handling the entire operation by manual labor almost certainly should not go immediately to full automation. For one thing, too many details probably would be overlooked and the resulting system would be inflexible in some respects and consequently would quickly become impractical as the warehousing needs changed. Also, unless the warehouser has depth in his personnel that he is not presently using, he would encounter many problems in operating and maintaining the unfamiliar automatic equipment. A warehouser who presently relies mainly or entirely on manual operations should first mechanize to get a feel for the kind and size of benefits that he can derive from mechanization and to train his personnel to work with mechanized equipment and get the most out of it. After he has assimilated this initial change, he can better consider further mechanization and automation.

With the problems defined, engineers attack them by breaking the operation down into the functions. Isolating the functions in this manner enables the engineers to relate other solutions in those areas to these specific problems.

An example of this approach is the recent study of warehousing for a high-production factory turning out thousands of cartons of products. It was first thought that the product should be stored in gravity flow-through lanes. However, analysis showed that the tremendous volume would require a prohibitive amount of space for storage on gravity conveyors. When the problem was broken down into the essential problems of storing and order picking, it was seen that if the storing were done in large lot quantities the order picking could also be done in large quantities. A study of the order make-up showed that most orders could use a complete unit load of suitable size, or multiples of this unit load. The number of unit loads was found to be approximately 1000 per day, which related the problem to a previous installation in which stacker cranes were used to handle 100 to 150 unit loads in and out of storage per day. A system for palletizing like products at the ends of the assembly lines was adapted, and a simple conveying means was devised to take the unit loads to and from the storage area. Stacker cranes were applied in the storage area to stack and retrieve pallets.

The solution left one remaining problem—how to handle less-than-pallet loads without depalletizing completely. Various solutions were investigated, and the most promising was the use of vacuum heads on a transfer machine. Each head always holds a single layer of product (picked off the top of a pallet), so when that amount of product is needed it is simply deposited on a collecting conveyor. This turned out to be a fast and efficient way of handling the product.

Another example of problem solution by this approach occurred in a paper mill where different types of paper were being taken off the winders and transferred to a storage area, one upon the other, in random fashion. When orders were processed, several rolls usually had to be removed to get at the wanted roll, and this caused extra handling and required an overhead crane. The warehouser solved the problem by adapting sorting techniques that had been devised for sorting coils of steel in a steel warehouse. He

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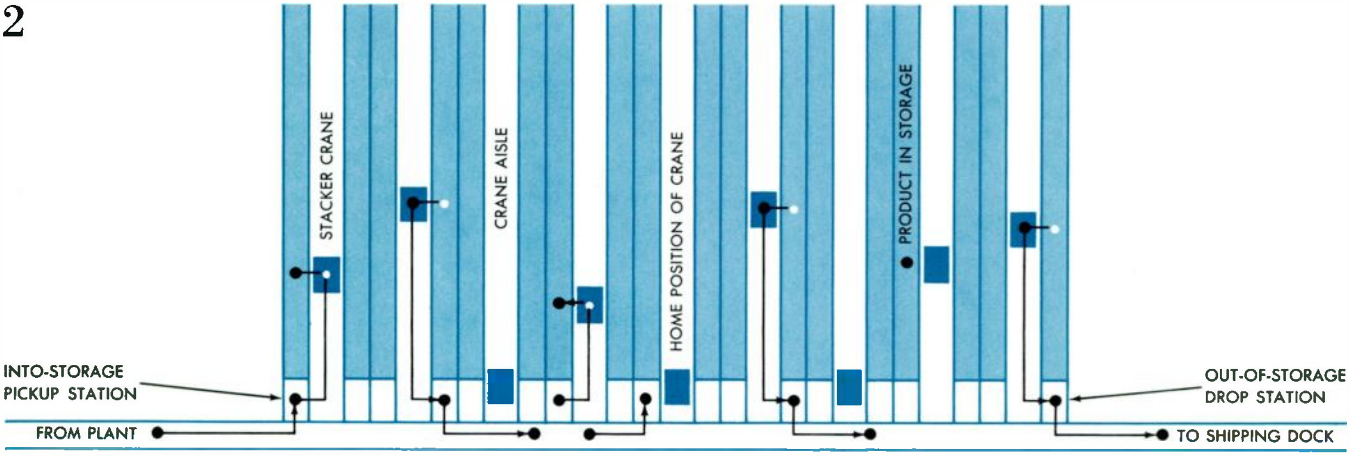

LOGIC CONTROL DIRECTS STACKER CRANES to place and retrieve products in this warehouse. The cranes receive coded instructions in their home positions and act on the instructions to store products diverted from the main conveyor or to take products from storage and place them on the short branch conveyors for delivery to the main conveyor. A computer directs the logic control, deciding which crane is to be used and which bin a product is to be stored in or removed from.

put a sloping floor in the storage area, provided a lane with an electrically controlled gate for each type of roll, and thus created a set of gravity flow-through racks.

Computer or Logic Control?

Logic control makes decisions electrically in accordance with built-in circuits, or "logic." All of the decisions have been thought out ahead of time by the design engineers and incorporated into the control. Logic control can be as simple as an electrical interlock on one drive that stops another drive if the first one stops. It can be as complicated as the automatic sequencing control for assembling raw materials for blast-furnace charging, which requires some 10 000 logic elements. (A logic element is a device that receives two or more electrical signals and gives an electrical output based on its function and the input signals. It may be a static device, such as an electronic circuit, or electromechanical, such as a relay.)

Logic control has the advantage of being more easily understood than computer control, and this tends to make it easier to use.

Computer control performs logic functions too, but it can also calculate the best way to do a job on the basis of information available at that moment. In other words, it can optimize freely. Logic control can't optimize, except when circuitry for optimizing under specific conditions is built into it.

A computer has many standard functions—add, subtract, compare, and so on—that can easily be made up and changed in order of use. This order of use, or planned procedure, is called the program. Programming requires that the process be completely understood, but this is not as difficult in warehousing as it is in complex manufacturing processes.

Two general types of computers are applicable to warehousing. A process computer calculates, from programmed formulas and signals received from the process, what changes should be made in the process to maintain the desired output. A data-processing computer also follows programmed formulas to compute for billing, inventory, or warehouse commands, but generally it receives only prepared input information and no feedback information from the process.

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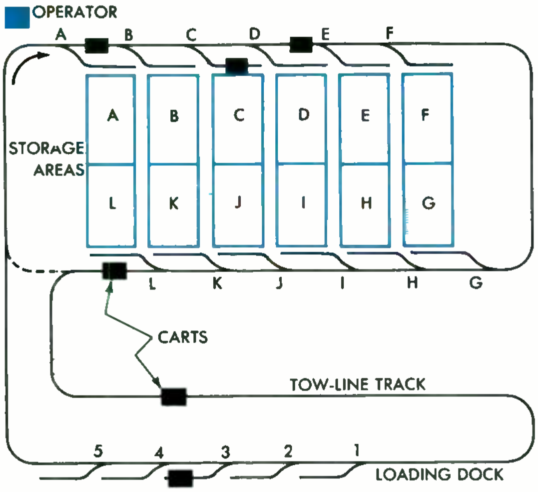


A SIMPLE ROUTING SYSTEM could consist of a tow line pulling carts past storage areas for loading and past a shipping dock for unloading.

Many logic control systems have been misnamed computer controls. This is unfortunate, since it tends to blur the real and useful distinctions between the two types of control system.

When should a computer be used, and when logic control? This question is hard to answer in a brief and general way, but there are reliable guides.

First, logic control should be used where it is adequate for the present and future tasks. Its largest potential area of application is in step-by-step automating of small and medium-size warehouses (less than 40 000 square feet). It can provide good automation of one or several functions with the lowest investment. However, for any warehouse, but especially for larger ones, the user must weigh the simplicity of logic control for immediate functions against the ability of computer control to perform those functions *and then take on additional functions.* The proper decision can only be reached after the warehouser and a supplier have studied the specific operation.

The number of outputs required from a computer substantially affects the cost of applying one and thereby affects the choice. Providing equipment for 100 to 200 outputs (such as the control of gates) can increase the cost of a small computer system from 30 to 100 percent above the base cost of the computer.

A computer should be used where the automated warehouse functions are routine, so that relatively few outputs are required, and where storage of inventory information will partially (30 to 60 percent) justify the system economically. A computer's great ability is decision-making, so the more decisions a control system has to make before an output is required, the easier it is to justify a computer system. Typical decisions include quantity of product available, cost of present inventory at any time, nearest location of a product, and distance an order should travel on a conveyor before the control system starts assembling a new order.

Some operations can economically use both logic control and a computer. This marriage eliminates one false approach, that of loading a computer with everything it can do without considering whether some of the functions can be performed better or at less expense by other reliable control means.

Either control method should be viewed simply as a tool, like mechanization, to improve service, decrease cost, and increase productivity. Automatic control used in this way will continue to grow in number and variety of applications.

Summary

Warehousing is being constantly improved by modern mechanization and automation techniques. Each job must be studied carefully as an individual case. An effective approach is to break the job down into its basic functions so that previous solutions to problems in those functions can be related to the job. This breakdown also helps systems engineers take an unprejudiced look and a fresh start at problem areas.

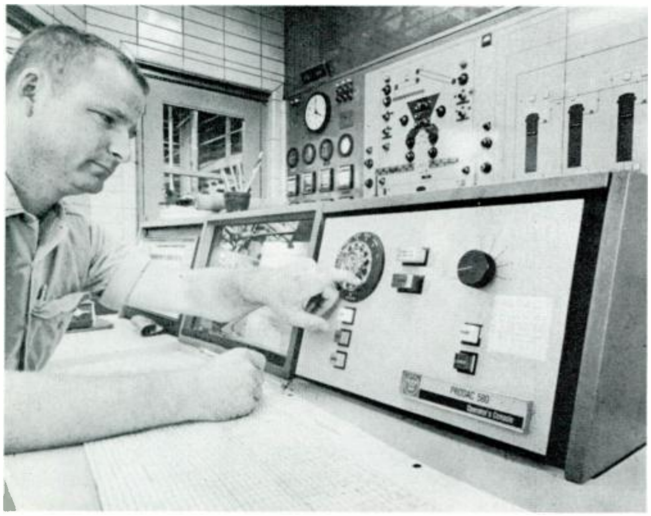
Closed-Loop Control Computer System Operates Paper-Mill Digester

The first closed-loop on-line control computer system in the pulp and paper industry is now operating a continuous digester at the Gulf States Paper Corporation plant in Demopolis, Alabama. The digester produces pulp, the material from which paper is made, by treating wood chips with chemicals.

The paper company expects direct computer control of the digester process to save it more than $250,000 a year. In addition, it intends to extend computer control to the wash plant, bleach plant, and paper machine to further improve plant efficiency and reduce operating costs.

Computer control of the digester reduces operating costs in several ways. First, closer control reduces variation in the operating level of the digester and thereby increases digester throughput. Reducing variations in throughput decreases the amount of wood destroyed by overexposure to the chemicals, and the improved control reduces the amount of chemicals used. The process steps that follow digestion also benefit from a better and more constant pulp supply. For example, the amount of bleaching chemicals required is reduced. With the previous control method, excess amounts of bleach had to be used to compensate for variations in pulp quality. Continuous monitoring of the process reduces maintenance costs by indicating the best times and areas for maintenance. Finally, the computer's excess capacity is used to solve complex engineering, marketing, and management problems.

THE DIGESTER OPERATOR'S CONSOLE includes a trend recorder, a printer for logging and alarm printout, an alarm acknowledge pushbutton, and a telephone dial. The operator dials information into the control computer system, which then draws on this information (and on information received from its program and from the process) to operate the digester.



The decision to automate the digester with a process control computer system was reached after an extensive systems study of the papermaking process. The study showed that pulping with a continuous digester was the most promising place to start because it is the initial major process in making paper and strongly influences the processes that follow. Better understanding and control of the pulping process would lead to better control of the entire papermaking operation.

The Prodac 580 computer has been programmed to maintain the desired permanganate number (a measure of pulp quality) under both steady-state and dynamic operating conditions. This is accomplished by a combination of anticipating (feed-forward) and feedback control techniques. In addition, the computer controls such primary variables as chip feed rate, chemical input, and pulp output.

Only a portion of the computer system's full capacity is being used in controlling the digester. A priority-interrupt system permits the computer to maintain control of the process while performing data-processing tasks, interwoven among the control operations.

The computer has a core memory of 8192 eighteen-bit words, which can be increased to 16 384 eighteen-bit words. A drum memory of 32 000 words also is used. Access time to all core-memory locations is 1.8 microseconds. Add time is 8 microseconds and average multiply time is 38 microseconds. An average of 100 000 arithmetic and logic operations can be performed per second. ■

Cost of Sea-Water Conversion Reduced

Flash-evaporator plants can now be built to produce fresh water from sea water and other mineral-laden water at lower cost than ever before—less than 50 cents per thousand gallons. This economic improvement has been made possible by recent technological advances in design, manufacture, and operation of the plants.

In design, experience with smaller plants has supplied the technical data needed to build giant plants producing several million gallons a day. Such plants would be more economical to operate, per gallon of pure water produced, than smaller ones are. Also, design experience has made plant layout more flexible. A flash evaporator can now be divided into modular units or integrated with another plant (a chemical processing plant, for example) to minimize the amount of connecting piping and material required and to achieve the most efficient arrangement.

Refinements in manufacturing methods have reduced the amount of steel needed to build a plant.

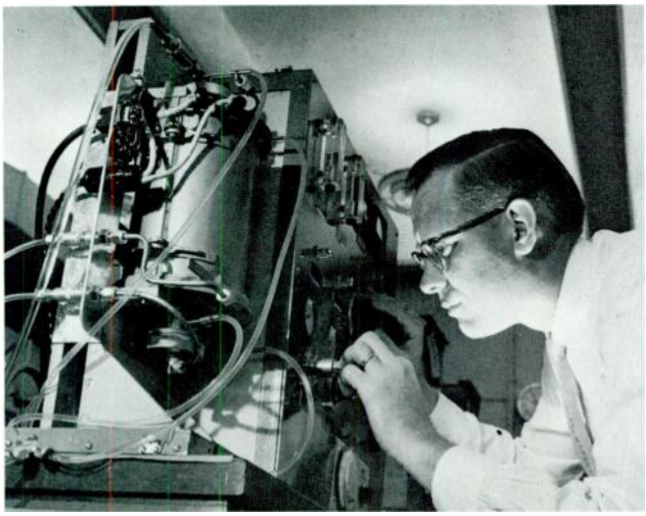
The latest advance is in plant operation. It is a method for chemically treating the sea water before it is fed into the plant. The Office of Saline Water, U. S. Department of the Interior, uses this method at its Westinghouse-built plant near San Diego, California. The treatment has permitted an increase in the operating temperature at that plant from 190 degrees to 250 degrees F. (Scale formation in the inner tubing had previously prevented use of the higher and more efficient heat level.) This improvement increased capacity 40 percent—from an initial output of 1 million gallons a day to 1.4 million gallons. The increase was obtained with only a slight rise in operating costs and virtually no increase in capital investment. ■

Fuel Cells for Use in Space Have Solid Electrolyte

Solid-electrolyte fuel cells developed for possible aerospace applications combine simple and compact construction with high power output per unit weight. A small prototype battery made by combining three of the new cells produces slightly more than two watts, weighs 1/5 of an ounce, and occupies 1/3 of a cubic inch of space. This is equivalent to an output of 150 watts per pound and electrolyte current of 780 amperes per square foot of cell area. Larger batteries, which will deliver up to 100 watts, are now being built.

The electrolyte in these cells is a solid ceramic made of zirconium and yttrium oxides, so there are no liquid or pasty chemicals to cause trouble in a zero-gravity environment. Hydrogen (the fuel) and oxygen gases flow into the battery, and water vapor (the reaction product) flows out. The vapor can be condensed to provide pure water.

ALL-SOLID FUEL CELLS are being evaluated for possible use in outer space. A small battery consisting of three of the experimental cells is housed in the cylindrical oven in the foreground, which maintains them at their operating temperature. Large batteries of these fuel cells would generate enough heat to maintain their own operating temperature.



Operating temperature of the cells is about 1750 degrees F. The smaller batteries are placed in ovens to maintain this temperature, but large ones (500 watts or more) would generate enough heat to maintain their own operating temperature.

Research engineers have designed a complete power system, based on these cells, to evaluate the capabilities of such a system for powering long space missions. Their calculations show that total power-plant weight, exclusive of fuel and fuel storage, would be 50 to 100 pounds per kilowatt of electric power, depending on the mission length for which the system is designed. This is high performance for fuel cells. It is partly the result of using a solid electrolyte, which permits connecting cells directly together in series to form systems that are compact and light because they have no bulky nonactive components. Also, the high operating temperature permits use of a small light radiator for dissipating excess heat. (The housing of the battery itself serves as the radiator.) Fuel-cell power systems that operate at low temperatures would need large radiators to prevent overheating.

The prototype battery was developed for the U. S. Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. ■

Scanning Electron Microscope Maps Surface Details

A new type of microscope, called a scanning electron microscope, reveals fine surface detail on solid areas no larger than the period at the end of this sentence. Resolution and depth of focus are better than can be achieved with optical microscopes.

Like a conventional electron microscope, the instrument "sees" with a beam of electrons. However, instead of forming an image by transmitting the beam through the specimen, the instrument scans the surface by sweeping a fine electron beam across it and builds up a picture from secondary emission electrons.

The main use of the instrument so far has been in studying the surface structures and surface electric fields of molecular electronic devices and other microelectronic structures and surfaces. The microscope, which is the first successful one in the United States, was developed at the Westinghouse Research Laboratories. (See photograph, inside front cover.) The basic design of the instrument was originated at Cambridge University in England.

In operation, electrons are accelerated to high speed by an applied voltage and focused with magnetic coils to form a beam. Other magnetic coils guide the beam across and down the surface of the specimen to scan it. The electron beam can be made as small as 0.1 micron in diameter, so it can scan in very closely spaced lines for high resolution.

The scanning beam causes the specimen to emit low-energy secondary electrons in numbers proportional to the shape and nature of the specimen surface. These secondary electrons are collected by a scintillating crystal, which converts them to visible light. The light is converted by a photomultiplier tube into an electrical control signal for a picture tube. The signal causes an electron beam in this tube, scanning in synchronism with the first beam, to display an image of the specimen surface.

The number of lines composing the picture can be varied in steps from 250 to 1000. The picture can be displayed at a magnification as high as 10 000 times, about 10 times better than can be achieved with an optical microscope.

Besides revealing surface structure, the scanning electron microscope reveals differences in voltage on a semiconductor surface. For example, the beam can observe the differences in potential between the regions of a planar transistor and thereby inspect in great detail the quality of the device and the quality of the processes used to make it.

Because of these capabilities, use of the instrument discloses device imperfections and malfunctions that could not be found by previous testing methods, and it brings new insight into the basic construction and operation of microelectronic devices.

The scanning electron microscope is also used for fabricating semiconductor devices. In this use, the electron beam substitutes for a beam of light in exposing selected areas of a photosensitive emulsion that coats the surface of a semiconductor material. The emulsion is then processed chemically to produce the mask used in subsequent operations that form the device. The fineness of the electron beam makes very fine detail possible.

The investigations into ways of applying the instrument to the manufacture of semiconductor devices are being performed for the U. S. Air Force, Electronic Technology Division, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

New Literature

Silicon Controlled Rectifier Designer's Handbook is a 384-page book on controlled-rectifier characteristics, applications, and design considerations. It includes descriptions of new design techniques, such as improved gate firing and its effect on turn-on time and dissipation, improved methods for using transient thermal impedance and calculation of maximum junction temperature, series and parallel operation, and protection techniques.

Application information for conventional controlled rectifiers includes switching amplifiers, inverters and converters, servo amplifiers, light dimmers, static contactors, and ultrasonic generators. Typical applications for the new gate-controlled switch (turnoff silicon controlled rectifier) also are described. Some of these are dc circuit breakers, dc choppers, dual-position power switches, transformer-inverter circuits, power shift registers, and static polarity-reversing switches.

Price, $2.00. Order from Westinghouse Semiconductor Division distributors or from Westinghouse Electric Corporation, Printing Division, Box 398, Trafford, Pa.

PRODUCTS FOR INDUSTRY

SOLID-STATE SPEED CONTROLS FOR FRACTIONAL HORSEPOWER MOTORS serve dc shunt, dc series, and universal (ac and dc) motors. The type 901 and 902 Hi-Torque units handle, respectively, motors rated to 1/15 and 1/3 horsepower. They employ silicon controlled rectifiers with feedback to provide better speed regulation than the conventional adjustable transformer-input type of control. Applications include small machine drives, test stands, mixers, and laboratory apparatus. They can also be used as adjustable dc voltage sources for lamp dimming, resistance heating, and electronic experimentation. Rated input is 115 volts ac, single phase, 50/60 cycles. *Westinghouse Semiconductor Division, Special Products Department, Youngwood, Pa.*

COROX HEAVY-DUTY BOLT HEATER heats hollow metal holding bolts and studs to full linear expansion in 15 to 30 minutes. It is used in the manufacture and servicing of heavy steam machinery, other pressure-restraining equipment, mechanical and hydraulic presses, large die blocks, and heavy metal platens. It is also useful for expanding the large adjusting bolts on mechanical presses to release the presses when they stop on dead center. Standard ratings range from 1 kw to 15.2 kw at 120 volts, and effective heated lengths from 12 to 60 inches. *Westinghouse Manufactured Products Division, 1844 Ardmore Blvd., Pittsburgh, Pa. 15221.*

STATIC ADJUSTABLE-SPEED AV-S DRIVE consists of a dc motor, power rectifier, control system, and operator's controls. Efficiency is higher than that of m-g sets, and size and weight are less. Use of static components with inherent long life minimizes maintenance. No warm-up time is required, and a timing network provides controlled smooth acceleration to operating speed in about three seconds. Control is by manually positioned potentiometer. The all-static power supply regulates the voltage applied to the motor armature in response to feedback signals from a speed sensing and correcting circuit in the control system. An IR compensation network senses the error introduced by variations in armature current with load, and initiates corrective action to hold machine speed constant. Motor field is under constant excitation. Ratings go from 1 to 5 horsepower for single-phase models and from 5 to 60 horsepower for three-phase. Power supply requirements for standard models are 50 to 60 cycles and 220 volts. *Westinghouse Systems Control Division, Buffalo, N. Y. 14205.*

ABOUT THE AUTHORS

Dr. E. A. Sack, who describes the present state of affairs in molecular electronics in this issue, has a "solid" background—in solid-state devices. He came with the Westinghouse Research Laboratories in 1954, after receiving his PhD from the Carnegie Institute of Technology. His first assignment was in research and development on color television systems and related solid-state devices. From here, he moved to research on electroluminescent, ferroelectric, and photoconductive devices.

In 1960, Dr. Sack was made manager of the Electronics Department of the Research Laboratories, where he was responsible for research and development programs that included molecular electronic and semiconductor devices, electroluminors and photoconductors, and electroacoustic devices and systems. Dr. Sack was appointed manager of the new Solid State Devices Department of the Research Laboratories in 1961, and was responsible for a comprehensive program covering all phases of solid-state device research, engineering, techniques development, and pilot production. When the Molecular Electronics Division was formed in 1962, Dr. Sack was appointed Manager of Engineering. Dr. Sack was selected for the Outstanding Young Electrical Engineer Award by Eta Kappa Nu in 1959.

The team approach is a familiar one for **Paul H. Jeynes** and **Clarence J. Baldwin,** coauthors of the series of articles on engineering economics that begins in this issue. Jeynes, with Public Service Electric and Gas Company of New Jersey, and Baldwin, with Westinghouse, have worked together since 1958 when the two companies joined forces to develop simulation techniques for studying electric utility system expansion.

Jeynes graduated from Sheffield Scientific School in 1918 with a PhB degree, and from Yale Graduate School in 1920 with an ME degree. He started with Public Service as a cadet engineer in August 1920.

Jeynes' first assignment was in test engineering. His work in engineering economics began in 1925 when he was assigned to economic studies of interconnections, generation scheduling, and railway electrification. This was the first of a series of assignments in both the engineering and accounting departments in which Jeynes was involved in various phases of engineering economics. His work led to his appointment to the position of Engineering Economist for the company in 1957, the position he held until his retirement in September 1963.

Jeynes' studies have resulted in a number of original contributions to the field of engineering economics. When he was the Depreciation Engineer in the accounting department, he developed original methods for making statistical analyses of plant mortality experience, and for predicting future average lives, salvage values, and types of retirement dispersion. As Distribution Plant Engineer, he studied economic choice, profitability, and valuation and allocations for rate-making. He also developed original procedures for load sampling and analyses of customer class load and losses.

As Engineering Economist, Jeynes developed methods for estimating minimum acceptable rate of return, a key concept in revenue-requirements analysis. He has taught courses in public utility economics and is the author of the book *An Abbreviated Course in Engineering Economics*. This book is the basis for courses given in Public Service and in other electric utility companies.

C. J. Baldwin is a familiar contributor to these pages, with several articles describing methods for solving power system problems. He is manager of the generation section of the Electric Utility Engineering Department, where he is responsible for system planning studies, power system control investigations, auxiliary systems for power plants, and studies of new power generation sources.

Baldwin is a graduate of the University of Texas (MS in EE) and holds a professional EE degree from MIT.

R. O. Brown and **J. E. Donahue** pool their steam-turbine experience in describing large tandem-compound turbine designs produced by advance design techniques.

Brown earned his BSME at Swarthmore College in 1949 and his MSME at Drexel Institute of Technology in 1955. He joined Westinghouse on the graduate student course in 1949 and then served in the U.S. Army Corps of Engineers from 1950 to 1952. He returned to Westinghouse as a thermodynamic design engineer in the steam divisions. As manager of the advance design section, Large Turbine Division engineering, Brown is now responsible for the advance design and development of large and medium turbines and components (16.5 mw to 1000 mw). He has contributed to the development of high-performance low-pressure turbine blades and exhaust hoods and is responsible for the design of the combined HP-IP element for turbines in the 500- to 600-mw range.

Donahue graduated from the University of Connecticut in 1944 with a BSME degree. He joined Westinghouse on the graduate student course and, after brief stints in the Boston engineering and sales office and the Pittsburgh area, was assigned to the mechanical design section of the Large Turbine Division engineering department. He is now a supervisory engineer in that section. He has contributed to the improvement of steam turbines in such areas as pressure vessels, piping, foundations, anchors, and inlet features.

B. H. Vester began concentrating on space guidance in 1961, when he was made manager of the Space Communications and Guidance Development Section of the Air Arm Division. The radar transponder system that grew out of this work has been applied to NASA's Gemini program, as described in this issue. As Director of Engineering for the Gemini Radar Project, Vester has participated in the application.

Vester came to Westinghouse on the Graduate Student Course in 1950. Prior to space guidance and communications, Vester participated in the design and development of autopilots for jet aircraft, magnetic modulators for missile radar, and airborne pulse doppler radar.

Vester is a graduate of Virginia Polytechnic Institute (BSEE) and holds an MSEE from Johns Hopkins University. In his spare time, he is an active radio amateur (W3TLN). He has written several articles on high-frequency crystal filters and their use in single-sideband transceivers.

H. A. Zollinger's career has been spent in the engineering of material-handling drives, controls, and systems. He is a prolific writer on the subject, with many articles in the trade and technical press and in the *Westinghouse ENGINEER*.

Zollinger earned his BS in electrical engineering at Michigan College of Mining and Technology in 1951. He joined Westinghouse on the graduate student course, was assigned to the material-handling section of the industrial engineering department, and is now engineer in charge of the material-handling section in the Manufacturing Province, Industrial Systems. He has contributed heavily to the development of saturable-reactor controls for hoists and cranes, Thyristor control of squirrel-cage and wound-rotor motors for variable-speed drives, and ac mill motors for steel-mill cranes and auxiliaries.

Zollinger received his MS in electrical engineering from the University of Pittsburgh in 1958, and he earned a business and management certificate there in 1961. He received honorable mention in 1961 in Eta Kappa Nu's competition for the title Most Outstanding Young Electrical Engineer.

ATOMIC POWER . . . from Pittsburgh to Italy

The first of 120 nuclear fuel assemblies for the Enrico Fermi atomic power plant being built by Societa Elettronucleare Italiana (SELNI) in Trino, Italy are shown being prepared for shipment. Each 10-foot assembly consists of 208 stainless-steel tubes loaded with hundreds of uranium-dioxide fuel pellets. The Italian power plant is expected to be in operation in 1964.