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World Radio History

the cover

Head-on view of a traffic light, typical of those at many of the world's intersections. Automation of traffic control, as described in the article on pages 30–43, can do much to alleviate the problems engendered by the vehicular explosion

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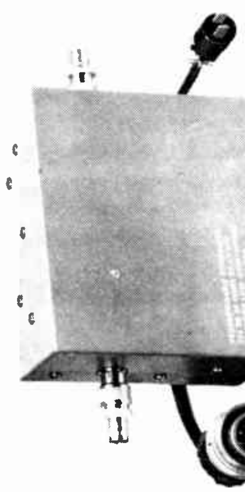

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World Radio History

Marty Warskow heads up AIL's Department of Transportation Research. With Howie Burns and Ted Hooton as coauthors, the problems of designing air terminals are described for our IEEE friends who are nearly all interested in this subject, either as frustrated passengers or as concerned technologists.

Design for the Future in Terminal Air Traffic Control

During 1967, New York's three major airports handled over 1,000,000 air operations. In 1980, the area's major airports should be prepared to handle over 1,600,000 operations, according to a recent Federal Aviation Administration (FAA) forecast. In addition, for 1980, it is predicted that over 6,000,000 general aviation aircraft operations will occur at other general aviation airports in the New York region.

Events of the summer of 1968 have left no doubt in aviation circles that airport and airspace congestion is a serious current problem. Yet in 1980, management will undoubtedly have to accommodate not only the growth at the major airports, but in addition, a sizable proportion of the six million other competitors for airspace positive control or advisory service.

How does one forecast the overloading of airspace and airport facilities? This paper describes the application of techniques and methodologies useful for such forecasts.

The techniques for analysis have been developed over a period of several years. In application, they are relatively economical of time and money, since they do not involve heavy personnel commitments as in real-time simulation programs. Their use does require an extensive background in air traffic control and airport operation, and detailed knowledge and information on many items.

Figure 1 indicates a likely sequence of use of the techniques which are described in the following paragraphs. The procedure works from the known present situation into the future terminal area and airport design.

Transition Airspace Analysis—Transair Model

Transition airspace would be defined as that airspace within an area that is large enough to incorporate aircraft climbout and descent paths to and from all the major airports in a terminal area. For example, in the New York area we would consider that this would include an area of about 100 miles square and to an altitude of approximately 40,000 feet.

There is an essential requirement that the transition airspace capacity be known because we must ensure that any one airport's capacity is not further limited by that of the surrounding airspace. In other words, there is no point in developing super airports within a terminal area, unless the surrounding airspace and control procedures are adequate to handle the airport traffic.

In the terminal airspace there are many arrival and departure routes for each airport to be considered. Many points of conflict between aircraft which require control action can occur at the intersections of the air routes. The measure of this control action or complexity (hence workload) is therefore a clue to the capacity of the system. If we can establish that a certain intersection gives rise to many control and economic problems in today's airspace, we can deduce its present capacity. The system capacity would consider the total complexity of all intersections. Assuming that certain equipment and procedural changes will be forthcoming in the future, we can then estimate a complexity capacity of intersections and the system for forecasting purposes.

A computer program has been prepared using as inputs a description of the airway routes, the rate of traffic flow and aircraft type on each route, the climb and descent performance of those aircraft types, and requirements relative to level-out for en route flight. This computer program was developed and applied to the New York area as part of airport system analyses for the Port of New York Authority. It can be applied to other and less complex areas.

If the TRANSAIR analysis shows overloading of the airspace at the selected traffic demand, then it follows that either the airspace use should be redesigned or congestion (holding) will be caused by the overloaded condition. Holding increases workload as each aircraft is kept in the system longer. Thus a deteriorating airspace control situation can readily occur with the only quick solution to limit traffic demand—use restrictive flow control.

In one example problem, it was shown that an increase of traffic of 2.5 times resulted in an increase in complexity of control of 6 times.

A basis is provided by this technique for examining an air route structure to determine how much more complex the overall control problem will become, and how complex the control problem is by intersections. This provides a basis for organizing the air route layout to minimize complexity.

Approach Departure Path Analysis (AD Path)

Approach and departure paths in the vicinity of the individual airports must have a more detailed examination than that given in the gross examination of TRANSAIR. This is accomplished by actually laying out approach and departure paths to and from each airport for every combination of runway use.

To determine the combinations of runways which must be considered, the airport configuration with any restrictions due to noise or obstructions, traffic, etc., is observed and studied to assign wind directions to combinations of runway use.

Once the runway combinations are known, IFR approach and departure paths are laid out for most efficient use of these combinations. It is thus possible to determine items which will restrict capacity such as:

1. Unusual lengths of straight-in approach path.
2. Unusual length of single lane and altitude restricted departure paths (for example, the Teterboro Airport outbounds).
3. Conflicts which cannot be resolved by altitude or lateral separation.

Once the items which may restrict capacity have been determined, it is essential to find the percent of time at which they occur. To determine this requires that a weather analysis be performed for each airport, and where interairport conflict occurs, for two airports simultaneously. Computer programs have been prepared to accomplish the weather analyses for either single or dual airports.

Thus, through the AD path and weather analyses, runway configurations and airport use can be analyzed to provide a basis for later capacity computation.

Practical Annual Capacity and Hourly Capacity

The ultimate aim in studying terminal area operations is to maximize airport capacity and minimize delay and efficient routing. A basis has now been laid for proceeding to capacity and delay computations.

When the airspace is studied, as described, and any other actions or restrictions determined, it is possible to reflect these findings in capacity computation. The hourly capacity (PHOCAP) computations are accomplished first.

Briefly, the technique utilizes mathematical models based on queuing theory. The delay to operations (landings and takeoffs) is computed and practical capacity is selected as an operating level with reasonable delay.

The technique of computing the practical annual capacity (PANCAP) is essentially an evaluation of delay occurring during the hours when PHOCAP is exceeded. PANCAP is selected at a delay level to provide reasonable service without excessive delay over a one-year period. An essential point of this technique is that it can permit bringing into a terminal assessment the interaction between airports. Since it computes capacity over a time period of one year, it can be used to show the effect of interairport conflict during the appropriate times of the year. Since it is also based on a delay evaluation (just as PHOCAP), it thus can be exceeded, but at the price of higher delay.

Annual Delay Computation

Another important tool in terminal area evaluation is the ability to compute air and ground delay to operations.

Application of these techniques will:

1. Provide a factual base for terminal area planning and airport system capacity, and enable choices between alternate solutions.
2. Provide a factual base for staging a multi-airport development program to minimize delay, or to control delay at a level commensurate with other considerations, as for example, added facility costs due to multiple airport operation.

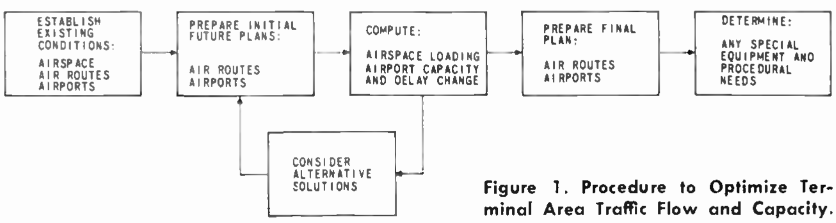

Figure 1. Procedure to Optimize Terminal Area Traffic Flow and Capacity.

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Forum

Readers are invited to comment in this department on material previously published in IEEE SPECTRUM; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession.

The Boston arm

Reference is made to your report in the November 1968 issue of IEEE SPECTRUM (p. 160) about the "Boston Arm," especially to the statement that "... In the late 1950s the British and the Russians had begun to use electric signals from muscles to operate a simple open-and-close artificial hand ..."

I would appreciate it if you would publish the following explanation to clarify once and for all the true scientific priority of an important invention so far obscured by the turbulent post-World War II years.

The inventor of the first electronically operated artificial arm and hand is Dr. rer. nat. Reinhold Reiter, then student at the Munich University. His first written report is dated May 1945. On August 30, 1945, he submitted the official patent application through the patent attorney Weickmann (Munich). An extended application was resubmitted on October 18, 1946, through Justizrat Heinrich Hippler, notary public in Munich.

The first printed publication appeared in the September 1948 issue of the publication, *Grenzgebiete der Medizin*. The placement of electrodes is identical to that of the Boston Arm. The opening and closing of fingers was actuated by muscle contractions upon command from the brain. The pulse shapes and original pulse amplifier are shown in the paper.

As Dr. Reiter's business manager, I participated in all demonstrations, hospital testing, and prototype building in Munich, and I have a complete file of the original data on this invention.

Further development of the system was terminated due to the lack of adequate funds after the German currency reform in 1948. One preproduction sample of the "Reiter Kunsthand" was shown publicly at the Exportmesse Hannover (Hannover Export Fair) in spring 1948 by the firm Anders & Co.-Gauting, our pilot run subcontractor. This simple, reliable design suitable for mass production stirred considerable interest.

After receiving his doctorate, the inventor selected a different area of specialized research as his field of interest. The field of myoelectricity as applied to prosthetic research was thus left open for new entries. The development of transistors destroyed size and power consumption barriers.

Since 1955, Dr. Reiter has published over 70 scientific papers and authored two books in the area of bioclimatology, atmospheric, meteorologic, tropospheric, aerosol, and radiation research. He is now in charge of "Physikalisch-Bioklimatische Forschungsstelle," a research establishment in Garmisch-Partenkirchen.

I have been fully authorized by Dr. Reiter to undertake this step to clarify the priority of the "Kunsthand" invention. The available documents were shown recently to Dr. Dudley S. Childress from the Medical School of Northwestern University, who is engaged in a similar myoelectric prosthesis research project. Dr. Childress expressed his interest in correcting the situation by notifying the leading publications in this field about the early accomplishments of Dr. Reiter.

Marian V. Podlusky, Chicago, Ill.

Marian Podlusky's illumination of Dr. Reiter's premier development of an electromyographically controlled prosthesis provides additional evidence (if anyone really needed it) of the fallibility of information retrieval systems. Despite a carefully compiled bibliography of 156 entries in one of the original M.I.T. graduate student theses and my now seven-year membership on the Committee on Prosthetics Research and Development of The National Academy of Science–National Research Council, neither I nor any of my colleagues was aware of Dr. Reiter's work. We very much appreciate having history set straight.

I would, however, like to avail myself of this opportunity to draw several distinctions between Dr. Reiter's design (and the early British and Russian hands, which are very similar) and our "Boston arm."

One comment reflects that sophistication made possible in part by postwar developments in electronics and electromechanical components. Thus, whereas the German, British, and Russian hands in their original form were off–on, open-loop devices, the "Boston arm" provides proportional control between the muscular activity of the amputee and the response of the limb and force feedback of the load carried by the limb.

But the more significant difference between our development and all previous and, in fact, current electromyographically controlled prostheses is our deliberate and careful symbiosis of the brain and neuromuscular physiology of the amputee with the device. Whereas, for example, Dr. Reiter's hand used unrelated muscles in the upper arm to bring about finger motion, we use the EMG from those residual muscles in the amputee's upper arm stump to control the heretofore anatomically related elbow joint. As a consequence an amputee fitted with the "Boston arm" rotates his electromechanical elbow by literally thinking, in the normal, volitional sense, of flexing his biceps and triceps muscles. This use of anatomically sound efferent neuromuscular control coupled with force, motion (and, in research versions, position) feedback into the afferent sensory nervous system of the amputee provides a prosthesis that more closely approximates the cybernetical ideal.

Robert W. Mann, M.I.T.

Understanding the brain

In response to the question of "Understanding the Brain" (Sept., p. 52) I should like to propose that a useful definition of understanding a physical component or process is: The ability to *duplicate* the component, *synthesize* the process, and, most important, to *demonstrate an improved* process or component.

Philip Emile, Monsanto

World Radio History

Focal points

Color Television Study Committee sets up plan of work at first meeting

The newly formed Color Television Study Committee[1] held its first meeting at the headquarters of the Society of Motion Picture and Television Engineers (SMPTE) in New York on Thursday, September 26, 1968. Each of the organizations invited to participate in the activities of this committee was represented by one or more engineers. If the meeting were to be categorized by a single word, that word would be enthusiasm. It is evident that the problem of variability of color seen on television receivers in homes has been worrying discerning engineers for many months, and this committee is expected to be a means for improving the situation.

Early in its deliberations, the committee recognized that variation of color on a home viewer's screen could result from a change of any single component of the whole chain between the original live scene and his picture tube. If the committee were to avoid being bogged down in a lengthy and detailed study of every one of the components of the broadcasting system, it would be imperative that the most serious causes of variability be identified and the efforts of the committee be concentrated on these items.

The honest concern of the committee members over the problem of variability of color seen on home receivers was at no time more evident than during the ensuing discussion aimed at locating the causes of the most serious variations. Transmitter people mentioned the difficulty of ensuring that an operating transmitter is within its tolerances and pointed out that not only were measuring techniques incompletely specified, but that all too often, suitable measuring equipment for use in an individual transmitting station was not readily available. The receiver people spoke of problems ranging from inadequate design of receivers to the impossibility of frequent changing of circuit design to keep up with the proliferation of phosphors in picture tubes, with chromaticities different from those mentioned in the FCC Rules. Beyond the problems of scene lighting and of colors of costumes and sets, the broadcasters expressed their greatest concern over the standardization of alignment or adjustment of monitors used for evaluating color quality as a program is sent on its way. Those members of the committee skilled in the field of film and of video tape pointed out that either of these recording media often caused color shifts. In film the problems may arise from both scene staging and film processing. On the other hand, in video tape the major sources of concern are operating techniques and shortcomings of equipment design.

One important observation was made during this discussion. Variations in the broadcasting system are more noticeable on a receiver having a white balance at the present value of 9300 K than on a receiver for which the white has been color-matched to Illuminant C, on which the FCC Rules have been established.

As a result of this discussion, the committee agreed that initially its efforts should be directed toward investigation of the following topics:

1. Colorimetry of television camera systems.
2. Color film and film-camera chains.
3. Standardization of color monitors.
4. Characteristics of tubes and chromaticities.
5. Tolerances on the numbers that make up the specifications for the broadcast signal, as found in the FCC Rules and Electronics Industries Association (EIA) Specifications.

Some aspects of the colorimetry of color television cameras are being studied by the Studio Facilities Committee TR-4.4 of EIA, but a small group was appointed by Chairman Benson of the Color Television Study Committee under the chairmanship of E. P. Bertero, a representative of the National Association of Broadcasters (NAB), to review the problems and to recommend appropriate action.

Arrangements were made for a field test in the Chicago area to determine the effects on a received picture of variations in the radiated signal within the tolerances permitted by the FCC Rules. Several transmitters and receivers will be used in this test. The transmitters will be available for the tests by the networks represented on this committee through the NAB. The performance of the transmitters at the times of the tests will be checked by the transmitter operators and by members of EIA Committee TR-4.1. Receivers will be furnished not only through EIA Committee R-4, but also through the efforts of the IEEE representatives on this committee.

To complement this field test, a request was directed to the SMPTE that its Engineering Committee on Video Tape Recording be asked to determine the effect on the output signal from a video-tape recorder of varying the input signal within the tolerances permitted by the FCC Rules.

In addition, the SMPTE Engineering Committee on Television has been asked to expand its study of color monitors to include an investigation of the possibility of standardizing the chromaticities of the phosphors used in the picture tubes.

It was brought out by several members that a study group of the Canadian Broadcasting Corporation had collected information on some of the problems facing the Color Television Study Committee. Chairman Benson was directed to invite the appointment by the CBC of an observer to this committee to broaden the base of its study.

W. T. Wintringham
Chairman
IEEE Standards Committee

1. "On uniformity of television color reproduction," *IEEE Spectrum (Focal Points)*, vol. 5, p. 161, Nov. 1968; *J. SMPTE*, vol. 77, pp. 1203–1204, Nov. 1968.

World Radio History

New definitions issued for International System units

In a lecture given in Philadelphia in 1884, Lord Kelvin said:

"You, in this country, are subjected to the British insularity in weights and measures; you use the foot and yard. I am obliged to use that system, but I apologise to you for doing so, because it is so inconvenient, and I hope all Americans will do everything in their power to introduce the French metrical system. I hope the evil action performed by an English minister whose name I need not mention, because I do not wish to throw obloquy on anyone, may be remedied. He abrogated a useful rule, which for a short time was followed, and which I hope will soon be again enjoined, that the French metrical system be taught in all our national schools. I do not know how it is in America. The school system seems to be very admirable, and I hope the teaching of the metrical system will not be let slip in the American schools any more than the use of the globes. I say this seriously: I do not think anyone knows how seriously I speak of it. I look upon our English system as a wickedly brain-destroying piece of bondage under which we suffer. The reason why we continue to use it is the imaginary difficulty of making a change, and nothing else; but I do not think in America that any such difficulty should stand in the way of adopting so splendidly useful a reform."

Nine years earlier, the United States had become a signatory to the Treaty of the Metre. As things have turned out, adoption of the "splendidly useful" reform has made slower progress in the United States than it has in Great Britain, where conversion of industry to the metric system is actively in progress, with the intent that the major part of the changeover will be completed by 1975. However, even in the U.S. the British units have, for some years now, been defined in terms of the metric units. For example, the inch is, by definition, 0.0254 metre exactly, and the pound avoirdupois is 0.45359237 kilogram.

The International System of Units (SI) is based on the metre, the kilogram, the second, the ampere, the kelvin, and the candela. The Treaty of the Metre established the General Conference on Weights and Measures, which acts on technical proposals that originate in seven advisory committees, of which one is the Advisory Committee on Units—Comité Consultatif des Unités (CCU). Since publication of the "IEEE Recommended Practice for Units in Published Scientific and Technical Work,"[1] the CCU slightly modified the wording of the definitions of the base units of SI (also see Ref. 2). "Authorized" English versions of the official French definitions have issued,[3] and are presented in the following. For use in English, the spellings gramme and gram, metre and meter, are equally recognized, as are some differences between British and U.S. spelling. In the text presented here, customary U.S. spelling is used, except for "metre," to avoid such combinations as "micrometer," which is

Définitions des unités de base du SI
Definitions of the base units of SI

(translated from French)

CGPM: Conférence Générale des Poids et Mesures: General Conference of Weights and Measures
CIPM: Comité International des Poids et Mesures: International Committee of Weights and Measures

mètre (m)	*metre (m)*
Le mètre est la longueur égale à 1 650 763,73 longueurs d'onde dans le vide de la radiation correspondant à la transition entre les niveaux $2p_{10}$ et $5d_5$ de l'atome de krypton 86.	The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.
(11e *CGPM* (1960), *Résolution* 6)	(11*th CGPM* (1960), *Résolution* 6)
kilogramme (kg)	*kilogram (kg)*
Le kilogramme est l'unité de masse; il est égal à la masse du prototype international du kilogramme.	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
(1re *et* 3e *CGPM*, 1899 *et* 1901)	(1*st and* 3*rd CGPM*, 1889 *and* 1901)
seconde (s)	*second (s)*
La seconde est la durée de 9 192 631 770 périodes de la radiation correspondant à la transition entre les deux niveaux hyperfins de l'état fondamental de l'atome de césium 133.	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
(13e *CGPM* (1967), *Résolution* 1)	(13*th CGPM* (1967), *Résolution* 1)
ampère (A)	*ampere (A)*
L'ampère est l'intensité d'un courant constant qui, maintenu dans deux conducteurs parallèles, rectilignes, de longueur infinie, de section circulaire négligeable et placés à une distance de 1 mètre l'un de l'autre dans le vide, produirait entre ces conducteurs une force égale à 2×10^{-7} newton par mètre de longueur.	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
(*CIPM* (1946), *Résolution* 2 *approuvée par la* 9e *CGPM*, 1948)	(*CIPM* (1946), *Resolution* 2 *approved by the* 9*th CGPM*, 1948)
Note. L'expression "unité MKS de force" qui figure dans le texte original a été remplacée ici par "newton" adopté par la 9e CGPM.	
kelvin (K)	*kelvin (K)*
Le kelvin, unité de température thermodynamique, est la fraction 1/273,16 de la température thermodynamique du point triple de l'eau.	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
(13e *CGPM* (1967), *Résolution* 4)	(13 *th CGPM* (1967), *Résolution* 4)
candela (cd)	*candela (cd)*
La candela est l'intensité lumineuse, dans la direction perpendiculaire, d'une surface de 1/600 000 mètre carré d'un corps noir à la température de congélation du platine sous la pression de 101 325 newtons par mètre carré.	The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.
(13e *CGPM* (1967), *Résolution* 5)	(13*th CGPM* (1967), *Résolution* 5)

Transients and trends

Total 1969 expenditures for research and development in the United States are expected to reach $25.9 billion according to the annual forecast by the Columbus Laboratories of Batelle Memorial Institute. The 1969 total is an increase of 3.6 percent over the estimated 1968 expenditures but represents a distinctly slower rate of growth than in any year since 1953 when expenditure figures were first compiled. The modest increase in total 1969 expenditures, as Batelle sees it, will result largely from additional funds provided by industry and by colleges, universities, and other nonprofit institutions. Federal support is expected to remain at about the same level as in 1968.

If the expenditure estimate is broken down by source of funds, it is expected that Federal government spending will total $15.6 billion; industry, about $9 billion; colleges and universities, about $938 million; and other nonprofit institutions, about $295 million.

The declining growth rate of Federal expenditures represents the continuation of a trend. Over the past ten years, Federal expenditures on research and development grew at a compound rate of nine percent per year. However, the forecast points out, the growth rate over the last four years has slowed to about six percent per year. The outlook for the next ten years sees the annual rate of increase ranging between four and eight percent.

Japanese production of business machines more than doubled from 1962 to 1967 to a dollar value of $121 million according to the U. S. Department of Commerce. In a study released recently it is reported that Japanese production has shifted from manual and mechanical devices to electric and electronic machines. The large buildup is attributed to progress in domestic technology; entry of Japan's top producers of electronic equipment, sewing machines, cameras, and film into the business machine sector; and an increasing number of licensing and joint venture arrangements between Japanese manufacturers and foreign firms, many from the U.S.

Fourteen nuclear-electric power plants with a combined generating capacity of about 13×10^9 W net were ordered by U.S. utilities in 1968. In a report released by The Atomic Industrial Forum, Inc., it is pointed out that these figures were well below the totals for the record year of 1967 and for 1966. The new contracts brought the number of purely commercial nuclear power plants ordered so far by U.S. utilities to 80 with a total capacity of 63 to 64×10^9 W.

On a conservative basis the 80 plants represent a direct capital investment of some $9 billion not including fuel. On this basis their nuclear systems—the reactors and associated equipment—may account for $3.5–4.0 billion. Assuming that present costs hold good, their requirements for fuel materials and services over their lifetimes may involve expenditures of some $25 billion.

As utilities sought to avail themselves of economies of scale, according to the report, the trend toward larger units continued strongly. The average capacity of the 14 new plants was more than 900 MW compared to about 830 MW for the 1967 series and about 800 for the 1966 series. Six of the 14, with ratings of more than 1000 MW, will be at least as large as the biggest steam generating unit now operating in the U.S. or anywhere in the world. Only one of the 14 is smaller than 600 MW. All of the 14 new plants are to be equipped with reactors cooled with boiling or pressurized water and fueled with uranium slightly enriched in the isotope U-235.

While many factors doubtless contributed to the 1968 decline in orders, there seemed to be no question, according to the report, that some reduction was inevitable following the abnormally intense activity of 1966 and the even higher order rate of 1967.

Over-the-air subscription television has been authorized by the U.S. Federal Communications Commission as a supplemental broadcast service to start after a six-month waiting period. The purpose of the waiting period is to provide time for Congressional and court review. The new rules will take effect June 12, 1969. Before that date, the FCC will issue technical standards for subscription television systems. No applications for station authorizations will be accepted until the technical rules are adopted and no grants will be made until the rules become effective. The question of rules requiring community antenna television carriage of subscription television signals from subscription television stations was left open and a notice of proposed rule making was announced. The portion of the pay television inquiry dealing with wire or cable subscription television as a separate form of subscription service was terminated.

In over-the-air subscription television, usually both the sound and picture signals would be transmitted in scrambled form by the television station and could be viewed intelligently only by those having unscrambling devices attached to their television sets. The FCC has emphasized that the service is supplemental to present conventional television. It will be permitted only on one station in a community and only in communities that, in addition to the subscription television station, receive service from four conventional television stations so that ample television fare will be available.

The growth rate of the U.S. electronic components industry will be affected in 1969 by a slowdown in the rate of government spending for electronic equipment coupled with increased consumer income tax payments according to Dr. L. C. Maier, vice president and general manager of General Electric's Electronic Components Division. He forecasts that sales of electronic components will lag behind the overall electronic equipment industry, increasing only about 2 percent to just over $5.8 billion. Component sales in 1968 totaled $5.7 billion, up 4 percent over 1967.

The total electronic equipment industry will increase sales by 3 to 4 percent in 1969, Dr. Maier predicts, to about $25 billion. He sees a 15 percent gain in the automotive segment, a 3 percent increase in consumer electronic equipment, a 6 percent growth rate in both industrial electronic and communications equipment, a 2–3 percent increase in government electronic purchasing, and a slightly lower growth rate than normal for the computer equipment industry. The replacement market should maintain its current level in 1968, he feels.

A ten percent rise in engineering activity in 1969 accompanied by increased personnel demand has been predicted by the National Society of Professional Engineers. The society also forecasts an increased reliance on technicians to assist the engineers and a trend toward involvement of engineers in the solution of various social problems.

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objectionable because it is also the name of a device.

1. "IEEE recommended practice for units in published scientific and technical work," *IEEE Spectrum*, vol. 3, pp. 169–173, Mar. 1966.
2. Barrow, B., "IEEE takes a stand on units," *IEEE Spectrum*, vol. 3, pp. 164–168, Mar. 1966.
3. "Comité Consultatif des Unités, Session de 1967," Imprimerie Durand, 28-Luisant, France.

Control engineering is course topic at Liverpool

The Liverpool Regional College of Technology in England has announced that multivariable process control will be the subject of a short course of lectures to be given on Monday evenings, from February 10 through July 14.

The objective of this course is to present the application of modern control theory techniques to the analysis and design of process control systems. An introduction to the relevant aspects of digital computer programming will be given, followed by demonstrations and individual use of the college computer. The fee for the course is £6.

Further information is available from K. R. Jones, Department of Electrical and Control Engineering, Liverpool Regional College of Technology, Byrom Street, Liverpool, 3, England.

Cincinnati will host laser safety conference

The Second International Laser Safety Conference will be held March 24 and 25 under the auspices of the Laser Laboratory of the Medical Center of the University of Cincinnati and the U.S. Public Health Service. The meeting site will be Stouffer's Cincinnati Inn.

Recent developments of laser instrumentation of significance in laser safety programs and of laser applications in relation to increased exposure for operating personnel will be considered, as will be current studies of laser safety programs in regard to acute and chronic exposures of eyes and skin, and air-pollution hazards. Also, current legislation at federal and state levels relating to control of laser devices and applications will be reviewed. The conference will feature workshops to establish recommendations and revisions of current laser safety standards and demonstrations of new laser devices.

For program details and reservations, write to Dr. Leon Goldman, International Laser Safety Conference, care of Laser Laboratory, Children's Hospital Research Foundation of the Medical Center, University of Cincinnati, Elland and Bethesda Avenue, Cincinnati, Ohio 45229.

Guidebook is published for immigrant engineers

A guidebook designed to help immigrant engineers make the adjustment to professional working and living conditions in the United States has been published by the Engineering Manpower Commission of Engineers Joint Council. Written by Dean W. P. Berggren of the University of Bridgeport, Conn., the 61-page handbook contains sections on professional recognition, work and community conditions, legal and welfare questions, engineering salaries, professional societies, units and conversions, government employment, and other information.

The Commission became aware of the need to help immigrant engineers when government studies disclosed that between 3000 and 4000 were entering the U.S. every year. The book also contains a chapter alerting prospective employers to some of the differences they can expect to find in the newcomers. To help ease communications, an appendix provides an engineering vocabulary, together with abbreviations and, probably most helpful, a list of slang terms in common use among engineers in the United States.

The new guidebook may be obtained for $3.00 per copy, prepaid, from Department P, Engineers Joint Council, 345 East 47 Street, New York, N.Y. 10017. Discounts are available on bulk quantities.

NBS now offers data on engineering standards

The National Bureau of Standards (U.S. Department of Commerce) is now prepared to offer information services on published engineering standards and specifications.

The Information Section of the Bureau's Office of Engineering Standards Service has collected some 16 000 engineering and related standards and specifications published by more than 350 U.S. trade, professional, and technical societies. These standards have been cataloged and indexed and are maintained in a technical library. In addition, a Key-Word-in-Context Index of all of the standards in the collection has been compiled. The Information Section will function both as a technical library and as a referral activity in providing answers to questions on engineering standards and standards activities, and in directing inquirers to the appropriate organizations for copies of published standards.

The collection of published standards and the compilation of the KWIC Index will enable the Information Section to answer such questions as: Are there any existing standards for a given product? Have test methods been established for determining the various characteristics of materials or products? Has the nomenclature in a particular field been defined? Have specifications for a certain material been established by a nationally recognized organization? Where and how can they be obtained?

In its work with the organizations that develop and promulgate engineering standards, the Bureau's role in general is to provide the measurement standards and techniques upon which these standards are based. Also, through its Office of Engineering Standards Services, NBS has worked cooperatively with industry groups, under procedures published by the Department of Commerce, in developing voluntary standards for specific products. These standards, now identified as Product Standards, are included in the collection.

Written inquiries concerning published standards should be directed to: Information Section, Office of Engineering Standards Services, National Bureau of Standards, Washington, D.C. 20234.

Speech communication to be M.I.T. summer program

"Speech Communication" will be the subject of a special summer program to be offered by the Department of Electrical Engineering at the Massachusetts Institute of Technology in Cambridge, June 23–July 3.

The aims of the course are to present the fundamentals underlying the speech process and to discuss applications, particularly in the areas of machine processing and generation of speech. The basic material examines the acoustic, physiological, phonetic, and phonological aspects of speech, and covers aspects of digital signal processing and simulation as they apply to speech. The program includes some laboratory work on speech analysis and synthesis utilizing spectrographic techniques and a digital computer.

Further information is available from the Director of Summer Session, Room E-19-356, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

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Spectral lines

Nutritive fallout from the publication explosion. Some months ago, a cartoon in a slick magazine showed a firing squad, in academic gowns, caps, and hoods, concentrating its attention on a blindfolded colleague with back to the wall. The dean in command of the squad was explaining to an intrigued bystander, "It's publish or perish, and he didn't publish." The words took me back 35 years, to rebellious collegiate evenings when I was collaborating on an article about the criterions for academic survival. The outcome, which appeared in the May 1935 issue of *The Harvard Advocate*, was called "Publish or Perish." We were concerned with what seemed to us a purely local phenomenon—as, in fact, at that time it was. The description of what was happening in the first years of J. B. Conant's administration as president of Harvard was a joint effort; but the catchy title, which has become a cliché, is a measure of the originality and the rhetorical talent of Victor H. Kramer, then an elfin undergraduate, now a long-established lawyer in the District of Columbia.

Conant was reacting to the policies of his predecessor, the Boston aristocrat A. Lawrence Lowell, who was accused of selecting his permanent faculty on the basis of whether they were his cousins or not. In the reasonably long run, it is not clear to me which system gave the better result. Probably Conant's did, though that it did would be hard to prove. Neither system was perfect. What is clear is that the influence of this initially local disturbance has been profound. The ripples of response have spread not only throughout Academia (where the results have not infrequently been ridiculous), but also into the world of engineering. They are surely not the sole cause of the publication explosion, but they have made their contribution, which may be larger than it should have been.

Such musings floated to the surface of consciousness when I sat down to write a few lines about the publication process in the IEEE. Those lines are still to be written, because the reminiscences generated a different thread of thought. What has found its way onto paper may seem to imply that the large publication program of the Institute owes much of its growth to acceptance of a questionable criterion for academic promotion, and that the large—and expensive—program of the Institute is therefore based not simply on a fad, but on a fad that has no relevance to engineering. In some small part, that may be true.

Nevertheless, I would argue with conviction that however harmful the doctrine of Publish or Perish may have been in the academic situation, the spillover into engineering has been a nearly unmixed blessing. Many of us well remember a time when a laboratory engineer from Large Company A felt that he was in a compromising position if he was talking to a laboratory engineer from a rival concern, Large Company B. We (and this is not an editorial we, but a presumptuous we, which is intended to include everybody from laboratory assistants to the chairmen of the boards) can be glad that those days are over. To whatever extent the academic compulsions have acted to generate publication in engineering, we should be thankful for them. As publication has increased, secretiveness has decreased, and the resulting openness benefits us all.

A total absence of secrecy on engineering matters is not to be expected. Of the several reasons for a company to have a laboratory, one of the strongest is the hope of gaining an advantage over the competitors. To gain that advantage, some secrecy is certainly helpful. Less than we have now would be enough, but it is hard to know where to draw the line in each case. That difficulty is nicely exemplified by the fate of a paper recently submitted to SPECTRUM. It was one of the "how-to-apply-it" articles that came in response to the November "Spectral Lines." It looked useful. Three weeks later, I got two letters on the same day. One was from a reviewer, saying that the paper is technically sound but says nothing that is not already well known. The other was from the author, saying that his company's patent department had asked him to withdraw the manuscript from circulation.

One of the few successful directors of industrial research laboratories perhaps 40 years ago—I think it was Willis Whitney of the General Electric Company—said, "When you lock the doors of the laboratory, you lock out more than you lock in." To the extent that Publish or Perish has helped to keep the doors unlocked, and has helped to generate the cordial (even though guarded) interchanges at engineering symposiums, our capability has profited and our livelihoods—together with those of the nontechnical population that we serve—have been improved.

J. J. G. McCue

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EHV transmission in the Soviet Union

V. I. Popkov *Academy of Sciences of the U.S.S.R.*

The total output of Soviet electric stations at the beginning of 1968 was 135 million kW; by 1970 it is expected to reach 180 million kW. There are ten interconnected power systems in the country. The European Power Grid unites six of the systems, with a total power output of 68.5 million kW and covering a territory of 6 million km² with a population of 160 million. Plans for the period to 1980 call for the use of higher voltages; 1200 kV for ac and up to ±1100 kV for dc transmission.

Progress in electric power transmission in the U.S.S.R. has been considerable owing to the use of higher and higher voltages. Practically speaking, the voltage rise of power transmission lines has followed the rise of total energy generated in the country, as illustrated in Fig. 1. The curves in black show the voltage rise of power transmission lines, with projections to 1980. The curve in color illustrates the increase of Soviet electric energy production; note that it is the square root of energy that is actually plotted here. Since the growth of electric energy production shows no tendency to decline, one may expect the need of still higher voltages than those achieved now or planned for the nearest future.

Background

There are specific conditions in the Soviet Union that favor the development of extra-high-voltage (EHV) transmission lines. First is the tendency toward maximum centralization of power stations, inaugurated with the first plan of 1922. It is characterized by the construction of powerful thermal and hydroelectric plants having typical capacities of 1800, 2400, and 3600 MW. Currently, 14 thermal electric stations are in operation and some 30 additional thermal plants are being constructed with power capabilities in excess of 1000 MW.[1]

Besides the great operating hydroelectric stations on the Volga (2300 and 2530 MW in Kuibyshev and Volgograd, respectively) and on the Angara (4050 MW), a station having a total capacity of 5000 MW is being put into operation on the Enisej; the first two 500-MW units are already functioning. Other hydroelectric stations, with capacities from 1000 to 4300 MW, are under construction in Siberia, Middle Asia, and other regions of the country.

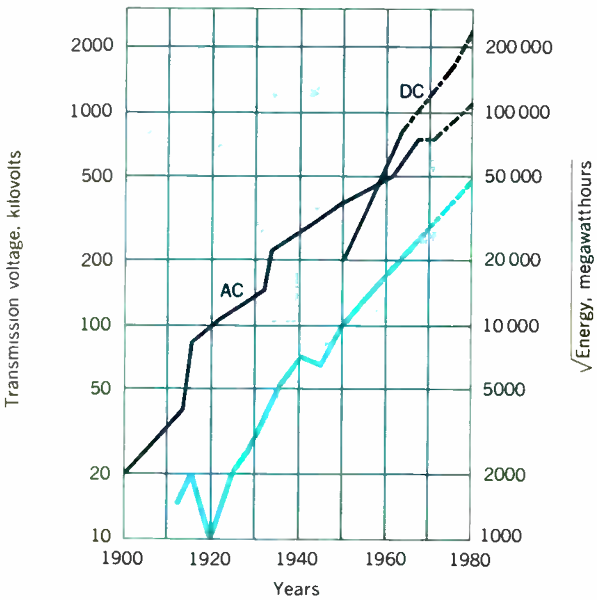
The total power of electric stations, which at the beginning of 1968 was equal to 135 million kW, is expected to reach 180 million kW by 1970, thereafter increasing annually by 18 to 20 million kW. Such a course of development assumes the existence, and the need for further development, of transmission lines with great power capacity.

There is another relevant feature of system construction in the Soviet Union. The idea of "natural" junctions of networks of regional electric systems with "weak links" between them was definitely rejected. Instead, the plan calls for long-distance intersystem connections capable of transmitting large blocks of power. Because of the huge geographical size of the U.S.S.R., the use of extra-high voltages is most desirable. Figure 2 shows EHV lines (330, 500, and 750 kV for ac and 800 and 1500 kV for dc) that are in operation or under construction. At present there are ten interconnected power systems (IPS). In four of them (south, northwest, North Caucasus, and Transcaucasus), 330-kV lines are used for intersystem power ties; in others, 500 kV is used for transmission trunk lines.

Since 1956, the length of 500-kV lines in the U.S.S.R. has reached as much as 9000 km in a single circuit calculation. These lines form main connections for the European Power Grid (EPG). A continuous chain of 500-kV lines, Volgograd–Moscow–Kuibyshev–Cheljabinsk–Sverdlovsk–Nizhnij Tagil (lines 1, 2, and 3 of Fig. 2) with a total length of 3000 km, of which 2000 km consist of double-circuit lines, links the power systems of the Volga Basin Center and the Urals. Together with the connected 800-kV Volgograd–Donbass south system (line 4), which connects the Caucasus and Transcaucasus with 330-kV lines of the Northwest Center, the EPG unites six of the ten interconnected power systems. Total power output of 68.5 million kW covers a territory of 6 million km² with a population of 160 million. In Central Siberia, 500-kV lines with a total of 2800 km are also used.

The high transmitting capacity of long-distance 500-kV lines (as high as 1000 MW per circuit at a length up to 1000 km) leads to the conclusion that they will retain their significance as intersystem connections in the regions of their development for the next 15 to 20 years. Considering the expected power rise of the IPS and the necessity to increase the transmitting capacity of intersystem ties, 750 kV ap-

FIGURE 1. Transmission voltages (shown in black) and the square root of electric energy generation (shown in color) in the Soviet Union from 1900 to 1980.



Because of the rise in electric power generation and the huge expanse of the U.S.S.R., long-distance 750-kV lines are most attractive. To gain experience at this voltage, a 90-km 750-kV line near Moscow has been commissioned

pears to be most attractive for regions using 330-kV circuits. The first long-distance 750-kV line is being planned for the south power system. In order to provide valuable design and operating experience, a 90-km 750-kV line near Moscow was commissioned in 1967.

Some rather serious problems face Soviet engineers in the sphere of transporting energy resources. More than 90 percent of the potential energy resources of all kinds are concentrated in the eastern regions of the country, including 60 percent in Siberia, whereas 80 percent of the power consumption is concentrated in the European part of the Soviet Union. According to estimates of some experts,[2] the decline of power resources in the European regions of the U.S.S.R. and the Urals suggests the transmission of up to 300 billion kWh from Siberia and North Kazakhstan to the EPG in the near future, at distances up to 4000 km.

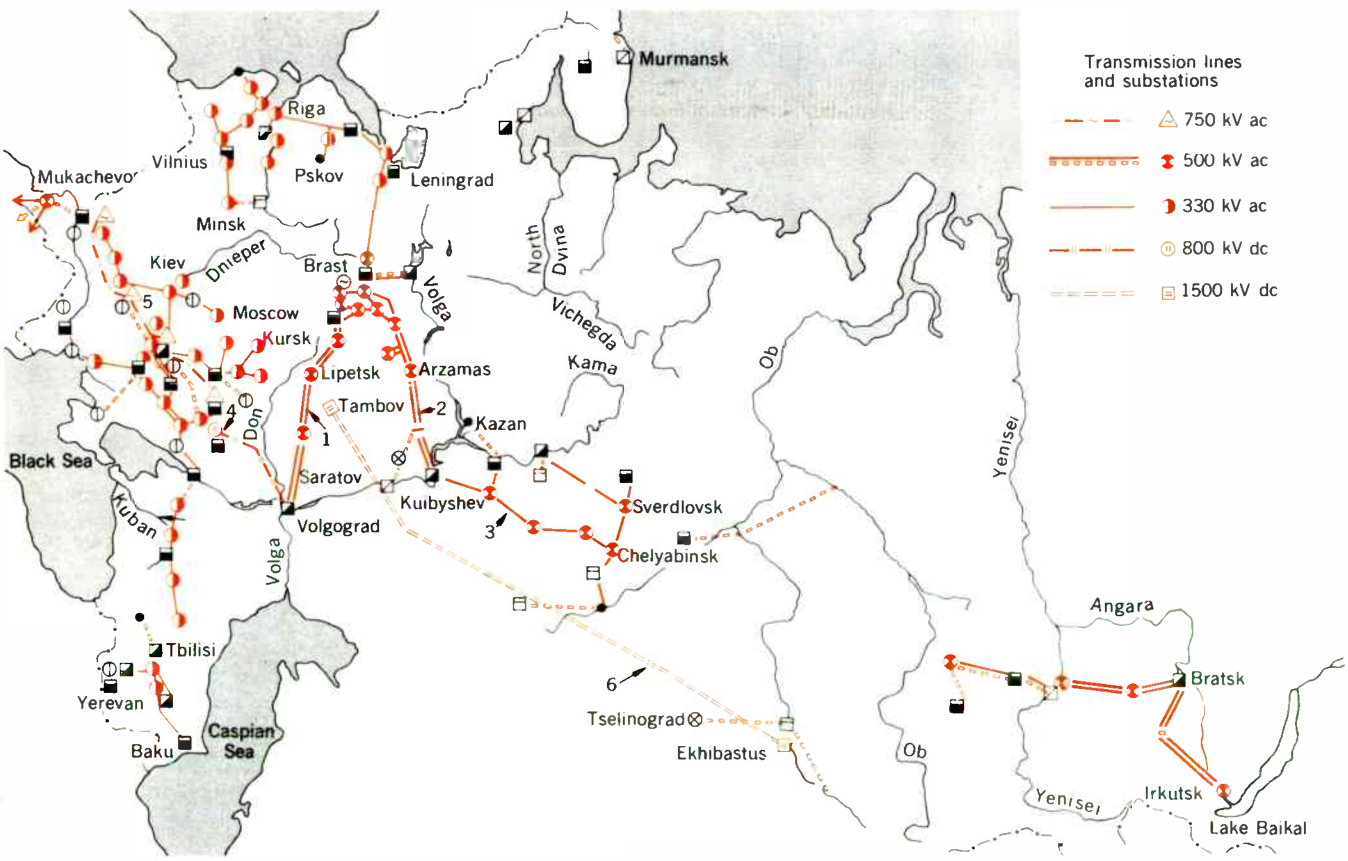
An economic solution to problems of this magnitude may be achieved by the use of 1500-kV ($\pm$750 kV) dc transmission lines.[1] The first 1500-kV dc line, which has a capacity of 6000 MW and is planned for the mid-1970s, will connect North Kazakhstan to the Center, a distance of 2500 km (line 6 of Fig. 2). The cost per kilometer of such a line is expected to be only 15 to 20 percent higher than that of a 750-kV ac line; the capacity, however, will be more than twice as great. For long-distance lines, the cost of compensating equipment for three-phase lines and the economy of the dc line offset the expenditures for current conversion. Plans to 1980 call for the use of still higher voltages—1000 to 1200 kV for ac and $\pm$1100 kV for dc transmission.

Problems with EHV lines

In investigating stability, various models and the theory of similarity were widely used. Through the use of strong-action field regulation, synchronous compensation, and other methods, it was found that the limit of transmitted power may be increased up to 20 percent with good stability. Saturable reactors with rotating magnetic fields appear also to be promising.[3] A study, using dynamic models, has demonstrated the effectiveness of dc transmission-line regulation making use of the parameters of a connected ac system to increase the stability of the latter.[4] Among new possibilities, half-wave or resonance ac transmission lines are being investigated.

Investigations of overvoltages and insulation problems

FIGURE 2. Soviet EHV lines in operation or under construction.



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began in the late 1940s with the first 1000-km 400-kV transmission line. The study of insulation behavior at extra-high voltages required some new approaches. For example, it was necessary to investigate switching-surge flashover voltages for all types of insulation using long impulses to simulate internal overvoltages on long lines. Because high-voltage electrical discharge phenomena are not well understood, no modeling was possible; full-scale studies were therefore required. Statistical and probability methods for characterizing electrical insulation strength and for choosing overall sizes of lines and substation equipment were also required.[5,6]

Figure 3 gives values of switching-surge flashover voltages for different air clearances measured on a full-sized model of a 750-kV line tower carrying 4xACSR-600 600 conductors—that is, four-bundle steel-reinforced aluminum-cable conductors in which the total aluminum cross section is 600 mm^2, with the adjacent conductors 600 mm apart.[6] It is noted that for voltages greater than 2500 kV, increasing the separation distance has little influence upon electrical strength; it therefore appears to be hardly reasonable to increase the insulation distance to obtain electric strengths greater than 2500 kV. For this reason and because of problems in limiting switching surges, we regard the probability of transmission voltages of about 1500 kV as doubtful. On the other hand, 1140-kV lines, which are being considered in the U.S.S.R., seem to be quite realistic.

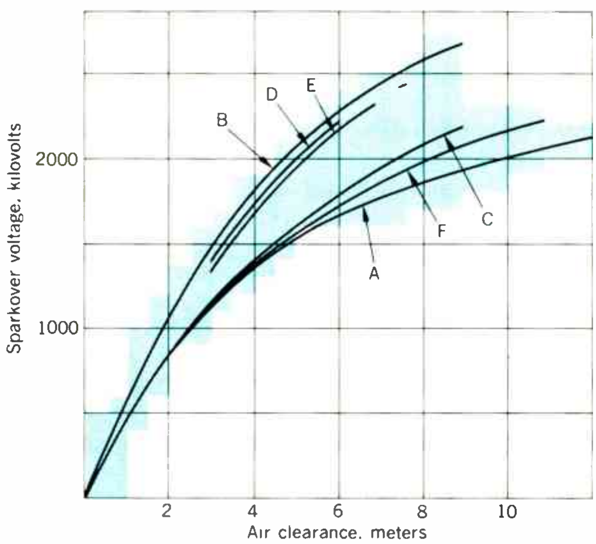
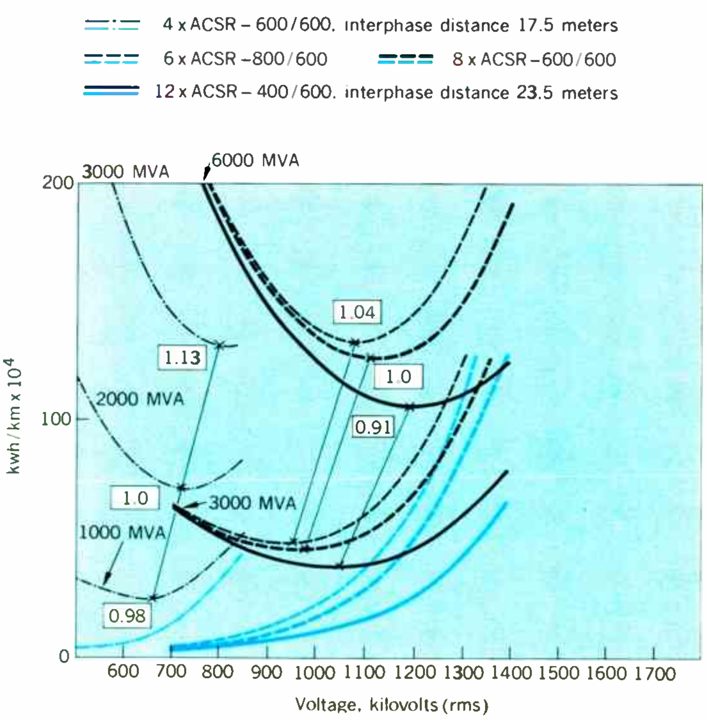


FIGURE 3. Sparkover voltage (50 percent discharge probability) vs. air clearance on 750-kV-line prototype tower with 4xACSR-600 600 conductor. A—Rod to plane. B—Rod to rod. C—Ring to ring. D—Line to model of vehicle column. E—Conductor to post crossarm and conductor to traverse. F—Ring to plane.

FIGURE 4. Expected energy losses for 750-kV lines. Curves in color are corona losses. Curves in black are total losses (ohmic+corona). Crosses indicate points of minimum total losses. Figures in boxes are the ratio of the actual to the permissible surface gradient according to specified radio-interference levels.



The theory of corona effects and radio interference is well developed in the Soviet Union. Original methods and apparatus designed in the country were employed to measure corona losses directly on 400- and 500-kV lines.[7] Using available meteorological data, probable corona losses on the designed 750-kV transmission line in the south power system can be estimated.[8] The average annual energy losses resulting from corona are expected to be 18.8×10^4 kWh/km, or an average annual power loss of 21.5 kW/km. Losses may vary widely between months of the year and hours of the day, resulting in an average loss of 16 kW/km in the April–September period and 27 kW/km for the October–March period. Forty percent of the energy losses may be attributed to an 8-hour period of the night.

For loads of 2500 MVA, minimum total ohmic and corona losses for a 750-kV line are given in Fig. 4. Corona losses represent about 25 percent of the total losses. To obtain the same corona losses with conductors of smaller cross sections, it would be necessary to extend phase-to-phase distances to 23.5 meters.

According to Soviet standards, the level of radio interference may exceed 34 dB for not more than 5 percent of the year in the frequency range of 0.5 to 2 MHz at a distance of 100 meters from the line. This requirement is equivalent to the permissible average level of radio interference in good weather of 25 dB.[9]

With further rise of transmission-line voltages, reduction in corona losses and radio interference may be realized by using more conductors in a bundle than by a small number of expanded conductors, as shown in Fig. 4. We note that at 1200 kV, optimum results correspond to eight-conductor bundles; at higher voltages, however, even 12-conductor bundles do not appear to be effective.

The 750-kV Konakovo–Moscow line

A 90-km line connects the 500-kV thermal station in Konakovo (actual capacity, 2400 MW; planned capacity, 2600 MW) with the Belyi Rast Substation near Moscow. Besides transmitting 1200 MW of power, the line serves as a prototype for future high-voltage lines. The length of the designed span of the line is 430 meters; the steel portal towers on guys have 35-meter crossarms that are 30 meters above ground. The conductors used are 4xACSR-600 600. Supporting insulator strings are single-chain, with an overall

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length of 5.2 meters. They consist of 27 quenched-glass insulators characterized by an electromechanical breaking load of about 30 tonnes. The cost per kilometer of line is 69 000 rubles (about $77 000).[10,11]

At each substation there is a bank of three 417-MVA 750/500/10.5-kV single-phase autotransformers. Regulation of voltage under load on the 500-kV side is provided in the range of ±7.5 percent by regulating the 30-MVA 10.5-kV winding connected to the common neutral point of the high- and medium-voltage windings. No-load losses are 250 kW; short-circuit losses, 800 kW.

Air circuit breakers are used for operative switching, clearing of short-circuit currents, and the automatic reclosing of the 750-kV line. The circuit breaker consists of three similar poles, permitting both three-pole and single-pole control; each pole contains self-controlled half poles. Arc extinguishing is achieved by compressed air. When the circuit breaker is switched off, the compressed air fills the gaps of the extinguishing chamber, keeping the contacts open. When switched in, the compressed air remains in the containers and control columns.

The protection of the 750-kV substation is fulfilled by two arresters. The first is installed on the line side behind the line circuit breaker; the other, in the immediate vicinity of the autotransformer. In both types (magnetic spark gaps with rotating arc) reinforced construction is used. The disks of working resistance of the arresters are made of Tervit, a newly developed high-current-capacity material.

The 750-kV line in the south IPS

The interconnected power system of the south is one of the largest interconnected systems in the country. At present, its specified capacity is 24 000 MW; by 1975 the capacity of the stations in the system will reach 60 000 MW. Their basic source of electric supply is large thermal power stations of 2000 to 3000 MW; hydroelectric stations account for only 10 percent of the installed capacities.

There are ten district power systems within the IPS of the south. The main ties between systems are realized by branched 330-kV networks carrying out distribution as well as intersystem functions. The IPS of the south is connected not only with the Soviet Union EPG, but also with systems in Hungary, Rumania, and Czechoslovakia. In power pools adjacent to the IPS of the south, the 500-kV east and 400-kV west networks are already developed.

With the rise of power systems and loading of substations, 330-kV networks will practically stop serving intersystem functions after 1970. On the other hand, the rise of interconnected power systems will provide sufficient overflow of power between separate systems. To 1975, power overflow of about 1 million kW, directed from east to west, will be possible. The same amount of overflow will be available for emergency reserve interchanges within the power pool and for interchanges with adjacent interconnected systems situated to the east and west of the IPS of the south.

Economically, one 750-kV line requires about 10 percent less in capital investment and 3 percent less in operational expenses than two 500-kV lines of the same total capacity. Considering all factors, the 750-kV line was recommended as the new system voltages for the south IPS; the construction of a branched network using this voltage is anticipated between 1975 and 1977.

The first part of the 750-kV line, scheduled for 1972, will be 1000 km long and run from the eastern part of the IPS to the western part (line 5, Fig. 2). It will connect four 750-kV substations: Donbass (750/500/330 kV) with the 330-kV networks of the Donbassenergo system and through 500-kV lines with power systems of the Center and Northern Caucasus; Dnieper and Central Ukrainian substations (both at 750/330 kV) and West Ukrainian (750/400/330 kV) at 400 kV with the interconnected "Peace" power system. The construction of the line and main equipment of the substations will be similar to the 750-kV Konakovo–Moscow line.

A condensation of a paper, "Use of 750 kV in the U.S.S.R. and Some Considerations Concerning Higher Voltages," presented at the American Power Conference, Chicago, Apr. 23–25, 1968.

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In 1930 he was graduated from the Technical High School in Moscow with the diploma in electrical engineering. Since then he has worked in various research institutions dealing mainly with high-voltage engineering problems and physics of electrical discharges in gases. His chief contributions have been in the theory and physics of dc and ac corona and related problems.

As vice director of the Krzhizhanovsky Power Institute from 1953 to 1959 he was concerned with general problems involved in EHV transmission. In 1948 he received the degree of doctor of technical sciences. Dr. Popkov is the author of some 70 published scientific papers.

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On professional salaries

What is man's monetary value to man? The answer to this question can tell us much about our value system as a people, and point the way to positive change if such change is called for

Richard P. Howell *Stanford Research Institute*

The determinant of the salary that a man is paid for his services can involve many factors, both naturally and artificially evolved. The evaluation of a man's monetary value is particularly complex in the case of technical professionals whose product cannot easily be judged by clear-cut measures such as amount of sales made or runs batted in. In this article, data from a group of job applications from almost 30 establishments and from the results of a random sampling of faculties of more than 500 colleges and universities are analyzed. As a result, a number of biographical characteristics are identified that, on the average, affect salary levels of such professionals. In addition, a method is demonstrated for weighting the factors involved and presenting the results in a more comprehensive manner than that employed in existing salary surveys.

Are you satisfied with your pay? How much *should* a person get paid? Almost everyone has opinions on the subject. The trouble is that each theory is flavored by a value judgment that will vary with the individual.

Many inequities do exist—the fact that an entertainer is paid more in a week than a trained, productive engineer is paid in a year illustrates the point. And have you hired a plumber lately?

What then is the key to man's monetary value to man? Obviously, many forces are at play, some of which evolved naturally—such as the public's clamor for a person's unique aptitudes (Willie Mays' bat, for example). Others are artificial forces, such as union bargaining. The answers concerning man's monetary value to man will more likely be found among the naturally evolved salary and wage levels.

An unusual amount and depth of information (including salary) on about 50 000 scientists, engineers, and faculty members provides us, in this article, with the basis for studying the effect of some of the naturally evolved forces on salary determination of these vital professions. Our data come from two sources: (1) a group of job applications, and (2) a survey. The first source consists of copies of over 35 000 job-application forms completed by engineers and scientists in the defense research-and-development (R&D) industry of three widely separated cities. This large number of applications (names removed) provided by almost 30 different establishments formed the basis for a Stanford Research Institute (SRI) study concerning the structure and dynamics of that industry.[1,2] Since the starting salary and the present (as of late 1964) salary data were also included, the combination of the more significant biographical details as well as salary levels was available to us in our efforts to gain a clearer understanding of compensation levels and practices among these professionals.

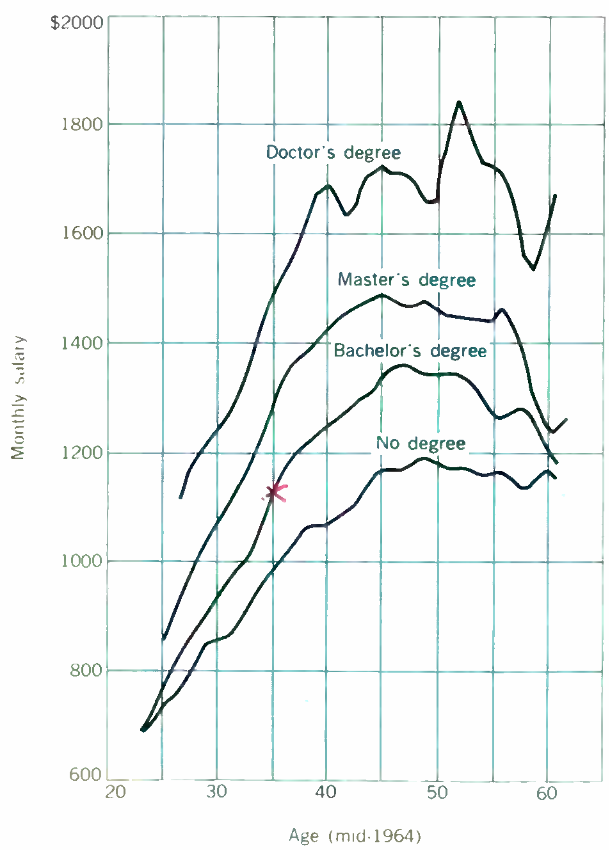
The second source consists of the results of a survey of 15 494 faculty members in 1963. This survey represents a one-in-ten random sampling of faculties from 593 four-year colleges and universities employing over 100 000 professionals.[3] A meaningful 95 percent responded to the six-page questionnaire distributed by the Office of Higher Education. Recently made available to SRI, these data will be analyzed to construct models that we hope will be even more comprehensive than those discussed in this article.

The reader should keep in mind that our data are three to four years old, and salaries have been increasing in the interim. The Engineers Joint Council estimates that the median salary of all degree-holding engineers has been increasing at about 7 percent per year since 1964.[4]

Lack of desirable measures

Many traits that affect salary levels need better objective measures. How would you measure empathy, for example,

FIGURE 1. Average monthly salary of engineers scientists, by degree level and age (five-year averages weighted binomially) in Los Angeles and Boston defense R&D establishments.



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I. Average monthly salary of female engineers scientists in Los Angeles and Boston defense R&D establishments (N=311)

Degree Level	Agc									
	20-24	25–29	30-34	35–39	40–44	45-49	50–54	55 49	60–64	N
Bachelor's	$679	$775	$ 872	$ 989	$1061	$1033	$1050	$ 880	$765	200
Master's	700	850	1028	1045	973	1284	1325	1347	—	34
Doctor's	—	—	—	1105	1040	—	1420	—	—	4
Other or none	—	675	746	931	946	864	813	831	—	73

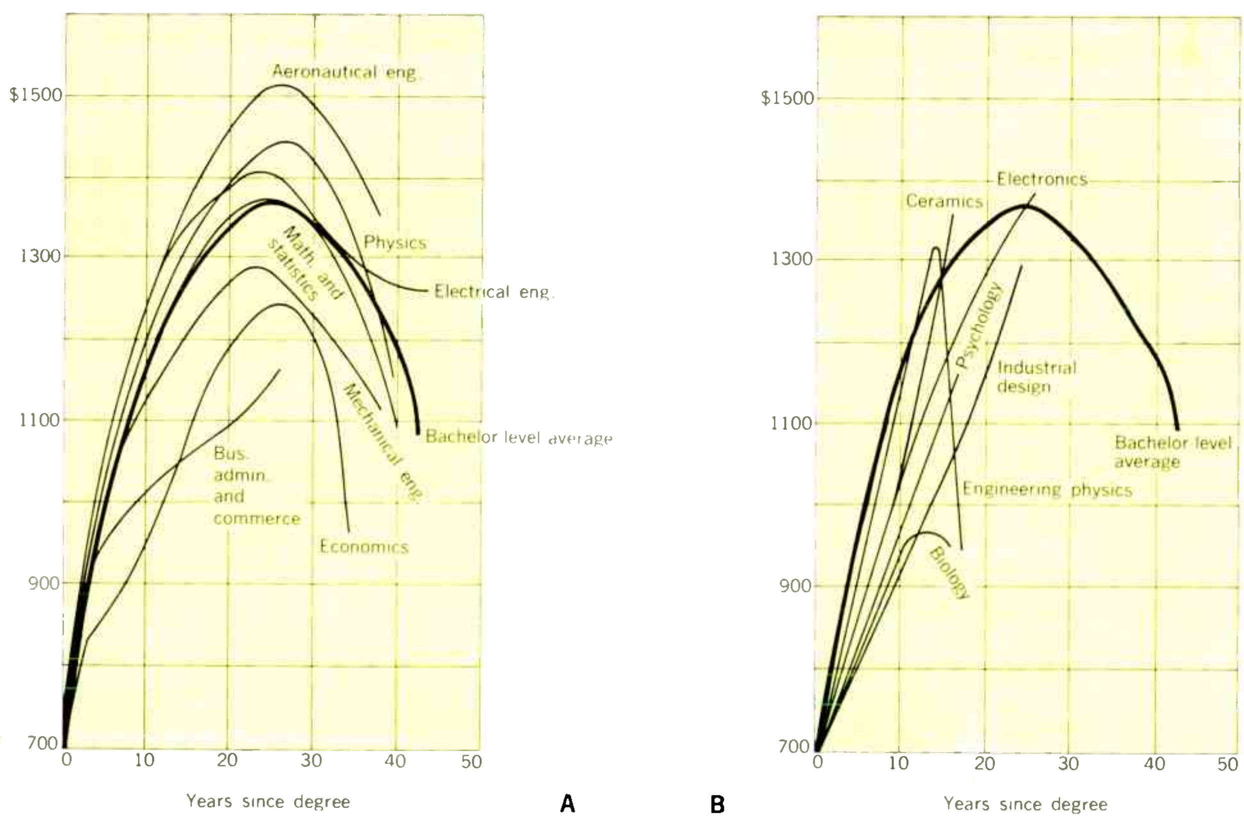
or sense of humor, or quality of output, or many other factors of significance to salary levels? Some potential measures that might have been useful, such as test scores, interviewer ratings, or reference checks, were not available to us in our analysis. The attributes of the individual on the job his function, his performance, his contribution—were likewise not among the data available. These capabilities and performance measures undoubtedly have impact on salary levels, and would have benefited our analysis.

The industry study began, then, on the premise that much of the traditional application form fails to give useful clues concerning the potential value of a person. Similarly, questionnaires, such as those distributed in the faculty survey, have widely recognized drawbacks. Nevertheless, we believed that available data, if dissected, would be found to reflect, indirectly, personal attributes having a bearing on salary levels. Degree level, for example, may imply a level of intelligence and may also reflect personal motivation; age must be a fair expression of experience; length of time on previous jobs may reflect loyalty and perseverance; sex may measure personality differences; and so on. Hence, although the measures at our disposal were imperfect, through analysis and interpretation they might lead to a better understanding of the factors determining salary differentials.

Some determinants of salary levels in high-technology industry

Our industrial data were considered in terms of average monthly salary, and in terms of average annual increase (post-hire) in monthly salary. These measures provide, on the monthly basis, an idea of the relative value placed on various attributes of the engineer or scientist by the industry; on the annual increase basis, they provide a means for ob-

FIGURE 2. Average monthly salary of engineers scientists with the bachelor's degree, by education major and age for Los Angeles and Boston defense R&D establishments (curves fitted by third-degree polynomial). A—Older fields. B—Newer fields.



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II. Average monthly salary of engineers/scientists with bachelor's degree as related to number of full-time jobs held in Los Angeles and Boston defense R&D establishments

Number of Full-Time Jobs Held	Age 20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64
1	$810	$ 936	$1118	$1450	$1576	$1561	$1513	$1620	$1200
(N)	(103)	(418)	(215)	(101)	(64)	(14)	(6)	(1)	(1)
2	$829	$ 955	$1153	$1369	$1511	$1505	$1580	$1481	$1117
(N)	(11)	(277)	(254)	(142)	(117)	(78)	(27)	(8)	(3)
3	$663	$ 950	$1132	$1372	$1496	$1548	$1533	$1411	$1157
(N)	(3)	(95)	(179)	(155)	(142)	(70)	(18)	(9)	(3)
4		$1045	$1121	$1289	$1425	$1487	$1337	$1417	$1282
(N)	(0)	(26)	(88)	(122)	(126)	(50)	(14)	(10)	(5)
5		$1044	$1161	$1342	$1441	$1342	$1408	$1466	$1178
(N)	(0)	(5)	(47)	(87)	(95)	(46)	(23)	(10)	(4)
6		$1315	$1136	$1318	$1464	$1490	$1336	$1530	$1253
(N)	(0)	(4)	(20)	(36)	(67)	(40)	(16)	(7)	(3)
7			$1141	$1306	$1291	$1468	$1214	$1410	$1330
(N)	(0)	(0)	(8)	(20)	(31)	(28)	(11)	(7)	(2)
8			$1102	$1263	$1399	$1397	$1363	$1327	$1350
(N)	(0)	(0)	(5)	(15)	(28)	(19)	(9)	(7)	(5)
9				$1355	$1513	$1270	$1395		$1276
(N)	(0)	(0)	(0)	(2)	(4)	(3)	(2)	(0)	(5)
10								$1080	
(N)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)
11 or more					$1100	$1363	$1174	$1130	$1460
(N)	(0)	(0)	(0)	(0)	(1)	(3)	(1)	(1)	(1)

Note Outlined area indicates limit of data considered relevant in view of sample size

taining a grasp of the dynamics involved.

In mid-1964, the average monthly salary of the engineers or scientists under study amounted to $1097. As revealed in existing salary surveys, this figure varied widely with the following determinants: level of education, age (or years since degree), and industry group. Salary was also found to vary, in a study comparing Los Angeles and Boston engineers and scientists, with sex, university or college at which degrees were obtained, specialty studied, number of prior jobs held, geographical location, length of time with present and past companies, and marital status. The companies concerned primarily with research (rather than development) paid an average salary of $1204, compared with $1092 for professionals in development activities.

It was discovered that salary change (dynamics) was related to degree level, to age, to number of jobs held, to type of last organization, to sex and marital status, and even to the particular channel through which recruited.

Figure 1 shows, in a form familiar to those who have studied earlier salary surveys, the age, degree, and salary relationships. But what interesting variations are hidden in those curves! Take the female engineer or scientist, for example. Compare her average income as shown in Table I with the overall incomes shown in Fig. 1. Is the Civil Rights Act of 1964 preventing discrimination because of sex? Not when these data were compiled. Or take the variation among specialties shown in Fig. 2. See how those with the older, well-entrenched specialties in the industry average higher salaries than those with newly established specialties.

Everyone, it seems, concludes that the engineer or scientist who has "been around" will earn a greater salary because of the incentive increase he obtains with each job change. This is not so, according to our data. As revealed in Table II, the under-age-30 "job hopper" is ahead, on the average, but after age 35, the stay-put professionals shoot ahead. If one considers costs of job changes (moving, loss of vested interest, etc.), lifetime earnings favor those who stayed put on their first job or kept job changes to a minimum. (However, analysis employing present-value techniques might alter this conclusion.)

Value of prestige colleges and universities

Fifty-nine universities and colleges were identified as the major sources for the degrees of engineers and scientists in Los Angeles and Boston. The universities were rank-ordered on the basis of the amount of average monthly salaries received by the graduated engineers and scientists at various age and degree levels. Table III shows the results of

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III. Average monthly salary of engineers/scientists with bachelor's degree, by age and source of degree, mid-1964, in Los Angeles and Boston defense R&D establishments* (N=8699)

Rank Order by Salary+	Age 25–29 School	Avg. Salary	(N)	Age 30–34‡ School	Avg. Salary	(N)	Age 35–39 School	Avg. Salary	(N)
1	Ariz. State	$1121	(17)	Harvard	$1250	(6)	Harvard	$1533	(3)
2	U.S. Nav. Acad.	958	(4)	Cal. Tech.	1192	(27)	Ohio State	1511	(23)
3	Cal. Tech.	957	(27)	M.I.T.	1161	(44)	Cal. Tech.	1450	(23)
4	Rensselaer	924	(30)	Rutgers	1156	(7)	Stanford	1421	(21)
5	U. Maine	920	(7)	U. Cincinnati	1154	(13)	Oregon State	1381	(22)
6	M.I.T.	918	(67)	Northwestern	1112	(10)	Georgia Tech.	1375	(24)
			(81)						
7	Purdue	899	(109)	Worcester Poly.	1111	(7)	Case Inst.	1374	(13)
8	N.Y.C. College	897	(56)	Brooklyn Poly.	1101	(31)	Cornell	1371	(12)
9	{St. Louis U.	895	(11)	N.Y.U.	1094	(24)	M.I.T.	1363	(48)
	U. California}		(81)						
10	Harvard	893	(9)	N.Y.C. College	1090	(42)	N.Y.C. College	1340	(39)
11	Stanford	891	(19)	Columbia	1087	(3)	U. California	1314	(103)
12	U.C.L.A.	888	(245)	Rensselaer	1085	(32)	U. Michigan	1266	(40)
13	Marquette	887	(14)	Brown	1078	(9)	N.Y.U.	1262	(22)
14	N.Y.U.	880	(20)	Purdue	1064	(81)	U. Colorado	1261	(62)
15	Brooklyn Poly.	876	(24)	Carnegie Inst.	1063	(16)	{U.S. Nav. Acad.	1260	(12)
							U. Washington}		(32)

Rank Order by Salary+	Age 40–44 School	Avg. Salary	(N)	Age 45–49 School	Avg. Salary	(N)	Age 50–54 School	Avg. Salary	(N)
1	Harvard	$1525	(4)	U. Cincinnati	$1582	(11)	U. Washington	$1715	(13)
2	U. Cincinnati	1513	(3)	Carnegie Inst.	1577	(12)	Stanford	1690	(1)
3	Cal. Tech.	1503	(29)	M.I.T.	1574	(12)	St. Louis U.	1640	(2)
4	M.I.T.	1473	(34)	Columbia	1550	(1)	U. Cincinnati	1625	(2)
5	Case Inst.	1458	(12)	U. Michigan	1543	(41)	Carnegie Inst.	1595	(2)
6	N.Y.C. College	1447	(25)	{Penn. State	1541	(7)	Oregon State	1545	(4)
				U. Oklahoma}		(12)			
7	Columbia	1404	(5)	Tufts	1535	(2)	M.I.T.	1520	(7)
8	Carnegie Inst.	1403	(13)	N.Y.C. College	1503	(4)	U. Minnesota	1497	(18)
9	Brooklyn Poly.	1400	(14)	Worcester Poly.	1500	(4)	N.Y.U.	1491	(9)
10	U. Rhode Is.	1397	(3)	{Cal. Tech.	1498	(33)	U. Maine	1485	(2)
				U. Texas}		(12)			
11	Georgia Tech.	1395	(22)	San Jose State	1495	(2)	Illinois Inst.	1463	(3)
12	{S. Methodist	1382	(5)	Harvard	1480	(3)	Rensselaer	1444	(5)
	U. Alabama}		(10)						
13	Lowell Tech.	1380	(1)	U. Alabama	1463	(6)	U. California	1442	(29)
14	{Brown U.	1378	(4)	Ohio State	1462	(23)	Harvard	1426	(5)
	U. California}		(96)						
15	U. Michigan	1374	(54)	U. California	1461	(73)	Cal. Tech.	1424	(14)

* Based on an analysis of 59 universities identified as major sources of bachelor's degrees by E/S's in the establishments studied.

+ Only first 15 universities in ranking are shown.

‡ Omitted from this group is one individual from Southern Methodist University with a salary of $2303.

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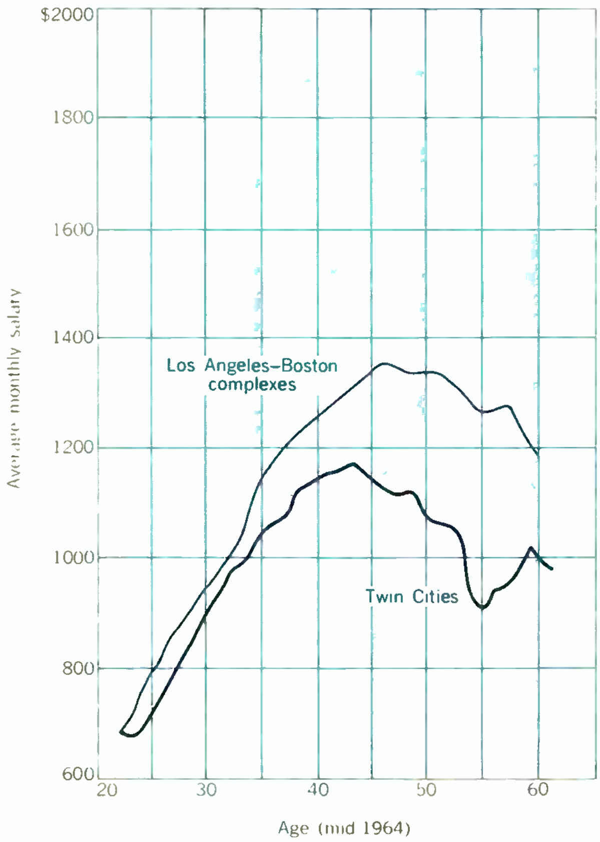

FIGURE 3. Average monthly salary of engineers and scientists with bachelor's degrees, by Twin Cities and Los Angeles defense R&D establishments (five-year averages weighted binomially).

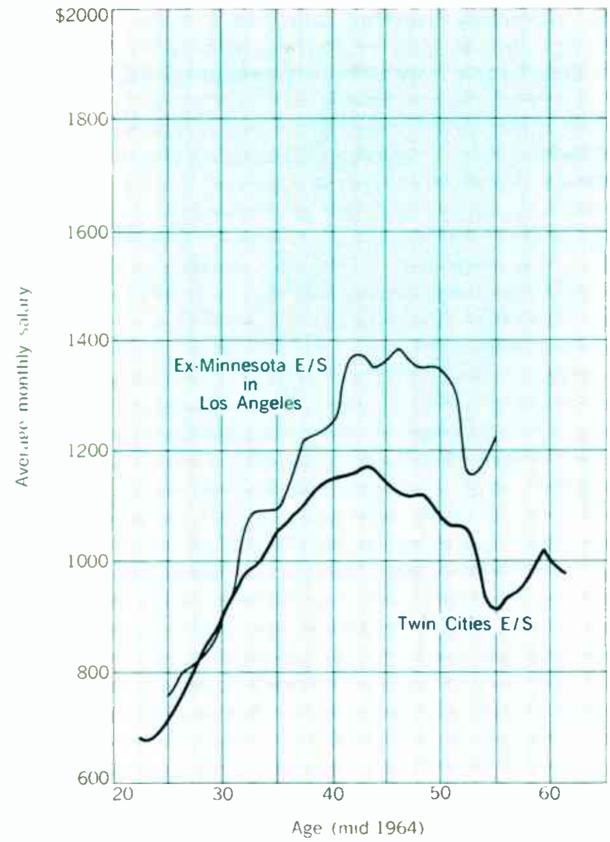

FIGURE 4. Average monthly salary of engineers and scientists with bachelor's degree, by age—Twin Cities E/S's vs. Minnesota E/S's who migrated to Los Angeles (five-year averages weighted binomially).

the bachelor-degree-level ranking. (E/S here and elsewhere means "engineers and scientists.") For all three degree levels (bachelor, master, doctor), the California Institute of Technology, the Massachusetts Institute of Technology, the Carnegie Institute of Technology, and the University of Michigan were identified with alumni (engineers and scientists) of above-average salaries. For two out of three of the degree levels, Harvard, College of the City of New York, University of California at Berkeley, New York University, Brooklyn Polytechnic, Columbia, Stanford, Ohio State, and Cornell were identified with alumni receiving higher salaries.

In speculating about the reasons for the differences, we asked the question: "Are they caused by the excellence of education, by subjects taught, by the competitive screening of registrants, or by the social network among alumni?" For the moment, we may only speculate; the answer lies beyond our data.

Impact of where you live on your salary

It is known that salary levels vary from area to area. An immediate explanation for this is the difference in the cost of living in different areas. However, closer study indicates that this factor does not adequately explain the salary variations in most cases. Consider the difference (Fig. 3) between the salaries of Los Angeles/Boston engineers and those in the Twin Cities (Minneapolis–St. Paul). The cause of such great variations is unclear. Since, as will be shown, the Boston salaries are lower than those in Los Angeles, one might infer that the age and size of the high-technology complex is a factor. A policy of the Defense Department, National Aeronautical and Space Administration, and other agencies that may also have contributed to the differences is the practice of letting large contracts first to one large contractor and then to another, thus increasing the competition for and movement of professionals from one firm to another—and escalating salaries with each move. The lower turnover rate that exists in Minneapolis/St. Paul supports this argument. Note, also, how the Twin Cities salaries peak at an earlier age, which may be explained by the new computer technology in the area. Figure 4 refutes any argument that the differences are caused by variations in the individual professional from one area to the next. In this illustration, the salaries of 250 engineers who had migrated from the Twin Cities to Los Angeles were compared with the remaining workforce.

Point-of-hire traits affecting post-hire increase

Regarding some of the dynamics of change, it is seen from the following list that in high-technology industry, the largest average annual increase in salary occurs in the 35–39 age bracket, with the largest jump occurring between the 20–24 and the 25–29 age group (note the drop in the past-50 age brackets). Average annual increase in monthly salary by age: 20–24, \$62.15; 25–29, \$71.08; 30–34, \$73.27; 35–39, \$75.46; 40–44, \$72.09; 45–49, \$67.23; 50–54, \$60.54; 55–59, \$57.92; 60–65, \$55.09.

The different rate of change in each age group results in

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IV. Average annual increase in monthly salary by number of full-time jobs held (including current one)

No. of Jobs	Annual Increase
1	$60.00
2	69.36
3	71.67
4	74.03
5	70.20
6	70.68
7	71.77
8	71.33
9	69.79
10	59.84
11	54.17
12 or more	63.18

V. Average annual increase in monthly salary by type of last organizational affiliation

Affiliation	Annual Increase
University (teaching)	$80.59
Other U.S. government	78.18
Armed services (civilian)	75.49
Other defense company	73.46
Armed services (military)	73.18
State government	71.92
University (student)	69.79
Nondefense company	67.22
Self-employed	65.50
Not known	61.63

VI. Average annual increase in monthly salary by marital status when hired

Status	Increase
Male:	
Single	$68.30
Married	72.91
Divorced or separated	65.55
Female:	
Single	55.93
Married	59.08
Divorced or separated	54.80

VII. Average annual increase in monthly salary by recruitment channel

Channel	Annual Increase
Advance opportunity	$92.50
Personal acquaintance in company	71.84
Company recruitment	70.37
Special knowledge of use of company	67.94
College recruitment	58.66
Advertising:	
Newspaper	54.98
Magazine	62.79
Trade journal	64.64
Walk-in	58.21
Placement service agency	53.66

the "peaking out" of the average salaries shown in Fig. 1. Why does an engineer/scientist beyond the age of 50 receive a lower salary? Is it because (1) those of greater abilities and higher salaries have graduated to administrative functions and hence are not in the population studied, or (2) escalation in salaries is reflected in age brackets where turnover is highest, or (3) the older professionals have become technically obsolescent?[5]

In Table IV, the average annual increase in monthly salary is highest for those engineers and scientists who were holding their fourth full-time job at the time of the study. Note that there is very little variation in average increase for those holding their second and third, or fifth to ninth job.

Table V shows that engineers and scientists whose last position was faculty teaching at universities received the highest average increase in salary (probably reflecting a greater ratio of advanced degrees), whereas those who were formerly self-employed received the lowest. Table VI presents the influence of marital status on salary. Men and women who were married at time of hire received the highest average increases in salary. Those divorced or separated at time of hire received the lowest average increases.

The avenue of recruitment for engineers or scientists evidently had impact on the rate of subsequent salary advancement. As shown in Table VII, those who avowed ambition (advancement opportunity) experienced a greater rate of increase than others. It is of interest that the second category, "personal acquaintance in the company," was the largest single hiring channel (over two out of five professionals). Note that this category, named in response to the question as to why the respondent applied to the particular company, is not mutually exclusive. An applicant may have applied on the advice of a friend, but he also may have been aware of openings by reading advertisements.

Factors affecting faculty salaries

The questionnaire survey conducted in 1963 and recently reported by the Office of Higher Education (HEW)[3] found that many situational and personal considerations affected

VIII. Computation of hypothetical salary norm

Factor	Application of Salary Model: Hypothetical Case Coverage	Adjustment Factor	Dollars Adjusted
Geographic location	Los Angeles	1055 = constant	$1055
Maturity	Born in 1931 (33 years old)	$(0.987^{31} = 0.667)$ (1055 × 0.667) = $704	704
Sex	Male	$0.852^{0} = 1$	704
Length of time with employer	Five years	$1.013^{5} = 1.067$	751
Bachelor's degree	Bachelors	$1.141^{1} = 1.141$	857
Specialty (school)	Engineering	$1.075^{1} = 1.075$	921
Number of prior jobs	2	$1.060^{2} = 1.124$	1035
(Number of prior jobs)^2	4	$0.995^{4} = 0.980$	1014
Estimated salary			$1014

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faculty salaries. For example, although the average salary for the total four-year universities and colleges sampled was $8300, the male average was $8600 versus $7900 for females. Age seemed to influence salary levels, with a range from $6100 for those 30–39 to an average of $9800 for those 64 and over. There was no peaking, however, as found in high-technology industry. Faculty members with a doctorate degree averaged $9500 versus $7100 for those without. New faculty members averaged $7000 versus $9200 for those who had changed institutions during the past year and $8400 for those not changing institutions. Those teaching predominantly freshmen and sophomores earned an average of $7300 compared with $8600 for those teaching primarily juniors and seniors. Graduate faculties averaged $11 000. Other factors that had impact on salary were size of institution; whether institution is public or private; whether student body is all male, coeducational, or all female; whether students are predominantly white or Negro; geographical location of institution; and courses taught.

Clearly, faculty salary surveys comparing only the four categories of professors, associate professors, assistant professors, and instructors bury faculty characteristics that are likely to cause significant average salary variations from one institution to the next.

IX. Use of equation in comparing populations

Exponent	Parameter: Los Angeles $1055*	Parameter: Boston $983*
BY	0.987	0.986
SEX	0.852	0.872
LEN	1.013	1.016
BA	1.141	1.135
MA	1.140	1.104
PHD	1.208	1.242
RSCN	0.950	0.953
TUIT	1.005	1.001
SCI	1.054	1.076
ENG	1.075	1.075
SSCI	0.984	0.955
BUS	1.002	0.988
DIVERS	1.032	1.068
NJOBS	1.060	1.070
$(NJOBS)^2$	0.995	0.993

* Constant

X. Hypothetical engineer's salary in Los Angeles and Boston

Hypothetical Trait	Adjustment Factor: Los Angeles $1055*	Adjustment Factor: Boston $983*
Age 33; BY = 64 − 33 = 31	0.667	0.646
Sex male	None	None
Length of time on present job = 5 years	1.067	1.073
Bachelor's degree	1.141	1.135
Engineering major	1.075	1.075
Number of prior jobs = 2	1.124	1.115
$(NOBS)^2 = 4$	0.980	0.972
Computed salary norm	$1014	$901

* Location constant

Integration of factors affecting salary levels

With the benefit of critical hindsight, one wonders, in light of the foregoing findings, why more meaningful efforts at understanding compensation levels and practices have not been attempted. Probably the greatest impediment has been the sheer magnitude of the analysis task. Without the use of a computer, the costs of the type of data manipulation we have carried out are prohibitive, and the more esoteric analyses suggested in the following would be very difficult. Hence today, with the advent of the computer, it is feasible to change our emphasis from concern about obtaining a representative sample to concern about the pertinence of the content being analyzed.

Although early industrial salary analyses simply compared average industry salaries, subsequent studies considered average salaries related to age, and later, average salaries related to age and degree levels. More recently, gross functions such as supervisory versus nonsupervisory were additional factors considered. The progression thus is directed toward multiple variate analysis—where many factors are weighted in order to yield closer relationships with salary levels. We believe, however, that the multiple regression analysis described here represents the first such analysis. [This analysis was conducted for the Office of the Director of Defense Research and Engineering, Assistant Director (Laboratory Management).[6]]

In this procedure we obtain an equation that best expresses the salaries in terms of the values of the many personal attributes. The analysis itself is performed with a standard computer program. An example of one of the early equations developed, using the data on 27 000 engineers and scientists from Los Angeles, is

$$\$ \text{ monthly salary} = \$1055\ (0.987)^{BY}\ (0.852)^{SEX}\ (1.013)^{LEN}\ (1.141)^{BA}\ (1.140)^{MA}\ (1.208)^{PHD}\ (0.950)^{RSCN}\ (1.005)^{TUIT}\ (1.054)^{SCI}\ (1.075)^{ENG}\ (0.984)^{SSCI}\ (1.002)^{BUS}\ (1.032)^{DIVERS}\ (1.060)^{NJOBS}\ (0.995)^{NJOBS^2}$$

in which

BY = last two digits of birth year
SEX = sex; male 0, female 1
LEN = number of years with present employer
BA = bachelor's degree (0 or 1)
MS = master's degree (0 or 1)
PHD = doctor's degree (0 or 1)
RSCN = return to school full time (0 or 1)
TUIT = tuition in $100 paid to undergraduate school
SCI = major in science (0 or 1)
ENG = major in engineering (0 or 1)
SSCI = social science major (0 or 1)
BUS = business and economics major (0 or 1)
DIVERS = diverse majors (0 or 1)
NJOBS = number of jobs including present

Using this equation to derive a salary norm is much like computing compound interest (with the base $1055 being equivalent to initial investment). Suppose we apply the equation to a hypothetical engineer as demonstrated in Table VIII. Note that traits that do not apply would have a zero exponent and hence would drop out of the equation (as demonstrated in the case of sex).

From a practical standpoint, this equation, developed

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from data transformed to a logarithmic base, would be computed using logarithms. The equation represents only one of many deduced. (It and the subsequent comparison were developed by Martin Gorfinkel of Stanford Research Institute. The coefficient of correlation was 0.70.) Other equations took entirely different forms (e.g., nonexponential), but all considered many characteristics simultaneously, and their inclusion yielded statistically significant relationships.

One way of using such equations for comparing areas, companies, or types of organizations is exemplified in Table IX. In this instance, we are comparing 2000 Boston scientists and engineers with those from Los Angeles, using the form of equation given previously.

It is revealed from the constant in this equation that salary rates are lower in Boston than in Los Angeles; other surveys have shown this geographical difference also. The Boston employer pays somewhat more relatively (2 percent) for the female professional than does his Los Angeles counterpart. He also rewards loyalty at a greater rate (1.6 percent compounded for each employee's year as opposed to 1.3 percent). Boston employers pay less than those of Los Angeles for engineers and scientists who attended high-tuition colleges as undergraduates and for those with master's degrees. Although a professional with a master's degree is paid relatively less in Boston, remunerations for the other degree levels are relatively equivalent. A comparison of how an engineer might fare in the two areas is shown in Table X.

Aside from their value as a better instrument for administering salary, the techniques described could successfully implement management policies. For example, if policy is to pay equally, regardless of sex, the 0.872 and 0.852 SEX parameters might be changed to 1.00, assuming that these equations are employed in setting average salaries. Or, if a concerted effort is being made to upgrade personnel, the salary could be used as a sort of "score" in the hiring of employees, and minima could be set below which applicants would not be considered.

Keeping in mind that the foregoing results are exploratory and based on poorly scaled and incomprehensive data inputs, one might speculate upon the greater accomplishments possible with more complete personnel data either available or obtainable to most organizations, such as test scores, performance reviews, self-evaluations, and so on.

Career planning

Finally, an understanding of such models as those discussed here should be helpful in career guidance. True, salary level probably should never be considered the main criterion in career planning, but should be one of the aspects to consider. It is worthwhile to be aware, for example, that changing jobs frequently may act as a salary detriment. Similarly, the salary value of advanced degrees should be recognized and equated to their cost. Anticipating technological trends and demands may lead to the selection of the career with greatest promise.

Conclusions

The monetary value of one man compared with that of another can become very complex. The evaluation is particularly involved in considering technical professionals whose product cannot easily be translated into dollars of sales, runs batted in, or other measures that are relatively clear-cut or repetitive in nature. Although we may never be able to identify all of the traits of value to an employer of professionals (indeed, the value systems may vary among employers), we have identified biographical characteristics that, on the average, affect salary levels of this valuable workforce. Moreover, we have demonstrated a method for weighting the factors involved and for presenting the results in a manner that is more comprehensive than practiced in existing salary surveys.

We have substantiated findings of earlier surveys that the salary of professionals is a function of age, degree level, specialty studied, geographical location, sex, and industry. We have discovered that additional job experience affects salary favorably at first, but as the number of previous jobs held increases, a point is reached beyond which salary will be unfavorably affected. We found also that a professional's salary advancement after he is hired appears to be a product of his reason for applying for work, his marital status, and the type of his last employer. We found that the particular college or university attended affects average salaries. Loyalty is valued more highly in some areas than in others.

Faculty salaries, in addition to faculty position category, were shown to be affected by the faculty member's degree level, by type and color of student body taught, by size of institution, by nature of institution (public versus private), and by job mobility.

Yes, the factors determining man's value to man are complex and difficult to determine, but the solution will tell us much about ourselves, our value systems as a people, and, if we are disappointed in the answer, point the way for positive change.

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Richard P. Howell (SM) is involved with a wide variety of topics concerned with the management of technical change. More specifically, his activities have been directed toward achieving an understanding of the structure and dynamics of research and development. As a senior researcher with the Stanford Research Institute since 1956, Mr. Howell has played a major role in SRI's R&D Study Series, which span the organizational, personnel, material, facility, and financial aspects of this sector of the economy. Previously, he held participating and consulting positions concerned with analysis and management controls in industrial organizations in Milwaukee, and the San Francisco Bay area. He received the B.S. degree in mathematics from the University of Washington in 1942. Following graduation, he was commissioned an ensign in the U.S. Navy Reserve. Here he served in Air Defense, Shore Patrol, Attack Transport, and Submarines until his release as a lieutenant in 1946. Under Navy sponsorship, he has done graduate work at the University of California at Los Angeles. He has published a number of papers and monographs in the literature.

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Computer-controlled vehicular traffic

Many of our major cities are so choked by motor vehicles—and so deficient in alternative means of mass transportation—that the total jam-up of urban travel has evolved from prospective nightmare to grim reality. Well-planned automation may be the antidote to this hardening of the traffic arteries

Gordon D. Friedlander

Burndy Library

It is no exaggeration that a kid on roller skates can propel himself crosstown, from the East River to the North River, on any of Manhattan's midtown streets in considerably less time than that required by a motorist. And we all have had the frustrating experience of spending more time in a bus between an airport and center city than in making the actual flight of 500 km or more. About five years ago, Boston, Mass., got a foretaste of what complete vehicular strangulation can be like when the granddaddy of traffic jams immobilized all surface transportation downtown for more than three hours. But the future may not be completely bleak: thanks to the digital computer, sensor inputs—and a lot of software synthesis—traffic intersections can be placed under machine control to break up the traffic bottlenecks that have become one of the major blights of our cities.

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In the United States, unfortunately, we are addicted to the private car—particularly big, fat, and powerful models—as our first choice of transportation, and we have cultivated a distinct aversion to the widespread use of mass transportation systems no matter how superior they may be in comfort and as time-saving modes of travel. Perhaps we have not become adjusted to the almost complete inaccessibility of many center city points by motor vehicle, to the lack of adequate parking facilities, and to the harsh and punitive police countermeasures against parking ban violators, all of which are making our cities obsolete not only for residents but also for the satisfactory conduct of business, commerce, and industry. In view of this singular car complex, the only short-term remedy seems to lie in more efficient traffic-control systems.

Computer-controlled traffic systems are presently in operation in three cities in North America: Toronto, Ont., San Jose, Calif., and Wichita Falls, Tex. Other systems are being planned for such European cities as Madrid, Rome, Glasglow, and London. New York's complex scheme ran into unexpected difficulties last year, with the cancellation of a $5 million contract for the installation of computer equipment controls for an area in the Borough of Queens.

In August 1968, the writer visited Toronto and San Jose to obtain the details of the operational systems in those cities, and he was fortunate in receiving detailed information on the function of the system in Wichita Falls. Also, through the courtesy of the English Electric Company, information on the experimental schemes now being established in London and Glasgow was obtained.

Toronto: the need and the answer

Metropolitan Toronto is probably the most rapidly expanding urban area in Canada, having grown in population from about 500 000, at the end of World War II, to almost two million today. Its area comprises some 285 square miles (738 km^2), in which are situated heavily trafficked residential communities (Don Mills, Scarborough, Agincourt, etc.), major shopping plazas, and industrial parks, in addition to a downtown business district (bounded north to south by Bloor Street and Lake Shore Drive, and east to west by Jarvis and Bathurst Streets), and an uptown business section along Eglinton Avenue.

Over the past decade a number of its many tram lines have been eliminated, particularly following the completion of the east–west Bloor–Danforth subway elevated line in 1966. Although this final mass transit link, supplementing the existing Yonge Street and University Avenue north-south subway lines, was designed to ease peak-hour traffic congestion by providing alternative transportation, the street traffic along the narrow streets of the business sections is still impeded by some trolley lines that have not yet been phased out.

No city in Canada has more cars per capita. The result: the typical traffic snarls that beset every major city on the North American continent.

Could the computer help? The idea of automated traffic control for Toronto dates back to 1957, but at that time neither the available hardware nor software was adequate to handle a task of such complexity. With the existing equipment, the intensity of traffic congestion could not be measured and decisions based on the overall traffic situation at any critical time could not be made. It was obvious, therefore, that the state of the art in automatic traffic control could not handle either the present or future needs.

Faced with this impasse, Metro Toronto Traffic Commissioner Sam Cass, in late 1958, called in the New York consulting firm of Peat, Marwick and Livingston, and posed the leading question: "Will an electronic computer solve our traffic problem?" The consultants logically reasoned that since computers were capable of controlling industrial processes, such as the flow of products in oil refineries, they should be capable of controlling the flow of traffic.

The pilot study—a success story. From 1959 to 1961, nine traffic signals along 2.8 km of one of Toronto's busiest downtown streets were linked to a Univac 1107 computer. A comparison of this automatic system with the usual time-cycle control of traffic lights indicated that computer control reduced the average delay per vehicle by 11 percent in the evening rush hours, and by 28 percent during the morning peak hours. Congestion at all times was reduced by an average of 25 percent a notable achievement for a very limited test system.

With these promising results, Toronto decided to proceed

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with Phase 1 of the Metro Toronto Automatic Traffic Signal System (Fig. 1), which was subsequently completed in September 1963. This phase included the primary downtown business district, plus two of the city's principal thoroughfares: Yonge Street, north from the Lake Ontario waterfront to Wilson Avenue; and Eglinton Avenue, east from Dufferin Street to Laird Avenue.

From this initial stage, the Metro Toronto system has been expanded and extended to its present scope: more than 600 traffic intersections, distributed throughout an area of 240 square miles (622 km^2), under computer surveillance and control. Thus, in the transition of this article now from history to hardware, we will find that Toronto's extensive traffic-control apparatus is. . .

More than a matter of nuts and bolts

The objective of a computer-controlled traffic system is to move vehicles through city streets at as close to maximum volume as can be achieved. This maximum volume is a highly critical measurement in which studies have shown that even *one excess vehicle* released onto a street can trigger a traffic slowdown. The rate of deterioration of flow increases sharply as each additional vehicle enters the area. Thus the most important element in the Metro system is the inductive loop detectors, or sensors, buried in the street pavements. Each detector loop consists of four turns of 16-gauge Teflon-insulated fixture wire encapsulated in a rubber–plastic base. The normal single-lane installation consists of a rectangular 122- by 244-cm loop, embedded in a slot in the pavement. The sensor is usually placed about 90 meters in advance of the intersection, and the connection to the associated electronic equipment, which is situated in the intersection, or traffic-control, box (see Fig. 2), is made by a coaxial cable.

The sensors have been installed throughout the Metro area and coupled back to the computer[1] by the use of simple telemetry equipment and lines leased from the Bell Telephone Company of Canada. These same lines are used to monitor traffic-signal operation, thereby enabling the computer to ascertain which signal aspect is being displayed at all street intersections under machine control. Additional telephone lines are used to permit the computer to assume direct control of the signals by machine intervention and to change their aspect when required. When completed, the Toronto Metro system will ultimately control about 1000 street intersections and utilize input information provided by 2000 vehicle sensors.

Systems logic. As we have noted, the dynamic inputs of the system are from detectors strategically placed in selected streets. These sensors are *not* traffic counters; rather, they detect the presence of a metal mass and transmit binary data to the central computer. A constant "0" indicates no vehicle; a binary "1" indicates the presence of a vehicle.

The actual traffic count is done by the computer; the

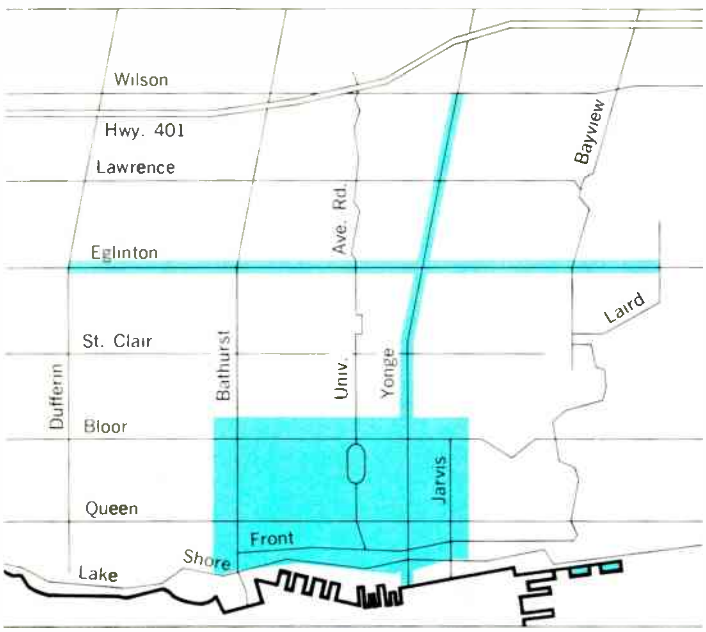

FIGURE 1. Map of Phase 1 of the Metro Toronto automatic traffic-signal system. All traffic lights in the shaded areas were computer controlled as of September 1963.

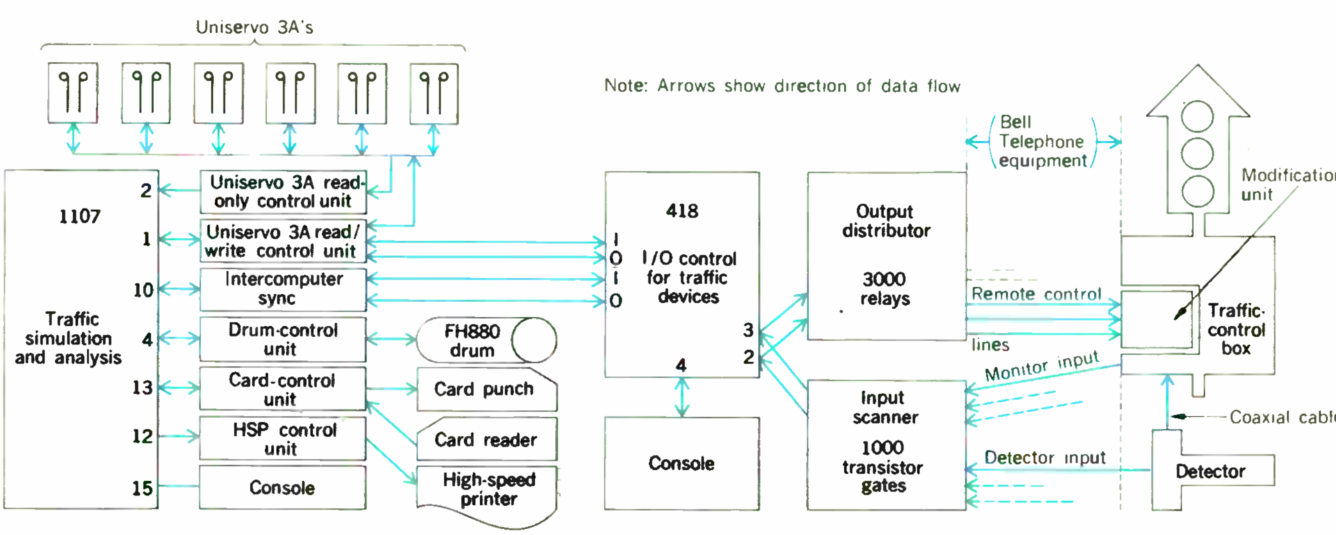

FIGURE 2. Block diagram of the Toronto computer-controlled traffic system, from street detector input to the Univac 1107 processor.

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binary signals are multiplexed on the telephone lines and connect to a multiplexer at the computer control center. By means of the multiplexer, signals are distributed to their correct address in the Univac input scanner (Fig. 2), which, in turn, is monitored several times per second by the Univac 418 satellite computer. Thus a detection followed by the "absence of a vehicular presence" is a "one-car count" to be stored in the computer memory.

Following some data processing and reduction in the 418, the information is transmitted to the central computer, a Univac 1107, which determines the optimum traffic-light pattern for the city, and returns the information to the 418. From there, the data go to the Univac output distributor, which contains electric relays that open or close in response to a "0" or "1" from the 418. Each binary point in the distributor (relays) and in the input scanner (transistor gates) can be addressed by the 418. Note that each binary point refers to a unique traffic-control box at an intersection.

Monitors in the traffic-control boxes provide data to the 418 computer in order to confirm that the controller responded correctly to instructions. Should any part—or all—of the system malfunction, the computer will relinquish control to a timer in the traffic-control box. To provide complete protection, the 418 must report constantly via a hold relay to each controller or the controller in the traffic-control box will automatically override and revert to a preset time cycle.

The complete cycle of examining the traffic situation throughout Metro Toronto occurs about once each second. Simultaneously, the 1107 stores data for future analysis and for use by the Traffic Planning Department in running its other projects and programs off line.

Main modes of traffic control

The basic green-yellow-red cycle of traffic signals can be modified in two ways: the timing interval of the cycle can be changed, or the "split" between the length of each color phase can be altered. Also, "advanced green" signals can allow one-way traffic to move on left turns that cross oncoming vehicles in the opposite direction. In the Metro system, the following five modes are in effect:

1. *Fixed progression.*—This mode simulates operation of "synchronized" or staggered time signals. It permits vehicles to proceed at normal preset speeds to experience minimum stopping in passing a series of signals.

2. *Volume-density mode* (Fig. 3). At the beginning of a cycle, an assured green phase is provided, proportional to the number of vehicles arriving during the previous red phase, to allow all delayed vehicles to clear the signal at the intersection. At the expiration of the assured time, the green phase is maintained only as long as the volume of vehicles approaching green is greater than the number of vehicles stopped for red.

3. *Variable progression mode* (Fig. 3). The computer calculates average flow of traffic over a grid in each of two opposing directions: inbound and outbound. Signal offsets may be selected to favor inbound, outbound, or average traffic flows.

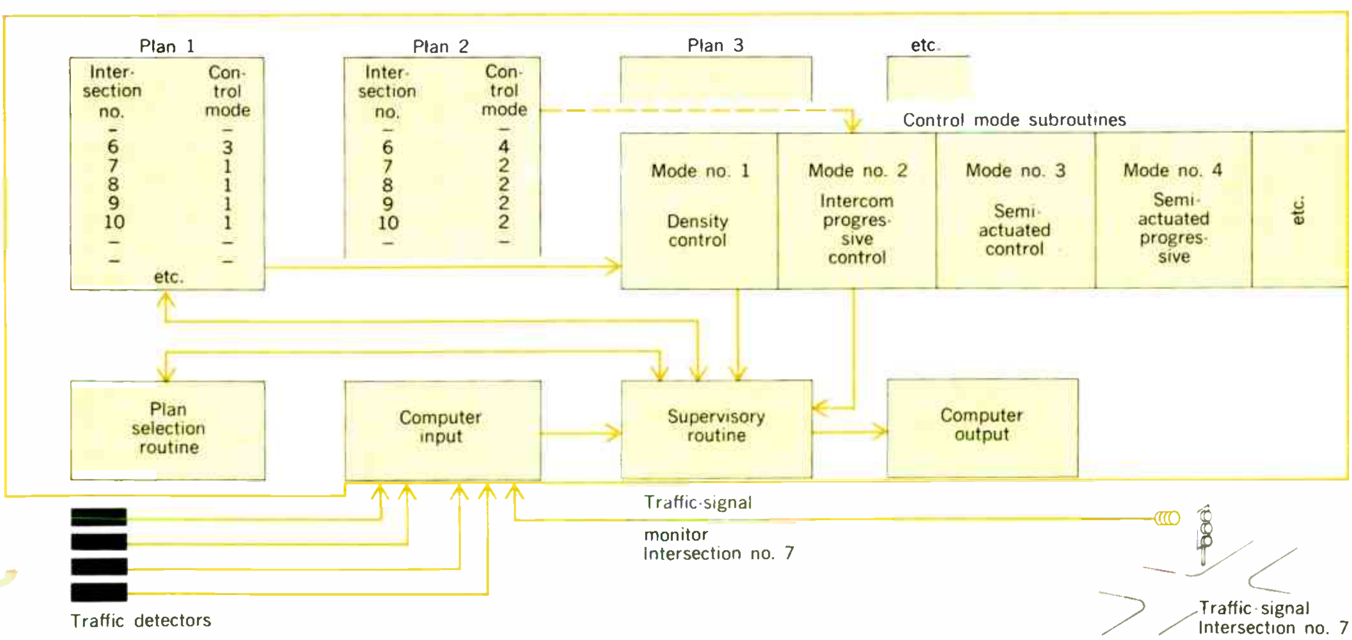
4. *Traffic responsive type 1* (TR1).—This type provides local control without coordination between intersections, and balances the accumulated vehicle-seconds of delay for traffic that is waiting with volume of traffic proceeding on green. When "advanced green" is provided, this mode permits a variation in advance time proportional to the length of the waiting queue in the left-turn lane.

5. *Traffic responsive type 2* (TR2).—Type 2 provides coordinated control of a traffic artery or grid. A common cycle length for all intersections is established, based upon maximum average traffic volume in any direction. The speed of response to cycle length change to volume change is completely variable.

The Toronto system: an operational summary

Originally, the traffic-control center, with its Univac 1107 processor, 418 satellite computer, and peripheral equipment, was installed in the old City Hall building, but with the

FIGURE 3. Block diagram of Metro Toronto's master control program, showing four of the main modes of traffic control.



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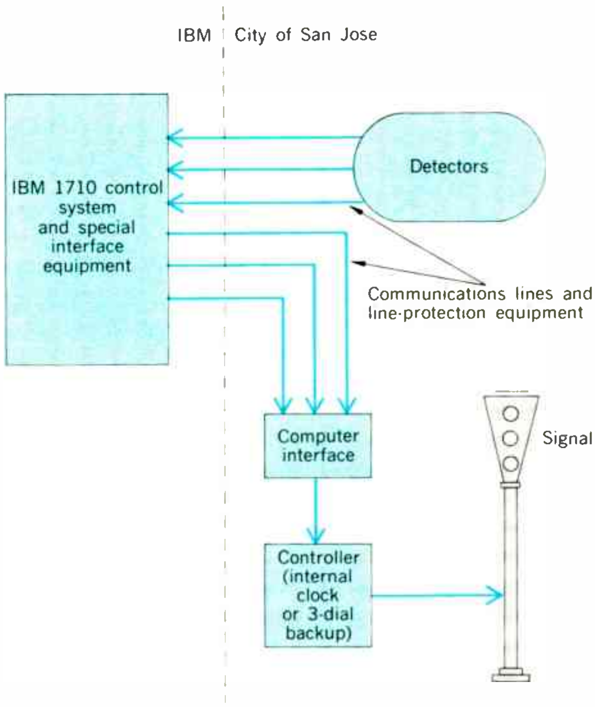
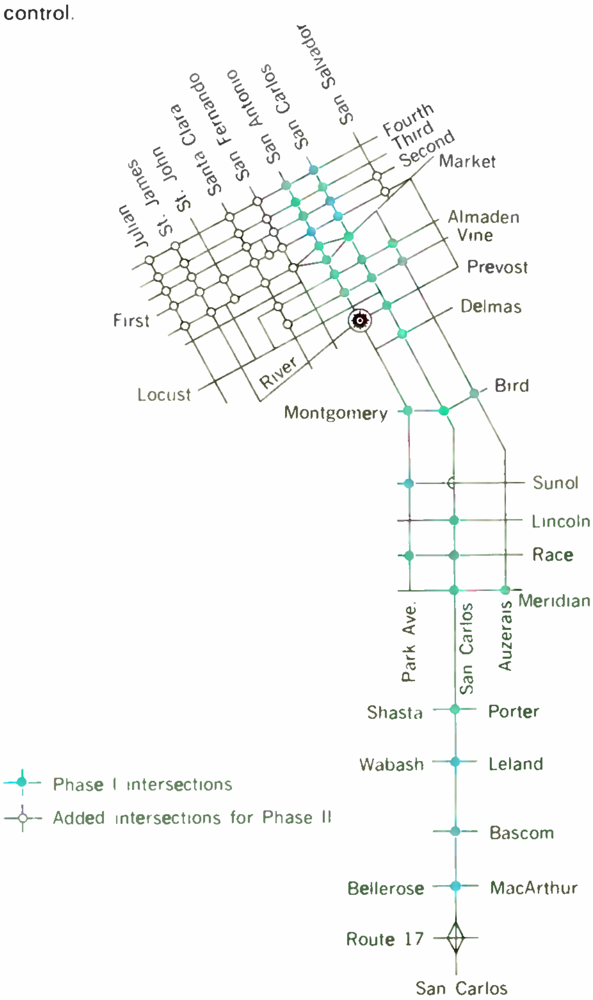


FIGURE 4. Block diagram showing the delineation of equipment responsibility between IBM and the City of San Jose.

FIGURE 5. Phases I and II of the San Jose program. Map shows all of the street intersections presently under machine control.



expansion of the control system by phases, the entire control center was relocated to more spacious quarters in the Police Building on Jarvis Street.

In operation[1] the computer analyzes the input information from the vehicle detectors. This enables the machine to determine both the volume and average speed of traffic o all streets within the Metro Toronto control area. By utilizing these data, it can determine the optimum timing to be provided at any signal, together with the offset, or intersignal timing relationship, most likely to attain the through movement of vehicles with a minimum of involuntary stops. By operating in this manner, the system automatically adjusts to cope not only with the predictable daily variations in traffic, but also with such special situations as major accidents, fires, sporting events, etc., as well as with the effects of changing weather conditions (heavy snow, rain, and ice).

A unique and valuable feature of the system, and one that was touched upon under the subheading of systems logic, is that while the computer is controlling traffic on line, all inputs concerning traffic movement and signal operation are recorded on magnetic tape at one-second intervals. These data are, therefore, available for off-line processing to obtain statistical analyses and to provide new clues and insights into the variable factors governing traffic flow. This dual capability is particularly useful in appraising the relative merits of the five different operating modes and in predicting the capability of the system to handle future demands efficiently.

In the beginning of the Phase I operation of the Metro control system (1963), all signals on an arterial thoroughfare or principal street were connected to the computer at the same time, and a series of before-and-after "floating car" speed and delay studies were conducted to assess the effectiveness of the operation. In other words, test cars were run over sections of the city both under and outside of computer control for similar distances. Although the statistics obtained from these test run studies were very encouraging, the actual long-term extrapolations were made very difficult by two factors: an unpredictable rate of increase in traffic volumes caused by the population growth of the Metro area, and an increasing preference by drivers for less congested, although longer, routes.

In 1966, however, a more dramatic demonstration of traffic flow improvement made possible by machine control was provided by a one-week-long shutdown when the computer center was relocated to its present site. Speed and delay studies conducted on arterial streets before, during, and after this shutdown indicated that, under computer control, travel time was reduced by about 44 percent and the number of involuntary stops was decreased by approximately 53 percent.

During the course of system expansion (1963 to the present), a comparison of accident statistics between controlled and uncontrolled arterial streets indicated a reduction of 13 percent for the controlled streets. A large part of this reduction was found in the decrease in rear-end collisions because of the freer flow of traffic and the fewer involuntary steps inherent in controlled traffic.

Although the Metro system is still incomplete in its area coverage, and the operational procedures are not yet optimized, the Metro Traffic Commission estimates the economic savings of the system to motorists and the city to be (the order of $20 million per year in time saved and accidents avoided. Considering that this saving has been

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achieved for a total capital investment thus far of about $5 million, and an annual operating cost of about $600 000, the advantages of the system are quite evident.

Computer control in San Jose

In June 1964, the city of San Jose (population 400 000) and IBM initiated a joint study agreement to determine the feasibility of using a digital computer for the control of traffic signals. In 1965, the actual computer control of signals was effected, and on December 31, 1966, the study was concluded.

Nine of the salient results and conclusions of the 2½-year study were as follows:

1. By both computer measures and by the use of timed vehicle operations, a significant improvement in traffic flow was obtained. This improvement was documented by marked reductions in average vehicle delay and the trip time of cars traveling through the test area.
2. In the first phase, in which 32 city intersections were placed under machine control, the average vehicular delay was cut by 14 percent, and the probability of a stop was reduced by almost 18 percent.
3. The reductions for Phase I provided an annual cost saving to the motoring public of more than $250 000.
4. These improvements were extended significantly by means of microloop techniques (to be explained later in this article), which concentrated on critical street intersections, and through on-line progression changing.
5. For Phase II, which enlarged the control area to 59 intersections, the average delay per vehicle was reduced by 12 percent and the probability of a stop by 7.3 percent (for the entire system).
6. These reductions (for the additional intersections) achieved an annual cost reduction of about $200 000 to city motorists.
7. Although the economies of Phases I and II cannot be directly related, a conservative estimate of about $300 000 in annual reduction in motorist expense seems reasonable for all 59 intersections.
8. The flexibility of control, the capability evaluation, and the high-reliability factor were noteworthy advantages of the computer-control system.
9. The computer proved to be a "maintenance watchdog" by indicating the approaching failures of equipment on the street before a crisis situation could develop.

Equipment, manpower, and control-center responsibilities. Under the provisions of the joint test agreement, the city of San Jose provided the necessary detectors, controllers, communication lines (and their protective devices), and the installation and maintenance of these items; IBM furnished the 1710 control system (see Fig. 4), special interface equipment for detectors and controllers, and the installation and maintenance of same.

In the manpower area, the city supplied a traffic engineer, two programmers, drivers for the floating car, and installation, maintenance, and analysis personnel. The site manager, additional programmers, a statistician, a research engineer, designers, and consultants were assigned to the project by IBM. San Jose provided the computer-control center and IBM placed its computer facilities at San Jose and Kingston, N.Y., at the ready disposition of the test personnel for backup duty.

Description of the general system. As previously mentioned, the project was divided into two parts, Phase I and Phase II, which were designated to indicate a separation in

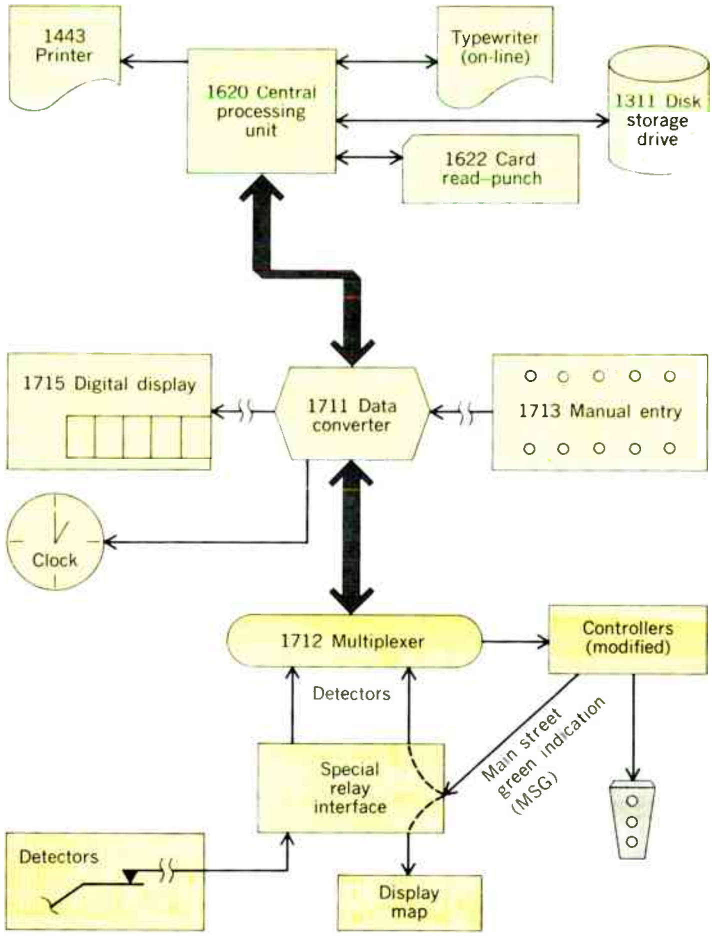
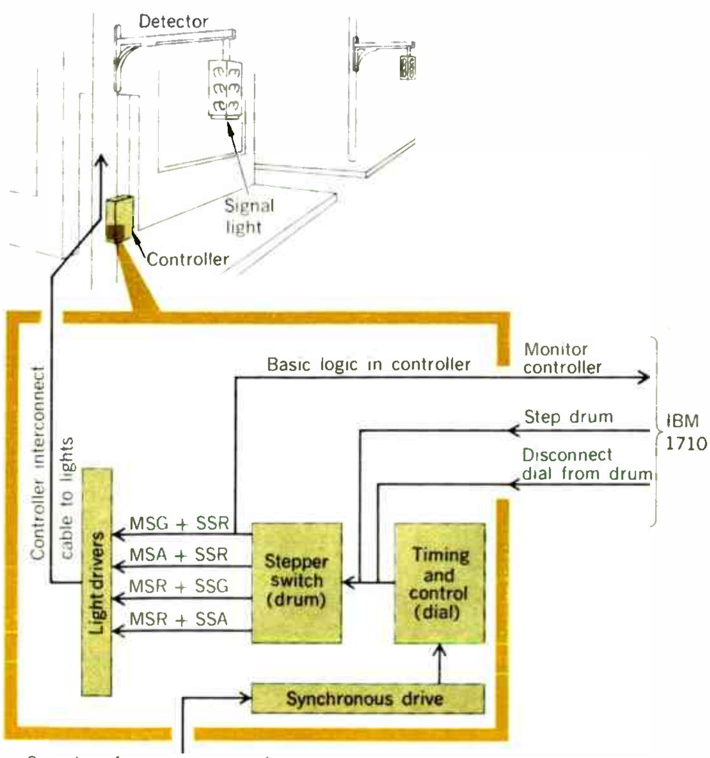


FIGURE 6. Block diagram of the central computer equipment presently installed in San Jose.

FIGURE 7. Diagram showing logic elements installed in a typical San Jose street controller.



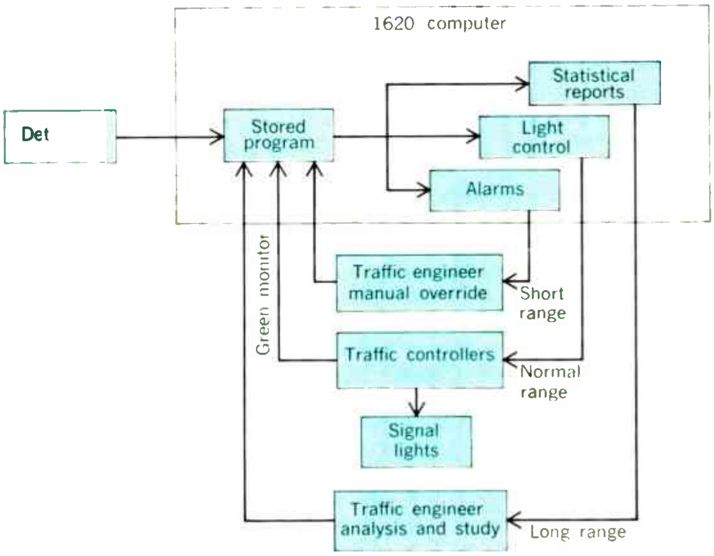
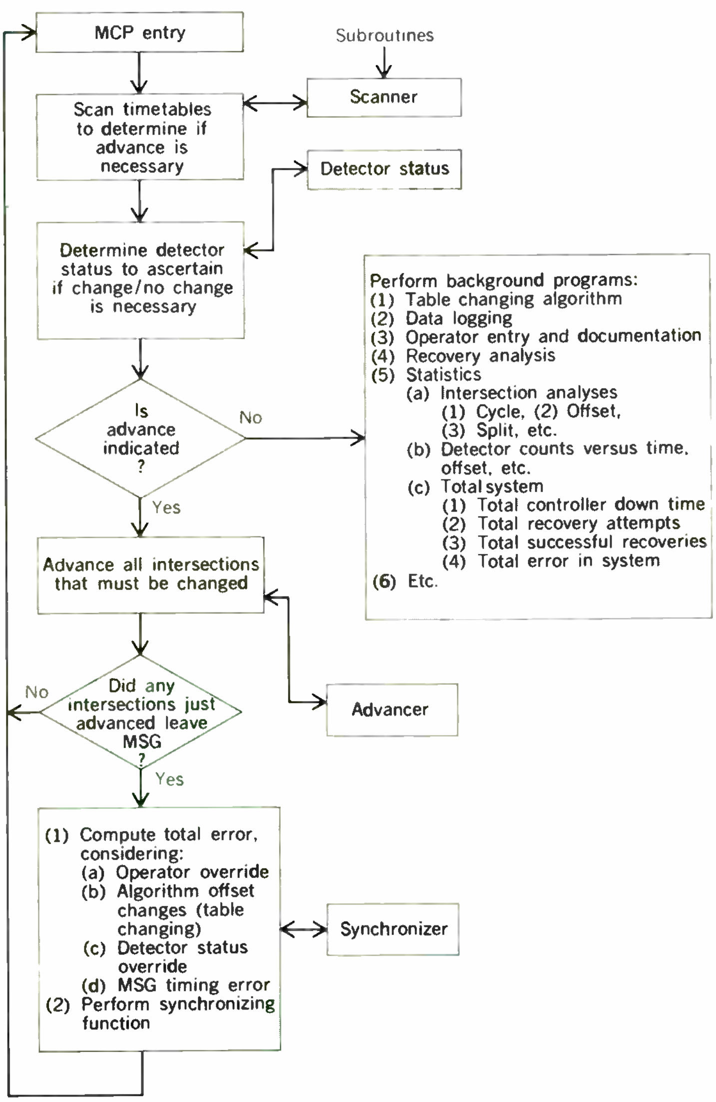


FIGURE 8. Block diagram of control loop relations in short-, normal-, and long-range parameters.

FIGURE 9. Block diagram of the San Jose master control program. Note the sequential program steps, plus the subroutine program possibilities of the scanner, detector status device, advancer, and synchronizer.



time and location. As indicated in the Fig. 5 diagram, Phase I included 32 intersections on San Carlos, Auzerais, and Park avenues. Phase II encompassed the complete project area by incorporating Phase I plus 27 additional intersections in the downtown area. Phase I employed 200 loop detectors and Phase II about 400.

The central computer equipment. As shown in Fig. 6, the IBM 1620 is the computer portion of the IBM 1710 Traffic Control System used in San Jose. The 1620 contains 60 000 digits of core storage, which house the control programs and data storage necessary to control the entire traffic network. All arithmetic functions, logical decisions, and commands for traffic-signal control are handled in this unit. Every device in the entire traffic complex operates under the complete and continuous monitoring or control of the 1620 central processing unit. Directly connected to the 1620 is an alphanumeric console typewriter whose primary function in the system is as an indication and record-keeping device.

Referring to Fig. 6, we see that there are eight peripherals in the system block diagram:

1. An IBM 1311 disk-storage drive, which is used to store large volumes of data generated by the system. It also contains programs, subroutines, and complete traffic operating tables; and it can store two million digits of information.

2. A 1711 data converter that serves as an intermediate processing station. It controls the interrupts to the 1620 computer, and houses the pulse counters that are used to accumulate detector information. It also contains the real-time clock that regulates the basic timing for the entire system.

3. A 1712 multiplexer and terminal unit, by means of which a variety of binary devices may be actuated or entered into the IBM 1710 system. The 1712 is used as the terminating device for all system entry and exit points.

4. An IBM 1443 on-line printer that is capable of printing 120-character lines at 150 lines per minute.

5. A 1622 card reader punch, capable of reading at the rate of 250 cards per minute and punching 125 cards per minute, to provide an input for data and programs.

6. A 1713 manual entry unit to provide a convenient method of entering up to 12 digits of information into the IBM 1710 system. (These 12 digits can be interpreted by the system as instructions, data, or requests for particular system responses.)

7. An IBM 1715 digital display unit that furnishes a continuous four-digit display to the operator. The display can be used to show the requested values of vehicular speed, stops, splits, cycle lengths, and offsets following interrogation by the 1713. The term "offset" is used for the timing differential from a predetermined reference point.

8. A display board that shows a map of the control streets.

The 'nitty-gritty': how the system operates

Computer functions. The computer is connected to the controllers and detectors by cable (see Figs. 7 and 8). It is programmed to change traffic-control parameters according to some predetermined schedule, or strategy, whose elements consist of time of day, varying competing volume ratios, varying stop factor ratios, lane occupancy (spot density), phase lengths computed from assumed discharge rates, or any combination of these factors within machine power. It may control all of the intersections or any required number of them. The traffic engineer, however, may interrupt the computer's process to change operational or measurement parameters, such as cycle length or passage time, and he may disconnect any or all controllers under machine control. The engineer may also request—and receive—printed data regarding direct or computed detector measurements immediately as they occur in the street.

The machine records the following for the daily log: time of beginning of computer control, intersections dropped, and pattern changes.

Types of data stored for retrieval. The machine records and "time stamps" either direct or computed detector measurements on the disk storage for later retrieval and analysis. Since all approach lanes to all intersections are detector equipped, a measured estimate of system stops and delays can be computed (assuming no cars queued behind the detector) in the following manner: the number and time stamp of actuations between the end of the green phase, less vehicle passage time, and the end of the red phase, less passage time, are recorded as "stops." The time duration of these stops is also measured, accumulated, and stored as "delay."

Special intersection control—'microloop.' The machine may be programmed to include a special individual intersection control technique, called microloop, on a limited number of intersections. Within this technique, the computer can adjust the cycle length; and the phase length can be expanded or contracted within limits imposed by the required pedestrian walk time.

A typical application of this technique can involve a number of phase-adjusting traffic factors: First, the engineer may chose from historical record a certain ratio of competing approach volumes to determine the cycle split, with arbitrary lower and upper cycle lengths and no offset. Next, he may choose stop factors (current stops divided by current demand) to modify his initial volume ratios.

Detector types and functions. The detectors are mainly of the inductive loop type and are located in each approach lane to each signal. They are placed in the pavement from 71 to 175 meters from the intersection stop bar. There are approximately 320 loop detectors wired into the system. In addition, about 80 pressure-pad detectors have been installed. These are all permanent, embedded, nondirectional detectors that cover one lane, and they are primarily used for measurement of volumes in conjunction with the computer.

Most of the loop detectors are RCA Ve-Det 4-Pak. They are solid state and provide a mercury-wetted relay output. The detector oscillator is crystal-controlled and crystals of various frequencies are used to avoid interference between nearby loops. The detector amplifier senses the change in the loop's effective inductance, caused by a vehicle passage, by a phase-shift detection circuit. The phase-shift detection is amplified and closes the output relay. Four detector amplifiers may be powered by one detector power supply, and the amplifiers and power supply are packaged in one case. The loop detectors are used to measure stops, volume, delay, speed, and lane occupancy by sending their inputs to the computer, which makes the calculations.

Both the pressure-pad detector and the loop detector provide a contact closure output, which is transmitted to the central computer by a grounded signal wire. This wire selects a relay at the control center and repeats the detector's relay closure. The relay contacts at the center are connected to the 1710's pulse-count input, and the computer interprets and measures these contact closures, and duration of closure, as speed, volume, etc.

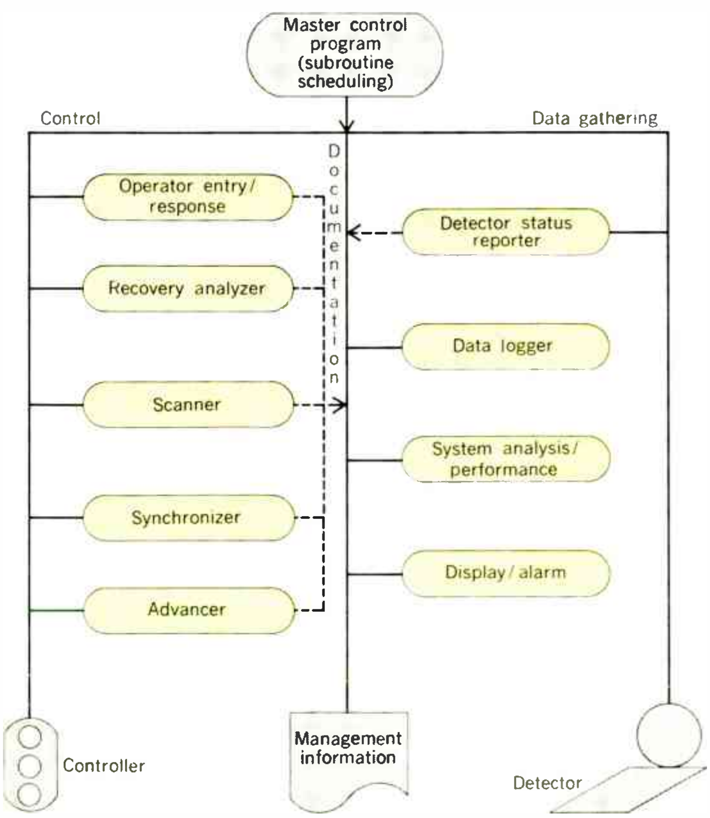
Controllers. All controllers are Type "F" Econolite, with expansible three-dial mechanisms. Two pretimed master controllers are situated at the computer center and control the system when the computer is in the off-line mode. And there is provision for automatic transfer of control from the computer to master in emergency situations by manual override.

All the controllers were modified to adapt them to computer control; this was done by installing three relays in each controller. One of these, the hold-on-line relay, is used to disconnect the dial drum advance and drum release contacts from the drum motor. The timing dial will continue to rotate until it reaches the "green" key of the principal street in the intersection, and it will remain there during the computer-control operation.

If the computer senses that a controller is not responding to its command, that controller is released by the computer. The local controller (see Fig. 7) then operates on the preselected dial or, if the controller is inoperative, maintenance personnel are summoned to make the necessary repairs. But in either case, the computer prints a message that it has relinquished control over this controller and notes the time such action was taken.

In addition to the three basic relays, several three-phase controllers on San Carlos Street (San Jose's principal thoroughfare) have been provided with one additional computer-controlled "all signals red (ASR)" relay, which is used to turn all traffic-signal indications red when this relay

FIGURE 10. Block diagram of the master control program's scheduling function that can initiate subroutines at nine points between street detectors and signal light controllers.



is operated. The ASR, for example, would be used to permit the computer to skip a phase when there was no traffic demand on that phase. By using such controller modifications, the computer can control all of the signal intervals and coordinate any intersection with another intersection or any other intersections. Also, in the event of a computer failure or communications breakdown, the controllers will revert to the three-dial (red yellow green), pretimed, interconnected control system.

Master control program operation

Using the real-time clock as a basis, the master control (MCP) program (Figs. 9 and 10) initiates periodic tests for a requirement to advance the controllers. These tests are performed by the scanner, which determines if the right time has arrived for a stepping action, and the detector status reporter, which examines actual traffic demands. The stepping action is then performed for the MCP by the advancer.

The MCP receives a monitor pulse once per cycle and this pulse verifies the status of the lights on the street. The time at which this pulse occurs is then related to the time at which it should occur (which is determined by the cycle length and offset) and any deviation from this schedule is revealed. The MCP then reconciles all influences that affect the action of a controller such as operator intervention, algorithm offset changes, and traffic demands indicated by the detectors. If the monitor pulse does not occur, the controller is returned to local control and the operator is notified.

Before advancing an intersection controller from the principal, or "main street green" aspect (called MSG), the advancer checks the contact of this signal for closure. If an intersection fails this closure check, its "hold" relay is dropped (thereby returning the intersection to local control), and pertinent data are recorded for the recovery analyzer subprogram and the system operator is notified. The remaining intersections to be advanced are then advanced. But regardless of these considerations (and a subsequent MSG check), the advancer updates the following records in the header table: time next sequenced, current time-sequence address.

For intersections that have just left MSG, two additional entries are made in the header table: observed time leaving MSG, and required time leaving MSG. Control is then returned to the master control program.

Synchronizer. The asynchronous operation of the traffic-control program permits the synchronizer, in one subprogram, to perform all synchronizing functions — including the initial synchronization at startup — continuous damping of any accumulated errors in the system (time lag in relay responses, etc.), placing recovered controllers in synchronization, and resynchronizing to a new offset progression pattern as directed by an offset table change. Further, the traffic engineer has control over the amount of correction performed in one traffic-light cycle, thereby ensuring synchronous phasing of all signals without disruption of normal traffic flow.

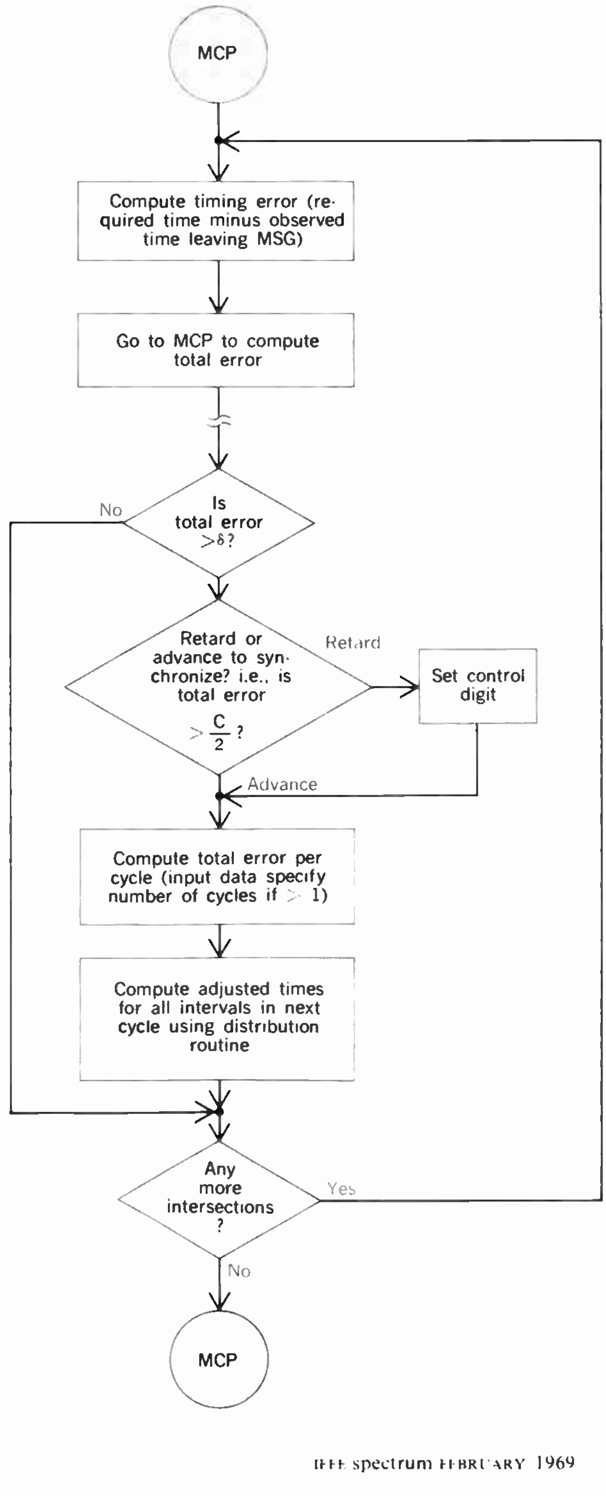
After computing the timing correction (defined as the difference between the required time for leaving MSG and the observed time of leaving MSG), the synchronizer (Fig. 11) takes into consideration the following before computing a final correction: operator intervention, detector counts of actual traffic conditions, offset progression table changes, and the timing correction. The synchronizer then determines whether synchronization can be achieved more rapidly by shortening or lengthening the traffic-light cycle.

Fallback. Return to local control may be either scheduled or nonscheduled. For the nonscheduled condition (system equipment failure), it is imperative to avoid erratic traffic sequencing of signal lights. Thus a smooth transition from computer to local control is readily accomplished under normal operating conditions by the fallback subprogram (see Fig. 12).

A final word on San Jose

The system in operation in San Jose, Calif., is far from optimized. Although historical records are kept for off-line

FIGURE 11. Diagram of synchronizer subroutine and its alternative bypass under certain conditions.



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analysis and constant updating of procedures and settings, there are variables outside of city system control that pose continuing problems. If one consults a map of the San Francisco Bay area, one can readily see that San Jose lies at the apex of an inverted triangle at the southern end of the bay. San Francisco and Oakland (each about 80 km north) funnel southbound traffic toward San Jose along two arterial freeway systems. The inbound/outbound flow patterns along these freeways are historically very unpredictable. Further, the bay area is rapidly becoming an area of heavy industrial concentration; traffic volumes at peak hours *to and from* San Jose are steadily increasing. Indications thus are that the San Jose system will not be stabilized until both San Francisco and Oakland institute some form of machine control also.

Boiled down to its essentials, the San Jose system, like Toronto's, varies the time cycle of traffic signals in accordance with two on-line variables: traffic density and speed of flow. The computer, in real time, digests all of the instantaneous data from the street intersections under machine control, makes the necessary decisions, and relays this information to each of the street controllers that control signal aspects.

At present 60 intersections in the city are under computer control; ten more may be put on line, if desired. Eventually, 100 intersections will be controlled, and, at this point, the maximum practical number will be reached. At present, San Jose's system goes on line at 6:45 A.M., and off at 9:00 A.M. (morning peak hours). In the evening, the system is back on line from 4:00 P.M. to 6:00 P.M.; finally, it is on line for the third time from 8:00 P.M. to 2:00 A.M.

Statistics for 1968 indicate a 15–16 percent reduction in involuntary stops. The operational cost of the system is a bargain when compared with the $7500 saved for the motorists each day in time as well as in repairs of collision damages.

The system in Wichita Falls

According to Roy L. Wilshire,[2] traffic engineer for the city of Wichita Falls, Tex., the IBM 1800 computer is rapidly "transforming the place into a city of green lights." The system, in operation since October 1966, compiled an impressive record in its first year; vehicle stops were reduced by 8 percent, vehicle delays were reduced by 18 percent, and accidents were reduced by 8.5 percent below the figures for noncomputer operation.

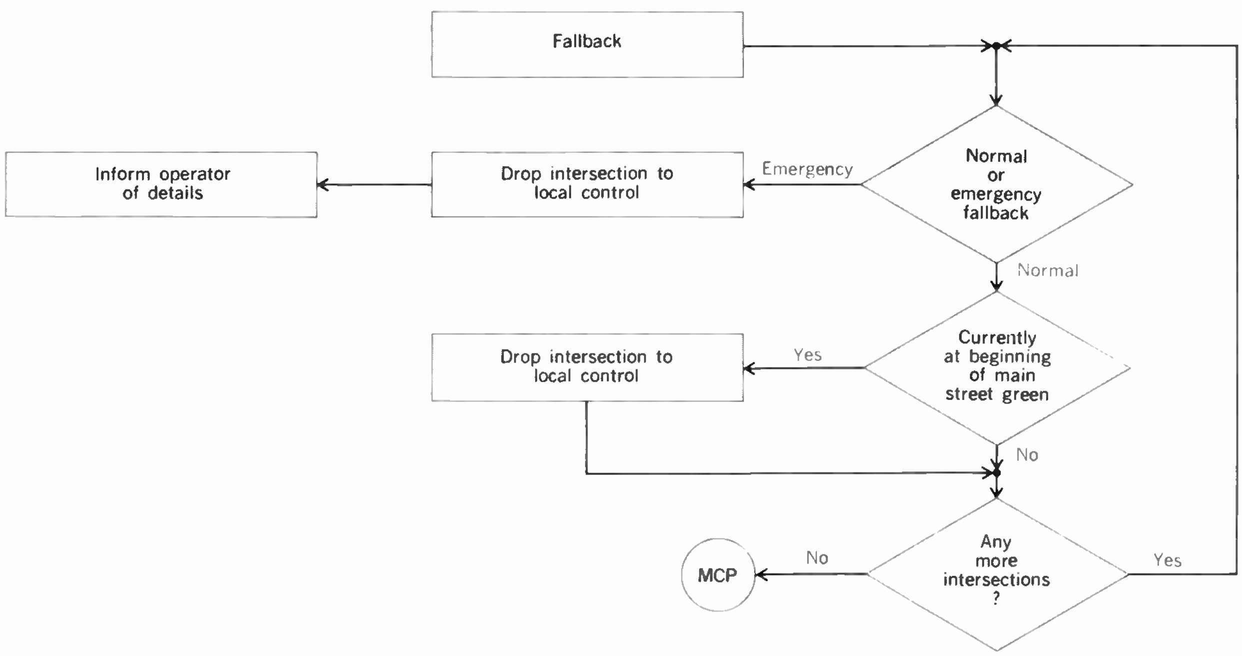
Peak-hour average speeds in the city have increased from about 32 km/h to 48–56 km/h, under computer control, in the approaches to and exits from the downtown area of this city of 115 000 population. It is estimated, based on a vehicle count of 90 000 per day, that motorists save $1500 in operating costs and 60 hours of time each day.

The computer centralizes both control and surveillance, and it provides the city with more meaningful data on downtown traffic than that which had been acquired in 15 years' use of a fixed-time system.

The IBM 1800. Since its installation, the 1800 has been controlling 57 street intersections in a 47-square-block downtown and peripheral area of the city. In the near future, 20 additional intersections will be placed under machine control, for a total of 77 in all. The 1800 has the capability of controlling up to 500 intersections and 300 detectors. At the present time, data are fed to the computer from 63 detectors at about 25 locations. The 19 pressure detectors in the system, of course, provide only vehicle count data; the loop detectors, placed in the pavement 75–90 meters ahead of the intersections, furnish vehicle count, speed, and lane-occupancy data, and permit stops and delays to be measured.

Operating unattended,[3] the computer checks each pressure detector more than 60 times each second. This permits the machine to "grab" a vehicle as it crosses the narrow pad. It checks each induction loop detector about 15 times per

FIGURE 12. Scheduled release of control diagram (fall-back), initiated when computer releases its functions to local street controllers.



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second. The computer next processes these data to determine:

1. Whether more vehicles are entering or leaving the downtown area.
2. How the volume at any given instant compares with the average volume for that time slot.
3. Whether lane occupancy is becoming excessive.
4. Whether the progression of the signal cycle matches the actual speed of the motorist.

By means of the strategically located detectors, and based on its input analyses, the 1800 selects the optimum of 17 different traffic-light timing sequences. The selected signal cycle then applies over the entire system. For example, a 47-second red yellow-green cycle is used during off-peak hours and it is gradually increased by two-second increments during peak periods to a maximum of 58 seconds, based, of course, on the computer's re-evaluation of the detector data every cycle.

Details of the advanced System 1800

To explain the details of the System 1800 operation, similar to that in use at Wichita Falls, the Fig. 13 block diagram should be helpful in that it is simplified to a one-lane detection-counter configuration. As we have seen, traffic counts can be detected by lane and direction. Speeds, length of vehicle, and lane-occupancy data can also be collected on a real-time basis. For communication, the system requires dedicated lines: telephone, microwave, and induction loop detectors.

To accumulate so much data on a real-time basis, two magnetic wire loop detectors, spaced about 3 meters apart, must be installed in each lane. Also, two types of electronic pulses must be transmitted from each detector: a pulse count and a pulse duration. The detectors are read by the computer either every second or every fraction of a second, depending upon requirements. The computer also functions on a timed basis to calculate simultaneously the speeds and lengths of vehicles.

Speed detection is the key to both vehicle length and lane-occupancy determination. It is collected from the combination pulses of the two induction loop detectors. While a pulse is registered by the first detector, the time to the nearest hundredth of a second is recorded in the 1800, and the pulse duration is turned on. The same thing happens when the vehicle enters the magnetic field of the second detector. The time is also recorded in the computer when the pulse duration for each detector is terminated. The exact speed of the vehicle is computed from "beginning and ending" recorded times obtained from both detectors since they are a fixed distance apart. By using the same data, vehicle length can be computed. The counters operate on a millisecond basis, whereas the computer functions at microsecond speeds to do the on-line computations and the storing of the collected data.

The loop detectors, which require fine tuning to be accurate, are constantly monitored and checked by the computer, and the length of the vehicle is used to determine a separate speed indication from each detector. In practice, three speeds are recorded for each vehicle; the two additional speeds are used to check detector accuracy. If a predetermined discrepancy occurs between the recorded speeds of the same vehicle one or both of the detectors are malfunctioning and require adjustments.

Lane-occupancy information can also be collected on selected routes by placing a second set of detectors in the roadway a few hundred meters down the road. In this instance, the computer will keep track of the number of vehicles (by the distance between the two pairs of detectors) on a time basis. Lane occupancy is tallied in an accumulator. Counts are added as vehicles enter the surveillance section and are subtracted as they leave the section. Lane-occupancy data are stored for predetermined time intervals.

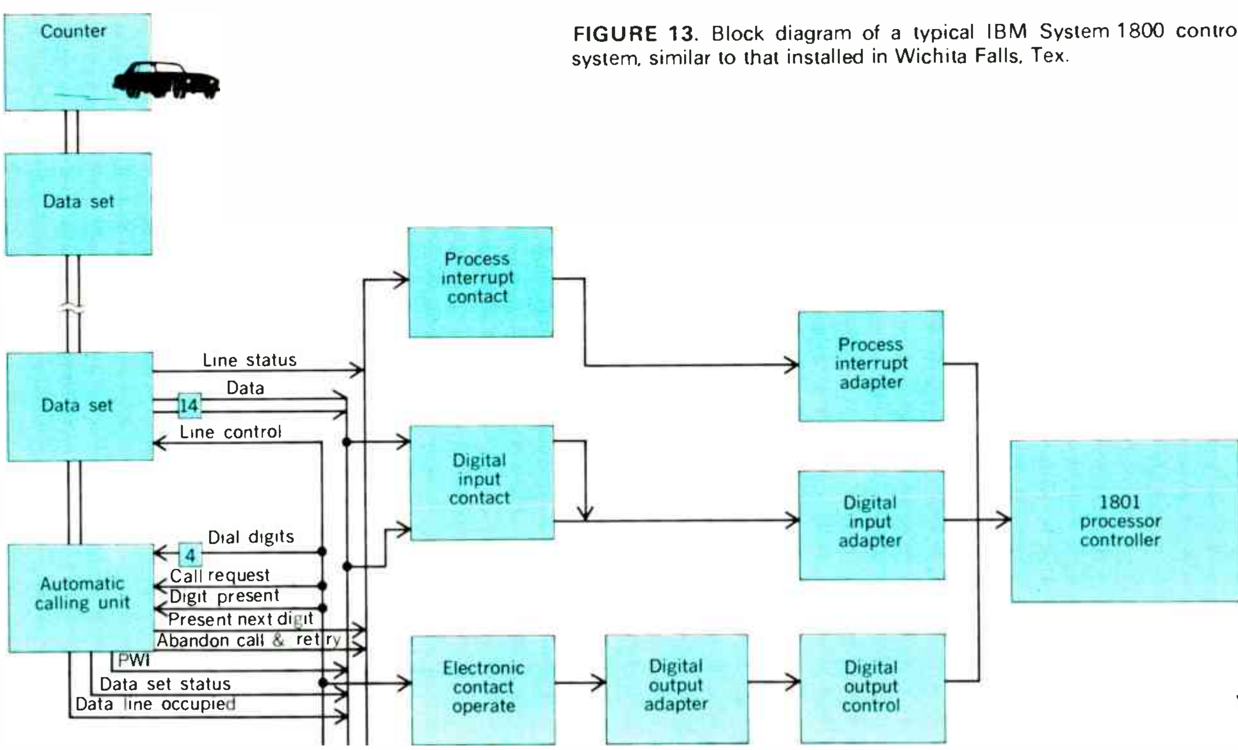

FIGURE 13. Block diagram of a typical IBM System 1800 control system, similar to that installed in Wichita Falls, Tex.

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As a point of interest, vehicle lengths are also computed to enable materials engineers to determine sub-base and pavement depth requirements for new construction, since multiple regression techniques permit vehicle length data to be related to equivalent axle or wheel loads. These, in turn, provide the variable factors for computer determination of pavement depths.

Experiments with the computer in Wichita Falls

The city of Wichita Falls is now experimenting with a new computer program that will effectively permit every intersection to operate on its own within a background system. In this mode, typically, the green-signal indication times at each intersection will be changed each cycle, if necessary, to meet the constantly changing demands of traffic. This advanced technique is possible because of the speed and power of the 1800 digital computer. The machine has an internal storage capacity of 16 000 words, plus one magnetic tape disk that stores up to 512 000 additional words of information, such as operating programs, lane occupancy, speed, volume, stops, and seconds of delay. A card reader/punch and a typewriter console linked to the computer are used for surveillance, a wide variety of reporting, and even graphic plotting.

Street map display. The display board at the computer center is used to monitor the exact operation of each street intersection, with red, yellow, and green lights duplicating the same signal indications that are in effect at each intersection. A blue light indicates computer control of each individual intersection, and this light (on or off) tells at a glance whether an intersection is on line or has been dropped from this system because of mechanical or electronic circuit trouble. As is the case in San Jose, when an intersection is dropped, the conventional fixed-time control system takes over until the computer resumes control.

The 1800's console typewriter automatically prints out a continuous record of dropped intersections, and the time each incident occurs. A typical entry might be: "1st bad intersection no. 54, time 6.632 hours." On the next cycle, the computer automatically attempts to restart the intersection. If this effort fails, the typewriter repeats the same message. When this occurs, it is a signal that mechanical repairs are necessary at the scene either on the local controller or the communications system. There is no further printout until the trouble has been corrected; then the typewriter will print, for example, "begin TPC (traffic pattern change)," followed by the pattern number and the time. When the intersection is back in synchronism with the overall control pattern, the typewriter prints out: "end TPC," plus the pattern number and the time.

Some critical intersections. In Wichita Falls, four intersections have been designated as critical. If, for any reason, the computer should drop all of them, it would then drop the entire network, which would subsequently revert to conventional interconnected fixed-time control. This is a fail-safe measure, which would, in effect, preclude a situation whereby two systems would be operating simultaneously —the four critical intersections on fixed-time control and the balance of the network on computer control.

Retention of the old fixed-time system has many advantages, however, because it can be used from 8:00 P.M. to :00 A.M. when traffic flow is light. At these times, the computer is used off line for other analysis tasks similar to those in Toronto and San Jose.

Computer programs elsewhere

New York: the lights that failed. Back in 1963, New York City's Traffic Department initiated a large-scale program for the development of a computer-controlled traffic scheme for the entire city. When fully implemented, it was planned to be the world's largest and most comprehensive traffic-responsive interconnected electronic signal-control system.

During October 1965, the city took its second step in the program when a $5 million contract was awarded to a major supplier for building the control equipments and components necessary to meet the Traffic Department's specifications. Unfortunately, the progress on this phase, which would have controlled about 100 intersections in the Borough of Queens, was beset by difficulties from the outset. Early in 1968, the Traffic Department was forced to cancel the contract. Thus the outlook for New York is now uncertain, but one thing is clear: the program for computer controls has been set back by a number of years.

The British approach. The Marconi Company,[4] a subsidiary of the English Electric Corporation, has recently supplied the central control equipment for a comprehensive area traffic-control experiment in Glasgow, Scotland; and for a complementary experiment in West London, the General Electric Corporation is supplying closed-circuit surveillance equipment, vehicle queue detectors, and signal-controller interposing units to work in conjunction with a Plessey system. The Marconi Company and GEC Road Signals Ltd. are cooperating in this field, and their combined effort in both experiments should permit them to supply complete area traffic-control systems that incorporate the most advanced techniques.

The Glasgow experiment. The central data-processing and on-line control functions for about 80 signal intersections will be achieved by a Marconi Myriad Mark I computer employing integrated circuits to give a high computational speed and reliability. The machine has been installed with a 16 384-word core storage, and a magnetic drum storage of 80 000 words. The cycle time of the core storage is 1.4 microseconds; basic arithmetic operations are performed in 2.8 microseconds.

The input/output peripheral equipment consists of two 1000-character-per-second paper tape readers, a 150-character-per-second paper tape punch, and an on-line typewriter that can be used for both input and output. Also, an on-line graph plotter is available for graphical data output.

The traffic-control peripherals permit the input of single-bit information from pneumatic detectors and traffic signals at 25-millisecond intervals and output of control signals to individual intersections as required. An analog-to-digital converter has been incorporated to process the signals received from inductive loop detectors. The analog current signals are converted into seven-bit digital equivalents for input into the computer.

Detectors. As already indicated, both pneumatic and inductive loop detectors will be used; the former are installed on the approaches to each intersection. Small inductive loop detectors, approximately 4 meters long and 2 meters wide, will be placed to detect the formation of queues of traffic at intersections. Longer loops may be used to indicate the number of vehicles present on the road between any two given intersections.

Data-transmission equipment. Communication between the computer and the control equipment at the majority of intersections is by means of multicore cable, using a sepa-

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rate pair for each individual control function. For ten of the 80 intersections, frequency-division multiplexing over leased telephone circuits is employed. The use of these two types of data transmission in the same experiment will enable their relative traffic-control advantages to be assessed.

Modes of control. The Glasgow experiment will consider the following eight modes of control:

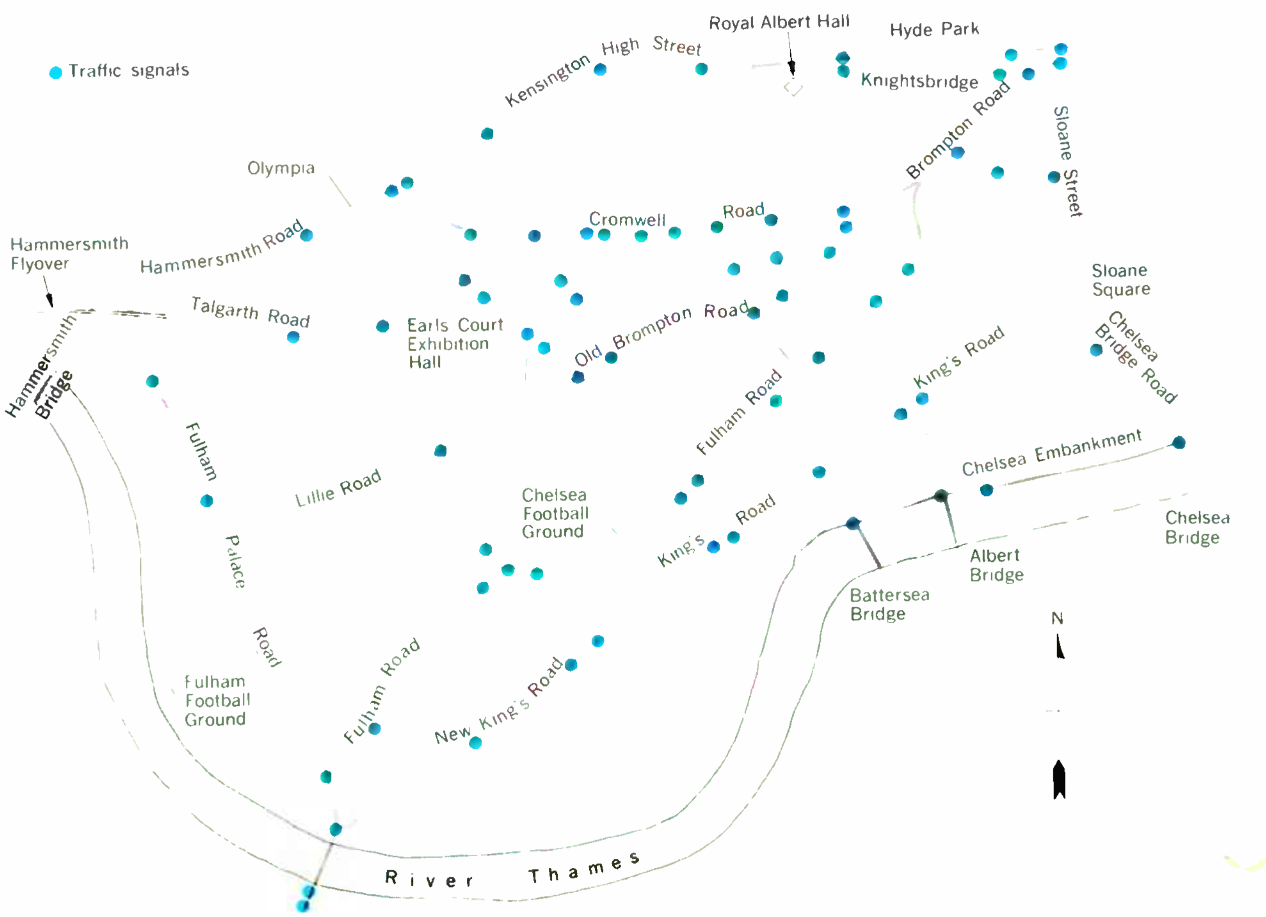
1. Fixed-time progressions, based on historical data on traffic conditions, with some provision for manual selection according to variable weather conditions.
2. The availability of fixed-time programs in which selection is based upon an evaluation of traffic conditions at representative points.
3. Isolated vehicle-actuated operation.
4. The "maximum traffic" system, which is presently used to interconnect about 45 signals on main streets in central Glasgow.
5. The "flexible progressive" or "bias" system used for linking vehicle-actuated signals.
6. A saturation flow mode applied independently to each intersection.
7. A form of control that maintains an equal degree of saturation on each phase of an individual intersection.
8. A form of control based on knowledge or prediction of the traffic expected on each approach, up to one cycle ahead, and designed to select the time of the next phase change to minimize total delay at the intersection.

The first five modes of control have been used in other cities, but insufficient data have been published for satisfactory comparisons. The latter three modes, as far as is known, have not been used elsewhere.

Performance assessment. The principal criterion for evaluating the performance of each control system will be trip time as measured by the "floating car" method. It is felt that emphasis should be placed on the reduction of trip times on heavily trafficked routes rather than upon routes carrying little traffic. Therefore, measured trip times for different links in the traffic network will be weighted according to the observed flow in the link. Weighted trip times will then be totaled to give an overall performance index. On each test trip of the car, the number of stops made at traffic lights will be recorded and may be used as an additional means of comparison. In addition, when assessments are being made, the information from vehicle detectors on the perimeter of the controlled area will be processed by the computer to give a continuous record of incoming traffic flows. Observations taken under abnormal flow conditions will be discarded.

By assessing the performance of one control system a number of times, it should be possible to establish a relation between flow and trip time for that scheme. One difficulty with the floating car method, however, is that errors made by drivers during test runs may not be noticed until the data are studied at a later date. To overcome this problem, float-

FIGURE 14. Map of portion of West London (England) in which computer-controlled traffic experiments and traffic surveillance are now under way.



ing cars will eventually be equipped with radio telemetry links with the Myriad computer. This will facilitate on-line analysis of the data so that if errors are made by the driver, he can be informed of them by the computer and requested to repeat a part of the run.

The London experiment. The experiment currently under way in a section of West London is attempting to produce a control system that will minimize traffic delays in a busy part of that city. The information gained from the development of this control system will then provide the basis for efficient systems elsewhere. The area selected for the test (Fig. 14) covers about 6½ square miles (about 17 km²), with some 70 signal-controlled intersections. The area contains two major exhibition halls, two football fields, two important shopping centers, and three commuter routes.

At present two Plessey digital computers are being installed: one will have a 16-K-core store of 24-bit words, and a magnetic drum backing store, and will act as the central processing unit; the other will function as a data scanner by organizing the transfer of information into and from the central processor. Closed-circuit television surveillance equipment is also being installed.

When the West London system is fully implemented, the functions of the central processor will be to

1. Accumulate and analyze the incoming traffic data.
2. Select, from a program of plans held in the computer, the strategic plan that is best suited for the traffic situation at any given time.
3. Adapt the plan, second by second, to traffic requirements on an intersection by intersection basis.
4. Transmit the necessary command signals to the local controllers to implement the control.
5. Monitor the signals to ensure that the commands are obeyed, and to monitor the traffic situation for the adjustment of the tactical control; also, to ensure that the traffic control is proceeding within the limits of expected variation.
6. Ring an alarm bell if a situation develops that is beyond the limits for which the computer is programmed (such as an accident, fire, water main break, etc.)
7. Prepare statistics and data for historical records and off-line analyses.

During the development of the system, various tests may be conducted by using manual control. But when the optimum control plans have been evolved, the system will be fully automatic and operator intervention will only be required when abnormal situations arise. When the computer requests operator intervention, it will be possible to select another computer-control program, or to control individual junctions manually while simultaneously monitoring the effects by closed-circuit television.

A final word. The computer-control systems in Glasgow and West London differ from other systems primarily in the amount of traffic data fed into the computer. In New York, for example, the planned average number of detectors per intersection was one; in Toronto, it is two; but, in West London, it will be six. The British engineers believe that to achieve a significant improvement over the performance of existing vehicle-actuated signals, their computer system must approach closer to the optimum in efficiency than has been necessary in other countries where less efficient fixed-time signals have been used.

An important aspect of both experiments will be the evaluation of control system performances. Initially, trip times and delays will be measured by injecting vehicles into the normal traffic streams and recording their progress on a number of selected routes within the controlled area. At the same time, traffic columns will be recorded so that these measurements can be related to the prevailing traffic conditions. The traffic engineers hope that, at a later stage in the system development, the computer will be programmed to determine trip times and delays automatically by using the data inputs from the vehicle detectors. To assist in evaluating the benefits derived from the computer-control schemes, other traffic engineering changes in the network areas will be kept to a minimum while the experiments are in progress.

Conclusion and summary

Computer-controlled traffic networks have taken hold, as is apparent from the operational systems in Toronto, San Jose, Wichita Falls; other cities, such as Baltimore, Md., and New Haven, Conn., have less sophisticated analog or master controller devices. Los Angeles, Calif., according to latest reports, is tentatively entering the growing list of metropolitan areas that are installing digital traffic-control equipments. The system there will probably first be applied to the freeways —a major problem region in the overall Los Angeles traffic snarl.

The exploding vehicular population then must be eventually subject to some form of practical controls just as the human population explosion must be controlled.

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Lethal electric currents

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Commercial-frequency currents of a few milliamperes flowing through the body will cause muscular contractions, resulting in the inability of the victim to release his grasp on a live conductor. Values of "let-go" current are very important criteria in the establishment of safe-current requirements. Since ventricular fibrillation, a condition in which circulation is arrested, is probably the most common cause of death from electric shock, studies of minimum fibrillating currents under various conditions are also significant. This article discusses investigations of both let-go and fibrillating current and presents some of the experimental data that have been obtained to date.

Knowledge of the effects of electric current on man is helpful in understanding the various hazards inherent in the use of commercial electricity. This knowledge is of assistance when establishing allowable leakage currents for electric appliances and electric hand tools. Quantitative knowledge of the minimum current likely to be fatal is essential for the design of grounding systems, for controlling the output of devices having exposed electrodes, and for the design of differential circuit breakers, etc. It is also helpful in the formation and justification of safety standards, and in analyzing accidents. The information may also be of value to the physician in explaining what may have happened to his patient, such as what happens when a swimmer gets an electric shock.

Man is very sensitive to electric currents. Although minute shocks are generally considered more objectionable than harmful, they must be taken seriously as a warning of potentially hazardous conditions, and thus their cause should be ascertained.

Current pathway

The great majority of electrical accidents involve a current pathway through the victim from one upper limb to the feet or to the opposite upper limb. For this reason we shall consider the various effects of the electric current on the muscles along its pathway as well as its effects on the heart as it passes through the chest—*through the chest*, that is, because at commercial frequencies the body acts as a volume conductor.

An earlier concept was that the main danger was arrest of respiration, which persisted after the shock had been discontinued. From this it was taught that prolonged artificial respiration was the only treatment. That concept was based on accident reports and on animal experiments in which the current passed through the lower and back part of the head, where lies the nervous center controlling respiration. It has since been found that this particular current pathway is extremely unusual.

Electric stimulation of muscles

Volunteer subjects from the Departments of Engineering and Physiology at the University of California, Berkeley, were given physical examinations of the circulatory and respiratory systems by physicians from the University of California School of Medicine, San Francisco. Electrocardiograms were also taken.

Only those individuals who were found to be in good physical condition, who had not experienced a recent illness, and who had normal blood pressures and electrocardiograms were accepted for the tests. For the most part, the younger subjects were students; many of the older members of the group were from the faculty or technical staff of the Department of Electrical Engineering or were physicians from the Medical School. Most of the subjects ranged in age from 21 to 25, and about 25 were between the ages of 26 and 46.

Except for its nuisance value, or for its "startle" effect in causing an involuntary movement triggering an accident, the smallest electric shock of importance is that current which causes a loss of voluntary control of the hand when an electrified object is grasped. As the magnitude of the alternating current is increased, the first sensations of tingling give way to contraction of the muscles. The muscular contractions and accompanying sensations of heat increase as the current is increased, and finally a value of current is reached at which the subject cannot release his grasp of the conductor.

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Appreciation of the deleterious effects of electric shock is necessary for maintaining eternal vigilance in matters pertaining to electrical safety and for the education of the public in the safe use of electric equipment

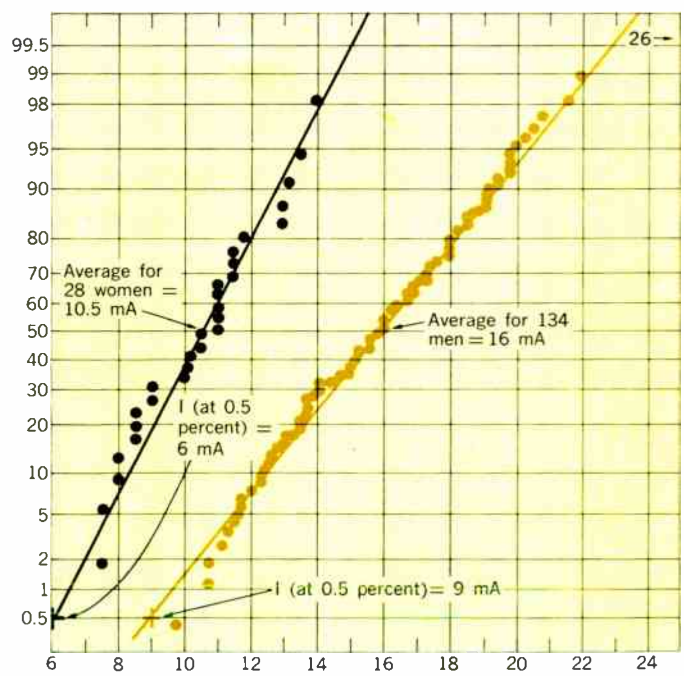
The maximum current at which a person is still capable of releasing a conductor by using muscles directly stimulated by that current is called the "let-go" current. Let-go currents are important, since an individual can withstand, without serious aftereffects, repeated exposure to his let-go current for at least the time required for him to release the conductor.

Currents only slightly in excess of one's let-go current are said to "freeze" the victim to the circuit. Such currents are very painful, frightening, and hard to endure. Points representing let-go currents for 134 men and 28 women are shown in Fig. 1. In these tests the subjects held in one hand, and then released, a small copper wire, and the circuit was completed by holding the other hand on a flat brass plate, or by clamping a conducting band wrapped with a saline-soaked cloth on the upper arm. The effect of electrode size was also investigated. It was found that the location of the indifferent electrode, the moisture conditions at points of contact, and the size of the electrodes had no appreciable effect on an individual's let-go current. The individual points representing the maximum value for each subject are plotted in ascending order to show percentile rank as a function of current. The data for the 134 male subjects and the 28 females follow a straight line on probability graph paper and are therefore normally distributed. As would be expected, the larger the number of points for a given test, the closer the points fell to the straight line, which represents the distribution curve. The average let-go current was found to be approximately 16 mA for men and 10.5 mA for women.

Although the let-go current depends largely upon the individual's physiological development, especially in the arms and wrists, psychological factors also play an important role in limiting both minimum and maximum values. Almost without exception, let-go currents in excess of 18 mA were observed in connection with friendly wagers between students. Thus, it was noted that the highest value was obtained on a student in physiology who boasted that he was as good as any engineering student. Although he made no complaints, it is more than likely that he had a sore arm for at least a week.

Average values are interesting, but it is important to determine the minimum likely let-go current for the general population. It was decided to specify as a reasonably safe limit for electric shock the 0.5 percentile value because, in all cases involving a considerable number of points, the actual values near the 0.5 percentiles are always greater than the theoretical values. This is inevitable because of the inherent characteristics of the mathematics of probability,

FIGURE 1. Let-go-current distribution curves for men and women (at 60-Hz commercial alternating current).



as it is evident that there exists a finite probability that even zero current would theoretically freeze a certain number of men to an energized wire. As a result of these experiments it is generally accepted that the safe let-go currents could be considered to be approximately 9 and 6 mA for men and women, respectively.

The muscular reactions caused by commercial-frequency alternating currents in the upper ranges of let-go currents, typically 18 to 22 or more milliamperes, flowing across the chest stopped breathing during the period the current flowed, and in several instances caused temporary paralysis of the middle finger. However, normal respiration resumed upon interruption of the current, and no adverse aftereffects were produced as a result of not breathing for short periods.

Figure 2 shows results of tests made to determine the effect of frequency on let-go currents. Sinusoidal currents from 5 to 10 000 Hz were used in these experiments. There is essentially no difference in the muscular reactions for frequencies between 50 and 60 Hz, which are the commercial frequencies used throughout the world.

It was not considered safe to apply currents in excess of those producing loss of muscular control to humans, and the only alternative is to administer shocks to animals and project the results to man in the light of observed effects and reactions. The answer to the question of what happens when a man swims into an electric field can be answered with the knowledge of the phenomena of loss of voluntary muscular control, together with observing the reactions of dogs when they are forced to swim into an electric field of increasing intensity and analysis of swimmer fatalities. When the field becomes sufficiently intense, the victim loses control of the muscles in the limbs, stops breathing, and sinks to the bottom. If he drifts sufficiently out of the electric field, he may be able to use his legs and kick his ascent, and thus be rescued. If not, he remains motionless on the bottom and dies from anoxia, but with little moisture in the lungs. If the victim receives a more severe electric shock, such as by contacting an energized object, say the frame of a defective appliance while in a bathtub, the shock may be sufficient to produce an effect on the heart known as ventricular fibrillation.

Ventricular fibrillation

When the heart goes into ventricular fibrillation the rhythmic contractions cease, pumping action stops, and the pulse disappears. The several causes of this phenomenon include electric currents flowing through the heart muscle, and the effect is due to derangement of function rather than actual damage to the heart itself. Ventricular fibrillation is considered the most dangerous electric shock hazard, because once fibrillation occurs in man, it practically never stops spontaneously. Death ensues within a few minutes, since the brain begins to die two to four minutes after it is robbed of its supply of oxygenated blood. Resuscitation techniques must be applied immediately if the victim is to be saved.

The usual treatment consists of prompt rescue and *immediate and continuous* application of artificial respiration, preferably the mouth-to-mouth method. If the rescuer has been trained, artificial respiration should be combined with closed-chest cardiac massage, and resuscitation continued *all the time* the victim is being transported to a hospital. In the meantime the hospital authorities should be notified so that they may be ready to apply defibrillation immediately upon arrival. Victims of accidental electric shocks are now being saved by these procedures.

Relationship between fibrillating current and shock duration

The three factors believed to be concerned are body weight, current magnitude, and shock duration. It seems

FIGURE 2. Effect of frequency on let-go-current for men.

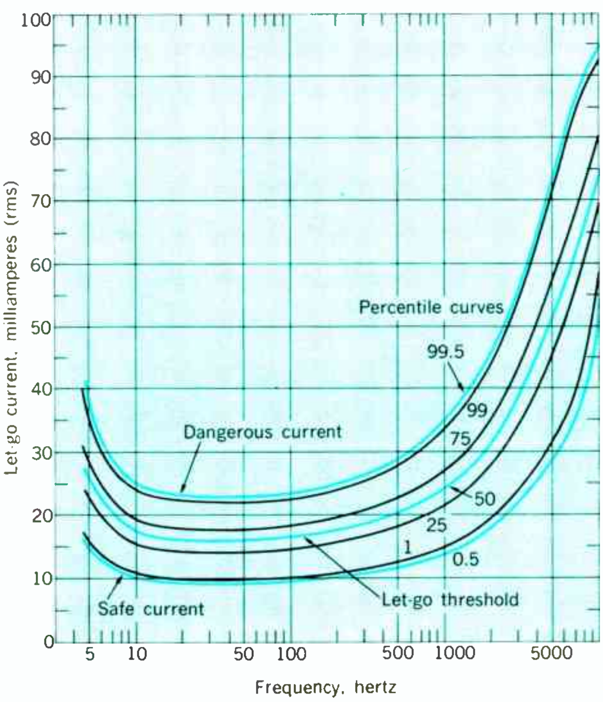
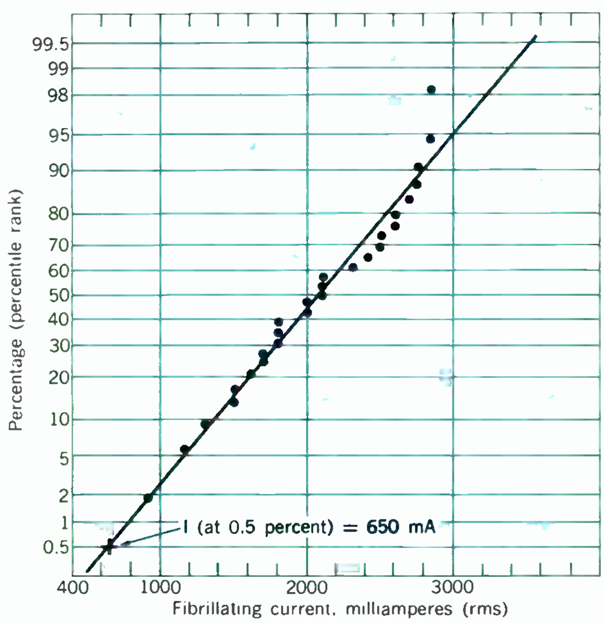


FIGURE 3. Minimum-fibrillating-current distribution curve for dogs (8.3-ms shocks). I at 0.5%=650 mA; I at 50%=2070 mA; I_{ave}=2070 mA.



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reasonable to assume that, over the range of body weights of the large animals tested (dogs, sheep, calves, and pigs), the same relationship holds between two factors: fibrillating current and shock duration. In fact, this assumption will be shown to be justified by the findings at the end of this tion.

Obviously, experiments involving currents likely to produce ventricular fibrillation cannot be performed on man, and the only recourse is to extrapolate experimental results obtained on animals to man. The method introduces uncertainties but it is the best that can be done. In addition, there exist relatively limited quantitative data on this subject. The first comprehensive work was that of Ferris and his colleagues in 1936 at Columbia University and the Bell Telephone Laboratories, New York. The second was by Kouwenhoven and his associates at Johns Hopkins University, Baltimore, in 1959. In 1963 Kiselev of the U.S.S.R. Academy of Sciences, Moscow, published a detailed experimental study of threshold fibrillating currents in dogs. In 1968, Dalziel and Lee presented a new analysis, which derives a very conservative relationship between the following three factors: body weight, current magnitude, and shock duration.[1]

The Kouwenhoven experiments covered shock durations from 8.3 milliseconds to 5 seconds, and the dog was used as the experimental animal. Typical distribution curves are given in Figs. 3 and 4. The Ferris experiments spanned shock durations from 30 ms to 3 seconds, and were made on several of the larger animals, comparable in body weight to man, and included sheep, dogs, calves, and pigs. In general the distribution curves were similar to those of Figs. 3 and 4.

The Ferris experiments included ten dogs, ranging in body weight from 18 to 26.7 kg, which received 3-second 60-Hz shocks, whereas Kiselev's investigation used 35 dogs with body weights varying from 5 to 24 kg, which received 50-Hz shocks of the same duration. Thus the Ferris results were obtained with heavier dogs and the Kiselev results were obtained with a larger number of dogs over a greater range of weight, but on the average they were lighter. It is believed that these data are comparable and may be combined to obtain a larger number of points upon which to base statistical conclusions. The test procedure in these investigations was to apply a series of well-spaced shocks of gradually increasing intensity until fibrillation occurred. In each case the electrodes were attached to the right front limb and the opposite rear limb, and involved a current pathway diagonally across the chest (the common current pathway in many fatal human accidents). In all of these tests the shocks were applied to include the phase of the heart cycle sensitive to fibrillation, and the effects of the small differences in the frequency of the shock currents are believed unimportant. Figure 5 is the distribution curve obtained by combining the 45 results for 3-second shocks on dogs obtained by Ferris in 1936 and by Kiselev in 1963.

The data consistently follow a straight line from the low values to at least percentile 50, and the analysis leans heavily upon evaluating the 0.5 percentile points. The average, mean value, or percentile 50, so useful in most statistical analyses, is of limited importance here because of the skewed nature of the response at the higher values, and the 0.5 percentiles must be obtained by extrapolation considerably beyond the limits of the experimental data. The somewhat unusual response is attributed to the complicated nature of ventricular fibrillation; the exact phenomena remain unknown at the present time, but the response possibly results from two or more modes of excitability of the heart muscle.

Figure 6 shows the 0.5 percentile points and the lowest experimental points for the various tests on dogs when plotted on log–log graph paper. The Kouwenhoven points total 191, with shock durations ranging from 0.5 cycle to 5

FIGURE 4. Minimum-fibrillating-current distribution curve for dogs (5-second shocks). I at 0.5%=25 mA; I at 50%=83 mA; I_{avg}=83 mA.

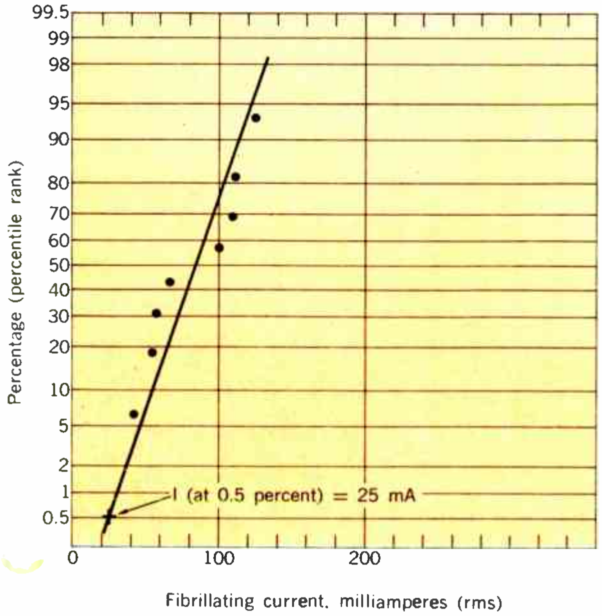
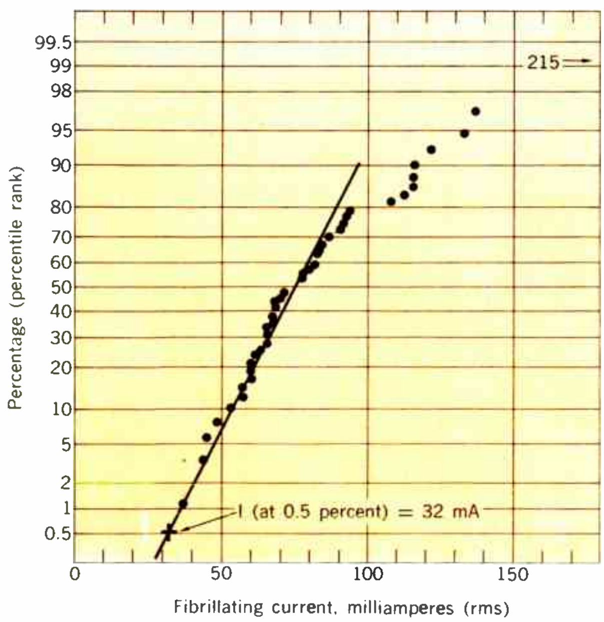


FIGURE 5. Minimum-fibrillating-current distribution curve for 35 Soviet and 10 U.S. dogs (3-second shocks). I at 0.5%=32 mA; I at 50%=75 mA; I_{avg}=81.3 mA; average weight=14.3 kg.



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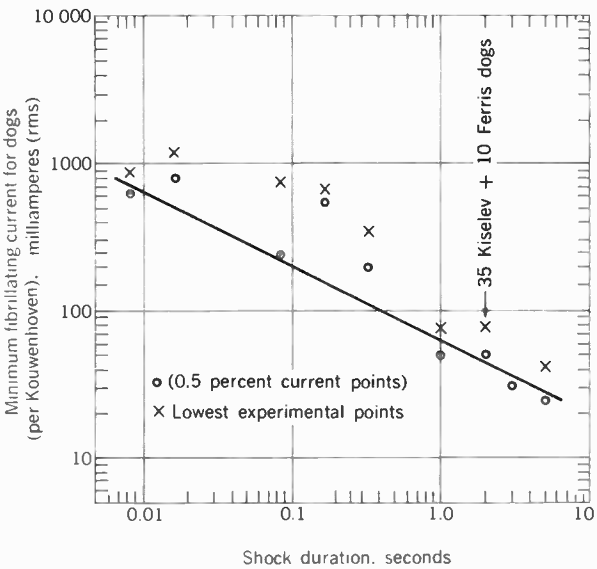
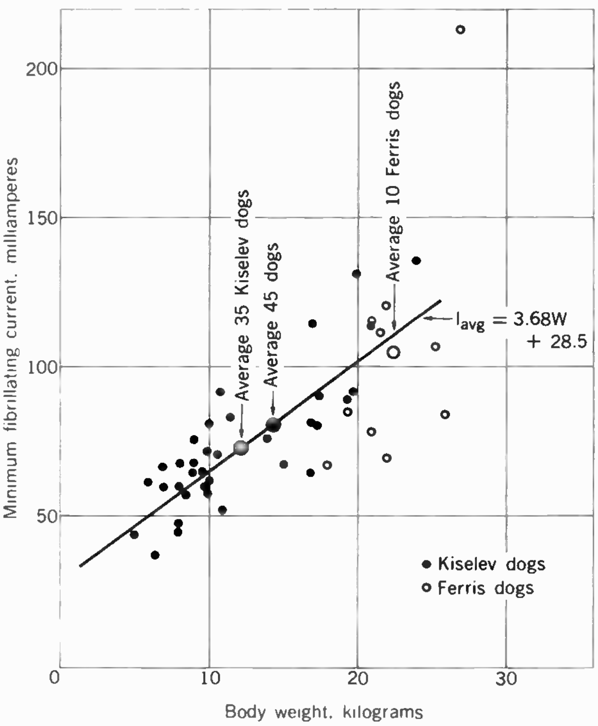


FIGURE 6. Minimum fibrillating current vs. shock duration for dogs.

FIGURE 7. Minimum fibrillating current vs. body weight for dogs (3-second shocks).



seconds. The Ferris Kiselev combined data resulted in the point at 3 seconds, and represent 45 points. The straight line representing the response was drawn by eye as governed by the 0.5 percentiles, and is below all of the observed experimental points. The line has a slope of $-1/2$, and may be represented by an equation of the form $I = K/\sqrt{T}$ milliamperes.

A similar analysis using the data obtained on sheep covering shock durations from 0.03 to 3.00 seconds resulted in a straight line similar to that of Fig. 6, and again the

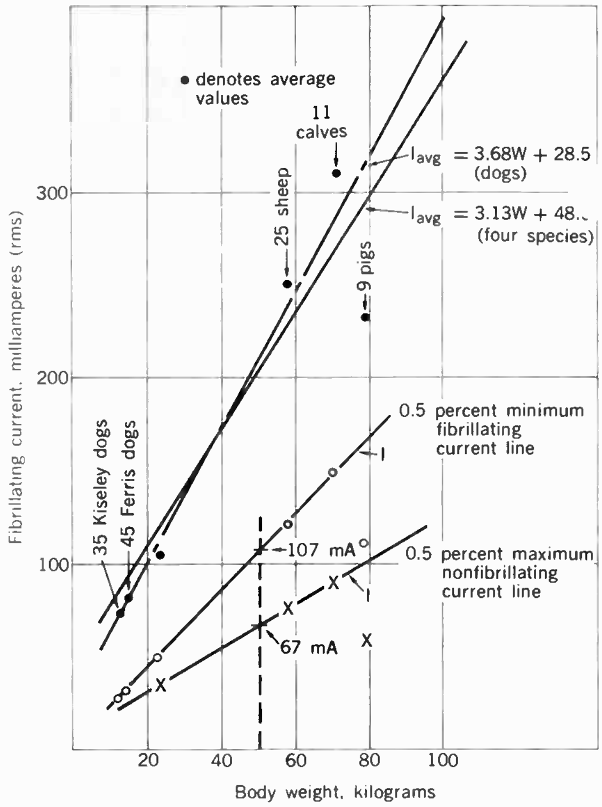


FIGURE 8. Fibrillating current vs. body weight for various animals (3-second shocks).

line representing the response has a slope of $-1/2$, and may be represented by a similar formula.

Relationship between fibrillating current and body weight

Figure 7 presents the relationship between minimum fibrillating current for 3-second shocks from the 35 Kiselev dogs and the ten Ferris dogs. The line of best fit, the regression line, was calculated by the method of least squares, using standard statistical procedures. Although there is some scattering about this line, the trend of the response clearly shows that the minimum current required to produce fibrillation is approximately proportional to the individual dog's body weight, and the degree of association, which is indicated by the correlation coefficient, is $r = +0.74$.

The average minimum fibrillating currents for 3-second shocks and the average body weights of animals comparable to man in body weight, consisting of 45 dogs, 25 sheep, 11 calves, and 9 pigs, are given in Fig. 8. The regression line for the group demonstrates that the fibrillating current is approximately proportional to the average body weight of the various species, and the correlation coefficient $r = +0.84$. The regression line for dogs, indicated by the dashed line in Fig. 8, is similar in slope and almost coincident with the regression line for the various animals (including dogs), from which it is concluded that the minimum current required to produce ventricular fibrillation is proportional to body weight, not only within the single species stud dog, but among the larger animals, probably including man as well.

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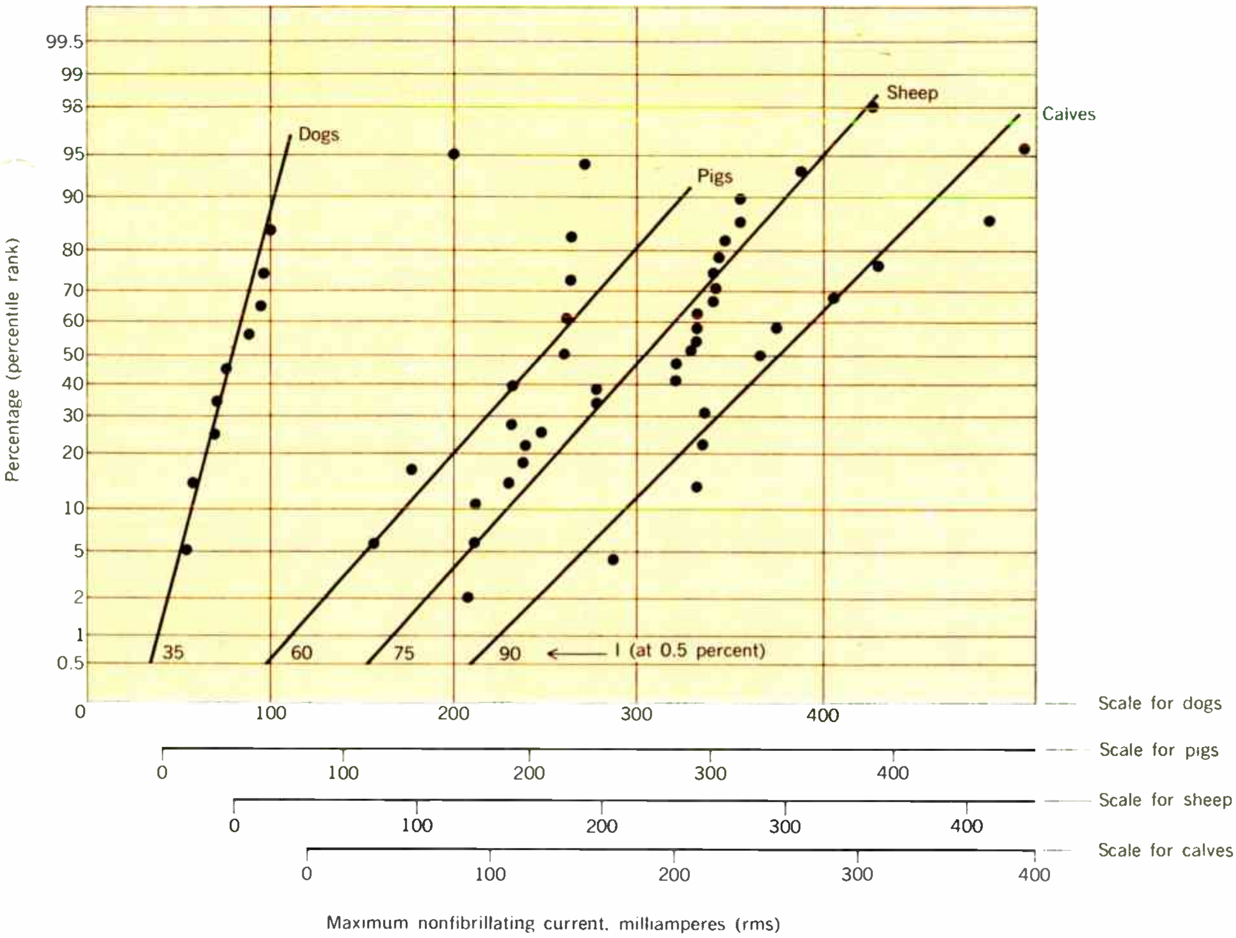

FIGURE 9. Maximum-nonfibrillating-current distribution curves for dogs, pigs, sheep, and calves (3-second, 60-Hz shocks).

Possibly the reason the average value for the nine pigs is much lower than the regression lines is due to the very small number of pigs available, and to the special, anatomical feature of the animal; namely, the relatively greater weight in the legs as compared with the other animals. Obviously, the configuration of the four legs does not materially affect the current distribution in the region of the heart.

Relationship between minimum fibrillating and maximum nonfibrillating currents

The 0.5 percentile points representing the minimum fibrillating currents for the four species are shown in the central part of Fig. 8. Because of the manner of conducting the tests, which consisted of applying serial shocks until fibrillation occurred, the actual minimum current just required to produce fibrillation must have been somewhat less than that given by the 0.5 percentile line. The last observed value of current immediately preceding fibrillation is called the maximum nonfibrillating current. Figure 9 gives the maximum-nonfibrillating-current distribution curves for dogs, sheep, calves, and pigs. The 0.5 percentile points from these maximum-nonfibrillating-current distribution curves plotted in Fig. 8 to fix the lowest line on the figure. The actual fibrillating current was certainly above this line. It is therefore obvious that the likely current just necessary to produce fibrillation for a given mammal is somewhere between these two 0.5 percentile lines, depending upon his body weight. It is believed that these conclusions may apply to all mammals including man—that is, a healthy, normally developed human adult.

Studies by W. R. Lee of 166 electrocutions at 50 Hz and 250 volts or less in England and Wales during the years 1962–1963 showed that 30 percent of the victims were females and 26 percent were persons under 20 years of age. Although the weight of an average man is 70 kg, in order to obtain results applicable to all adults, the writers suggest that the body weight of the typical adult victim of electric shock be given the conventional value of 50 kg.

The constant K for the electrocution equation is obtained by entering the abscissa of Fig. 8 at a value of 50 kg, and proceeding vertically to the two 0.5 percentile lines as follows:

$$I = K \sqrt{T}$$

$$K = \sqrt{T}\, I$$

$$K = \sqrt{3} \times 107 = 185 \text{ maximum}$$

$$= \sqrt{3} \times 67 = 116 \text{ minimum}$$

$$I = \frac{116 \text{ to } 185}{T} \Bigg]_{8.3 \text{ ms}}^{5 \text{ seconds}} \text{mA (rms)}$$

Unfortunately there is no direct evidence available re-

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garding threshold fibrillating currents for children, and in attempting to derive a figure for them certain additional assumptions must be made. First, does the young heart react in a way that is qualitatively different? In the Ferris data, the calves tested weighed 51 to 103 kg, which is well below the weight of the average cow or bull. Yet the points for calves fall close to the current vs. body weight lines in Fig. 8. From this it may be said, at least, that these results provide no evidence that youth per se exhibits a different type of response. Second, if we take 18 kg (40 lb) as representative of the weight of children in the range of 4 to 6 years, with a height of approximately a meter (40 inches), which is about as far as should be extrapolated at the low end of the lowest curves of Fig. 8, we obtain

$$I = \frac{\sqrt{3}\,(30 \text{ to } 40)}{\sqrt{T}}\Bigg]_{8.3 \text{ ms}}^{5 \text{ seconds}} \text{ mA (rms)}$$

The question naturally arises as to the applicability of the electrocution equation beyond the time limits upon which it is based. The shortest time for which data are available represents a half wave of 60 Hz ac, and the majority of shorter shocks might be classified as impulse shocks. There is little information about the effects of shocks of longer duration than 5 seconds. From 5 seconds to 20 or 30 seconds, Kiselev suggested that the threshold may remain fairly steady, dropping only slightly. For longer periods, there is some evidence that asphyxial changes may increasingly exert their influence and thereby lower the threshold even further.

It is important to note that ventricular fibrillation follows a normal distribution at low values of current with probability of fibrillation increasing up to about percentile 50, and then the probability decreases as indicated by the skewed nature of the distribution curves at the higher currents.

At higher currents fibrillation does not occur, and very strong short shocks will stop a fibrillating heart. This is the basis for defibrillating techniques—now standard hospital operating room routine for stopping fibrillation, which frequently results from several causes in addition to electric shock.

Currents considerably in excess of those just necessary to produce ventricular fibrillation may cause cardiac arrest, respiratory inhibition, irreversible damage to the nervous system, and serious burns. However, it should be stressed that there are at present no numerical data available regarding the current magnitudes necessary to produce these effects.

Lethal effects of electric shock

1. If long continued, currents in excess of one's let-go current, passing through the chest, may produce collapse, unconsciousness, asphyxia, and death.

2. Ventricular fibrillation is probably the most common cause of death in electric shock cases, and may be produced by moderately small currents that cause derangement of coordination within the heart rather than physical damage to that organ. When fibrillation takes place, the rhythmic pumping action of the heart ceases and death rapidly follows.

3. Shocks administered to hundreds of animals indicate that the minimum commercial-frequency electric current causing ventricular fibrillation is proportional to body weight and inversely proportional to the square root of shock duration. For a current pathway between major extremities in 50-kg mammals, the relationship is approximately 116 to 185 $\sqrt{T}$ milliamperes. It is believed that ventricular fibrillation in a normal adult worker is unlikely if the shock intensity is less than 116 $\sqrt{T}$ milliamperes where T is in seconds.

4. Currents flowing through the nerve centers controlling breathing may produce respiratory inhibition, which may last for a considerable period even after interruption of the current.

5. Cardiac arrest may be caused by relatively high currents flowing in the region of the heart.

6. Relatively high currents may produce fatal damage to the central nervous system.

7. Electric currents may produce deep burns, and currents sufficient to raise body temperature substantially produce immediate death.

8. Delayed death may be due to serious burns or other complications.

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Charles F. Dalziel (F) received the B.S. degree with honors in 1927, the M.S. degree in 1934, and the E.E. degree in 1935 from the University of California, Berkeley. From 1927 to 1929 he was testman and student engineer with the General Electric Company. He was with the San Diego Gas and Electric Company from 1929 to 1932 in charge of system protection, and during 1932 he taught at San Diego State Teachers College.

Since 1932 he has been with the Department of Electrical Engineering, University of California, Berkeley; in 1968 he became professor emeritus. From 1941 to 1944 he was supervisor of the University's Engineering Science Management War Training Program, and from 1944 to 1945 was chief technical aide for the National Defense Research Committee, Office of Scientific Research and Development. During the year 1951–52 he was Fulbright Visiting Professor to the Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin, Italy.

He has also served as a consultant to Kaiser Engineers, the Los Alamos Scientific Laboratory, Lawrence Radiation Laboratories, and the Rucker Company. Professor Dalziel is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi and is a registered professional engineer in the State of California. He is the author of more than 110 technical papers published in numerous professional journals throughout the world.

W. R. Lee was born in London in 1922 and received the M.D. degree from Guy's Hospital Medical School, University of London. He also holds the D.I.H. degree. He served as squadron leader in the Royal Air Force Medical Branch as medical officer for the British Railways. At present he is reader in occupational health at the University of Manchester (England), editor of the *British Journal of Industrial Medicine*, and medical adviser for the North Western Electricity Board. He has devoted many years to specialized research in the field of fatal electric shocks.

Dr. Lee is a Fellow of the Royal Society of Medicine ar member of the UNIPEDE Medical Group and the Society of Occupational Medicine.

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Trade secrets and the technical man

Increased legislative protection and favorable court judgments are not sufficient to keep trade secrets from being misappropriated. Corporate programs that include early legal consultation must also be instituted to prevent such transgressions

Charles M. Carter *Warwick Electronics Inc.*

The present scientific and technical world is one of complexity, magnitude, and rapid growth. In the face of such soaring progress, one subject has grown increasingly important and yet has remained somewhat of a mystery to people in the scientific and engineering community—that of "trade secrets." Although, as a general rule, these people have some working knowledge and familiarity with the patent laws, there is nevertheless an overall lack of understanding regarding the rights, obligations, and liabilities arising from the laws as applied to trade secrets. With the fluidity of the employment market and the rise in litigation concerning this area, it is therefore imperative that members of the community gain an nderstanding of these concepts. This article is intended to bridge some of the gap between trade secrets and the technical man.

What is a "trade secret"? Unfortunately, this is not a term that can be readily and explicitly defined. In broad terms, a trade secret has been defined by the courts as any business method, manufacturing process, formula, pattern, device, invention, improvement, design, or compilation of information that is used in a company's business and provides a competitive advantage. Novelty and invention—prerequisites for patent protection—are *not* necessary elements for a trade secret. On the other hand, a trade secret may be a patentable item. If it is patented, however, it can no longer be considered a trade secret, since secrecy is an essential element of this term. Moreover, ideas, processes, devices, etc., that are generally known to the public or within an industry cannot qualify as trade secrets. Thus, secrecy forms the dividing line between a trade secret and information or material in the public domain; and such a

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division cannot be bridged by merely disclosing the secret to employees or others in confidence.

Although people in the scientific and technical community have some working knowledge or familiarity with the patent laws, it may be helpful to review briefly the purpose and scope of our patent system so that a clear understanding exists as to the differences between seeking patent protection and maintaining a trade secret. The Constitution of the United States gives Congress the power to enact laws relating to patents in article 1, section 8, which reads: "Congress shall have power . . . to promote the progress of science and useful arts, by securing, for limited times to authors and inventors, the exclusive right to their respective writings and discoveries."

A patent only grants the applicant the right to exclude others from making, using, or selling the patented invention. The rights granted by a patent are given by the government in exchange for public disclosure. Such public disclosure is intended to promote the progress of "science and useful arts."

On the other hand, the one purpose of a trade secret is secrecy, and thus nondisclosure. It follows that trade secrets are not intended to promote the progress of science and useful arts, and that the patent system evolved as a motivation for public disclosure as opposed to maintenance of a trade secret.

Because a trade secret may be a patentable item, a difficult decision must often be made as to whether an item should be maintained as a trade secret or should be patented. This is particularly true regarding manufacturing processes or formulas because of the difficulty of policing patents relative thereto. This policing problem must be balanced against the possibility that the trade secret will be broken legally. If another party should independently stumble upon a trade secret, such a party is free to use or disclose the secret. For example, a trade secret may relate to the ingredients used in a product, and another party may legally break the trade secret by ascertaining the ingredients through chemical analysis.

The period of protection must also be carefully weighed in such a decision. Under the patent laws, the recipient of a patent is granted the right to a monopoly for a period of 17 years. On the other hand, a trade secret is effective as long as it is maintained a secret. It is apparent that trade secrets are playing a greater and greater role in our present technological society.

A classic example of the importance of trade secrets may be found in the closely guarded formula and process for Coca-Cola. This is one of the most well-protected secrets in existence today and has undoubtedly played an important part in the prosperity of the Coca-Cola Company. Hundreds of thousands of dollars have been spent by others in an attempt to legally break this secret—with no success. If the formula and process for Coke had been patented, they would be in the public domain today. However, because they have been maintained as trade secrets, the Coca-Cola Company has continued to maintain its competitive advantage.

Laws

In general, the protection granted trade secrets has arisen out of common law and equity, not out of statutory provisions. The basis, apart from breach of contract when a contractual relationship exists, has been in the form of an abuse of confidence or an impropriety relating to procurement. In the technological area, a confidential or fiduciary relationship that exists between the technical man and his employer parallels that, for example, of the attorney client relationship. The development of the law of trade secrets has resulted from a balancing of two conflicting elements: (1) protecting the owner of information, which is obtained through ingenuity, employee effort, and the employer's expenditure of time and money, and (2) favoring free competition by allowing an employee to use skills learned during an employment for the benefit of himself and society in general. The trade secrets law seeks to enforce increasingly high standards of fairness and commercial morality.

In recent times, various laws relating to trade secrets have been enacted or proposed. A number of states have enacted or modified criminal statutes relating to the wrongful taking or appropriation of property so that such types of corporation property as trade secrets are included. These states now include Arkansas, California, Colorado, Illinois, Maine, Massachusetts, Nebraska, New Hampshire, New Jersey, Pennsylvania, and Tennessee.

An indication of the typical scope of protection granted under such laws may be seen by referring to the law in Illinois. The term "property" is defined in section 15-1, article 15, chapter 38 (Criminal Law and Procedure), of the Illinois Revised Statutes as follows:

> As used in this Part C, "property" means anything of value. Property includes real estate, money, commercial instruments, admission or transportation tickets, written instruments representing or embodying rights concerning anything of value, labor or services, or otherwise of value to the owner; things growing on, affixed to any building; electricity, gas and water; birds, animals and fish, which ordinarily are kept in a

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state of confinement; food and drink; *samples, cultures, micro-organisms, specimens, records, recordings, documents, blueprints, drawings, maps, and whole or partial copies, descriptions, photographs, prototypes or models thereof, or any other articles, materials, devices, substances and whole or partial copies, descriptions, photographs, prototypes, or models thereof which constitute, represent, evidence, reflect or record a secret scientific, technical, merchandising, production or management information, design, process, procedure, formula, invention, or improvement.* [Italics mine.]

The penalty in Illinois for theft of such property is broken into several categories. If the value does not exceed $150, a convicted person (for his first conviction) can be fined up to $500 or imprisoned in a penal institution other than the penitentiary up to one year, or both. For subsequent convictions, he can be imprisoned in the penitentiary from one to five years.

If the property value exceeds $150, the convicted person can be imprisoned in the penitentiary from one to ten years. Whether this statute and other similar statutes will be limited in scope to "tangible property" is open to judicial interpretation. It is believed, however, that in most instances it has been the legislative intent to cover trade secrets per se. Moreover, it is apparent that the legislatures of various states have put teeth into the law regarding corporate property such as trade secrets in an effort to stop their ever-increasing misappropriation.

Since these statutes are relatively new, it is too early to determine their effectiveness and general desirability or undesirability. Strong interest has been expressed, however, in the protection of research and development through the implementation and enforcement of such criminal statutes. On the other hand, concern has also been expressed regarding the negative effects that might arise out of these statutes. These effects include, for example, the restraint of free flow of employment. Members of the legal profession are watching this area closely to permit the proper evaluation of the effectiveness of the statutes.

From time to time, attempts have also been made to promote federal legislation providing criminal sanctions for the interstate or foreign transportation of wrongfully appropriated trade secrets. One such attempt arose several years ago under the National Stolen Property Act after the indictment of seven people by a federal grand jury in a case involving a breach of a confidential relationship. As a result, a bill was introduced in the House of Representatives, but failed to pass. To date, there exists no such federal legislation.

In the case just cited (American Cyanamid Company vs. Fox, 1963), Fox, a former employee of Cyanamid, was convicted of masterminding a conspiracy to unlawfully appropriate pharmaceutical trade secrets of the Lederle Laboratories Division of American Cyanamid and sell them to companies in Italy and in other countries that do not provide pharmaceutical patent protection. The Act under which the indictments were granted only covered theft of "tangible goods" and, interestingly enough, was primarily aimed at cattle rustling!

Rights and obligations

he rights and obligations of the technical man in relation to both his former and his present employer will now be explored.

The technical man is generally free to use all of his general skill, knowledge, and experience to successfully complete a job, even if this ability were acquired while working for a former employer. He cannot be denied this right. Conversely, the technical man is under a confidential-relationship obligation to his former employer not to use, disclose, or induce others to use his former employer's trade secrets. He may even be enjoined from using, disclosing, or inducing others to use such trade secrets. At the same time, the technical man is under a similar obligation to his present employer not to use, disclose, or induce others to use in any unauthorized manner the trade secrets of his present employer.

Additionally, there is an obligation to the technical man's present employer not to disclose trade secrets of former employers, nor to induce his present employer to use such trade secrets.

In many instances, a fine distinction exists between what constitutes a trade secret and what constitutes general skill, knowledge, and experience. Such situations can often lead to litigation. This problem is amplified by the fluidity of today's technical labor force, which has resulted in an interplay of technical employees between competitors. Even though the burden is on the employer to prove that a trade secret does, in fact, exist and that an employee has breached a confidential relationship, the employee should not toss caution to the winds. Rather, when changing positions, he should take care to fulfill his confidential-relationship obligations while working within his general skill, knowledge, and experience. When questions or doubt arise, corporate legal counsel should be sought regarding clarification and guidance.

It is clearly established in law that an injunction may be obtained to stop misappropriation of trade secrets. As a general rule, though, there is no way of obtaining an injunction against unauthorized disclosure of trade secrets before such a disclosure occurs. An exception does arise when the court is convinced by the evidence and surrounding circumstances that an intent to misappropriate exists. This generally occurs when one company has made a major breakthrough and another company hopes to exploit the breakthrough by hiring away key employees.

A landmark case, which took place in 1963, involved the B. F. Goodrich Company, International Latex Corporation, and a chemical engineer (B. F. Goodrich Company vs. Wohlgemuth). The engineer was employed by B. F. Goodrich and had progressed to the position of manager of the pressurized space-suit department. He possessed full knowledge of many of the secrets and confidential facts relating to the Goodrich-developed space suit. In 1962, International Latex received a $1 500 000 contract for Apollo moon-flight space suits and hired the engineer away from Goodrich with a 30 percent pay increase. Goodrich then sought an injunction to prevent him from assisting in the development of space suits for International Latex. An injunction was granted on the basis that International Latex was attempting to gain his valuable experience in this highly specialized field, and that if he were permitted to work on space suits for International Latex, he would have an opportunity to disclose the confidential information of Goodrich.

Thus, the injunction was granted on the premise that it was the only way to prevent Goodrich from suffering irreparable injury. The court pointed out that the decision could have been based on the general rules of equity (implied

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relationship), but an adequate basis was already provided by the fact that the engineer had signed a confidential information-nondisclosure agreement.

A similar case in 1964 involved the E. I. du Pont de Nemours & Company and American Potash and Chemical Corporation. In that instance, American Potash advertised for a chemical engineer with titanium-oxide experience and thereafter hired an engineer who had handled du Pont's titanium-oxide production for ten years. Du Pont succeeded in enjoining him from working for American Potash in its titanium-oxide facility on the basis that disclosure of du Pont's secrets was inevitable if he were allowed to work in this capacity.

One thing should be made clear regarding cases where injunctions are granted. Injunctions only preclude engineers involved from working in specific areas and disclosing confidential information. Such engineers are not prevented from working for the new companies, but merely required to be placed in areas where they are not associated with the product that has been associated with the injunction.

In an earlier landmark case, Carter Products, Inc., *et al.* vs. Colgate-Palmolive Company *et al.* (1955), the court extended the legal obligation of the new employer in trade-secret cases beyond the realm of simply inducing a breach of confidential relationship by an employee (for example, by hiring a key engineer as in the B. F. Goodrich and du Pont cases).

The court maintained that a third party (new employer) who used another's (former employer's) trade secrets, obtained through a breach of confidential relationship (by an employee), either with actual knowledge of such a breach or with knowledge of facts from which the breach can be reasonably inferred, is as liable as the party who makes the breach. Carter, with the aid of a consulting firm, had developed the first pressurized shaving cream—Rise. Subsequently, a chemist who had worked on Rise applied for and received a job with Colgate-Palmolive without actually being sought out. Although Colgate alleged that they advised him not to "spill" any secrets, they asked him to develop a product like Rise. He apparently recreated the Rise formula from memory and created a product that outsold Rise on the market. While Colgate's words complied with the trade-secret laws, their actions did not. The court held that Colgate knew or must have known by exercise of fair business principles that the precise character of the chemist's work for Carter was, in all likelihood, covered by an agreement not to disclose trade secrets. Carter received $5 104 000 in damages from Colgate. From this case, it is readily apparent that the new employer, as well as the employee, has a legal obligation to the former employer.

Precautions of the employer

To balance the scales of justice, the trade-secret laws do impose certain obligations on the employer regarding trade secrets.

The employer must take positive steps in an effort to protect his secrets and prevent their unauthorized disclosure or misappropriation. The employer has the obligation to apprise and somehow make technical personnel aware of the sensitive areas involving confidential information. This awareness may be created by the surrounding circumstances, e.g., posted notices and signs or appropriate security precautions.

As a further precaution, the employer would be wise to require employees to execute an appropriate nondisclosure or confidential-relationship agreement. When the employer has complied with these obligations, he then may be entitled to appropriate relief for unauthorized use or misappropriation in the form of an injunction or damages or both.

Although a confidential relationship between a technical man and his employer regarding trade secrets may arise by implication as well as contractually, more and more companies are covering this matter in an employee agreement. Quite often, this is incorporated with an invention assignment agreement to form a combined "Patent and Confidential Information Agreement." The need for an express contractual relationship in this area has been heightened by court decisions that have watered down the scope of protection granted under an implied relationship. For example, in 1960, the court in Pennsylvania (Wexler vs. Greenberg) held that, in the absence of an express written contract, an agreement not to disclose would only be implied (1) if it could be established that the employer had confided a trade secret to the employee, or (2) if the employee had developed a trade secret under the supervision of and with the assistance of the employer under an explicit research project.

In view of the present tenure of the law, the tendency in employee agreements is to cover the trade secrets of the employee's former employer as well as the trade secrets of the new employer. Typical clauses employed are as follows:

> (a) I agree not to use or reveal to any unauthorized person, either directly or indirectly unless authorized by (name of employer), any information of (name of employer) relating to its inventions, improvements, designs, processes, trade secrets, procedures, and, in general, any of its business affairs of a secret or confidential nature.
>
> (b) I agree not to disclose to (name of employer), or to induce (name of employer) to use any information of others relating to their inventions, improvements, designs, processes, trade secrets, procedures, and, in general, any of their business affairs of a secret or confidential nature unless such information is in the public domain or unless authorized to disclose such information.

Additionally, various companies have supplemented the employee agreement with a "Trade Secret Policy," which

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is designed to advise employees of the possible consequences of unauthorized disclosure or use of company trade secrets and to set forth precautions or steps aimed at preventing trade secrets from falling into the hands of unauthorized persons. Typical steps to be included are as follows:

1. Conduct a security check on all new employees.
2. Carefully control visitors.
3. Require clearance for all speeches and papers.
4. Place confidential markings on all documents considered to be confidential.
5. Limit access to confidential material.
6. Have waste paper generated by employees dealing with confidential material destroyed.
7. Require employees to secure confidential material in their absence.
8. Conduct an "exit" interview with employees who are leaving to remind them of their obligations regarding trade secrets.

Some companies have gone so far as to include in the employee agreement a restriction on employment with a competitor subsequent to termination. Such provisions have been upheld if they were reasonable in the length of time and geographic area covered by the restriction. Of course, great care is required in drafting such a provision, which requires sound legal advice and consideration.

Recovery for breach

Now that it has been established that the new employer as well as the employee may be liable for breach of a confidential relationship between the employee and a former employer, the recovery aspect for such breach will be explored.

Generally speaking, the scope of recovery for trade-secret cases is quite similar to the scope of recovery in patent-infringement actions. As previously mentioned, an injunction may be obtained to stop unauthorized use of a trade secret. Additionally, under the certain specialized circumstances just set forth, an individual can be enjoined from working in a specialized area for a new employer if it is apparent that unauthorized disclosure is imminent.

There are four possible types of general awards that may be granted to the prevailing party in actions relating to trade secrets:

1. Damages, profits, or a resonable royalty
2. Punitive damages
3. Costs
4. Attorney's fees

As a general rule, the wronged party may recover either the other party's profits or his own damages (e.g., his profits if he had made the lost sales), but not both. When willful acts of unauthorized use of a trade secret occur, the courts have also granted punitive damages, i.e., additional damages to punish the willful wrongdoer. The additional allowance of costs for litigation are normally limited to those permitted by statute and are usually granted only in extreme cases. When circumstances justify it (e.g., in cases involving willful and wanton breach of a confidential relationship regarding trade secrets), attorney's fees may also be granted.

As indicated by the Carter-Colgate case, an employer who knowingly misappropriates another's trade secret, or who must have known of the misappropriation by exercise of fair business principles, may be held liable for damages. The former employee who breached the confidential relationship is jointly and severally liable for the damages. To seek retribution solely from the former employee is usually valueless because he rarely has sufficient property upon which to levy an execution.

Role of attorney

It should be apparent that the attorney can play an extremely important role in protecting both the employer and employees from misappropriation of the trade secrets of others. He is in a position to counsel both and to guide them away from the pitfalls of knowing or inadvertent misappropriation. Obviously, the implementation of both a trade-secret policy and a confidential-information employee agreement are helpful tools in this area. However, the attorney can only help if he is consulted.

Accordingly, if any doubt or question arises regarding a potential trade-secret problem, the legal staff should be consulted immediately.

Conclusion

As a standing rule, the technical man should exercise due caution to insure that he does not disclose to unauthorized persons or in any other way misappropriate the trade secrets of his employer or former employers. If doubt or question exists regarding a potential trade-secret problem, he should consult the corporate legal people. In turn, each corporation should take the necessary steps to insure the safeguard of its own trade secrets and to prevent misappropriation of the trade secrets of others.

If a person is in a position to guide corporate policy, he should see that steps are taken to protect the company in these areas. The potential consequences of the technical man or corporation failing to take the necessary precautionary steps are too great to underestimate and care should constantly be exercised.

Consultation with the legal staff before a problem appears is advised. If you wait until the problem exists, it may be too late.

Based on a paper presented at the 1968 National Electronics Conference, Chicago, Ill., Dec. 9-11.

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Illinois State Bar Association, the American Bar Association, the Bar Association of the Seventh Federal Circuit, the American Patent Law Association, and the Patent Law Association of Chicago. At present, Mr. Carter is also serving as a member of the Committee on Unfair Competition of the American Patent Law Association.

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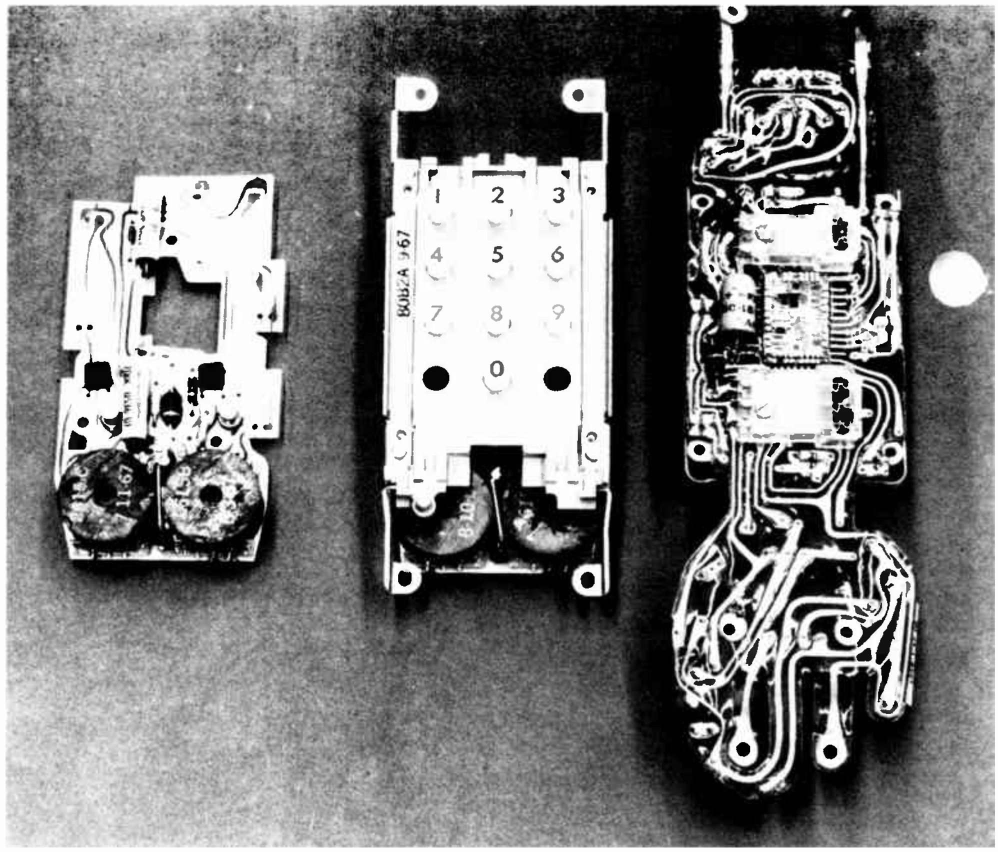

FIGURE 1. Contemporary LC device is shown on the left and newer RC audio oscillator, which will eventually replace the LC unit in Touch-Tone telephones, is shown in the small rectangular area in the center of the device at right.

Computer tuning of hybrid audio oscillators

The need for greater electronic sophistication in smaller packages is causing industry to develop new manufacturing and quality control techniques, including a computerized method of tuning a unique hybrid thin-film audio oscillator

Frederick H. Hintzman, Jr. *Western Electric Company*

A hybrid tantalum thin-film and beam-lead silicon device will be incorporated in the Bell System's Touch-Tone telephones of the future. This RC multifrequency audio oscillator will replace the LC device presently used in the Touch-Tone keyboards. The tuning process for the RC device requires that the tantalum thin-film resistors be custom adjusted to calculated values; and a tuning system driven by a small process-control computer has been designed to fulfill this function.

The dial incorporated in Bell System Touch-Tone telephones contains two audio oscillators to perform the dialing function. At present, the oscillators use *LC* circuits, as shown on the left in Fig. 1; however, the *LC* device is scheduled to be replaced by an *RC* device, which is the small rectangular area mounted near the center of the flexible printed circuit shown at right.

Both devices shown contain two multifrequency audio oscillators, each capable of generating four different frequencies. These oscillators, and the associated switching, are used to generate appropriate frequencies (a unique pair for each button on the dial) for dial-switching information.

Each *RC* oscillator contains a dc-coupled amplifier, a twin-*T* feedback network, and a buffer stage for connection to the telephone line[1] (Fig. 2). The tantalum thin-film portion of the device consists of two substrates, one co taining thin-film capacitors and the other containing th resistors.

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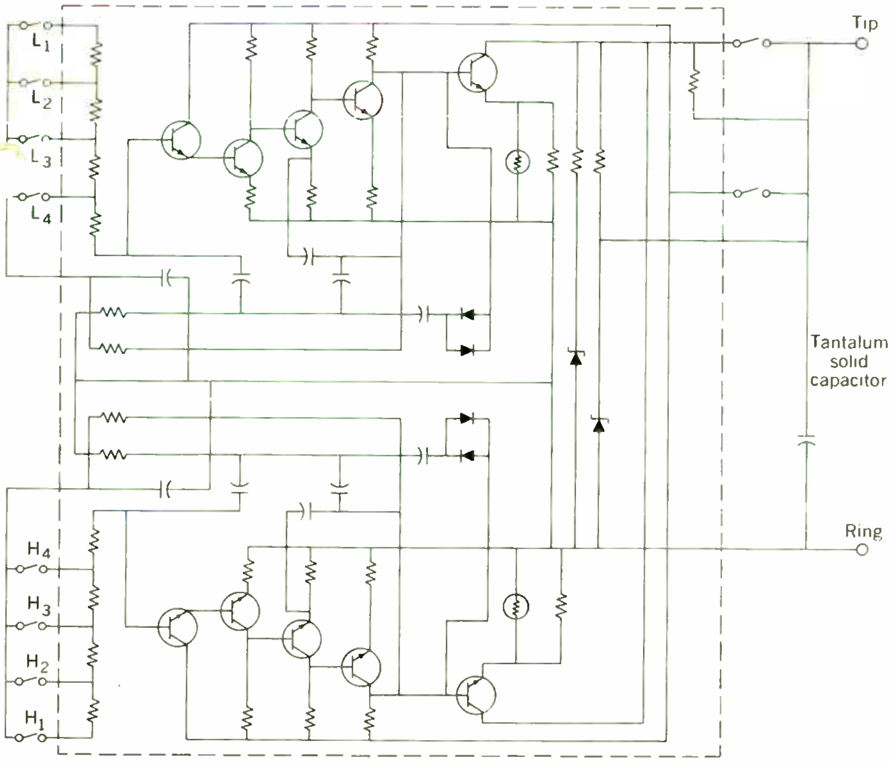


FIGURE 2. Schematic diagram of Touch-Tone RC oscillator circuit.

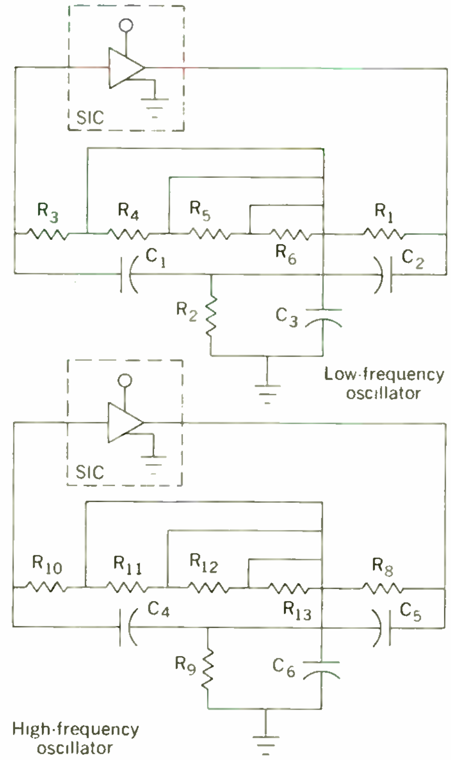
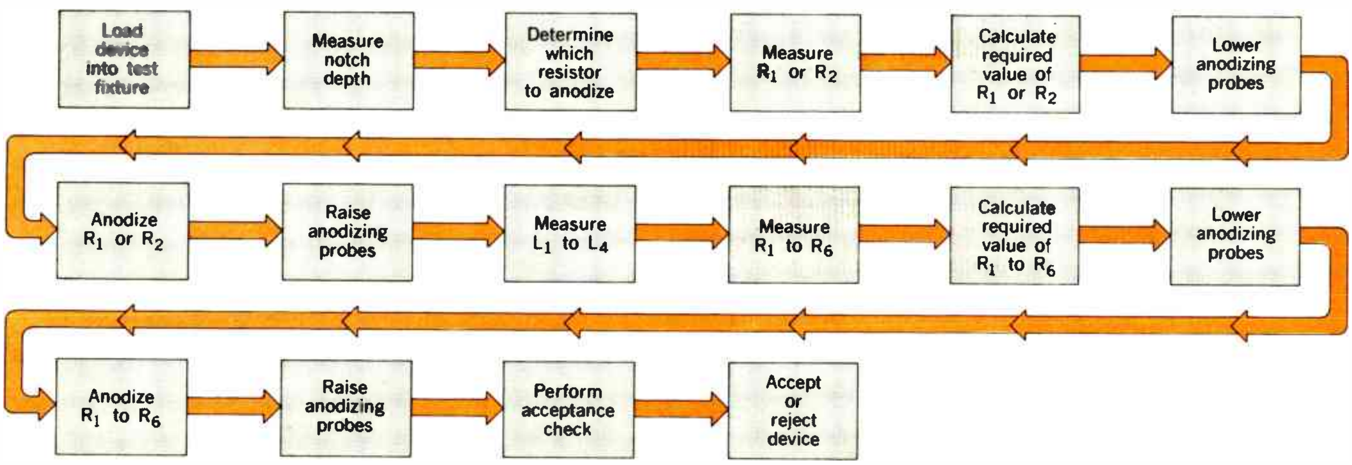


FIGURE 3. Tunable high- and low-frequency sections of the RC audio oscillator.

FIGURE 4. Flow diagram of the computer-controlled tuning process.



During manufacture the capacitor substrate is glued to the back of the resistor substrate. Interconnections are obtained by gold leads that are thermal-compression bonded to gold-film conduction paths on either end of the two substrates. External connections to the device are obtained by gold leads bonded to pads on either side of the resistor substrate. The beam-lead silicon circuits and two thermistors are thermal-compression bonded to appropriate points on the resistor substrate.

The tuning process

Each of the two twin-*T* notch filters shown in Fig. 3 contains six tantalum thin-film resistors that must be adjusted individually to calculated values through the process of anodization to obtain specified frequencies and amplitudes.[2]

The custom tuning process can be broken down into two basic steps: the first step involves adjusting the notch depth of the twin-*T* filters to design specifications. In the second step each of the frequencies is tuned to design value while the notch is held relatively constant (Fig. 4 and appendix).[3]

The notch-depth adjustment procedure begins by determining the original depth for a particular frequency of the four capable of being generated by each oscillator. Depending upon the value of the present attenuation relative to the design attenuation at the notch frequency, one of two resistors must be adjusted to a calculated value. The value

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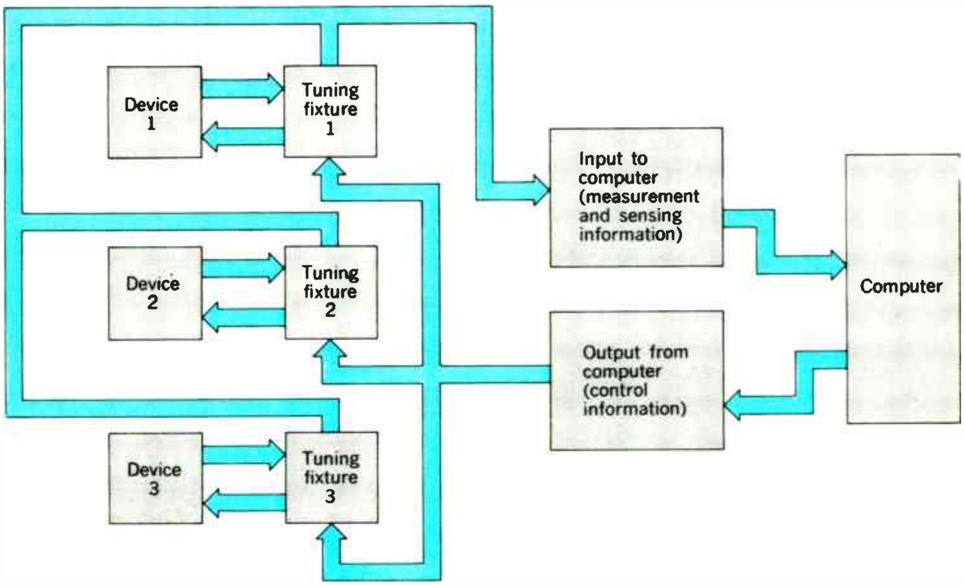

FIGURE 5. General block diagram of computerized tuning system used in the production of RC audio oscillators.

is a function of the two notch depths and the initial value of the resistor.

The frequency adjustment begins by measuring all four frequencies one oscillator is capable of generating. Next, the original value of the six resistors in the twin-T filter is measured; and from these measurements the final value of the resistors may be calculated. Finally, the resistors are anodized to the calculated values, thus completing the tuning process.

The tuning system

Prototype devices have been tuned using a manual tuning set, but such a method is not feasible during production because of the excessive time required. And a second problem is engendered by the extensive calculations required to determine resistor values.

A process control system has been designed that employs a computer to perform the required calculations and control the tuning process. In very general terms this system consists of tuning fixtures that make contact with the devices being tuned to accomplish the required measurements and anodization. Input to the computer, consisting of measurement and sensing information, enters through an appropriate interface. Calculations and logical decisions are performed by the computer, and control information is fed to the tuning fixtures through a control interface and to an output interface (Fig. 5).

Anodizing is the most time-consuming part of the process. Even with simultaneous anodization of all 12 resistors during adjustment to frequency, over one half of the tuning time required is for anodizing. The procedure consists of alternately measuring the value of the resistor being anodized and applying an anodizing current for a known period of time (Fig. 6) at several different anodizing rates. The greater the resistor variation from the desired final value, the greater the anodizing rate that is used. As the calculated value is approached, final resistor value tolerance requirements dictate that anodizing current be reduced in proportion to newly measured values.

The feasibility of two alternatives to reduce the anodizing time is being investigated. One alternative is to reduce anodizing time by keeping the anodizing rate constant and to apply the current for differing lengths of time, based on a predicted time required to bring the resistor to value. The second alternative involves increasing the value of the appropriate resistor by placing a known external "padding" resistor in series with it after the notch calculations. This would make it possible to perform frequency adjustment calculations without first performing the notch-anodizing step. All 12 resistors on one device could be adjusted to their final calculated value in one step and thus the notch adjustment step could be eliminated.

The values of the resistors are indirectly measured by an analog-to-digital converter. During measurement the notch resistors on the device are connected in series with accurate, standard resistors to a power supply (Fig. 7). The voltage across each resistor is read by the analog-to-digital converter, and the digital equivalent of the voltage is obtained and transferred to the computer. The equation

$$R_x = \frac{V_{R_x}}{V_{R_{std}}} \cdot R_{std}$$

is used to obtain the value of R_x, and its measured value is compared with the final desired value. The difference is used to determine the anodizing rate for the succeeding anodizing cycle.

Each anodizing cycle will contain three segments. The first segment is a period of time during which the anodizing transient from the previous cycle is allowed to relax. The next is associated with the measurement of the value of the resistors, where the computer calculates the present value of the resistors and sets the appropriate anodizing rates. The third segment involves anodizing. During this period all 12 resistors are simultaneously anodized at their own appropriate rate, and at the end of the time period the cycle will begin anew. The sequence of anodizing cycles will continue to repeat itself until all 12 resistors have been adjusted to value.

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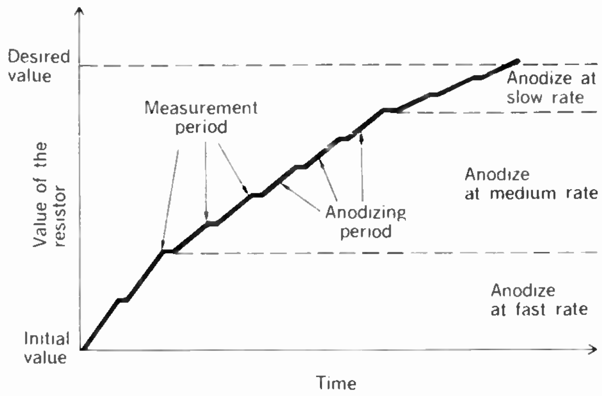

FIGURE 6. Anodizing a resistor to its correct final value involves alternately measuring the value of the resistor being adjusted and applying an anodizing current for a known period of time.

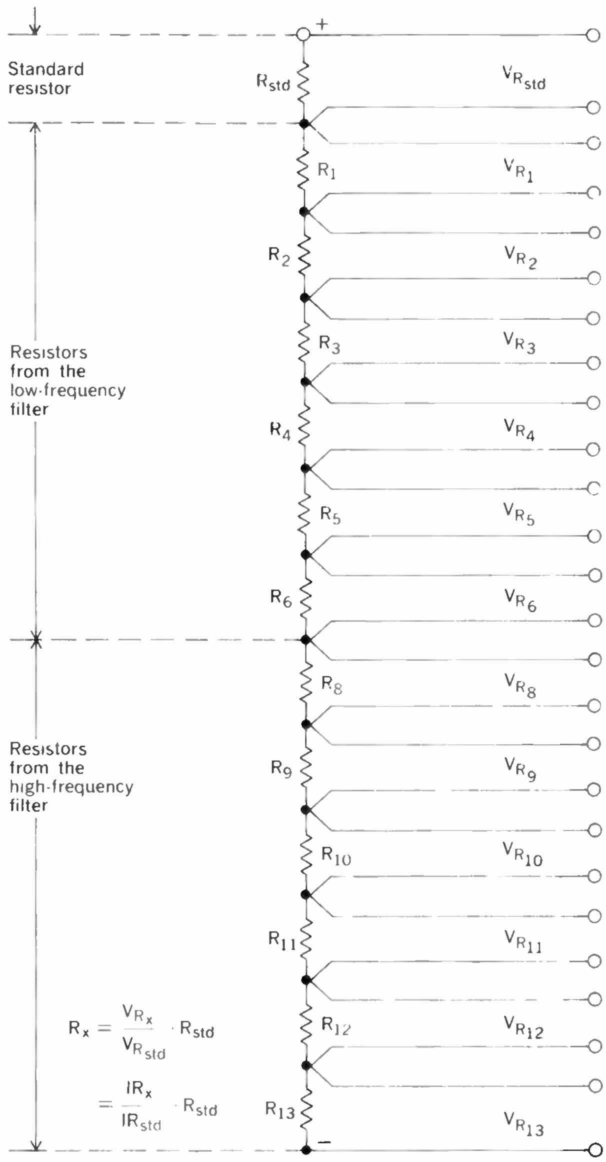

FIGURE 7. During measurement the notch resistors under adjustment are connected in series with high-accuracy standard resistors.

The heart of this real-time control system is a small, digital process-control computer. The system schematic showing all of the functional elements and how they are integrated into the tuning system is shown in Fig. 8. The system devices are all under computer control. All that need occur from an operating point of view is to load the tuning fixture with an *RC* device and signal the computer that a device is waiting to be tuned. The program is written in an interrupt mode to obtain maximum utilization of the computer for simultaneously driving more than one tuning fixture.

Tuning is an important part of the manufacturing process of *RC* devices, and an efficient and effective method of tuning is necessary to produce these devices economically. The system described meets this requirement and, in addition, provides the flexibility to incorporate innovations easily and quickly as they occur.

Appendix

The resistor adjustment calculations discussed in this appendix refer to the low-frequency oscillator. Corresponding measurements and calculations must also be performed for the high-frequency oscillator.

Notch adjustment

Procedure

1. Measure twin-*T* notch depth with switch L_3 closed (Fig. 2).
2. Determine which resistor to adjust and measure its initial value.
3. Calculate its final value.
4. Anodize the appropriate resistor to obtain the proper notch depth of X'.

Calculations

$$R_{x'} = R_x \cdot (1 + |a|)$$

where

$$a = \frac{X' - X}{22.0}$$

R_x = initial value of resistor to be adjusted
$R_{x'}$ = calculated value of resistor to be adjusted
X = initial notch depth
X' = design notch depth

If $a > 0$ then $R_x = R_2$
If $a < 0$ then $R_x = R_1$

Frequency adjustment

Procedure

1. Measure present values of frequencies L_1 through L_4 (Fig. 2).
2. Measure present values of R_1 through R_6 (Fig. 3).
3. Calculate final resistor values.
4. Anodize the resistors to obtain design frequencies.

Calculations

$$R_{1'} = R_1 \cdot \frac{L_4}{L_{4'}}$$

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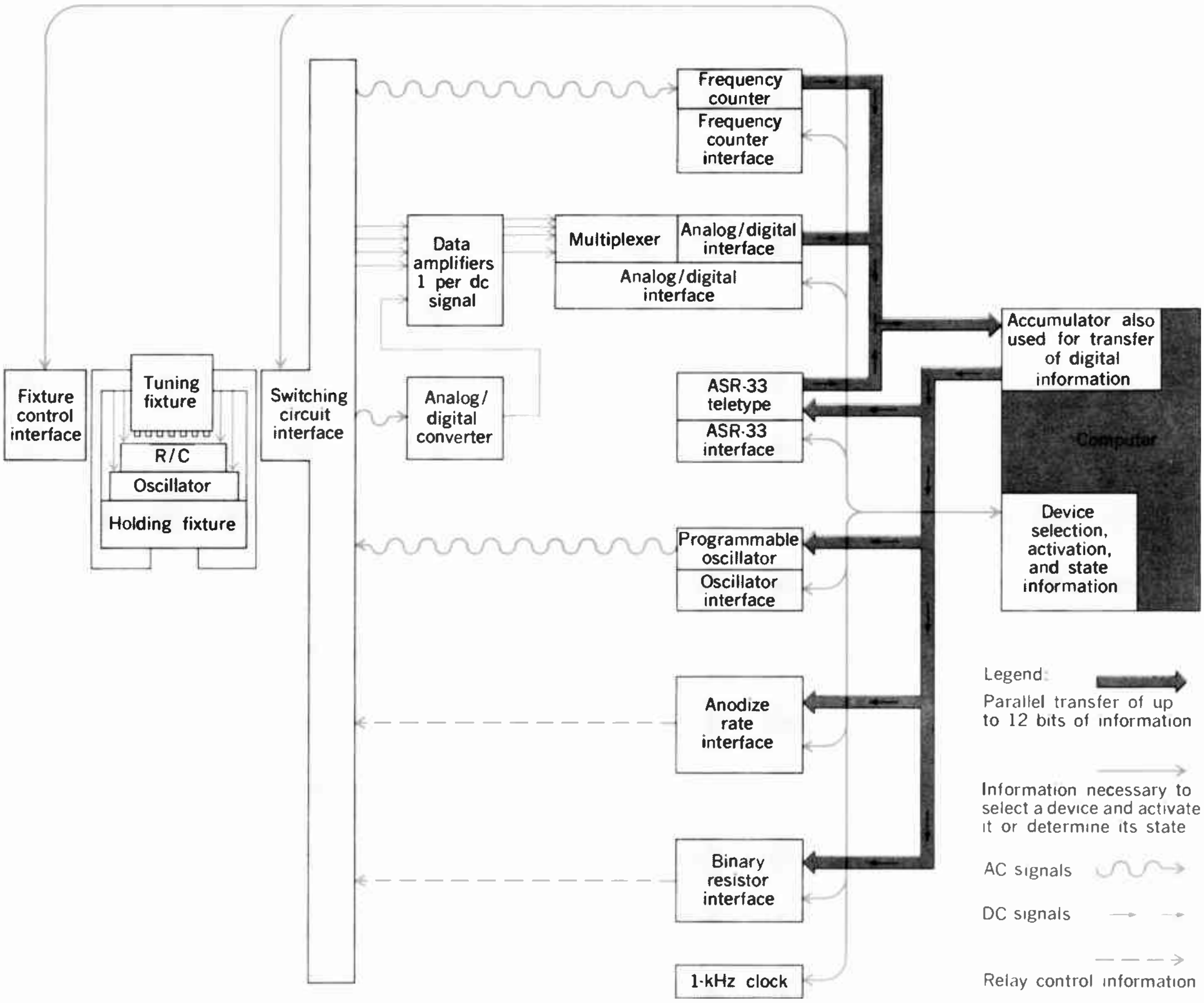

FIGURE 8. Schematic of computerized tuning system of Touch-Tone RC audio oscillators.

$$R_{2'} = R_2 \cdot \frac{L_4}{L_{4'}}$$

$$R_{3'} = R_3 \cdot \frac{L_4}{L_{4'}}$$

$$R_{4'} = K \cdot (R_3 + R_4)\left(\frac{L_3}{L_{3'}} - \frac{L_4}{L_{4'}}\right) + R_4 \cdot \frac{L_4}{L_{4'}}$$

$$R_{5'} = K \cdot (R_3 + R_4)\left(\frac{L_2}{L_{2'}} - \frac{L_3}{L_{3'}}\right) + K \cdot R_5\left(\frac{L_2}{L_{2'}} - \frac{L_4}{L_{4'}}\right) + R_5 \cdot \frac{L_4}{L_{4'}}$$

$$R_{6'} = K \cdot (R_3 + R_4 + R_5)\left(\frac{L_1}{L_{1'}} - \frac{L_2}{L_{2'}}\right) + K \cdot R_6 \cdot \left(\frac{L_1}{L_{1'}} - \frac{L_4}{L_{4'}}\right) + R_6 \cdot \frac{L_4}{L_{4'}}$$

where

R_x = initial value of resistor x
$R_{x'}$ = calculated value of resistor x
L_y = present value of frequency y
$L_{y'}$ = design value of frequency y
K = ln 10

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Economic aspects of the Pacific Northwest-Southwest Intertie

The Pacific Intertie system, one of the most ambitious power generating and distribution projects to date, includes the United States' first dc transmission lines, which are to be the longest in the world

Floyd E. Dominy *U.S. Bureau of Reclamation*

The Pacific Northwest–Southwest Intertie is the largest single electric transmission development project ever undertaken in the United States. It will connect directly or indirectly the major systems of the federal government and public and private electrical systems in 11 western states, promoting a maximum of electrical efficiency. The benefits to these areas of the United States, and to the rest of the nation, will be extensive: over a 50-year payout period the total estimated benefits amount to $2.6 billion, with a benefit-to-cost ratio of 2.5 to 1.

The Pacific Northwest–Pacific Southwest Intertie, approved by the Congress of the United States in August 1964, is the largest single electric transmission development ever undertaken in the United States. It will interconnect electric systems—public and private—from Vancouver, B.C., in Canada, and Seattle, Wash., in the United States, to Phoenix, Ariz., and cities in California. The intertie system will link directly or indirectly the major federal, public, and private electric systems in the states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The system will benefit the people as well as investor-owned utilities, rural electric cooperatives, municipal systems, and other public agencies—about 250 power systems in the 11-state area.

The intertie is a cooperative undertaking, bringing together the largest federal hydroelectric system in the United States, the largest municipal system in the United States, and the largest group of private systems in the western United States. It will thus require coordinated operation of all utility systems in the 11-state area so as to obtain maximum reliability of service as well as overall utilization of the generating capacity. The smaller utilities will also participate in the benefits.

From an engineering viewpoint, the intertie presents many challenging problems. When completed it will transmit 4600 MW of power. Two of the long transmission lines will carry direct current at extra-high voltages, an unprecedented technical undertaking in the United States. The extensive system also presents a diversity of problems in design of the converter terminals, transmission lines, and related facilities.

Scope of intertie

As indicated in Fig. 1, the intertie system comprises four principal extra-high-voltage (EHV) lines and related terminal facilities as well as several lesser supporting lines. Two of the long lines will be 800-kV dc lines, the first EHV dc lines to be constructed in the United States and the longest dc lines in the world. The other two major lines will be 500-kV ac lines. The remaining lines of the system will be a short 800-kV dc tie line, two short 500-kV ac tie lines, two 345-kV

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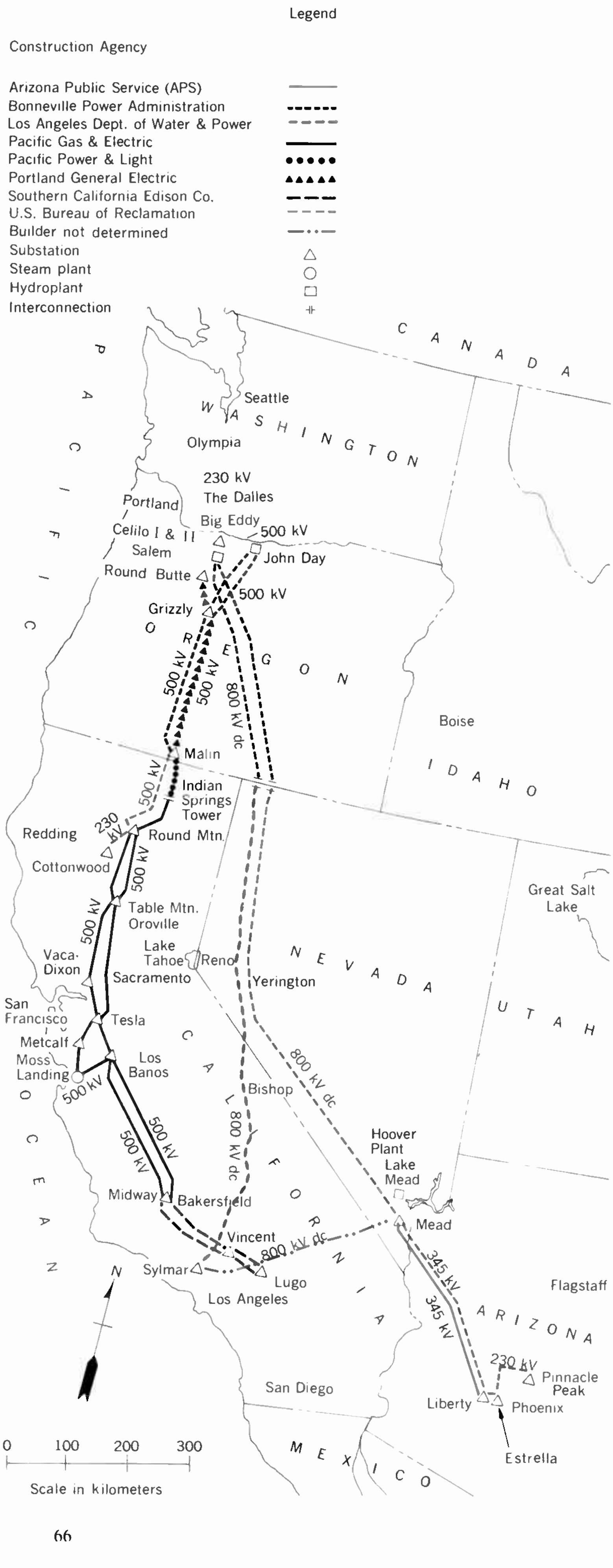

FIGURE 1. Pacific Northwest–Southwest Intertie.

ac lines, and two relatively short 230-kV ac lines.

One of the 800-kV dc lines of 1300-MW capacity will b built from the Celilo terminal in Oregon, near The Dalles Dam on the Columbia River, to the Sylmar terminal near Los Angeles, Calif., a distance of about 1375 km. The Bonneville Power Administration (BPA), an agency of the U.S. Department of the Interior and marketing agency for federally produced power in the Pacific Northwest, will construct the Oregon section of the line, and the city of Los Angeles will construct the Nevada and California sections of the line.

Another 800-kV dc line, also of 1300-MW capacity, will extend from the Celilo terminal about 1320 km south, to the Mead Substation near Hoover Dam in Nevada, and may ultimately be connected to the Sylmar terminal by the 800-kV dc tie line. BPA will build the 430-km northern section to the Oregon border, and the Bureau of Reclamation will construct the 890-km section from the border to the Mead Substation.

BPA will construct one of the 500-kV 430-km ac lines, having a 1000-MW capacity, from the John Day Dam on the Columbia River to Malin, Oreg., near the Oregon–California border. The Bureau of Reclamation is constructing the line from Malin to the Round Mountain Substation in California, a distance of 151 km. From this substation the California Power Pool will construct the line to the Los Angeles area. In addition, the Bureau will construct a 230-kV ac line extending 53 km from Round Mountain to the Cottonwood Substation near Redding, Calif.

Moreover, BPA will construct the second 500-kV ac line, 166 km long, also having a capacity of 1000 MW, from John Day Dam to Grizzly Substation; see Fig. 2. From that point to Malin, the line will be built by the Portland General Electric Company. The Pacific Power and Light Company will continue the line from Malin, which is 80 km south, where it will connect with the California Power Pool-constructed line to Los Angeles via Round Mountain.

The Bureau of Reclamation is constructing one of the 383-km 345-kV ac transmission lines from the Mead Substation to the Liberty Substation near Phoenix. The other 345-kV ac line was scheduled to be built by the Arizona Public Service Company; however, consideration is now being given to alternative proposals.

In Arizona, the 230-kV intertie transmission facilities between Liberty Substation and Pinnacle Peak Substation are being constructed and will be owned, operated, and maintained by the Bureau of Reclamation and the Salt River Power District pursuant to the terms of a long-term contract.

Transmission lines of the intertie will permit the Bonneville Power Administration and owners of nonfederal hydroelectric power plants to market their surplus peaking capacity. In the Northwest, there are, or there can be, installed at existing dams more generators than there is streamflow to operate the generators full time, thus creating excess peaking supply. The peaking capacity can be sold in California and other Southwest areas without diminishing the ability to produce firm power. This is because Sout west utilities, under off-peak conditions, can operate thei steam plants to replace energy used with the peaking capac-

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ity when surplus energy is not available in the Northwest.

The intertie will also enable the Bonneville Power Administration and owners of nonfederal generating plants in the Northwest to market their surplus energy. Surplus energy is produced when streamflows are higher than normal; but such power cannot be guaranteed for delivery day in and day out. Some $20 million worth of BPA potential secondary energy has been wasted annually over the spillways of Northwest federal dams for lack of a Northwest market. This secondary energy would be used by utilities in California and elsewhere in the Southwest that burn fuels that are more costly than the delivered price of Northwest secondary energy.

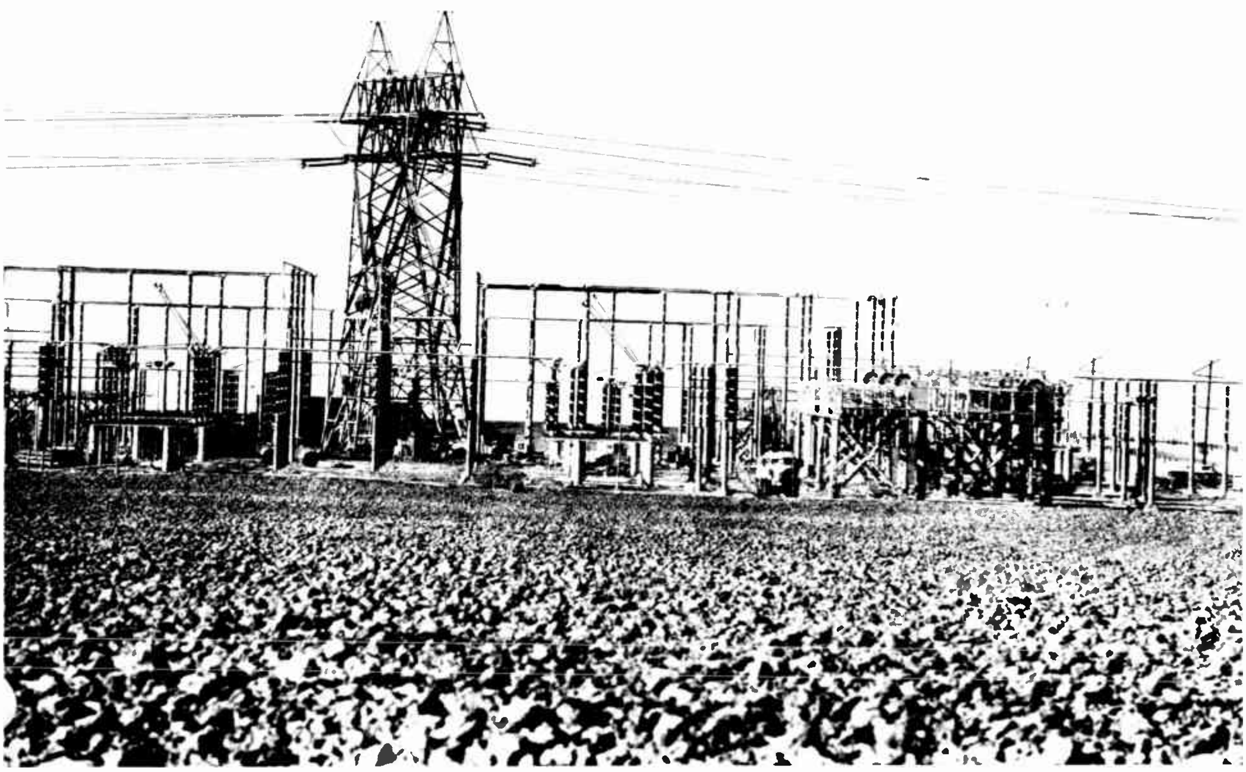
After completion of the dams in Canada, which are being constructed pursuant to a treaty between the United States and Canada,[1] only in a critical water period would the Northwest be unable to produce any secondary energy. However, by importing a small average amount of steam energy from the Southwest to fill in the "low spots" in the streamflow, the Northwest can be reinforced and thus be able to guarantee delivery of an additional 700 MW to loads in that area.

The intertie lines will permit exchanges of power and energy between the Northwest and Southwest to take advantage of diversity in streamflows and peak loads. In parts of the Southwest, peak loads occur during the summer months for air conditioning and irrigation pumping. In the Northwest, peak loads occur in the winter, mainly for heating. The Northwest, therefore, can transmit summertime surpluses of power and energy to the Southwest, and the Southwest can send a like amount of power and energy to the Northwest in the winter months, when they are needed. This permits utilities in each region to meet peak loads efficiently with less plant investment than if each region were to install 100 percent of the generation needed to meet its own peaks.

In the early years of the treaty, the intertie will enable marketing of Canada's share of the power and energy in California. Under the treaty, Canada is building three large storage dams on her side of the border. The dams will level out the flow of the Columbia River and enable existing dams in the United States to produce initially an extra 2800 MW of firm power and energy. Canada will receive half of this additional power and the United States the other half. However, Canada decided to sell her half of the treaty power in the United States for the first 30 years (until March 31, 2003), on a prepaid basis. The lump sum payment of more than $250 million is being used in financing construction of three storage dams in Canada.

These storage dams have completion dates of 1968, 1969, and 1973. Utilities, public and private, in California have agreed to purchase Canada's share of treaty power during the period it is surplus to needs of the Northwest. Assurance of the California market for treaty power thus facilitated the completion of arrangements to purchase and prepay Canada for its share of treaty power.

FIGURE 2. Bakeoven compensation station, near Maupin, Oreg., is a vital part of the intertie, as it serves to improve the transmission capacity of the long line by maintaining the required voltage level. Note towers and insulators, above the station, of the 500 000-volt John Day–Grizzly transmission line.



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Economic considerations

The benefits to the Pacific Northwest, the Pacific Southwest, and the nation that will result from the intertie development are enormous. Exclusive of postamortization benefits to the federal government, the benefit-to-cost ratio is at least 2.5 to 1. The benefits are the savings as subsequently discussed in this article, and cost is the investment in the intertie.

Over a 50-year payout period the total benefits measurable in dollars are estimated at $2.6 billion, approximately two thirds of which will accrue to preference customers. (Preference customers are those agencies that are given a priority in purchase of federally produced power.) There are important additional benefits, such as greater assurance of federal power supply for preference customers, advancement of EHV technology, assurance that the United States can meet its commitments relative to the Columbia River Treaty with Canada, conservation of exhaustible resources, reductions in generating reserves, emergency assistance between large electric systems, air pollution control, and other benefits that are not readily measurable in terms of dollars and cents.

Geographically, the estimated $2.6 billion in benefits is divided as follows: Pacific Northwest, $1 billion; California, $869 million; and Arizona–Nevada, $724 million.

A great part of these benefits results from deferral of steam-plant investment made possible by sales and exchanges of peaking capacity and energy over the intertie. Savings in deferred construction of steam-generating plants are estimated to be approximately equal to the cost of the intertie facilities. The intertie transmission lines will produce the same benefits as new generating plants without the financial responsibility.

Other benefits of the intertie will result from savings in fuel costs in the Pacific Southwest during such periods as secondary energy is available from the Northwest. Still other benefits will result from savings in price of power available through the intertie facilities that preference customers otherwise would have to obtain from higher-price sources.

As noted, the $2.6 billion estimate of gross benefits over a 50-year payout period does not take into account postamortization benefits to the federal government on its share of the investment. This additional benefit is estimated to be about $365 million (Pacific Southwest $175 million, Pacific Northwest $190 million) in the 25 years following payout. Postamortization benefits result from continued use of the intertie after payout at greatly reduced costs involving principally operation and maintenance and replacements. If the same charges on the line continue after the first 50 years, the postamortization benefits will be available for assistance to irrigation or other water-conservation projects.

The $365 million estimate of postamortization benefits is only for the federally constructed portion of the intertie. If all the recommended intertie facilities were constructed by the federal government, there would be additional benefits of nearly $300 million.

Benefits to Northwest preference customers

Among the most important intertie benefits to Northwest preference customers is an estimated increase in BPA net revenues of up to $20 million a year, with an average of $11 million to $12 million per year. These increased revenues will result mainly from sales and exchanges of secondary energy and surplus peaking capacity, and will aid considerably in keeping BPA rates low and offset customer rate increases totaling $550 million or more over the 50-year payout period.

These savings include the $55 million worth of firm power BPA would be able to sell in the Northwest as a result of sales of Canada's share of treaty power to the Southwest during the period of surplus. Additionally, Northwest utilities will save $20 million in the first five years of the treaty, representing the difference between what they would have to pay for power if they were to use it themselves and what they will pay for BPA firm power purchased to replace Canadian power sold in California. Some $12 million of this $20 million saving will accrue to Northwest preference customers.

With anticipated exchanges of peaking capacity for energy and purchase of off-peak energy from the Southwest to firm up Northwest secondary power, the Bonneville Power Administration—and therefor its preference customers—will have available some 700 MW of additional power at a 60 percent load factor. This in turn will enable preference customers to defer plant investment by some $70 million for the remaining life of the lines, at an annual saving to preference customers of about $6 million per year, or some $200 million over the last 35 years of line life, all with greater efficiency.

Other benefits to Northwest preference customers include reduced reserve requirements. Further, when they turn to steam generation, they will be more able to install initially the largest, most efficient steam generators, and sell short-term surplus generation in the Southwest over intertie lines. Also, those who have hydroelectric power generation facilities will be able to purchase off-peak steam from the Southwest to firm up their own hydroelectric power production.

Benefits to Southwest preference customers

Dollar benefits to preference customers served by the Bureau of Reclamation on the Bureau's Central Valley Project in California, Arizona, and Nevada will amount to about $600 million over the 50-year payout period. These savings will result both from purchases of lower-cost power and deferral of construction of steam-generating plants and associated equipment.

Los Angeles, by purchase of Canadian Treaty power and the exchange of surplus peaking capacity from the Northwest for off-peak energy from its system, will save about $50 million in investments the city otherwise would have to make in generating facilities.

Benefits to Colorado River Storage Project

When the states of Wyoming, Utah, Colorado, and New Mexico have fully used their entitlement to power from the Colorado River Storage Project, they will need new sources of power and energy. With the intertie system connected to the project's power system, power agencies in these states can make arrangements for additional supplies of surplus power and energy from the Northwest. The power would be transmitted over the intertie system to Phoenix, Ariz., and then by displacement to the points of use in the storage project.

Thus, two major beneficial effects will be obtained—power and energy will be made available at attractive rates, and additional dollars will be made available to the financin of the Colorado River Storage Project. Additional funds to be used for construction of irrigation projects in the Upper

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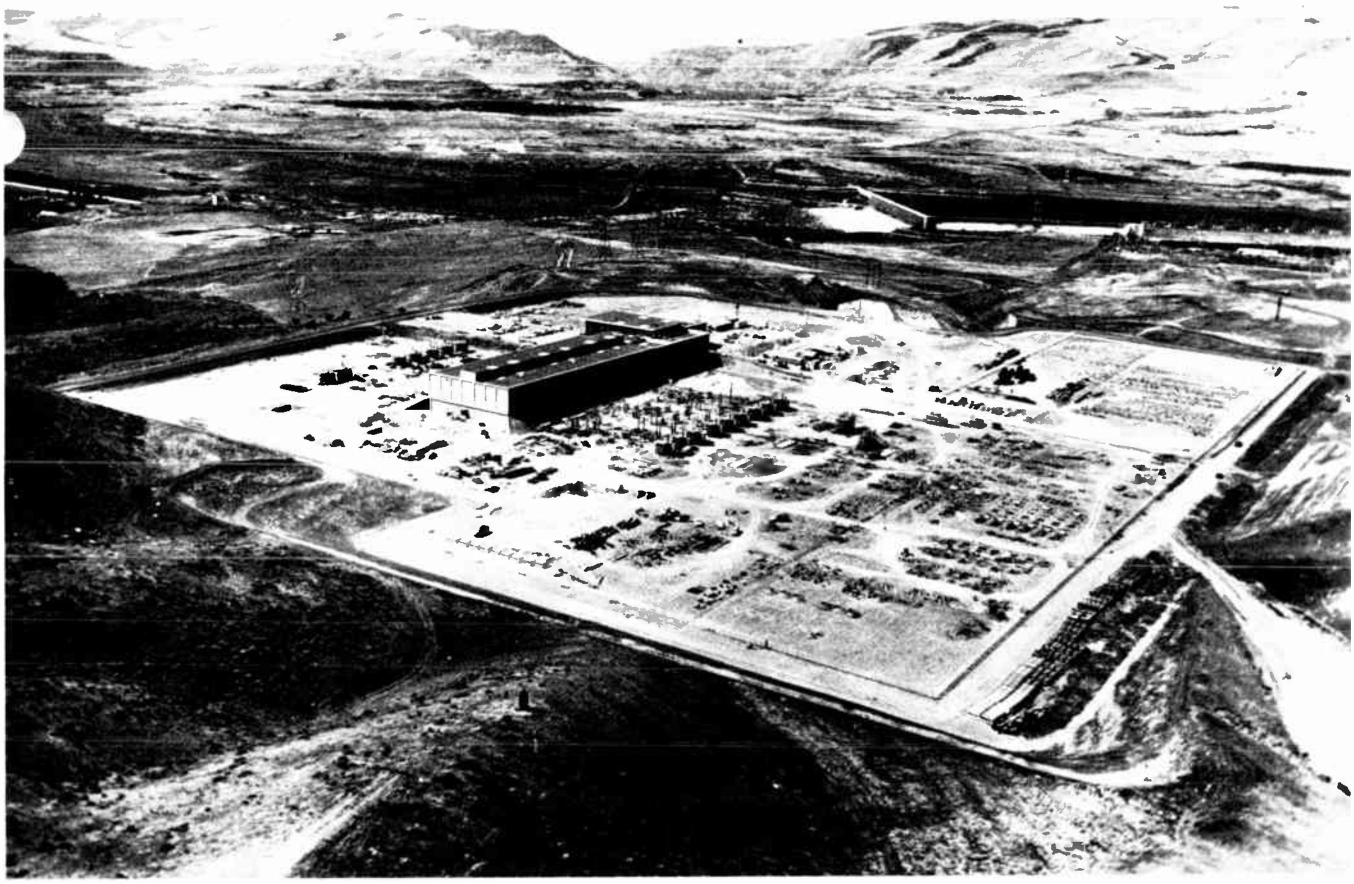

FIGURE 3. Aerial view of the Celilo Converter Station. The Dalles Dam can be seen in the background.

Colorado River Basin may come from revenues obtained from transferring Northwest power over the Storage Project system.

Economics of dc transmission

Direct-current transmission requires higher terminal costs but lower line costs than comparable ac systems. In effect, this means that in the United States transmission of point-to-point power overland, until now, was not of sufficient length and quantity that the low line costs could offset the high terminal costs. For the intertie, however, there is strong economic justification for undertaking dc transmission, both from construction costs and lower power losses.

The efficiency of direct current for transmitting power over long distances is evident in statistics on losses. When the comparisons are equal in the amount of power, distance, size of conductor, and peak voltage, ac line losses are appreciably greater than dc line losses. Also, a dc line with two conductors, and its ground connection, will lose about half its transmission capacity should one conductor become inoperative. On an ac circuit, however, if one conductor breaks down, all transmission ceases. In addition, if terminal ac equipment such as a transformer should fail, all transmission ɔuld be lost. However, if half the terminal equipment in a .c system should fail, the line can still transmit power at one-half capacity. The fact that the earth can be temporarily used as a return conductor for the dc line can be a great advantage.

As BPA engineers[2] have pointed out:

> "The overall investment per kilowatt of power delivered is less for dc than ac when the transmission distance exceeds approximately 500 miles [804 kilometers]. It is reasonable to assume that, as the art continues to develop and dc transmission becomes more generally used, the cost of dc terminals will be reduced to a greater extent than that for extra-high-voltage ac equipment."

Design considerations

Design of the intertie, particularly the features of the 800-kV dc power transmission complex, presents to systems, transmission-line, and substation-design engineers a diversity of problems not usually encountered in utility practice. Examples of such problems in the development of the 800-kV dc system are found in the design of the facilities for the converter terminals, provision for visitors at the converter terminals, selection of transmission-line conductor diameters, and considerations of line insulation, corona, radio interference, electrochemical erosion, and ground-return currents.

The aspects of design, and the many other complex considerations associated with the intertie development, are being successfully resolved by the cooperative efforts of many engineers in government and in the private sector, both in the United States and other countries.

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Converter terminals

Contracts for development of three of the intertie's four converter terminals have been awarded to a joint venture of two major equipment manufacturers, the General Electric Company of the United States and Allmanna Svenska Elektriska Aktiebolaget (ASEA) of Sweden. The three terminals, first of their type to be installed in the United States, are at the Sylmar, Mead, and Celilo Substations. The Celilo Substation will have two converter terminals, designated as Celilo I and Celilo II; see Fig. 3. Celilo I is under the General Electric–ASEA contract, and there is an option to procure the fourth terminal, Celilo II, from the same contractor.

The Celilo I converter terminal for the transmission line between the BPA power system and the Sylmar terminal at Los Angeles will use valves rated 133 kV, 1800 amperes. They will be arranged in a seven-valve six-pulse full-wave bridge arrangement, each bridge rated 240 MW. There will be six bridges series-connected ± 400 kV to ground. Three pairs of bridges will be arranged to operate in 12-pulse modes in order to minimize the low-order, normally present harmonics.

The Celilo II converter terminal for the line between the BPA power system and the Mead terminal will use valves rated at 200 kV, 1800 amperes, also arranged in seven-valve six-pulse full-wave bridges, each rated at 360 MW. There will be four of these bridges series-connected plus and minus 400 kV to ground. The bridges will be paired to operate in a 12-pulse mode to minimize ac system harmonic filter requirements.

The Mead converter terminal, the southern terminal of the Celilo II–Mead transmission line, will be adjacent to the ac portion of the Bureau of Reclamation's Mead Substation in Nevada, near Hoover Dam. The terminal will have two nominal 230-kV 60-cycle ac lines from Mead Substation and a ± 400-kV 1440-MW midpoint-grounded, dc line from the Celilo II terminal. The valves for the terminal will be rated at 200 kV, 1800 amperes.

Since the converter terminals will be completely novel types of installations in the United States, an unusually high number of visitors, both technical and sightseeing, may be expected. Because of this, the terminals are being designed to accommodate a greater than normal number of visitors. The specifications for the converter terminals call for the visitor areas to be constructed of materials of high quality and in such a way as to present an esthetically pleasing appearance.

800-kV design considerations

Fundamental to the design considerations of a dc intertie is the line voltage drop at full load. For a dc link intended for two-way transmission, this voltage drop determines the automatic underload tap-changer range requirement for both the rectifier and inverter transformers. A practical maximum value of voltage drop is about 10 percent. For the 800-kV 1300-MW tie of the intertie, the rated line current is 1800 amperes. On a percentage basis line loss is about the same as the voltage drop and, for this reason, much more than the economics of the converter station transformers is involved.

As previously mentioned, the four main intertie lines were planned for a combined delivery of 4600 MW of firm power. The two 800-kV dc lines would provide transmission capacity of 2600 MW. To achieve this firm transmission capacity, a 450-km 800-kV dc line was included for future construction to connect the Mead and Sylmar terminals of the two main 800-kV dc lines. Thus, for an outage of either of the intertie's dc lines, both southern converters would be connected to the remaining good line by means of the crosstie, and most of the load would be carried on the remaining line.

The conductor selected for the Bureau's portion of the 800-kV line running from the Celilo terminal II to the Mead terminal is to be a pole bundle consisting of two 1170-mm^2 ACSR (aluminum cable, steel-reinforced) conductors with 460-mm subconductor separation. The subconductor will be made up of 76 strands of 4.4-mm-diameter EC (electrical-conductivity-grade) aluminum and 19 strands of 2.1-mm-diameter steel. The outside diameter of the subconductor will be 4.6 cm.

It is expected that this conductor, when energized at 400 kV to ground, 800 kV between poles, will be satisfactory as far as radio interference is concerned. Tests conducted by BPA indicate that radio interference will be less with these conductors than with a 345-kV ac line using a single Chukar, 4.07-cm-diameter conductor per phase, with a 300-kV crest-to-ground rating.

The full load (1800 amperes) voltage drop of the 1320-km line, with an average conductor temperature of 67°C, is about 67 kV, or 8.4 percent. Line loss at full load is about 122 MW for the assumed average conductor temperature. With a 30-minute emergency loading of the line at double current (3600 amperes), the conductor temperature is expected to reach 113 C. Operation at this temperature is expected to be infrequent; however, the overall design of the line is based on an accumulated operating time at such elevated temperature of about 10 000 hours as an added margin of safety.

Supporting structures

The 800-kV dc lines will utilize towers of both self-supporting and guyed design. The principal structural material will be steel; however, about 161 km of the Celilo II–Mead line in Oregon will utilize structural aluminum. The selection of basic tower design used will depend upon terrain features and other factors, the most economical choice being used for each location. The line is expected to have about equal numbers of both tower types. The insulator strings supporting the conductors will be free-swinging on the tangent structures and will have a length of about 3.75 meters.

The sections of both the 800-kV lines in Oregon, as well as the whole of the line in Nevada to the Mead terminal, will be shielded with one overhead ground wire. It is expected that this shielding will provide adequate protection from flashovers caused by lightning.

Corrosion considerations

In cooperation with BPA and the city of Los Angeles, Bureau of Reclamation engineers have investigated many phases of the question of grounded neutral in EHV dc systems, where ground-return currents would flow with one of the overhead lines inoperative. Extensive field tests were conducted in which direct currents were circulated between test electrodes some 160 km apart.[3] This investigation program was considered to be essential in view of wide speculation over possible damage to buried pipelines, cables, metal support piling, and other facilities, where ground return was permitted.

The investigations have resulted in sufficient data to indicate that designs can now be made with firm assurance that

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corrosion effects on buried metalwork can be limited to less than those normally attributable to telluric currents associated with the earth's magnetic field and sunspot activity. This is true except within relatively small areas of possibly 40-km radius, surrounding each terminal grounding point (electrode). Within these small areas some relatively standard form of cathodic protection may be required, but probably not where ground return operation is limited to a few hours per year.

500-kV design considerations

Since the transmission distance is more than 1300 km, the 500-kV ac lines have to be constructed to operate in parallel and to have several intermediate switching stations. In order to transmit 2000 MW over the ac lines and maintain synchronism between the systems, a high degree of series compensation for line reactance is required. Studies show that series capacitors with about 70 percent compensation will be needed. In addition to the compensation for line reactance by series capacitors, it has been found necessary to compensate the 500-kV line with shunt reactors to absorb the capacitive line-charging current. The overall shunt-reactor installation of 2720 Mvar will compensate for about 83 percent of the total line-charging current. This is composed of 1880 Mvar of switched shunt reactors connected to autotransformer tertiary windings, and 840 Mvar of 500-kV reactors connected to the lines with isolators.

The conductors for the 500-kV ac lines must be adequate to carry 2000 MW for a substantial period if the paralleling line is out of service. To meet this requirement, the Bureau has chosen two 900-mm^2 ACSR (Chukar) conductors per phase for the 151-km section of line it is constructing in northern California. Similar conductors are used by the organizations constructing other sections. To minimize the capacitor installation required for stability reasons, the use of bundled conductors and minimum phase spacing is employed.

Engineering guidance task forces

Cooperation of the agencies engaged in planning development of the intertie is continuing through the design and construction phases and into the operating phase, which has begun for some of the features now completed. To accomplish this coordination of planning, design, construction, and operation, an Engineering Guidance Committee was organized with representation from each of the participating utilities. In turn, this committee established three task forces to carry out the work of coordination: the System Technical Studies Task Force, to predetermine the electrical performance of the intertie; the Design and Construction Task Force, with accountability in the major design and physical facilities area; and the Operations Task Force, to develop procedures for the normal and emergency operation of the intertie. These task forces, comprised of engineers from the cooperating organizations, have functioned satisfactorily.

As of June 1, 1967, the U.S. Bureau of Reclamation had awarded construction and supply contracts totaling more than $57 million for development of its portion of the intertie. Largest of the contracts awarded—$24 990 485—is for development, supply, and installation of the equipment for the Mead dc converter terminal. Three contracts totaling $24 859 660 are for construction of three ac transmission lines—the Malin–Round Mountain, Mead–Liberty, and Liberty–Estrella lines. The Liberty Substation is also under construction as part of the Liberty–Estrella line construction contract.

Current schedules call for completion of the contract for the Mead converter terminal by September 1972. Work on the Malin–Round Mountain and Mead–Liberty ac transmission lines, as well as the Estrella line and Liberty Substation, has been virtually completed. Construction of the 53-km 230-kV ac Round Mountain–Cottonwood line began in the summer of 1967 and was completed in October 1968. The 890-km 800-kV dc Oregon Border–Mead transmission line was placed under construction in the summer of 1968 and is scheduled for completion in late 1970 or in 1971.

Conclusion

Additional benefits from the intertie will accrue to the United States through construction activities that mean jobs, payrolls, profits, and increased local, state, and federal taxes. An estimated 9800 man-years of direct employment will be required in the field of erecting towers and related construction activities for the four principal intertie lines.

In the past, distance has dictated the range of power utilization, and has often decreed "power feast and famine" side by side. By employing dc transmission on a major scale, the intertie has now broken the "distance barrier" in the United States, and has made the transport of large amounts of electric power over extremely long distances economically feasible.

Virtually every aspect of the intertie, from planning through design, construction, and operation, presents challenging problems—several of unprecedented nature—to be studied and resolved. Working together, engineers of both public agencies and private enterprise are meeting these challenges to assure the successful accomplishment of this great undertaking.

This article is based on a paper presented at the 1968 World Power Conference held in Moscow, August 20–24. The original paper will appear in the proceedings of the conference, copyrighted by the Soviet National Committee.

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This article describes a monolithic integrated-circuit voltage regulator for use in medium-power applications in the achievement of "local" or "on-card" regulation. Included are design features, an explanation of circuit's operation, a dc analysis, regulation analysis, performance characteristics, design rules and considerations, and selected applications.

An IC medium-

The Westinghouse WC109T voltage regulator combines, on a single chip, a temperature-compensated reference voltage, a sense and comparison amplifier, a Darlington series control element, a constant-current preregulator, a current-limiting transistor, and a silicon controlled rectifier (SCR). A regulated output voltage ranging from 4 to 16 volts is provided by the regulator, with a current capability of 150 mA in its basic form. If currents greater than 150 mA are required, the regulator can drive up to 5 amperes using one external transistor. Adjustable overload protection is provided internally either by the current-limiting transistor or the SCR. Line regulation for the WC109T is typically 0.2 percent per volt change in input, and load regulation is typically 0.2 percent.

Being contained in the popular TO-5 package makes the WC109T attractive for use on printed-circuit cards. This provides "on-card" or "local" regulation, which has the advantage of eliminating the need for a single, large, costly, precision regulator for a system. In addition, this configuration allows each circuit function in a system to be powered independently of fluctuations in the main power bus. Interference and interaction between different parts of the system are minimized because of the high degree of board-to-board decoupling.

This medium-power regulator has applications in both analog and digital systems. For instance, it can provide regulated supply voltages to integrated-circuit operational amplifiers, and to logic circuits that are used in numerical control equipment, data processors, calculators, and servo systems.

Circuit descriptions

The block diagram of the WC109T voltage regulator is shown in Fig. 1. A portion of the output voltage is sampled and compared with a fixed internal reference; the resulting differential signal is amplified, and enables the series control element to increase or decrease the current to the load as required.

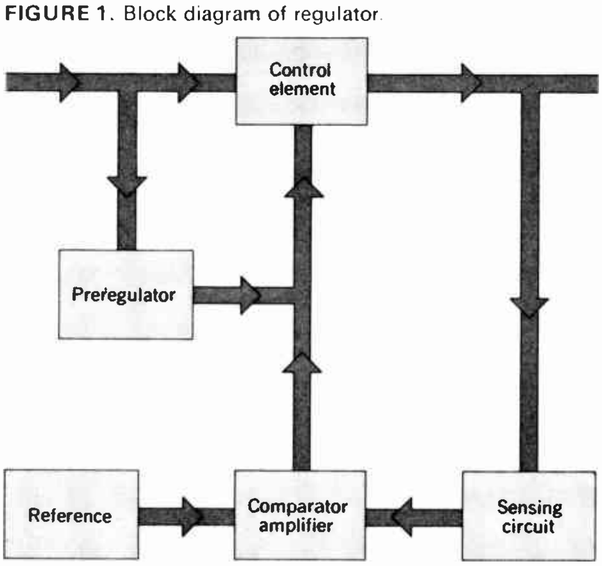
Figure 2 shows the regulator schematically. A temperature-compensated reference for the regulator is established by a 6.0-volt Zener diode Z_1 and a forward-biased diode D_1. The temperature coefficients of these two diodes are approximately equal and of opposite polarity, and thus the net coefficient is nearly zero.

The comparison element of the regulator is a differential amplifier used to achieve precise comparison and is self-temperature-compensating. Since the emitter resistance is not degenerative against differential signals, the output of the amplifier is proportional only to the transistor parameters and the differential input that results from the difference between the internal reference voltage at the base of transistor Q_1 and the sampled portion of the output voltage at the base of Q_2. If the voltage at the base of Q_2 becomes less than the fixed voltage at Q_1, the collector current of Q_2 will decrease, thereby allowing more base current to drive the control element. The reverse takes place for an increase in the sampled voltage. Effects of temperature variations are minimized with the use of the differential amplifier. The reason is that these variations appear as a common-mode signal, which is amplified very much less than a differential signal because the emitter resistance is degenerative against common-mode signals.

The Darlington-connected transistor pair constitutes the series control element of the voltage regulator. This element interprets the signal from the differential amplifier and drives more or less current to the load as necessary to maintain a constant output voltage. The Darlington connection provides the high current gain necessary to maintain the required load current.

An element of preregulation is provided for the WC-109T by a constant-current source to the collector of the differential amplifier and the base of the control element. This constant-current stage eliminates ripple currents, resulting from input variations, which would be fed to the base of the control element and amplified directly if only a resistor were used. Temperature compensation for the Zener and the p-n-p base-emitter junction is achieved by

FIGURE 1. Block diagram of regulator.



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power voltage regulator

Features of a recently developed monolithic single-chip voltage regulator for "on-card" applications include 0.2 percent line and load regulation and built-in overload protection

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diodes D_2 and D_3 respectively.

Another feature of this monolithic chip is a current-limiting transistor Q_7. If overload protection is desired, the emitter of Q_7 is used as the output, and an external resistor whose value will depend upon the desired current limit is connected across the base emitter junction of this transistor. When the current through this resistor establishes a sufficient base–emitter voltage to turn Q_7 on, bias current is drawn away from the series control element, turning the regulator off.

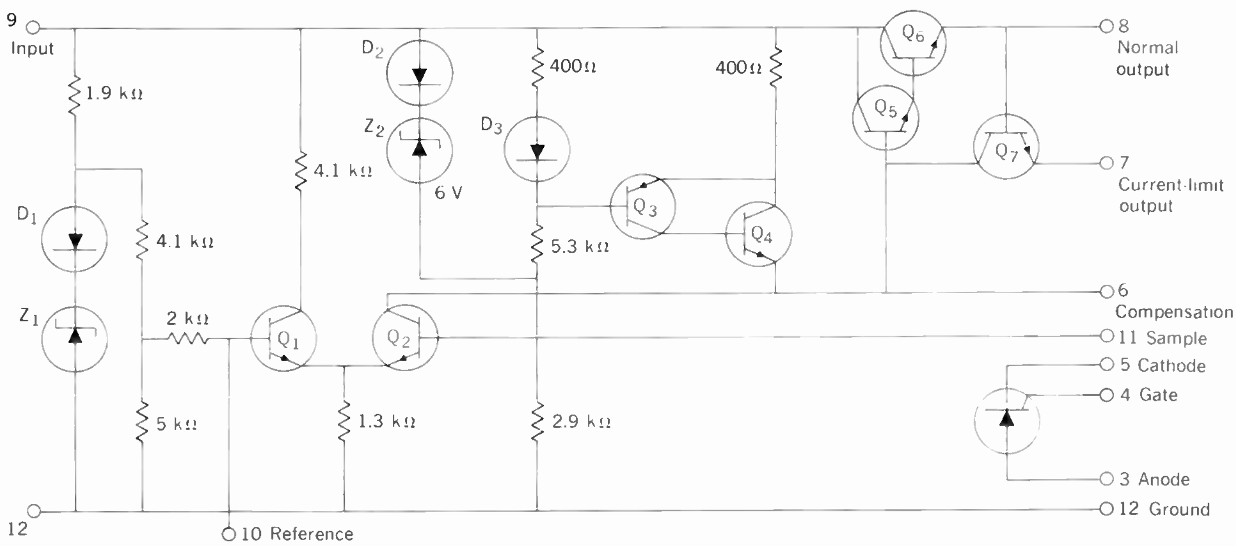
The SCR can be used to achieve foldback current limiting by the addition of a gate resistor and a sense resistor whose value depends upon the required maximum current. The anode of the SCR is connected to the base of the Darlington connection, the gate to the normal regulator output through a gate resistor, the cathode to the new output, and a sensing resistor between the emitter of the Darlington and the new output. When the current through this sensing resistor establishes a sufficient voltage to fire the SCR, base current is drawn from the Darlington element, thereby turning the regulator off and causing the load current to fold back.

DC analysis

The reference voltage at the base of Q_1 is determined by a 6.0-volt Zener diode and a resistor-divider network such that a reference voltage of 3.6 volts is achieved. Under quiescent operating conditions, the voltage at the base of Q_2 will also be at 3.6 volts, and hence the required output voltage can be established by an appropriate resistor divider or potentiometer across the output terminals, with the bleeder being connected to the base of Q_2.

A constant current to the base of the series control element and the collector of the differential amplifier is provided by the composite p-n-p transistor consisting of Q_3

FIGURE 2. Schematic diagram of regulator.



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and Q_4. This current is completely independent of input voltage variations and can be shown to be approximately 1 mA.

The standby current, which is consumed by the regulator when no current is being delivered to the load, is calculated to be

$$I_s = \frac{V_{in} - V_{Z_1}}{1900} + \frac{V_R - V_{be_1}}{1300} + \frac{V_{in} - V_{Z_2}}{2900} \tag{1}$$

which reduces to

$$I_s = (0.87V_{in} - 3.5) \text{ milliamperes} \tag{2}$$

The standby power dissipation, in milliwatts, is

$$P_{D_S} = 0.87V_{in}^2 - 3.4V_{in} \tag{3}$$

The total power dissipation is the sum of the standby dissipation and the power dissipated in the series element. It can be calculated from the following equation:

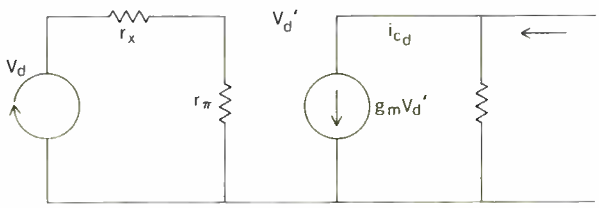


FIGURE 3. Differential-amplifier model.

FIGURE 4. Regulator small-signal block diagram.

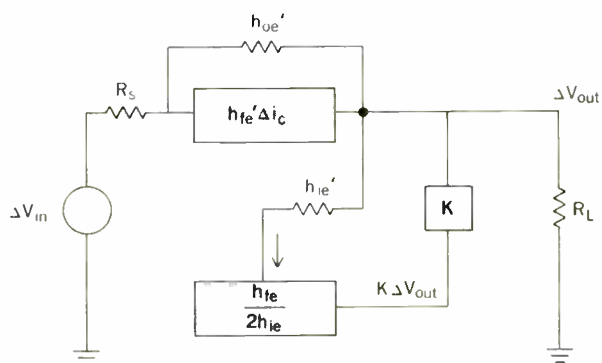
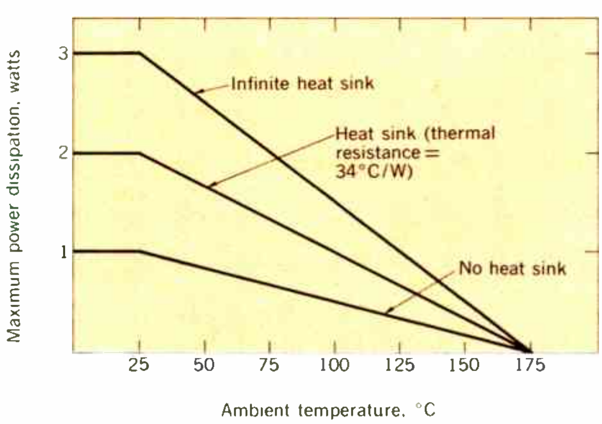


FIGURE 5. Maximum allowable power dissipation vs. ambient temperature.



$$P_{DT} = (V_{in} - V_{out})I_L + 0.78V_{in}^2 - 3.5V_{in} \tag{4}$$

where I_L is the load current in milliamperes and P_{DT} is in milliwatts. It is, of course, desirable to keep this power as small as possible by attempting to adhere to a minimum differential between input and output voltage.

Regulation analysis

Excellent line and load regulation is achieved primarily by the transistor parameters of the differential amplifier and series control element. To illustrate how regulation depends upon these parameters, analysis will first be made of the differential amplifier stage of the regulator. The differential mode model of this amplifier is shown in Fig. 3, where it is assumed that Q_1 and Q_2 are perfectly matched. The equivalent differential excitation voltage is

$$V_d = \frac{1}{2}(V_R - V_S) \tag{5}$$

where V_R is the internal reference voltage at the base of Q_1 and V_S is the sampled voltage at the base of Q_2. The differential collector current is

$$i_{cd} = \frac{1}{2}g_m(V_R - V_S)\frac{r_\pi}{r_x + r_\pi} \tag{6}$$

Since $V_R - V_S = K\Delta V_{out}$,

$$\Delta i_c = \frac{Kg_mr_\pi}{2(r_x + r_\pi)}\Delta V_{out} \tag{7}$$

where $K = V_R/V_{out}$. It can be shown that the product of the hybrid π parameters g_mr_π is the forward-current gain of the transistor, and the sum of r_x and r_π is the input impedance. Hence,

$$\Delta i_c = \frac{Kh_{fe}}{2h_{ie}}\Delta V_{out} \tag{8}$$

Equation (8) gives the change in collector current to the differential amplifier for a change in output voltage of the regulator. This will also be the change in the base current driving the series control element, since the emitter current of Q_4 is constant. Figure 4 shows the regulator in block diagram form. Line regulation is calculated to be

$$\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{h_{oe'}}{\frac{1}{R_L} + h_{oe'}\left(1 + \frac{R_s}{R_L}\right) + \frac{Kh_{fe}h_{fe'}}{2h_{ie}}} \tag{9}$$

where $h_{oe'}$ and $h_{fe'}$ are the equivalent parameters of the Darlington control element, R_s is the source resistance, and R_L is the load resistance. Since the last term in the denominator of Eq. (9) is much larger than the others, the following approximate expression is adequate:

$$\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{2h_{ie}h_{oe'}}{Kh_{fe}h_{fe'}} \tag{10}$$

Thus, good line regulation is achieved by the low input impedance of Q_2, low output admittance of the Darlington pair Q_5 and Q_6, and high forward-current gains of Q_2, Q_5, and Q_6.

Load regulation is dependent upon the output impedance of the regulator. Again using Fig. 4, and letting ΔV_{in} equal zero, the output impedance can be calculated as

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$$r_{out} = \frac{\Delta V_{out}}{\Delta i_L} = \frac{2h_{ie}}{K h_{fe} h_{fe'}} \tag{11}$$

Since low output impedance achieves good load regulation, again it is seen that high current gains of Q_2, Q_5, and Q_6 and low input impedance of Q_2 accomplish good regulation with load changes. It is interesting to note that by substituting Eq. (11) into Eq. (10), line regulation is also proportional to the output impedance. If typical transistor current gains of 50 and the input impedance h_{ie} of Q_2 of 1.3 kilohms is substituted into Eq. (11), the output impedance is found to be

$$r_{out} = (0.02)\frac{1}{K} \tag{12}$$

Since K is the ratio of the reference voltage (3.6 volts) to the output voltage, the output impedance can range from 0.02 to 0.08 ohm.

Performance characteristics

Regulated output voltages ranging from 4 to 16 volts with less than 0.5 percent regulation for a change from no load to a 150-mA load in 0°C to 75°C temperature environments are achieved with the WC109T regulator. Temperature stability of the output voltage is less than 0.007 percent per degree C without a heat sink. Input voltages can range from 9 volts to 24 volts nominal, whereas the differential between input and output voltage can range from 5 volts to 20 volts for proper regulator operation—provided, of course, that the maximum power rating of the device is not exceeded.

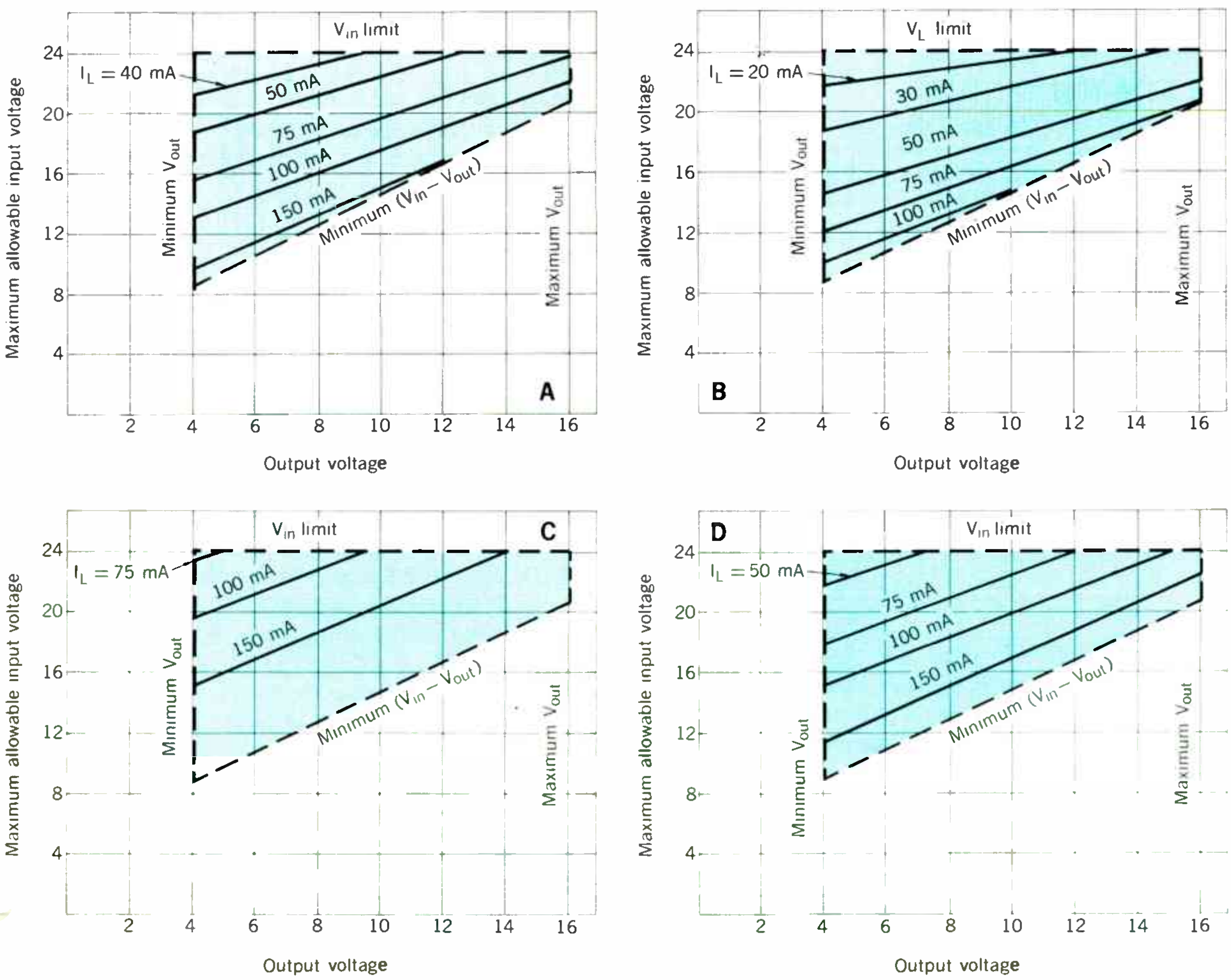
The input ripple attenuation is 40 dB at frequencies up to 20 kHz and the output impedance is typically 0.05 ohm in the same frequency range.

Design rules and considerations

In designing applications for a voltage regulator, precautions must be taken not to exceed the power rating of the device. It should always be remembered that any voltage regulator cannot be operating under maximum-voltage and maximum-current conditions simultaneously without exceeding the power rating.

The total power dissipation in the WC109T regulator is given by Eq. (4) as a function of the input and output voltage and load current, and it should never exceed a value of 1 watt at 25°C without a heat sink. If the ambient temperature is greater, the maximum allowable power dissipation must be derated so that the junction temperature will not exceed 175°C. Figure 5 shows the maximum allowable power dissipation over a temperature range from 0°C to 175°C with and without a heat sink. The maximum input voltage should

FIGURE 6. Maximum allowable input voltage vs. output voltage for various values of load current. A: $T_A = 25°C$, no heat sink. B: $T_A = 75°C$, no heat sink. C: $T_A = 25°C$, 34°C/W heat sink. D: $T_A = 75°C$, 34°C/W heat sink.



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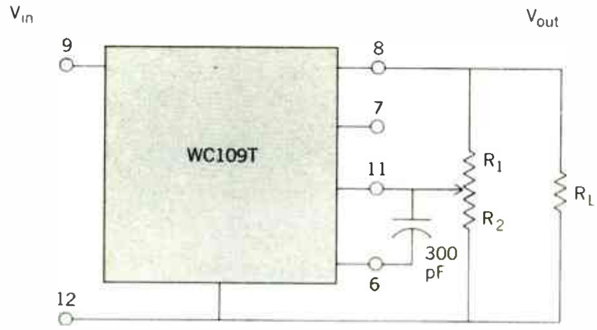


FIGURE 7. Basic 150-mA regulator.

FIGURE 8. 150-mA regulator with current limiting.

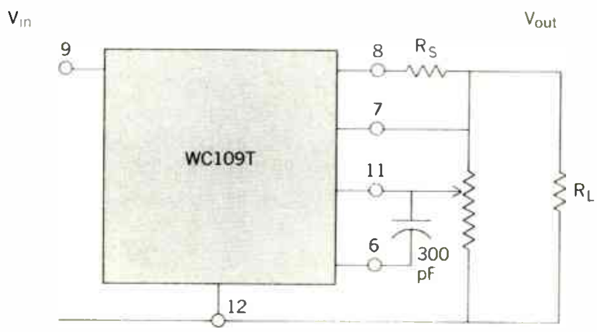
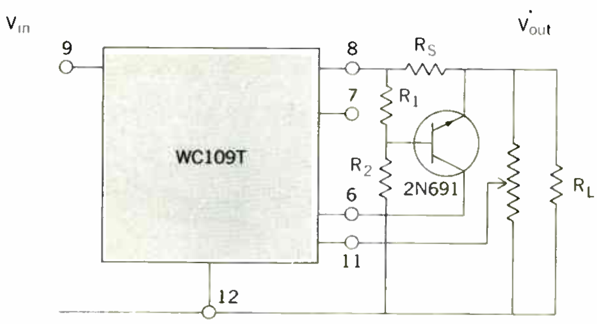


FIGURE 9. 150-mA regulator with foldback current limiting.



be selected to ensure that the total power dissipation calculated using Eq. (4) will not exceed the maximum rating under the required temperature conditions.

From Eq. (4), the maximum input voltage allowable for a given set of load conditions is

$$V_{in_{(max)}} = \frac{-a + \sqrt{a^2 + 3.48b}}{1.74} \quad (13)$$

where $a = I_L - 3.5$; $b = V_{out}I_L + P_{d_{max}}$; I_L is either the load current or the current driving an external transistor, in milliamperes; and $P_{d_{max}}$ is the maximum allowable power dissipation, in milliwatts. The equation is represented graphically in Fig. 6 for different temperature conditions, with and without heat sinks. Using these graphs, the maximum input voltage allowable so that the power rating is not exceeded can be found for a given set of load conditions and ambient temperature. It should be kept in mind, however, that the smaller the input voltage selected, the greater will be the efficiency.

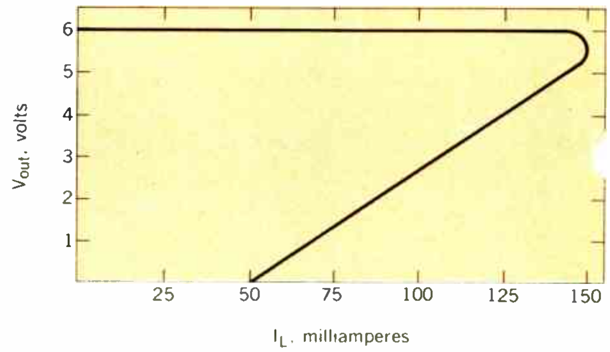
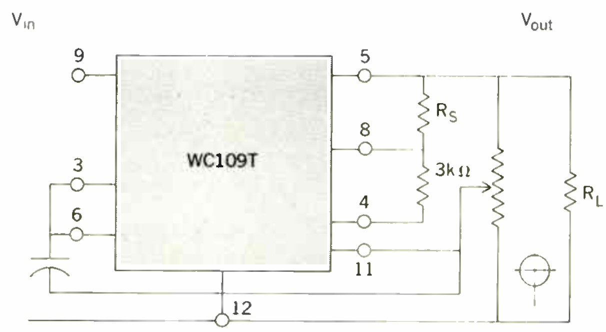


FIGURE 10. Output voltage vs. load current, showing overload protection with external transistor. R_S = 20 Ω, R_1 = 1.7 kΩ, R_2 = 3.3 kΩ.

FIGURE 11. 150-mA regulator with SCR overload protection.



When driving an external power transistor in a TO-3 package, the TO-5 package of the regulator must be isolated, since it is at ground potential. If the two cases are adjacent to a common chassis, the collector of the power transistor would be short-circuited to ground.

Applications

The basic regulator connection for loads up to 150 mA is shown in Fig. 7. The external elements required are a 300-pF compensation capacitor and a potentiometer or resistor divider for the sampling circuit. If a resistor divider is used, R_1 and R_2 should be chosen so that

$$\frac{R_2}{R_1 + R_2} = \frac{V_R}{V_{out}} \quad (14)$$

where V_R is the internal reference voltage. It is recommended that a trimmer pot, rather than a fixed resistor, be used, since the internal reference voltage will not be exactly the same on a large number of devices.

If regulator current limiting is desired, an external sensing resistor is connected as shown in Fig. 8. The value of this external resistor determines the maximum load current and should be chosen in such a way that

$$R_S = \frac{100}{I_{L_{max}}} \quad (15)$$

where the current $I_{L_{max}}$ is expressed in milliamperes and R_S is in ohms.

Foldback current limiting is often preferred over simple current limiting in that the load current is reduced to a small

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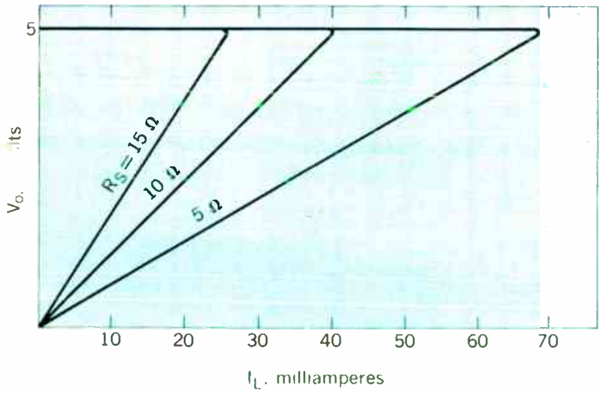
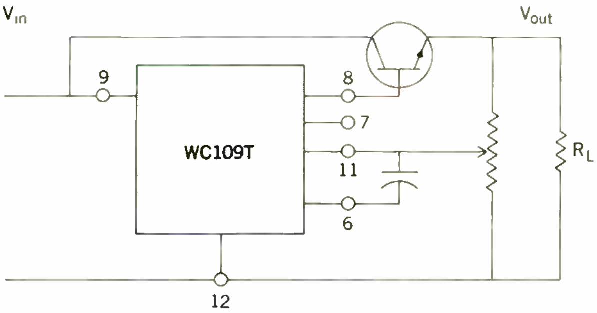


FIGURE 12. Output voltage vs. load current, showing overload protection with internal SCR.

FIGURE 13. Basic 5-ampere regulator.



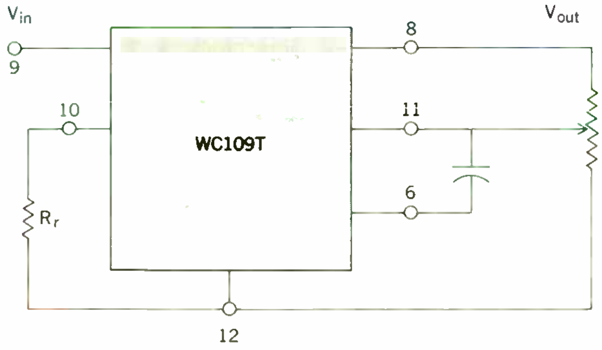


FIGURE 14. Regulator for outputs less than 4 volts.

FIGURE 15. Circuit for relatively high input voltages.

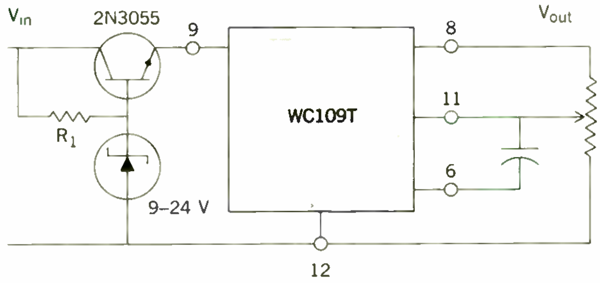
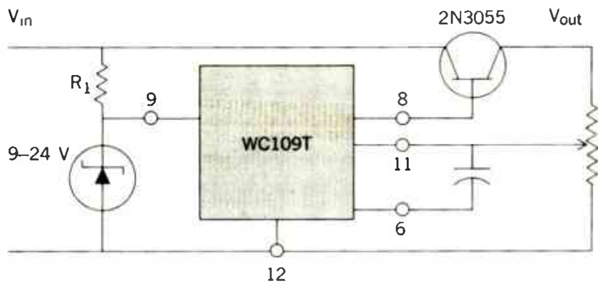


FIGURE 16. Circuit for increased input voltage and load current.



value, thus achieving better load protection and decreasing the power dissipated in the regulator. This type of overload protection can be obtained either with an external transistor and sensing resistor or internal SCR and sensing resistor.

An external transistor achieves foldback current limiting without the necessity of resetting the voltage after a short circuit occurs. Figure 9 shows the appropriate connection of the transistor and sensing resistor. When the load current reaches a certain value, the external transistor becomes sufficiently biased to turn on, thus drawing bias current from the series control element of the regulator and thereby turning the regulator off. The values of the external sensing and biasing resistors should be chosen to satisfy the following relation:

$$\frac{I_{L,\max}}{I_{S_0}} = \frac{(1-K)V_{out}}{0.7} \qquad (16)$$

where $K = R_2/(R_1 + R_2)$ and I_{S_0} = short-circuit current through R_S. Figure 10 illustrates typical results obtained using this method of current limiting.

Using the SCR for overload protection has the advantage of achieving complete cutoff when a predetermined maximum load current is exceeded. When this occurs, both the load voltage and load current immediately fall to zero, and thus both load protection and regulator protection are realized. Only when the input voltage is removed and the circuit is reset will the regulator again supply current to the ·ad. To obtain SCR overload protection it is necessary ·nly to connect an external sensing resistor and a gate resistor, as shown in Fig. 11. The value of the sensing resistor determines the maximum load current necessary to fire the SCR, with smaller resistances allowing larger maximum currents. Figure 12 illustrates results that were obtained by the use of this method of overload protection.

Applications requiring current larger than 150 mA can be achieved by employing the WC109T to drive an external power transistor, the gain of which should be high enough that the driving current from the regulator does not cause excessive power dissipation in the regulator. Figure 13 shows the basic connection for the 5-ampere regulator.

If an application requires a voltage lower than 4 volts, the WC109T can be readily adapted only by adding one external resistor between pin 10 and ground, as shown in Fig. 14. The value of resistor is chosen by the relation

$$R_r = \frac{4.3\,V_R}{3.6 - V_R}\ \text{kilohms} \qquad (17)$$

where V_R is the new reference voltage; it should be at least a half volt less than the required output voltage.

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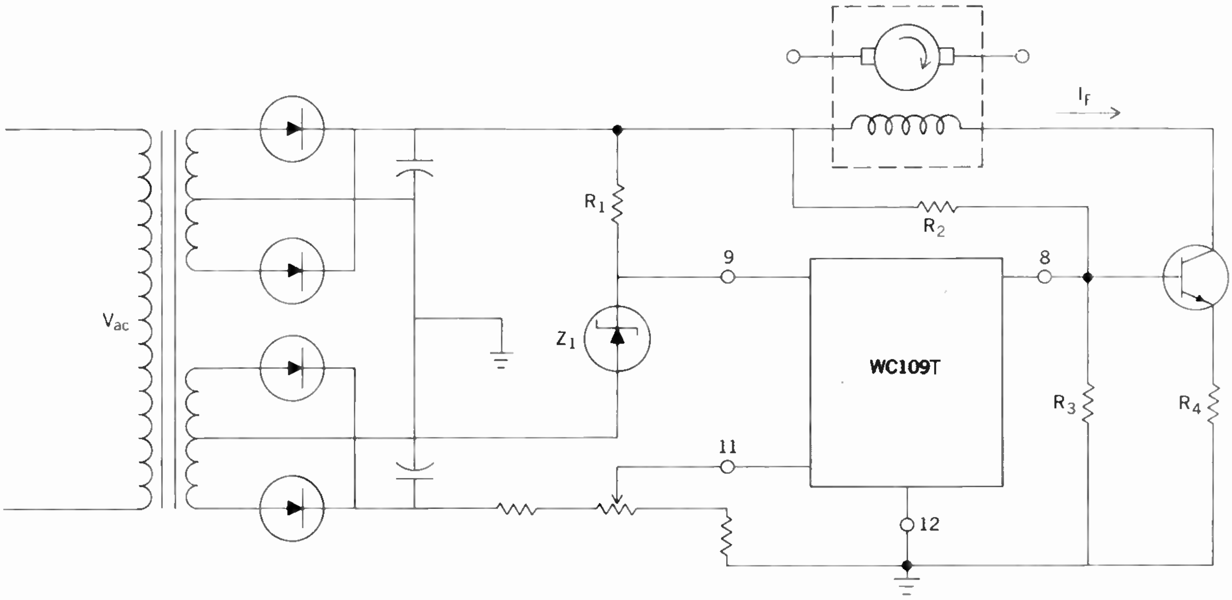

FIGURE 17. Circuit for ac load voltage regulator.

If an application requires an input voltage to the regulator that is greater than 25 volts or the voltage allowed by Eq. (13), an external transistor and Zener diode can be used, as shown in Fig. 15, to reduce the control-element voltage. The circuit also provides preregulation by keeping the input voltage to the regulator constant. An alternate method, shown in Fig. 16, allows greater load currents in addition to higher input voltages. The value of the resistor R_1 should be chosen so that the current through the resistor is sufficient to supply the Zener diode and regulator and to drive the external transistor. Therefore,

$$R_1 < \frac{V_{in} - V_Z}{I_Z + 0.87 V_{in} - 3.5 + I_L/\beta} \qquad (18)$$

where V_Z is the Zener voltage at the regulator input; I_Z is the Zener current, in milliamperes; I_L is the load current, in milliamperes; β is the gain of the external transistor; and R_1 is expressed in kilohms.

Figure 17 shows how the WC109T can be used to regulate the ac load of a motor-generator set by controlling the dc field current of the generator. The voltage at the input to the regulator (pin 9) is a portion of the rectified ac voltage being delivered to a load. The Zener diode Z_1 is selected so that the input voltage to the regulator is less than the maximum allowable value given by Eq. (13). R_2, R_3, and R_4 are chosen to establish the quiescent field current and properly bias the external transistor and R_1 is determined from Eq. (18). A portion of the rectified voltage of one primary coil of the transformer is sampled by the regulator and compared with the reference voltage at pin 10, which may either be the internal reference or an external reference as the application requires. The output current of the regulator increases if the sampled voltage is less than the reference voltage and thus drives the external transistor harder, resulting in an increase in field current of the generator. This action is reversed if the sampled voltage is greater than the reference voltage. The ac voltage will then increase or decrease with an increase or decrease in field current.

Summary

The discussion and applications presented show some of the design features and capability of the WC109T integrated-circuit voltage regulator. Two of the most significant features are the "on-card" regulator concept and the use of a silicon controlled rectifier in the overload protection circuit. The usefulness of this regulator is limited only by the initiative of the engineer in unfolding new and different areas of application.

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