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IEEE spectrum

features

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

departments

the cover

A panorama of the IEEE International Convention and Exhibition

Spectral lines

Units. For some time it has been evident that the IEEE should take a more definitive stand on the question of the units to be used in its publications. In this issue, several steps are taken toward clarifying and systematizing IEEE practices in regard to units.

First, at the recommendation of the Technical Activities Board and with the approval of the Publications Board, the complete text of the report of the IEEE Standards Coordinating Committee, "IEEE Recommended Practice for Units in Published Scientific and Technical Work," has been printed in this issue. In this report, the use of the International System of Units (SI) is recommended as the preferred system for all IEEE technical publications. The unusual step of publishing this entire report in SPECTRUM has been taken because of the importance of this recommendation to all IEEE members. In addition to the report, an authoritative statement by Dr. L. E. Howlett, who is president of the International Committee on Weights and Measures, has been included. Finally, an article entitled "IEEE Takes a Stand on Units" by Bruce B. Barrow discusses the historical background that led to the development of the International System of Units and its adoption in many technical fields.

It is the intent of the IEEE Publications Board to be active in encouraging the use of the International System in IEEE technical publications. While the international method of abbreviating units has been used in IEEE publications for at least a year, it is planned to adhere closely to the International System of Units in future issues of SPECTRUM, the PROCEEDINGS, and the STUDENT JOURNAL, and to encourage Group editors to utilize this system in their TRANSACTIONS.

Since the primary objective of IEEE is the dissemination of technical information, it is certainly not desirable to impede this flow of information by the use of units that are not standardized and are not readily convertible. It is our hope that the SI units will be adopted by all IEEE publications as quickly as possible and that this adoption will, in time, lead to a more rapid adoption of these units throughout the world. While the process of changing from a familiar set of units to a new and unfamiliar one is at best painful, it is clear that the job has to be done—and it will not be easier in the future than it is right now.

The March Convention. Once again the IEEE's International Convention will get under way in New York City, on the 21st of this month. It is anticipated that there will be more than 50 000 attendees from some 40 countries who will gather to hear the presentations of nearly 400 technical papers, to examine the more than 750 exhibits, and to attend the annual banquet, at which IEEE awards will be made. Perhaps most important, the convention will provide an opportunity for us to meet professional colleagues who are friends of long standing, and also to make new acquaintances who are active in fields of mutual interest.

This year, all the technical sessions are being held at a single location—the New York Hilton Hotel. All the exhibits will be held at the Coliseum. To facilitate access between these two locations, a free shuttle bus will be operated every eight minutes. A change has also been made in scheduling of the technical sessions; they will start and end earlier than in previous years. The exhibitions will open and close later. This should make it easier to both attend the sessions and visit the exhibits. An especially interesting and significant highlight session has been assigned for Tuesday night (March 22) on the provocative question: "After Apollo —What?" During this session a panel of outstanding experts will consider some of the promising areas of research and development that may be undertaken over the next decade after the major U.S. effort to land a man on the moon has been completed.

Full details concerning the technical program, exhibition, ladies program, and social events are given elsewhere in this issue.

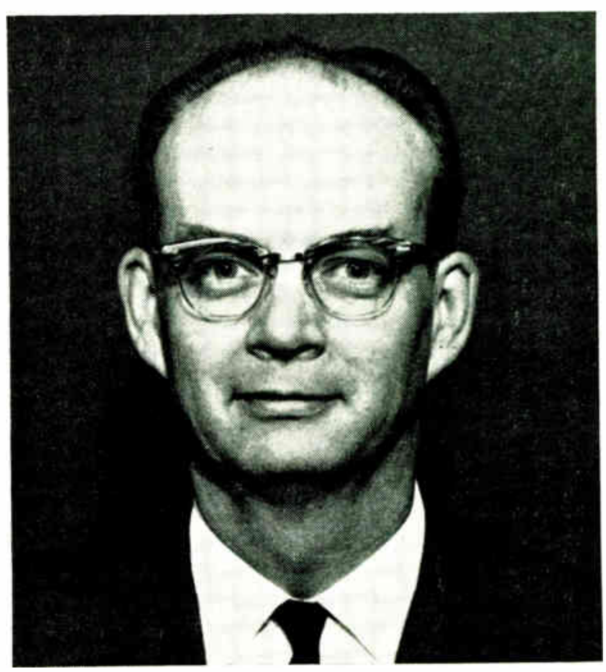
The IEEE as a professional society has a particularly significant role to play in bringing together those who have contributed the new knowledge which advances our profession and the engineers who have translated this knowledge into new equipment, devices, and systems, which have also advanced our profession. At the March Convention, this function of the IEEE is particularly evident. All members can profit by attending. *F. Karl Willenbrock*

Authors

Ultrasonic studies of solids (page 116)

Norman G. Einspruch (SM) received the B.A. degree from Rice University in 1953 and the M.S. degree from the University of Colorado in 1955, both in physics, and the Ph.D. degree in applied mathematics from Brown University in 1959. He joined Texas Instruments Inc. in 1959, where he currently directs the Electron Transport Physics branch of the Physics Research Laboratory. In this capacity he is responsible for research in physical acoustics, superconductivity, thin-film active devices, solid-state plasmas, the physics of semimetals, and hot-electron phenomena. From 1964 to 1965 he was also acting head of the Thin Film Physics branch, where he conducted research on ferromagnetic films, nucleation and growth of ultrathin films, properties of metal–semiconductor junctions, and Schottky barrier devices. As a research associate at Brown University, he studied the physical properties of solids by means of ultrasonics. Dr. Einspruch is the author of numerous technical articles. He is a Fellow of the American Physical Society and a member of Sigma Xi, Acoustical Society of America, and American Association for the Advancement of Science.

Trends in European engineering education (page 125)



Herman R. Weed (SM) has been active in the field of education since the beginning of his junior year at Pennsylvania State University, where he worked as a part-time instructor until he received the B.S.E.E. degree in 1945. He continued there for another year as instructor and then joined the Department of Electrical Engineering at Ohio State University, where he has served as instructor (1946–1949), assistant professor (1949–1955), associate professor (1955–1959), and professor (1959 to present). He received the M.Sc. degree in electrical engineering from Ohio State in 1948. During the summer of 1949 he worked as a development engineer for Westinghouse Electric Corporation in Buffalo, N.Y. From 1956 to 1958, in addition to his duties at Ohio State, he conducted seminars in electronics at the Wright-Patterson Air Force Base. He has served as a consultant to Robbins and Meyers, Inc., since 1953 and to Solid-State Controls, Inc., since 1961. He contributed to the ASEE's "National Goals in Engineering" study by reporting in detail on the technical education systems of 13 universities in nine countries in Europe.

The golden anniversary of electric wave filters (page 129)

Anatol I. Zverev (SM) received the Diploma of Engineering (M.S.) from the Leningrad Electro-Technic Institute and the D.Eng. degree from the Academy of Transportation. He was employed by the U.S.S.R. Ministry of Transportation as chief communication engineer and, at the same time, was a professor of transmission-line theory at the Academy of Transportation. During World War II, in the rank of military engineer, he was captured by the Germans, but was permitted to obtain an advanced degree from the University of Berlin. In 1943 he was a member of the staff of the Siemens and Halske Co. in Siemenstadt. In 1945 UNRRA placed him in charge of the International Professional School in Munich, where college facilities were provided for displaced persons. He joined the Atelie de Construction Electric de Charleroi, Belgium, in 1950, where he worked on carrier-line power systems and NATO radar systems. Since 1953 he has been with Westinghouse Electric Corporation, Baltimore, where he has been involved in communication, radar, data-transmission, and satellite navigation systems.

Human factors in engineering (page 132)

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

Relativity and electricity (page 140)

R. S. Elliott (F), whose specialties include electromagnetic theory and the electrical properties of materials, has been a professor of engineering at the University of California, Los Angeles, since 1958. He received the A.B. and B.S.E.E. degrees from Columbia University in 1942 and 1943, respectively, and the M.S. and Ph.D. degrees from the University of Illinois in 1947 and 1952, respectively. After completing his studies at Columbia, he worked for a three-year period at The Johns Hopkins University's Applied Physics Laboratory. While taking graduate courses at the University of Illinois he also served as an assistant professor. In 1952 he was on active duty with the U.S. Navy on a missile development program. He joined Hughes Research Laboratories in 1953 as head of their antenna research activities, where he worked on surface-wave antennas and arrays. In 1956 he helped to found the Rantec Corporation, and served as its vice president and technical director. Dr. Elliott has written numerous technical articles and has just completed a textbook on electromagnetic theory. He is a member of Sigma Xi, Tau Beta Pi, and the New York Academy of Sciences.

IEEE takes a stand on units (page 164)

Bruce B. Barrow (SM) received the B.S. and M.S. degrees from Carnegie Institute of Technology in 1950 and the degree of Electrical Engineer from Massachusetts Institute of Technology in 1955. In 1962 he received the Sc.D. degree from Technische Hogeschool te Delft (the Netherlands). From 1951 to 1955 he was a member of the research staff at M.I.T.'s Servomechanisms Laboratory, during which time he took a year's leave of absence as a Fulbright Scholar in the Netherlands. He was with Hermes Electronics from 1955 to 1958, giving special attention to communication system problems encountered in the design of tropospheric-scatter radio links. He was with the SHAPE Technical Centre, the Netherlands, from 1958 to 1962, where he conducted research on digital information transmission over fading radio paths. In 1962 he joined the Applied Research Laboratory, Sylvania Electronic Systems, and is now manager of the Communications Research Department. He has been concerned with applying the laboratory's efforts to advanced communication systems, and has directed research projects on coding techniques and on tropospheric-scatter propagation tests.

Ultrasonic studies of solids

Norman G. Einspruch *Texas Instruments Incorporated*

Ultrasonics is being used in many areas in solid-state physics. One is Fermi surface mapping of normal metals by the magnetoacoustic technique. The detailed knowledge gleaned is valuable in theoretical calculations of many of the electrical and optical properties of metals. Another area is that of "hard" superconductors. Measurements of ultrasonic attenuation in the study of the metallurgical microstructure of high-field superconducting alloys (such as the Nb-Zr alloys) could have technological significance, especially in the field of power transmission. A new ultrasonic tool has been developed to aid investigations—the depletion layer transducer. It has prominent advantages over a conventional quartz piezoelectric transducer, including a higher fundamental frequency and the ability to change the resonant frequency by varying the dc bias level. Along with the new transducer, a new piezoelectric semiconductor amplifier produces substantial amplification of ultrasonic waves in photoconductive CdS by applying a dc electric field in the direction of wave propagation. This feature could find use in acoustic delay line technology.

The radio-frequency pulse techniques developed for radar applications during World War II led directly to the use in solid-state physics laboratories of sound waves in this frequency range. A block diagram[1] of the system used in the writer's laboratory for measurement of the temperature dependence of the absorption of ultrasonic waves by solids cooled to the liquid-helium temperature range is given in Fig. 1. The attenuation comparator,[2] developed by R. Truell and his colleagues at Brown University, contains a pulsed oscillator that can produce a radio-frequency (10–200-MHz) pulse of about 1 μs duration. One hundred pulses per second excite the quartz transducer, which then produces a mechanical wave at the driving frequency. Since the electromechanical transducer is intimately bonded to the sample, the mechanical pulse is introduced into the sample and is reflected back and forth between a pair of carefully prepared parallel faces.

After each transit through the sample, a small portion of the energy in the mechanical pulse is reconverted to electric energy by the transducer, and this electric signal is suitably amplified, detected, and displayed on an oscilloscope. All of these functions are performed by the comparator. A photograph of an echo pattern illustrating the exponential nature of the attenuation is given in Fig. 2. The auxiliary oscilloscope with display scanner provides a convenient means for delivering to the Y input of an X-Y recorder a voltage proportional to the amplitude of a given echo in the pattern. Since the resistance of the carbon thermometer decreases approximately exponentially with increasing temperature in the liquid helium temperature range, the logarithmic converter delivers to the X input of the recorder a voltage roughly proportional to T^{-1}. With suitable modification, this arrangement is useful in studying dependence of the attenuation on any parameter for which a voltage analog can be derived—for example, the magnetic field dependence of the attenuation in metals at a fixed low temperature.

Metals

The technologically important transport properties of metals—their high electrical and thermal conductivities—result from the relative ease with which the conduction electrons move through the lattice formed by the positive metallic ions. This motion is limited by the scattering of the conduction electrons by impurities and by lattice vibrations (phonons). Consequently, introduction of ultrasonic phonons into a pure metal crystal and measurement of the absorption of these phonons give detailed information concerning the nature of the interaction between the conduction electrons and the lattice. For example, from measurement of the frequency dependence of the ultrasonic attenuation in a pure metal at sufficiently low temperatures such that the electronic attenuation dominates all of the other loss mechanisms, one can evaluate the relaxation time characteristic of the scattering of electrons by the lattice. This relaxation time is related to the relaxation times that are characteristic of the processes which limit the electrical and thermal conductivities.

The Fermi surface. In a normal metal at absolute zero temperature, all of the electronic energy states that lie below a critical energy (the Fermi energy) are filled; higher-lying energy states are unfilled. Instead of plotting a simple three-dimensional coordinate space with the axes labeled x, y, and z, let us plot the energy surface that bounds the electron distribution, in a three-dimensional wave-number space with axes labeled k_x, k_y, and k_z. This surface is known as the Fermi surface; the wave number $\mathbf{k}$ is the reciprocal of the wavelength of the electron multiplied by 2π. For a free electron moving in a uniform potential, the following relation holds:

$$\mathbf{k} = \mathbf{p}/\hbar$$

where $\mathbf{p}$ is the momentum of the electron; $\hbar = h/2\pi$, where h is Planck's constant. Detailed knowledge of the shape of the Fermi surface is valuable in theoretical calculations of many of the electrical and optical properties

There are many interactions of phonons with solids that may be expected to form the basis for sonic devices in the future. At present, however, they provide the researcher with a valuable tool for probing the nature of the solid state

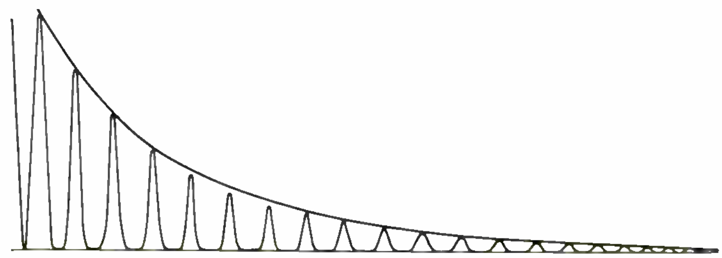


Fig. 2. Waveform of an oscilloscope trace illustrating the exponential nature of the echo pattern.

of metals. From the simplest theoretical viewpoint, the Fermi surface is a sphere; unfortunately, this approximation is not a particularly good one except in the case of the alkali metals, as has been shown for example for sodium and potassium. The Fermi surface of most real metals is usually a topologically complicated affair; a relatively simple, but well-studied Fermi surface is that of copper, which is illustrated in Fig. 3. This geometry was first inferred by Pippard[3] from measurements of the anomalous skin effect, and was subsequently verified by magneto-acoustic measurements. The mapping of Fermi surfaces by the ultrasonic technique has been exploited by R. W. Morse and his associates at Brown University. The measurement of the oscillatory absorption by a metal single crystal in the presence of an external magnetic field gives a direct measurement of the momentum of an electron traveling on the Fermi surface.

In the presence of an external magnetic field, the conduction electrons in the metal follow curved paths around the field; for simple metals the orbits are circular, as is shown in Fig. 4. As the magnetic field increases, the size of the orbits decreases, giving rise to an oscillatory absorption of the sound wave as the orbit size varies by a

Fig. 3. Geometry of Fermi surface of copper within the Brillouin zone. (After Pippard[3])

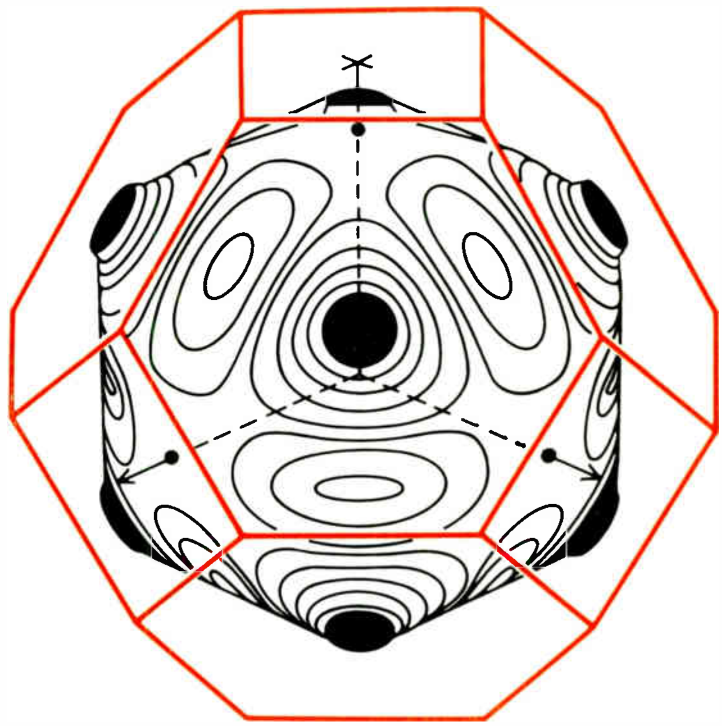
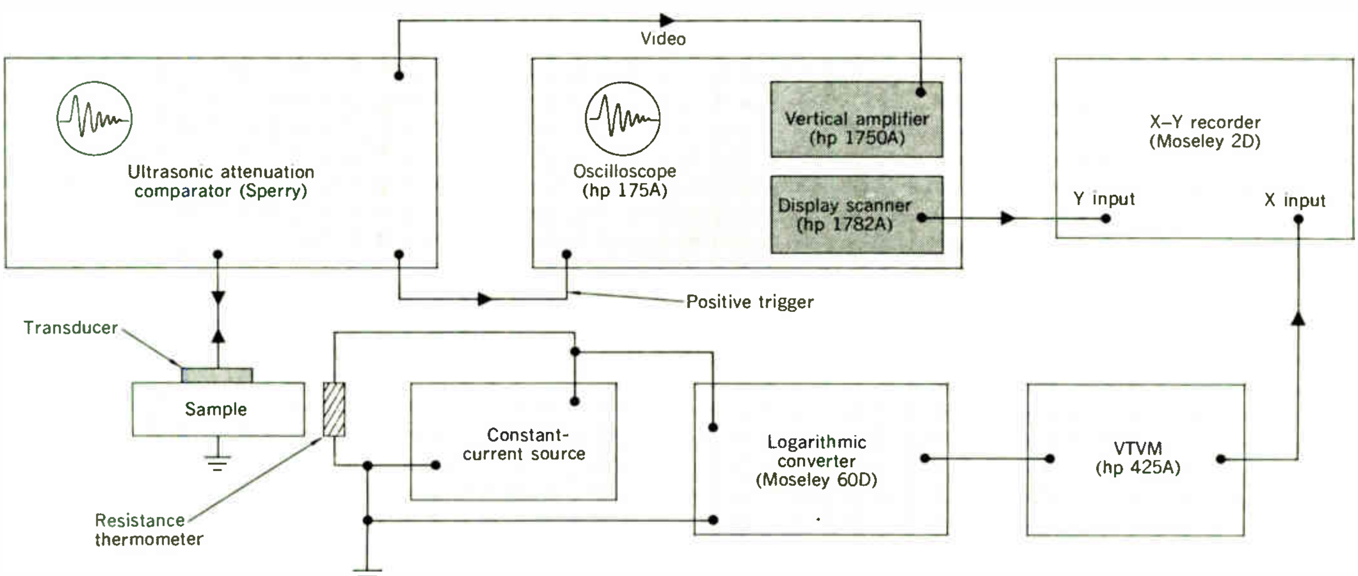


Fig. 1. Block diagram of equipment for measuring the temperature dependence of the ultrasonic attenuation in a solid at liquid-helium temperatures. (After Olsen et al.[1])



wavelength of the sound wave. The relation between the magnitude of the magnetic field and the radius of the orbit is given by

$$r = pc/eH$$

where p is the component of momentum normal to **H**, and c and e are fundamental constants. Since the attenuation goes through a one-period variation for a change in H corresponding to a change in orbit diameter of one wavelength, then the change in orbit radius is

$$\frac{\lambda}{2} = \frac{pc}{e} \Delta\left(\frac{1}{H}\right)$$

yielding

$$p = \frac{\lambda e}{2c} \Delta\left(\frac{1}{H}\right)$$

where $\Delta(1/H)$ is the periodicity of the plot of the dependence[4] of the attenuation on the reciprocal of the magnetic field, as is shown in Fig. 5. By suitably selecting the directions of propagation of the sound wave and the directions of the magnetic field, one can elucidate many of the topological features of the Fermi surface.

Superconductors. Although the phenomenon of superconductivity has been the subject of research by physicists since the time, over half a century ago, that Kamerlingh Onnes found that the resistance of a column of mercury vanished when it was cooled below ~4.2°K, a satisfactory theory of superconductivity has been available for less than a decade. Once again the ultrasonic technique has been found very useful in verifying some of the salient features of this theory, which is attributable to Bardeen, Cooper, and Schrieffer (BCS).[5]

Bömmel[6] in 1954 discovered that the attenuation of an ultrasonic wave dropped rapidly when a superconductor was cooled from the normal to the superconducting state. Early attempts to explain the temperature dependence of the attenuation in the superconducting state on the basis of the Gorter–Casimir[7] two-fluid model were not successful, since the attenuation dropped much more rapidly with temperature than did the relative populations of "normal" and "superconducting" electrons. Some recent data taken by the writer and his colleague L. T. Claiborne[8] on the compressional wave absorption in a superconducting indium–tin alloy are shown in Fig. 6. The excellent agreement between experiment and BCS theory is apparent. An important feature of the BCS theory is the existence of a temperature-dependent energy gap at the Fermi surface; this gap is analogous to the forbidden gap in semiconductors. The superconducting energy gap $\Delta(T)$ is zero at the transition temperature T_c, and increases monotonically to $1.76\ kT_c$ at $T = 0°K$. The presence of the gap reduces the number of electrons that can participate in phonon scattering processes; consequently, the attenuation is reduced as the temperature is decreased. The ratio of the attenuation in the superconducting state to the attenuation in the normal state is given by

$$\frac{\alpha_s}{\alpha_n} = 2\left[\exp\frac{\Delta(T)}{kT} + 1\right]^{-1}$$

Since as $T \rightarrow 0$,

Fig. 4. Circular electron orbits, occurring in simple metals, in the presence of a magnetic field. The orbit diameter decreases as the magnetic field increases.

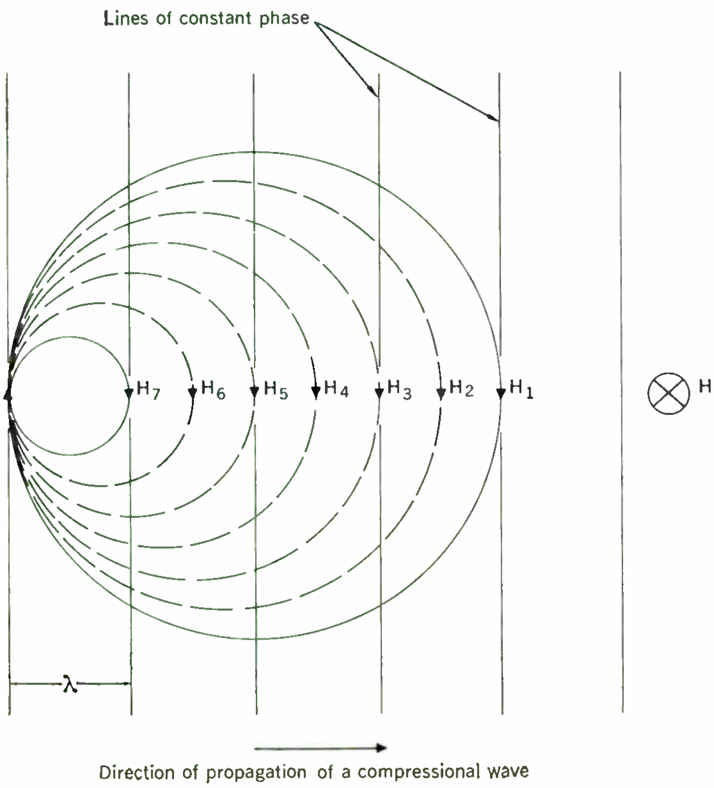
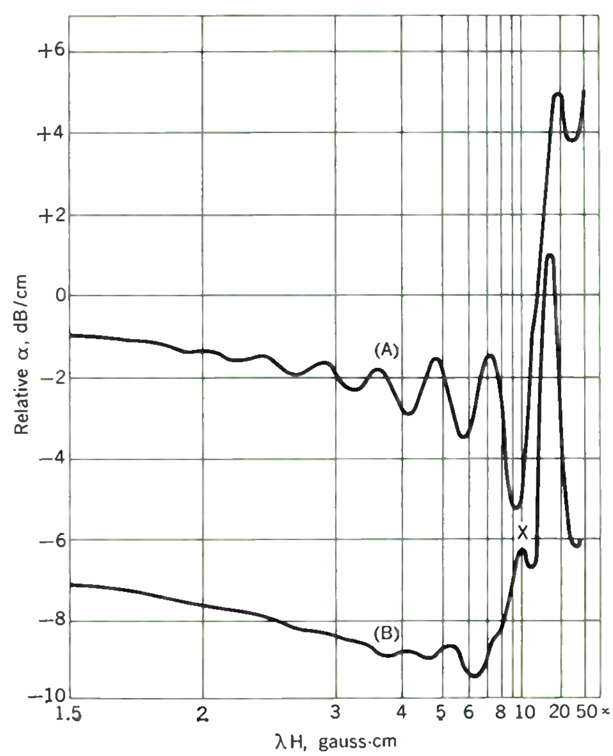


Fig. 5. Magnetoacoustic oscillations in Cu. Longitudinal 75-MHz waves propagating in a [001] direction. Curve A is for H ∥ [110]. Curve B is for H ∥ [100] and is displaced 6 dB/cm downward for clarity. (After Morse and Gavenda[4])



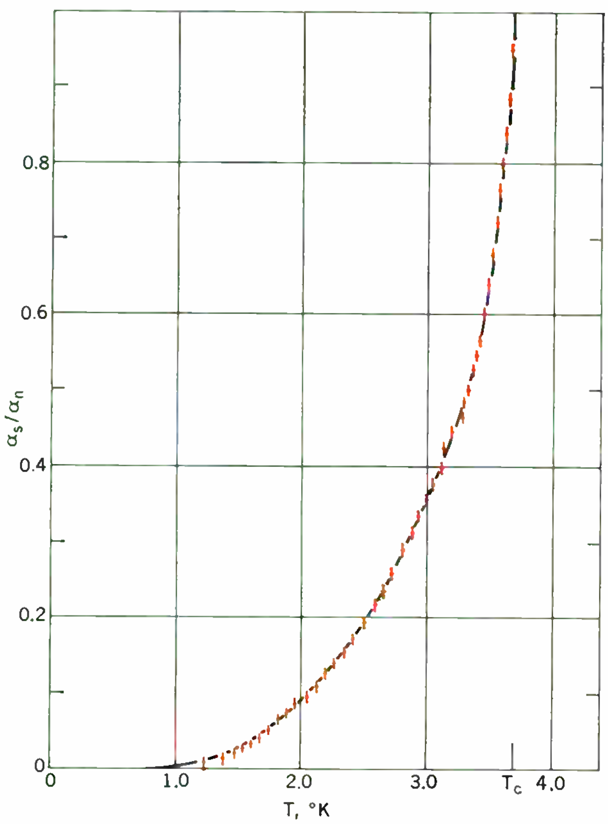
$$\frac{\alpha_s}{\alpha_n} \rightarrow 2 \exp \frac{-\Delta(0)}{kT}$$

the energy gap at absolute zero can be readily evaluated from a plot of ln (α_s/α_n) as a function of T^{-1}. The ultrasonic technique is ideally suited to the study of directional properties of superconductors, since, for example, specific heat measurements tend to average out effects due to anisotropy. At the present time, a detailed ultrasonic investigation of the anisotropy of the energy gap of tin and of the elimination of the anisotropy by the addition of small amounts of impurities is in progress.

The concept of a conductor with zero resistance has great appeal in many areas of technology, particularly in the generation and transmission of electric power. In the early stages of research, it was discovered that a superconductor can be driven normal at temperatures below T_c by the magnetic field associated with the passage of a current through the sample; unfortunately, for the elemental, or "soft," superconductors (e.g., Sn, Pb, etc.), the critical current is too small to be of use in a practical power-handling situation. However, in recent years research on the properties of solids has given rise to a class of materials known as "hard" superconductors, which are capable of remaining superconductors while carrying current densities substantial enough to be of technological importance; for example, high-field superconducting electromagnets fabricated from Nb–Zr alloy wire are now commercially available.

In view of the short electron mean free paths, which result from the presence of impurities and defects that ordinarily occur in these alloys, it was felt there would be no electronic attenuation of the type commonly observed in pure metals in the normal and superconducting state. However, Claiborne and the writer undertook measurements of the ultrasonic attenuation by Nb–Zr alloys in the hope of elucidating the nature of high-field superconductivity. As should have been anticipated, striking

Fig. 6. Comparison with the Bardeen–Cooper–Schrieffer theory of measurements of the ultrasonic attenuation in In-doped Sn. (After Claiborne and Einspruch[8])



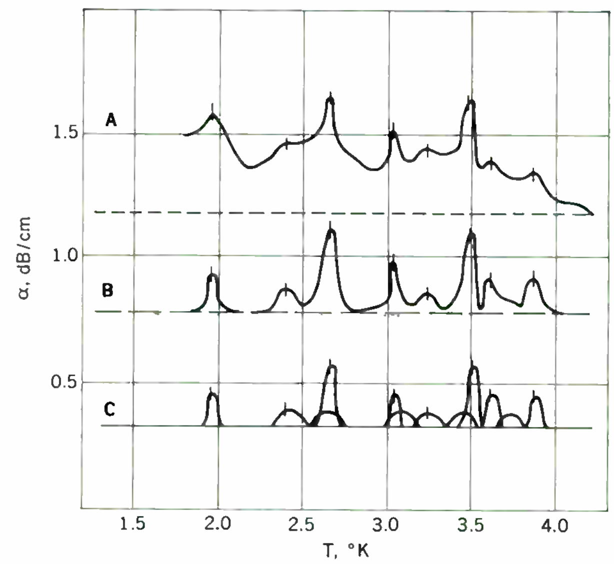
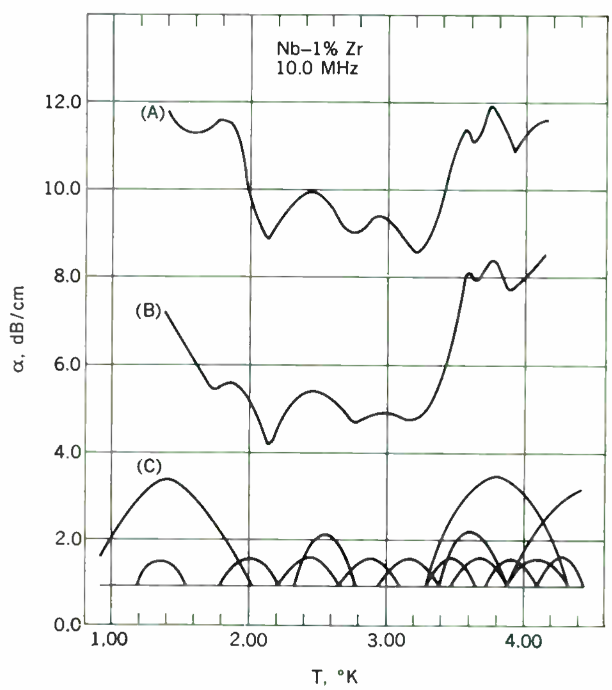


Fig. 7. A—Experimental observation of the temperature dependence of the ultrasonic attenuation in a Nb–1% Zr alloy at 16.5 MHz. B—Composite theoretical curve. C—Group of individual predicted peaks. (After Claiborne and Einspruch[9])

Fig. 8. A—Experimental observation of the temperature dependence of the ultrasonic attenuation in the same Nb–1% Zr alloy at 10.0 MHz. B—Composite theoretical curve. C—Group of individual predicted peaks. (After Claiborne and Einspruch[9])



deviations from BCS behavior were observed[9] in their first measurements on a Nb–1% Zr alloy, as shown in Fig. 7. They found that these data could be decomposed into three families of oscillations with the condition for oscillation given by

$$\nu_s = Nf(T) = N\nu_0(1 - bT^2 + aT^4)^{1/2}$$

where ν_s is the frequency of the ultrasonic wave used for the measurement, ν_0, a, and b are constants, and N is a series of integers. If the constants are evaluated for data taken at a given frequency, the positions of the peaks at any other frequency could be predicted with great success, as can be seen in Fig. 8.

These oscillations in the temperature dependence of the absorption of compressional ultrasonic waves have by now been observed by Claiborne, Olsen, and the writer in several superconducting Nb–Zr alloys, Nb–Mo alloys, polycrystalline La, and polycrystalline Sn. The general features of the data common to all of the materials investigated can be summarized as follows:

1. The structure is a property of the superconducting state.
2. Both the period and the amplitude of the oscillations are decreased as the sound frequency is increased.
3. Annealing decreases the amplitude of the peaks but does not seem to alter the temperature at which a given peak occurs.
4. The structure amplitude is sensitive to the parallelism of the sample faces. Large increases in peak amplitude can be obtained by making the surfaces parallel to a fraction of a sound wavelength.
5. There is some evidence that changing the sample thickness alters the absorption structure.
6. The absorption peaks are periodic in the temperature function $(1 - bT^2 + aT^4)^{1/2}$, which can be derived on a phenomenological basis.

For the foregoing reasons, the utility of the ultrasonic technique in studying the details of the metallurgical microstructure of the high-field superconducting alloys is apparent. It was then felt that it would be of interest to study single crystals of Sn that were not well annealed in the hope of discovering similar deviations from BCS behavior that would be produced by defects in the samples. Oscillations superimposed upon a recognizable BCS-type background were observed[1] and were analyzed using the technique developed for the superconducting alloys. The results of this analysis are presented in Fig. 9, where the temperature dependence of $Nf(T)$ is presented. The measured temperatures of the peaks are indicated on lines of constant $\nu_s l$, where l is the length of the sample. It can be seen that the temperatures at which peaks occur are extremely well determined by the resonance condition. The variation of structure with frequency for fixed length is indicated by the data labeled A, B, and C. The dependence on length is indicated by the data D and E, for which the measurement frequencies are 10.5 and 3.3 MHz respectively; the sample thicknesses are 0.156 and 0.454 cm respectively. The results for the widely different frequencies are almost identical because the products $\nu_s l$ are nearly equal. Thus, it is again indicated that the temperature-dependent absorption structure is determined by the product $\nu_s l$. The primary conclusion indicated by this investigation is that the deviation from BCS behavior is not a result of a mechanism typical of ideal elemental superconductors.

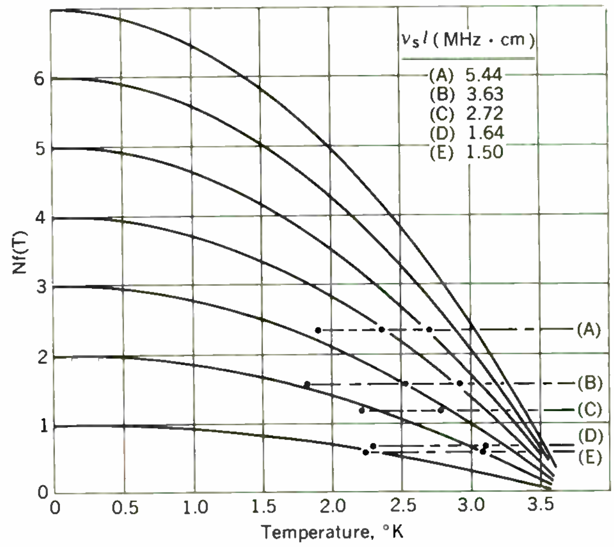
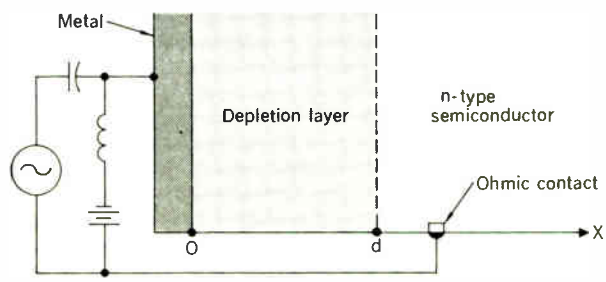


Fig. 9. The set of functions Nf(T) for Sn with N = 1 to 7. Points of constant $\nu_s l$ from the data are plotted according to the normalization procedure $(\nu_s l)K^{-1}$, where $\nu_0 l = K$. For this case K = 2.26 MHz · cm. (After Olsen et al.[1])

Fig. 10. A typical metal–semiconductor contact depletion-layer transducer. (After White[10])



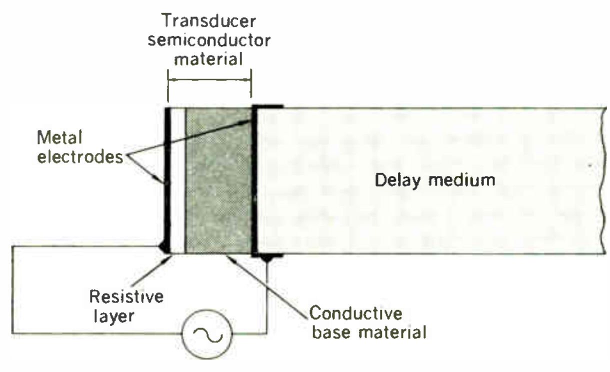
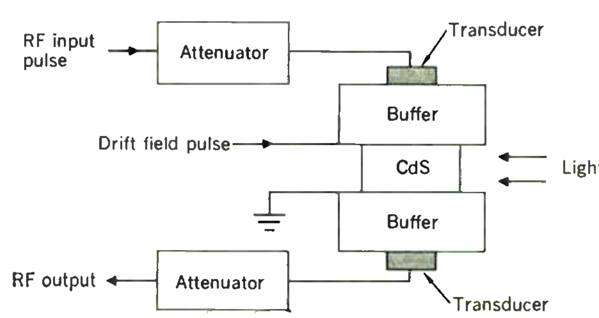


Fig. 11. Diffusion layer transducer. (After Foster[11])

Fig. 12. Piezoelectric semiconductor ultrasonic amplifier. (After Hutson et al.[13])



Depletion-layer transducer

A new electromechanical transducer, which operates as a result of the piezoelectric properties of some semiconductors possessing the sphalerite or the wurtzite structure, has recently been developed.[10] The theoretical range of operation of this transducer is 0.1 to 10 GHz. The active portion of the transducer is the high-resistance depletion layer, which occurs at a p-n junction or at a metal–semiconductor rectifying contact. This device has two prominent advantages over a conventional quartz piezoelectric transducer: (1) The depletion layer is thin; consequently, the fundamental frequency, and therefore the frequency for the maximum electromechanical conversion efficiency, is high. (2) The thickness of the depletion layer depends upon the biasing voltage; hence, the resonant frequency of the transducer can be altered by varying the dc bias level.

In the p-n junction transducer, a narrow junction in low-resistivity material is reverse biased with a dc voltage. Since the resistance in series with the junction is low, most of the voltage drop occurs across the junction, giving rise to an intense electric field. In a piezoelectric semiconductor, the field produces a mechanical stress which, in turn, elastically strains the junction. If an ac signal is superimposed upon the dc biasing voltage, an alternating stress is produced at the junction and introduces an elastic wave, which propagates into the bulk. In the rectifying contact transducer, the depletion layer is formed by reverse biasing the junction between a metal electrode and bulk n-type material. The principles of operation of the two types of devices are identical.

A one-dimensional model, which describes the operation of the device, will be summarized here. The thickness of the depletion layer, hence the fundamental frequency of operation, can be estimated by a straightforward application of Gauss' law, neglecting the piezoelectric interaction. Consider the rectifying metal–semiconductor contact, with the geometry shown in Fig. 10. In the plane of the contact, $x = 0$, the biasing voltage produces a negative charge; in order to preserve charge neutrality, a distribution of positive charge, the depletion layer, is induced in the n-type semiconductor, and extends a distance d into the bulk. Since the low-resistivity bulk material is grounded, $V = 0$ at $x = M$. For a semiconductor, in practical units,

$$\frac{\partial D}{\partial x} = \epsilon \frac{\partial E}{\partial x} = Nq$$

where D is the electric displacement, E is the electric field ($= -\partial V/\partial x$), ϵ is the dielectric constant, N is the density of ionized donors, and q is their charge. The differential equation thus derived is readily integrated to yield

$$m = (-2V_0\epsilon/Nq)^{1/2}$$

where V_0 combines the effects of the biasing voltage and the difference of the Fermi levels. Transducer thicknesses in the range 10^{-3} to 10^{-5} cm are readily obtained, corresponding to resonant frequencies of 100 MHz to 10 GHz, depending upon the biasing voltage and the concentration of impurities.

In one experimental arrangement, a [111] face of 0.1-ohm·cm gallium arsenide crystal, suitably plated to produce a rectifying contact, was bonded to one end of an X-cut quartz rod. The other end of the rod was placed in an 830-MHz resonant microwave cavity and served as the source of ultrasonic waves. The waves generated at the cavity were detected at the depletion-layer transducer; conversely, waves generated by the transducer were detected at the cavity, conclusively demonstrating transducer action.

Although the theoretical high efficiency of these transducers is yet to be realized, it appears that this device will be useful in studying ultrasonic effects in piezoelectric semiconductors, in which the sample and the transducer are integral. The device will also be useful, after development of improved circuitry, in ultrasonic studies in the UHF and microwave regions in a wide variety of materials.

The diffusion layer transducer,[11] illustrated in Fig. 11, is an interesting variation on the depletion-layer transducer. The active region of this device is a resistive layer formed by diffusing copper into the surface of a highly conductive single crystal of CdS; the diffusion process introduces deep acceptor levels which lead to a marked decrease in conductivity. Fundamental frequencies of operation as high as 1 GHz have been observed. Integrated transducer-delay line structures have been fabricated in one-inch-long CdS crystals; this technique for ultrasonic-wave generation is readily applicable to the practical realization of integrated ultrasonic amplifiers.

Thin films of insulating CdS epitaxially deposited on Al_2O_3 and MgO have been used[12] to generate phonons in the 0.5- to 2-GHz range. Transducers deposited on Z-cut quartz and fundamentally resonant at 3 GHz have been driven at 9 GHz and were found to have twice the electromechanical conversion efficiency of X-cut quartz at that frequency. Operation of this device at much higher frequencies is anticipated.

Ultrasonic amplification in piezoelectric semiconductors

In a remarkable experiment, it was demonstrated that substantial amplification of ultrasonic waves could be produced in photoconductive CdS by applying a dc electric field in the direction of wave propagation.[13] In a 7-mm-long crystal, gains of 18 and 38 dB were obtained at 15 and 45 MHz respectively. The experimental arrangement is shown in Fig. 12; the Y-cut quartz transducer is excited by an RF pulse from the transmitter, producing a shear wave that propagates in the CdS crystal oriented so that the ultrasonic wave propagates in a basal plane with particle displacement along the hexagonal axis. The dc drift pulse is applied to the semiconductor through diffused and evaporated indium contacts. The buffer rods serve as delay media and for electrical isolation. Measurement of the change in output signal with respect to the signal observed in the dark with no drift field yielded the following results:

1. With no illumination, the drift field pulse had no effect.
2. With no drift field, increasing illumination yielded increasing attenuation and increasing conductivity, as had been previously observed.
3. With the sample illuminated by the 5770 and 5790 Å mercury lines, the 5-μs drift field pulse had no effect unless it overlapped the 3.5-μs transit time of the 1-μs ultrasonic pulse in the sample. At overlap, the output signal was either increased or decreased with the maximum effect corresponding to complete overlap.

4. With the sample illuminated and complete overlap, variation of the drift field strength produced changes as shown in Fig. 13.

Two striking results of the observation are the appearance of acoustic gain and the crossover from loss to gain at 700 V·cm^{-1}; the drift field at crossover corresponds to a drift velocity equal to a shear wave velocity for CdS for electrons of mobility 285·cm^2·V^{-1}·s^{-1}; the previously reported Hall mobility of 300 cm^2·V^{-1}·s^{-1} is in excellent agreement with this determination. It was also observed that with no input signal, acoustic oscillations were produced by amplification of noise in the crystal in the presence of the drift field.

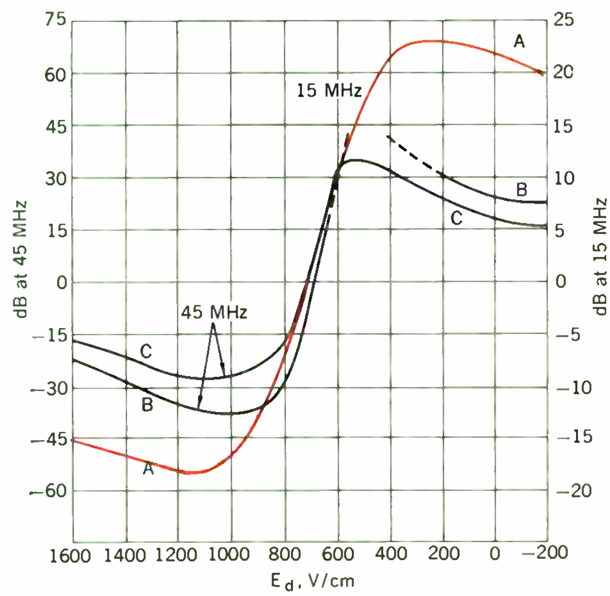


Fig. 13. Observation of ultrasonic amplification. (After Hutson et al.[13])

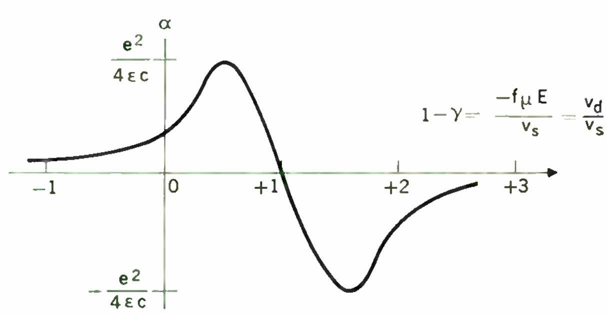
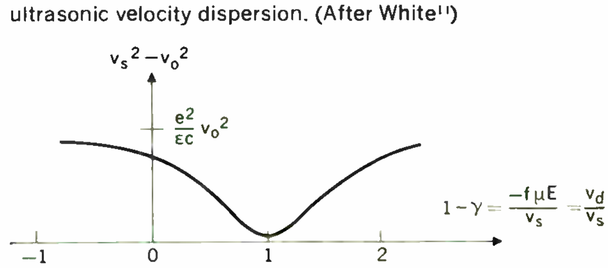


Fig. 14. Theoretical prediction of drift field dependence of ultrasonic attenuation and amplification. (After White[14])

Fig. 15. Theoretical prediction of drift field dependence of ultrasonic velocity dispersion. (After White[11])



Earlier phenomenological calculations on wave propagation in piezoelectric semiconductors were extended[14] to include the effects of a drift field on the sound absorption process. From the piezoelectric equations of state

$$T = cS - dE$$

$$D = dS + \epsilon E$$

and from the equations of motion for an elastic material, a wave equation

$$\rho \frac{\partial^2 u}{\partial t^2} = \frac{\partial T}{\partial x} = c \frac{\partial^2 u}{\partial x^2} - e \frac{\partial E}{\partial x}$$

can be derived; it should be noted that this is a one-dimensional analysis with the strain S defined as $\partial u/\partial x$; d is the piezoelectric constant, E the electric field, D the electric displacement, and ϵ the dielectric permittivity. Applying Gauss' law, the equation of continuity, and the expression for the current density J in an n-type material,

$$J = q\mu n_c E + qD_n \frac{\partial n_c}{\partial x}$$

the following equation can be obtained

$$\frac{-\partial^2 D}{\partial x\, \partial t} = \mu \frac{\partial}{\partial x}\left[\left(qn_o - f\frac{\partial D}{\partial x}\right)\right] - D_n \frac{\partial^3 D}{\partial x^3}$$

where μ is the electron mobility, n_c is the density of electrons in the conduction band, and D_n is the electron diffusion constant. The density of electrons in the conduction band may be written as

$$n_c = n_0 + fn_s$$

where n_0 is the equilibrium concentration of electrons, n_s is the space-charge density, and f is the fraction of the space charge that contributes to the conductivity; in the absence of traps, $f = 1$. Under small-signal assumptions, the electric field and material displacement are given by

$$E(x, t) = E_0 + E_1 e^{i(kx-\omega t)}$$

$$u(x, t) = ue^{i(kx-\omega t)}$$

where E_0 is the field due to the applied dc voltage and E_1 is the amplitude of the sinusoidal electric field that accompanies the ultrasonic wave. Combining the equations of state, the wave equation, and the third-order partial differential equation describing D, a dispersion relation is derived. Since k is complex, taking real and imaginary parts of the wave number yields, for $K^2 \ll 1$ and $\alpha \ll \omega/v_s$,

$$\alpha = \frac{K^2}{2}\frac{\omega_c}{v_s\gamma}\left[1 + \frac{\omega_c^2}{\gamma^2\omega^2}\left(1 + \frac{\omega^2}{\omega_c\omega_D}\right)^2\right]^{-1}$$

$$v = \left(\frac{c}{\rho}\right)^{1/2}\left[1 + \frac{K^2}{2}\,\frac{1 + \frac{\omega_c}{\omega_D\gamma^2} + \frac{\omega^2}{\omega_D^2\gamma^2}}{1 + \frac{\omega_c^2}{\gamma^2\omega^2}\left(1 + \frac{\omega^2}{\omega_c\omega_D}\right)^2}\right]$$

where v_s is the phase velocity of sound wave, $K = d^2/\epsilon c$, ω_c is the dielectric relaxation frequency ($= n_0 q\mu/\epsilon$), ω_D the diffusion frequency ($= v_s^2/fD_n$), and $\gamma = 1 -$

The golden anniversary of electric wave filters

The filter art has grown from relatively simple lumped-circuit ladder networks to synthesized active and passive networks that may make up 50 percent of the electronics of a satellite repeater

Anatol I. Zverev *Westinghouse Electric Corporation*

In filter technology, the synthesis techniques of Cauer and Darlington, among others, have come into widespread use. With the swing to higher and higher frequencies, these techniques have enabled circuit designers to obtain high performance with coils of moderate Q in L-C circuits, with quartz resonators of high Q, and with mechanical and ceramic resonators with desirable qualities somewhere between those of L-C components and of quartz.

In the evolution of the electronics industry, the first two major developments—radio and the electronic tube—were followed closely by a third, the filter. Filter technology was born in the year 1915 when K. W. Wagner, on January 7, and G. A. Campbell, on July 5, working independently on different sides of the Atlantic, both proposed the basic concept of the filter.* Their results evolved from earlier work on loaded transmission lines and the classical theory of vibrating systems. The year 1965, therefore, marked the golden anniversary of the electric filter.

During the past 50 years filters have so permeated electronic technology that the modern world is hardly conceivable without them. They direct, channel, integrate, separate, delay, differentiate, and transform all kinds of electric energy and information.

The generalization of the filter concept began when it was found that filter theory could be used to illuminate problems in mechanical and acoustical systems. By use of an electromechanical analogy, filter theory can be applied to many seemingly unrelated systems for which natural modes of vibration are of interest, e.g., loudspeaker design, crystallography, architectural acoustics, airframe behavior, and mechanical systems design. Filter theory first shows how to coordinate the action of several resonant elements in order to obtain uniform transmission over a prescribed frequency range. Then the concept of an ideal filter with lossless elements that delivers all of the input energy to its output over the widest possible frequency range establishes the requirements for broadbanding under prescribed constraints.

Application of filter theory has now gone far beyond these first generalizations. The concepts of exact synthesis techniques for prescribed transfer and immittance functions, of approximating arbitrary functions with realizable rational functions, of time domain synthesis, matched filters, parametric elements, and various other active devices, have added new vitality to an already flourishing technology.

Today, a systems engineer can specify almost any type of stable, single-valued analytic function as a block in a block diagram with a reasonable assurance that it can be approximated, realized, and built into an operating unit. This exact mathematical technique is so successful that the newer electronic systems are literally packed with synthesized passive and active networks. Satellite repeaters are a good example. More than half the blocks in a typical block diagram for such repeaters are called filters even though their function, in many cases, is radically different from what the term would have led us to expect 20 years ago.

Early filter development

In prefilter days, selectivity was obtained by the use of single reactances or single resonances connected in series or shunt. Much use was made of such terms as "ac blocking," "dc blocking," and "wave traps."

In contrast to these crude devices, the first scientifically designed filters consisted of a cascade of simple identical sections forming a ladder network. They were marvelously effective because the selectivity increased with the number of sections. The ladder could be simply and elegantly treated by the so-called image parameter theory, analogous to transmission-line theory, in which the parameters of the network are expressed in terms of the image impedance and the image transmission factor. Although this method was a great step forward, the resultant selectivity was far from optimum because the networks had no transfer zeros near the pass band and steep attenuation skirts were unobtainable.

The discovery by Zobel, published in 1923, of a practical method of designing selective filters with an unlimited number of reactances was undoubtedly a work of genius. It was the only known method until about 1940 and the only practical method until the mid-1950s. Zobel's theory is somewhat artificial in nature since it is based on image parameters that only approximate the effective operating parameters and assume nonphysical elements—the terminal image impedances. But Zobel's results not only enabled designs for arbitrarily prescribed stop bands, but also improved the end-load matching. This technique could reduce the pass-band error due to nonphysical constraints on the terminations. A further improvement in match was later obtained by Bode.

* The term filter is used here in its restricted sense. That is, a filter is a network of reactances that passes electric signals within one or more frequency bands and strongly attenuates all others except those in the immediate vicinity of the band edges.

Passive networks were also under investigation by a number of other researchers. In 1924 R. M. Foster published *A Reactance Theorem*. This theorem made it possible, for the first time, to realize a network that exhibited at its terminals a positive-real rational function as an impedance or admittance.

Foster partitioned the given rational function into a sum of partial fractions that could be identified easily as a series connection of impedances or as a parallel connection of admittances. Wilhelm Cauer then expanded the rational function into a continued fraction representing a ladder network. Each method gave two alternate networks, which were called canonical forms because they could always be obtained from a realizable immittance function and because they employed a minimum number of elements.

The theory of *L-C* one-port synthesis has since been ornamented with a great variety of elegant results but the basic theory was essentially complete when the Cauer forms were published. It was soon recognized that the Foster–Cauer methods could be adapted readily to give a more general theory of two-element-kind synthesis, i.e., the synthesis of *R-L* and *R-C* networks as well as of *L-C* networks.

It was realized, however, that mere adaptation of Foster's *L-C* synthesis was not going to solve the problem of synthesizing *R-L-C* networks from their given immittance functions. This much more difficult problem demanded a correspondingly more complicated solution. The first such solution was obtained, in brilliant fashion, by Otto Brune, and was published in 1931. The stage was now set for a breakthrough of such fundamental importance that it would overshadow even the great school of image-parameter design.

The modern era

In the late 1930s, both Wilhelm Cauer and Sidney Darlington were preoccupied with the nascent and, at that time, academic theories of exact synthesis. The new theory of filter design which they would generate would, at first, have little practical advantage, if any, over the old. Even though a small family of specialized problems that resisted image-parameter treatment would yield readily to the exact method, the principal motivation for its use lay in the fact that network theory demanded fresh insights that would carry a given problem successively through the following stages:

Approximation synthesis—to obtain a realizable transfer function that would approximate the requirements within a prescribed tolerance
Transfer-function synthesis—to manipulate the transfer function so as to give a realizable driving-point function
Realization or driving-point synthesis—to realize the driving-point function in an actual network

Darlington, in 1939, and Cauer, in 1940, both published the same theory to solve the set of problems just outlined and both displayed the same dazzling virtuosity in mastering a long sequence of thorny mathematical complications.

The importance of the new method was not recognized immediately. It could be used to design better low-pass filters but it failed to provide such designs in practice because of the extremely heavy burden of computation required. It was not until the advent of cheap computation methods, in the 1950s, that Cauer–Darlington filters came into widespread use. So many computer-prepared designs have now been published that designing an elliptic-function filter involves little more work than copying numbers out of a book, and this technique is actually easier than the image-parameter method. The older method is falling out of fashion because it can be generalized only at the cost of rapidly increasing artificiality and complication. Its principal virtue—simplicity—is then lost and no incentive remains to use it. Within its special field of application, however, it is still usable, and is used, despite the dictates of fashion.

The Cauer–Darlington theory is respected and admired because it is the first tall peak of a mountain chain whose limits we cannot yet survey. Consider, for example, the design of a system that consists of an operational amplifier embedded in a large *R-C* network. The *R-C* network has natural modes that must lie on the negative-real axis in the complex-frequency plane. The zeros may, theoretically, lie anywhere. By using either the *R-C* synthesis of Guillemin or that of Dasher, one can systematically realize a network with zeros in any locations except on the positive-real axis—a very light restriction. Cauer–Darlington synthesis will probably be used in solving the approximation problem. Image-parameter theory has no relevancy to such a problem.

We now synthesize networks and systems by employing a fusion of many theories produced by many authors. In this considerable body of literature there are many references to Cauer and Darlington, but this bibliographical distinction is currently being superseded by an even greater one. The use of these references is now disappearing gradually. It has been assumed that there is little point in listing the names that everyone now takes for granted.

Filter applications

Let us examine a block diagram of a typical receiver such as might be employed in radio, radar, ultrasonics, sonar, acoustics, or in mechanical or geophysical studies (see Fig. 1). The relevance of the theory of filters, reactance networks, and network synthesis is crucial in each of the blocks shown.

Receptor. The receptor is a transducer that converts the incoming signal energy into an electrical form suitable for processing by the receiver. The receptor may be an antenna, a piezoelectric transducer, a tape recorder head, or some other device. No matter what it is, the theory of reactance networks must be used in its design and optimization.

Impedance matching network. This network is not always a physical transformer with primary and secondary windings on a ferromagnetic core. It may be a low-pass ladder giving a prescribed Chebyshev pass band with controlled equal ripples and moderate to high attenuation outside the band of impedance matching. It may also be a bandpass filter that combines with the preselector.

Multicoupler. This device is designed to feed several receivers from the same receptor. It must maintain impedance matching with a high signal-to-noise ratio. Filters and hybrid networks are critical.

Preselector. The preselector is a bandpass filter that has low insertion loss for a high signal-to-noise ratio. It is usually tunable over the frequency range of the desired signals. While the most critical selectivity problems are dealt with in the IF block, the preselector must have high image rejection. It may be required to attenuate strong signals that otherwise would result in cross-modulation with the desired signal in the carrier amplifier.

Carrier amplifier. This device may be a reactance network, as in the case of a parametric amplifier. In other instances, the synthesis of interstage coupling networks is often paramount.

Frequency converter. The variable-frequency oscillator, frequency multiplier, and first converter contain important filter networks. The multiplier consists of linear and nonlinear reactances that give it many points of resemblance to a parametric amplifier.

IF filters. The entire character of the receiver is governed by the type of IF performance, as follows:

1. Conventional IF—Utilized here is a cascade of coupled resonators with 60-dB bandwidth that is twice the 6-dB bandwidth (i.e., shape factor is 2).

2. High adjacent-channel selectivity—This is obtained by symmetrical Cauer–Darlington elliptic-function filters. The shape factor may be as low as 1.01.

3. Single sideband—High selectivity is needed on the carrier side of the pass band but not on the other side. For economic reasons unsymmetrical stop bands are usually provided.

4. Gaussian—To obtain linear-phase filtering with low transient distortion for pulse transmission, antijamming, FM, and video applications, the Gaussian shape is optimum.

5. Matched filters—If a filter is excited by a nonsinusoidal voltage, certain time functions lead to much greater output than do others. By designing both the signal shape and the network to obtain a matched pair, a large output can be obtained that will cause the signal to stand out when used with conventional frequency-domain filters. A dominant feature here is that the improved signal-to-noise ratio at the receiver is obtained without increasing the peak power output at the transmitter. This technique extends the range limit of radar and sonar systems and it increases the information rate of communication links.

6. Coherent integrator—This is a sophisticated form of comb filter that extracts Doppler information from a radar return signal. When a succession of pulses having a coherent frequency content excites the comb, one comb-filter output adds the resulting damped sinusoids to produce a substantial pulse. The position of this pulse in the comb gives the target speed indication.

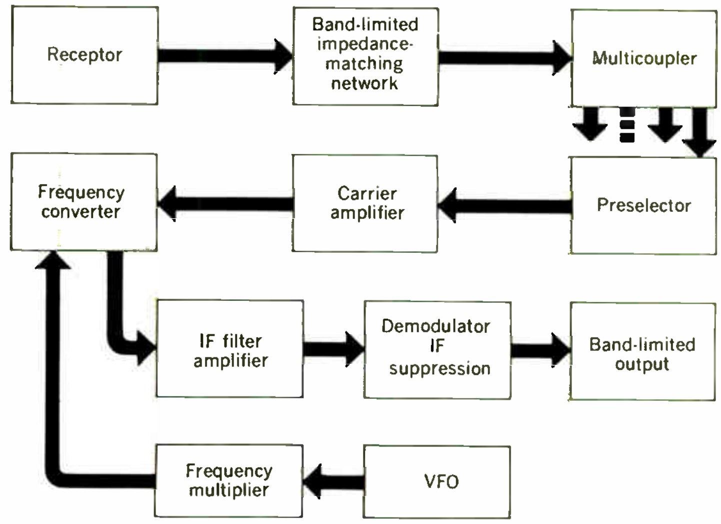


Fig. 1. Block diagram of a "generalized" receiver such as might be used in a variety of electronic systems.

The art of practical technology

From the beginning, the principal objective of scientific filter design has been to find theoretical methods that would accommodate actual physical components and fit them exactly into optimized networks. The desire of the creative engineer has been to produce hardware with performance that agrees exactly with the theoretical predictions.

This search for useful theories has led to some of the most elegant mathematics to be found in the practical arts. In *L-C* filters, for example, the inductors are often expensive toroids whereas the capacitors are relatively inexpensive. The constant search for optima has produced an ingenious method for designing "minimum-inductance" filters that use fewer expensive components and more inexpensive ones. Since high-Q coils are bulkier and more expensive than those of moderate Q, various theories have enabled "predistorted" and "equalized" networks to maintain high performance with coils of lower Q.

As electronic systems began to use more and more of the available electromagnetic spectrum, the need for very narrow bands became urgent. Filter design was developed to accommodate quartz resonators that offer practical Q's up to a quarter of a million and stabilities to match.

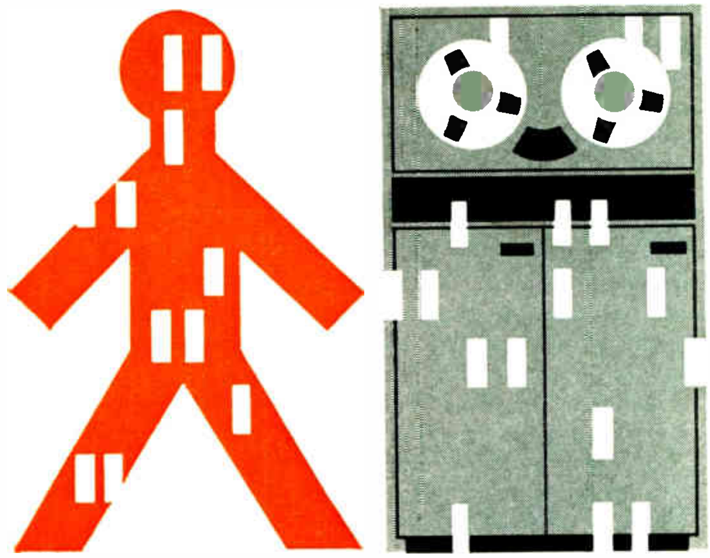
The quartz crystal, to a first approximation, is represented by a network of an inductance and two capacitors that are inseparably given as a single unit. Consequently, a considerable amount of fresh theory was needed to treat quartz networks as components so as to reap the advantages of their enormous Q figures. But quartz crystals are expensive, so additional resourcefulness was needed to make use of the cheaper mechanical and ceramic resonators that have quality factors somewhere between those of *L-C* components and of quartz.

As the electronic art progresses, ever-higher frequencies are used. At first, the problem of separating frequency bands in the VHF and UHF regions was met by using essentially the same theory as was used at lower frequencies. Individual resonances or reactances were realized by open- or short-circuited transmission lines. These hybrid filters used distributed elements to approximate lumped elements. As the upward frequency trend continued, it was found that helical resonators with electromagnetic coupling would serve.

The lumped-element concept ultimately was abandoned in favor of continuously distributed networks. With the new approach it became more sensible to start with the wave equation if one were to understand selectivity problems at microwave frequencies and above. This was in opposition to the old approach whereby lumped-circuit synthesis began with the energy equations that define storage and dissipation in R, L, and C.

The author acknowledges the assistance of P. R. Geffe in the preparation of this paper.

Human factors in engineering



Part I— Man in the man-made environment

Since the "knobs and dials" era, the human factors field has evolved in scientific sophistication, has undergone changes of name and emphasis, has influenced the design of hundreds of devices; but even now its borders are difficult to define

Nilo Lindgren *Staff Writer*

This introductory article describes something of the origin, setting, and evolution of human factors engineering as an organized discipline, and provides an overview of some of its major ramifications. It finds that despite the parochial military auspices under which the work began, HFE now encompasses a bewildering diversity of subjects and aims. It traces the development of the man–machine system concept (central to much human factors thinking), discusses the comparative roles of psychology and engineering, and, in the broadest sense, discusses the role of the human factors engineer vis-à-vis the question of man in the man-made environment. In conclusion, it asks whether or not there may be more to the HFE "name" problem than meets the eye.

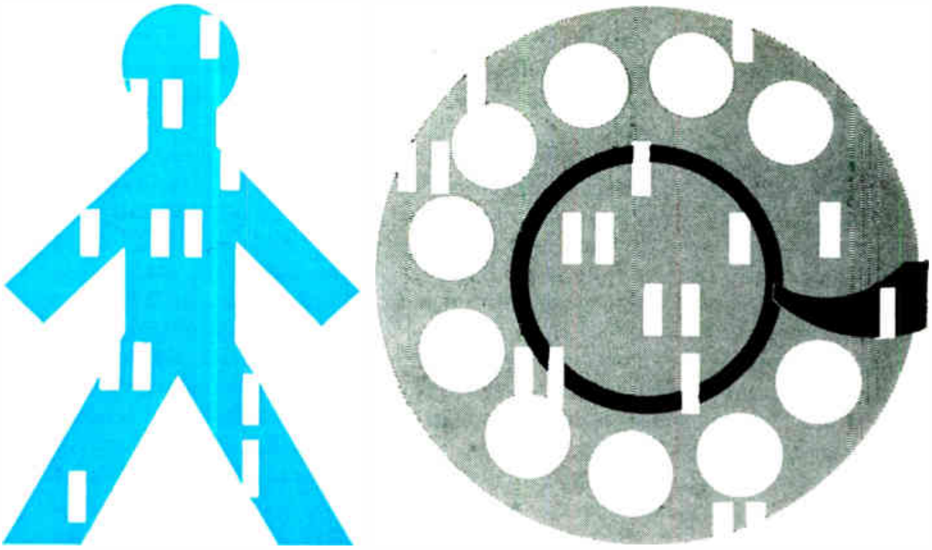
Common sense or science?

Contempt is probably the first barrier to overcome. The human factors field has long had a bad name, and one that admittedly still lingers on in some engineering circles. Those engineers who have not kept up with human factors developments are apt to exclaim contemptuously, "Oh, those knobs and dials people! It's all nothing more than common sense!" It is certainly true that the arrangement of knobs and dials on aircraft control panels or on radar consoles does not convey anything of the modern scientific mystique, but the knobs and dials era was only the very first manifestation of this emergent field of endeavor. A lot has happened since, and although someone like John W. Senders of the Administrative Committee of the IEEE Human Factors Group can still exclaim, "The curse of human factors is that it is not analytical!" the field does appear to be gradually assuming scientific wrappings.

Furthermore, it is true that in the past common sense and intuition often did suffice in the solution of "human factors" problems in engineering design and development. Even today, in the broadest sense, every engineer, whether consciously or not, whether successfully or not, must be a common-sense practitioner of human factors engineering in that he is involved in designing artifacts for human use. However, it is also true that increasingly he is being confronted by problems of man–machine systems so complex as to demand the services of specialists in the human factors field. But to know when and why he needs the specialist, the engineer needs to know what human factors engineering is, and what it can and cannot do for him.

Toward a definition

What is human factors engineering and what areas does it encompass? Why and how has it been emerging as a separate discipline? In the latter days of World War II, human factors engineers (then called human engineers) worked primarily on weapons systems, and their name became associated with fighter aircraft instruments and



controls, radar display systems, fire-control systems—with knobs and dials. The almost exclusively military context is still evident in a 1953 special panel report, prepared by Drs. Paul M. Fitts, S. S. Stevens, and others, on the role of the human engineer in national defense. This surprisingly homey example of theirs incorporates a pragmatic definition of the aims of human engineering: "A new weapon that can be operated only by a man with three arms is not engineered for human use, nor is a system to be relied upon in battle if it is so complex that only the scientists who designed it can maintain it in operation."[1] And: "Human engineering proceeds on the assumption that the capacities and abilities of men are set within certain natural limits and that the way to design good weapons is to adapt them properly to human capacities. . . . In collaboration with other engineers, the human engineer aims to develop new and improved equipment and man–machine systems that will simplify the operator's task and improve the probability of mission accomplishment."[1] The pursuit of this aim brought together, for the first time, psychologists, physiologists, physicists, design engineers of all kinds, and industrial engineers (most notoriously known for their time-and-motion studies). As Alphonse Chapanis and his colleagues point out in the first textbook to be prepared in the human engineering field (1949),[2] the work in the war began too late to do any real good. However, it has continued on a broadening scale since then and under a variety of names—applied experimental psychology, biotechnology, biomechanics, psychoacoustics, human engineering, applied psychophysics, engineering psychology, human factors, ergonomics (in Great Britain), operations research, systems research, man–machine systems—so that it is difficult to define the borders of the emerging human factors field without tracing the successive stages of its evolution. The plain fact is that now "human factors engineering" means very different things to different people. It is almost easier to ask: What is *not* human factors?

In the view crystallized by Fitts and his colleagues in 1953, the requirements were as follows: "In the design of military equipment, human engineering places major emphasis upon efficiency as measured by speed and accuracy of human performance in the use of the equipment. Allied with efficiency are the safety and comfort of the operator. The successful design of equipment for human use requires consideration of the man's basic characteristics, among them his sensory capacities, his muscular strength and coordination, his body dimensions, his perception and judgement, his native skills, his capacity for learning new skills, his optimum work load, and his basic requirements for comfort, safety, and freedom from environment stress."[1]

All of the human factors mentioned in that paragraph, and many others, have been extensively studied vis-à-vis the most varied machines and goals. Gradually, too, as the machines grew more complex, the emphasis of that view has shifted until now, in the most specialized sense, the man and the machine are taken as a single entity[3]—the man–machine system—and this conception perhaps more than any other now distinguishes the field from its parent fields.

The war between man and machine

Throughout all the stages of invention and evolution of machines, men have suffered accidents through their use, but nothing much was done about the accidents as such. It was accepted that machines take their toll of human life, and usually the accidents were characterized under the amorphous heading "human error and carelessness." In fact, it is a trait of human beings that once they do adjust to a machine, no matter how much awkwardness is involved, they resist having it changed even though the change means improvement in function, ease of use, and so on.

Perhaps events could have gone on in more or less the same way for thousands of years had not the social engine of the great Western Tradition slipped into high gear and hurled us all headlong into one revolution after another, engendering one generation after another of all forms of machines in these so-called industrial, technological, and informational revolutions, and radically modifying all human life on this planet.

As time has passed, the machines have grown bigger, more powerful, more complex, faster, more versatile, smarter, noisier, more dreadful, more noxious, and so populous that they threaten to choke up the space in which man lives. How men and machines can live together has become a deep social problem. To take only one instance, the automobile population of the United States is already one third the human population, and in the big cities where man now lives in a nearly totally man-made environment, the cars and the people are in such a tight competition for the same air and the same space that it is dangerous for the human to maneuver in any remaining available space and to breathe the air that has already been used once by the automobile. A man driving his car on a deserted country lane might be regarded as being in a just marginally symbiotic relationship with his machine, but in the city and on the superhighways the relationship is mutually destructive. Moreover, the city, the totally man-made environment, is becoming the normal condition for the majority of the people.

Many human factors engineers worry very much about these broad social and cultural effects; they feel that the "engineering" of man's environment to make it truly viable for "human" life is a legitimate concern of human factors endeavors. In this sense, it may not be totally absurd to view these human factors engineers as being among the first lines of counterattack against the steadily increasing encroachment of the machine. If one looks at it in this fashion, one can find representatives of the counterattack on the machine in all the interdisciplinary fields that have sprung up since World War II. The English cybernetician, Gordon Pask, for instance, foresees the machines of the future as being organized on biological principles so that they will have the characteristics of living creatures, whereby we humans can live in greater harmony with them. The desire to influence the design of machines so that humans can live with them in *all* respects (not just as the operators of them) then becomes both a broadly idealistic or utopian aim as well as a highly specialized practical one.

The human factors investigators who do worry about such broad questions are undoubtedly in the minority, although one may hope that their number is growing. The majority of these people, of course, have worked on the narrower and more specialized design problems that became apparent when the role of the human operator(s) in man–machine systems reached the critical point.

There is another aspect of the evolution of machines that made the need for intermediary specialists more crucial. Both designers and users have become specialists of different kinds, leaving a gap between them of distance and time, of language and communication, of knowledge of each other's intentions, capabilities, and needs. Topologically speaking, wherever a significant gap appears between the engineering designer and the eventual user(s) (including the innocent bystanders), there is probably the need for the services of a human factors specialist. (For those who have now been led to think that only the complex, high-speed machines are involved in this equation, we should mention such relatively simple problems as the design of gas stoves, for which the designer must decide on the most "logical" arrangement of the gas controls. The human factors findings even in such simple problems often turn out to be different from what common sense would dictate.) Wherever the gap widens, wherever the designer is isolated from the user or operator, wherever the artifact designed becomes steadily more complex, the danger grows greater that a mismatch or misalliance of user and artifact can, and is likely to, occur, unless the designer takes into account the special disposition, characteristics, and capability of the individual user. Such mismatches have indeed occurred, although their potential seriousness did not dawn in the engineering mind until the second World War, when all machines made a quantum jump in complexity, size, speed, maintainability, and so forth. Then, when thousands of men were being trained to operate the new machines, the consequences of "inhuman" design became more directly apparent in the great increase in "accident" rates. At that point, the engineers and psychologists began to take a closer look into the dark bin of what was called human error, and they have been getting into deeper and deeper problems ever since.

The first human factors groups

The first groups to become organized around the new specialty, which attempted to fit the machine to the man and which acted as a bridging discipline between psychology and engineering, were in the military laboratories. A good, concise recount of these first groups has been given by Henry P. Birmingham.[4] Early research work on antiaircraft fire control was done under the National Defense Research Committee, and similar work was going on in Great Britain and Germany (where it developed in the medical profession).[4] In 1945, a group was established at the U.S. Naval Research Laboratory in Washington, D.C., headed successively by Dr. Franklin V. Taylor and Henry P. Birmingham. This group, now called the Engineering Psychology Branch, is still very active, as is a group founded about the same time at the U.S. Air Force Aeromedical Laboratory in Dayton, Ohio, by Paul M. Fitts, who went on to head up a Human Performance Center at the University of Michigan until his untimely death last year. The first industrial groups were apparently founded some time later; an early one in the communications field was set up at Bell Labs under John Karlin, a psychologist, although much work on speech factors had been pursued there many years earlier by engineers without recourse to psychological methods and insights. Another early group was that at the Hughes Aircraft Company under Stanley Roscoe. Both the Bell and Hughes groups are still going strong.

A slightly different perspective on the origin of human factors was that taken by Ross A. McFarland, another early proponent of the field, a couple of years ago: "Human factors, as an organized discipline, may be said to have arisen within the aircraft industry and is to a great extent still centered there. In a recent survey of human engineering activities, it was found that virtually all manufacturers of airframes, missiles, helicopters, and aircraft components either have human factors programs within the company or utilize the services of specialists in this field."[5] Today almost every large industrial concern has at least one human factors group, and over the past decade and a half "literally hundreds of devices and systems have been affected to a greater or less extent . . . by human engineering considerations."[6]

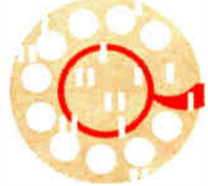
Broader professional recognition of human factors engineering came with the establishment of groups within a number of the older societies, as in the American Society of Mechanical Engineers; the Society of Engineering Psychologists, a branch of the American Psychological Association, was composed mostly of experimental psychologists, as was the Human Factors Society, a separate society founded in 1956. The Professional Group on Human Factors in Electronics was organized within the IRE in 1958. H. P. Birmingham, who was primarily responsible for getting this group started, has said that it was his feeling that human factors would need more engineering and mathematics "if it was going to go anywhere." This group has consistently maintained the deepest engineering and mathematical orientation in the new discipline. Its sixth annual meeting last May concentrated on problems related to the booming computer sciences, and the seventh meeting, scheduled for this May,[7] will reflect the current warfare in Vietnam and problems related to lunar exploration.

Add one part psychology, one part engineering, stir well

Psychology and engineering were the major ingredients. To these were added pinches of physiology, anatomy, physical anthropology, and many other basic disciplines; more recently, ingredients from the social sciences have been stirred in, as group performance capabilities became important in the larger command and control systems, for instance. How well is the cake baking? Judging from the fragrance, the mixture is taking on a new character. But isn't it too soggy in the middle? Quick, throw in more basic mathematics to leaven it and give it a more scientific structure! Maybe a cybernetic icing will make it look really good, or maybe it needs the cybernetics right at the core. The *ad hoc* recipes aren't satisfactory any more. There have been some very striking stages of achievement; however, one cannot escape the feeling that, if anything, the more significant and conclusive problems and achievements of this field still lie ahead. The cake is only half-baked.

As Franklin V. Taylor said in a long, brilliant discussion of the field some years ago, "At the start of the venture, all human engineering experimentation was *ad hoc* in nature. Today there is a growing belief that engineering psychology theory may be developed to a point where it will serve both science and technology far more effectively than purely empirical practical research ever could. This belief is leading many experimenting human engineering research programs to bend every effort to substitute basic human engineering research programs for programs"[6] concerned with specific devices only. This view is echoed again and again by the present leaders of the human factors field.

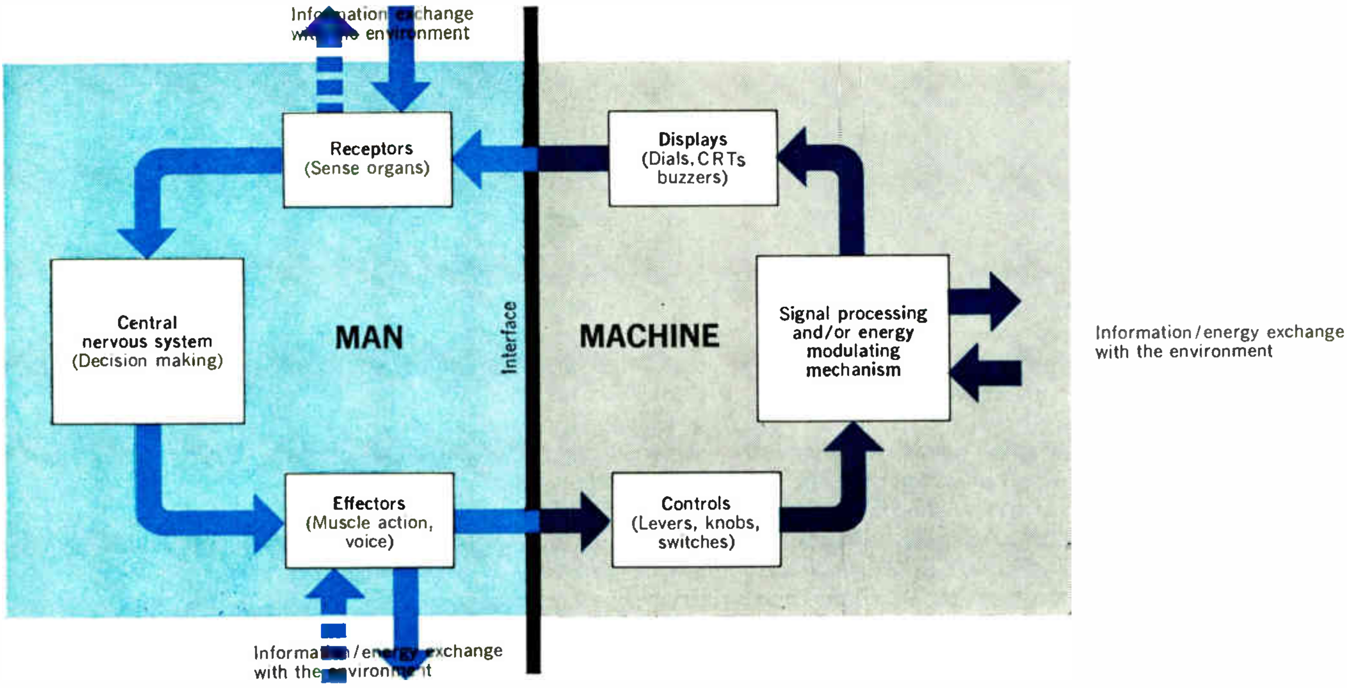
The fact that the field of human factors sprang from two such diverse disciplines—a conventional psychology on the one hand and a burgeoning technology on the other—has brought its share of built-in problems in the creation of a "new" discipline. What common bond was to hold the two together? It was not always clear how, and to what degree, the two outlooks were to cooperate, and who should be the dominant partner. It has fallen both ways. In some organizations, the psychologists have been and still are in the dominant position, and in others it is the engineers. Dr. J. C. R. Licklider, a remarkable figure in the modern interdisciplinary endeavors, points out that the evolution of the relationship in the different specialties—communications, manual control, computer systems, etc.—has also taken on an individual character and balance in each case.[8] In addition, the two disciplines evolved different languages (and concepts); experimental psychologists use terms such as stimulus, response, sensation, perception, understanding, meaning, attention, expectancy, drive, fatigue, and skill, which are entirely different from the terms used by engineers.



Despite the difficulties and friction, however, there is evidently little doubt about the contributions of the parent fields. Professor Thomas Sheridan of M.I.T. says: "The measurements we are making now are not radically different from those psychologists have been making since the time of Wilhelm Wundt." (Wundt set up the first experimental psychology laboratory in Leipzig in 1879.) Since that time, "experimental psychologists have been using human subjects for reaction time tests, memory tests, vision experiments, all kinds of things. But they had felt under no compulsion to couch their results in terminology an engineer could get his hands on, or to say or even imply when a man should be used for certain kinds of tasks and when a machine should be used. The classical psychological literature has no measures like information rate, control characteristics, or decision criteria of the kind engineers use. Now, however, there is getting to be a closer mix, because some of the psychologists are beginning to look at their classical problems with some of these engineering measures."[9]

The man–machine system concept

More than any other single concept, the man–machine system concept is the one around which most human factors engineers rally. It is perhaps now the core of the field. Thus, all human factors engineering can be thought of as dealing with the appropriate allocation of tasks between assemblages of men and machines, in which the two anomalous components—the man and the machine—are in such an intimate cooperative relationship that the designer is obliged to view them as a single system. Rather than being called upon to adapt a finished machine so human operators can live with it more easily, the human factors specialist wants to be in on the design from the very beginning to insure that the best trade-offs between man and machine functions are chosen. Clearly, the function of the man–machine system can vary from the very simplest (say, the design of a can opener—one man, one lever) to the most complex (say, command and control systems involving whole communities of operators and machines—all kinds of sensing and tracking devices,



The man–machine system concept, which is central to today's human factors thinking, treats assemblages of men and machines as single entities. This one-man, one-machine model shows the basic elements. The displays feed information to the man's receptors (his eyes, ears, proprioceptors), he makes decisions, and through his effectors (his muscles) he operates the machine controls. In many modern systems, the roles assigned to the man and the machine are critical to the success of the system design.

controls and displays, computers, hierarchies of decision-making processes, and so on). The illustration above shows a conceptual model of the man–machine system, which has been derived from one drawn by T. B. Sheridan and W. R. Ferrell of M.I.T., who describe the system thus: "We consider a man–machine system to be any assemblage of people and machines which are in significant communication with one another and which are performing a task sufficiently well-defined that independent and dependent variables and criteria of performance may be operationally specified."[10]

The concept was arrived at only by stages, but in retrospect these seem to have pursued an inevitable direction. The designer couldn't worry about whether or not a dial or knob was doing a good job for the human operator without considering what the dial next to it was doing, then wondering whether these dials were telling the operator what he needed to know about the functioning of the system, and what the operator really saw, heard, and felt. Was he being asked to do too much, or too little? How much was too much? Did he get enough feedback of information through the control knobs or sticks? How did he share his visual, aural, and proprioceptive attention among the many tasks given him? Under what overall conditions was he at his best? What could the machine do that the man was now expected to do, and what might the man do better than the machine? Thus, the thrust of studies went in two directions—deeper research into the behavior (functions) of the human, and deeper involvement in the design of the physical machine. It was a drift that also smeared together research and application.

Investigators in the human factors field, looking backward, report that they were not certain what they were after in those earlier days. John Hill of NRL says, "We were groping for something bigger. We didn't know just what it was. What we were trying to do, unconsciously, was influence the design of equipment. And after a while we realized we were looking at the man and the machine as an entity."[11] Inevitably, there was some friction in the process. Hill says that during consultative discussions in those days, the engineers and psychologists were often angry with one another at what they considered invasions of each other's territory.

Perhaps it was also inevitable, as the concept crystallized, and as the human factors engineers found themselves swimming in a sea of applications, that they should be gratified to be presented with the powerful tools of information theory, the new metalanguage, "appropriate to all system components, whether human or inanimate." Many of the members of this "new school" of thinking took very quickly to talking about human behavior in terms equally relevant to machines—people have certain kinds of inputs, outputs, coding, storage, information transmission, stability, transfer function, bandpass, and so forth. Some of the new school took their basic concepts and language from information theory while others derived their concepts from servomechanism theory.

As F. V. Taylor wrote about this turn of events, this "universal language of action . . . may overcome the problem of interscience translation, and at the same time eliminate psychology's conceptual endogamy. Norbert Wiener and his associates have, of course, pointed the way. In setting forth the idea of a construct metalanguage of control, the cyberneticists have taken an exceedingly bold and long first step."[6]

Information on human factors

The literature and information pertaining to human factors endeavors is already oppressively vast, exceedingly diverse, and rapidly growing, so that any engineer not acquainted with the field at all, but who feels he needs the services or insights possibly existing in this domain of information, has a real problem on his hands. Where does he turn?

One source estimates that at least 5000 documents are produced each year that have some direct relevance to the human factors field. The information comes from many scientific specialties. At least 300 English-language journals publish material germane to human factors, and there may well be an equal number of other-language periodicals producing such information.

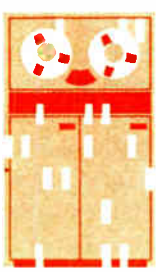
A number of the standard recent guides and handbooks are listed in the bibliography. One bibliography, compiled in 1956, alone lists 5666 books and papers that had to fulfill the requirement of containing "information of possible practical value to the designer."[12]

Nevertheless, owing to the great variety of machines being devised, to the fantastic complexity of human behavior in which it is still impossible to isolate independent variables, and to the extremely specialized functions demanded of the man and of the machine, it is generally recognized that none of these handbooks and guides are entirely satisfactory. As often as not, the engineer involved in the design of a man–machine system must carry out his own experiments to determine the important functional variables of the man and of the physical system, in order to assess the appropriate allocation of tasks between man and machine and to make whatever trade-offs the overall system design requires. Thus, the literature on methodology holds an important place in the human factors field, and the engineer must decide which of the available methods are best suited for his problem and his needs—simulation, direct observation, statistical methods, experimental methods, psychophysical methods, and so on.[13]

The single most comprehensive source of human factors information is the Tufts University's Human Engineering Information and Analysis Service, which is both an indexing operation and a human factors document repository. The Tufts indexing system is broken down into 15 major areas with scores of subdivisions. The reader is urged to seek out and read the abridged version of the Tufts system,[14] which is readily available, for it will give him some further insight into the complex and diffuse structure of the human factors field.

Aspects of human factors technology

Although it is ridiculous to load down a reader with any extensive catalog of the fauna and flora of the human factors jungle, it is impossible to avoid this if one wishes him to grasp both the real and potential significance of such activities. The investigations skimmed over in the following pages, drawn from a single recent volume,[15] may give the reader some feeling for the "many-faceted relation between man and his technology."



For those who might fear being swamped, some thoughts of Sheridan and Ferrell from their forthcoming book may provide the necessary keel. They say that it is not necessary for an engineer who deals with man–machine systems to encompass all, or even much, of psychology, physiology, sociology, and the other life sciences, but what is required of the engineer "as an inherent part of his responsibility" is a viewpoint that is "sympathetic to the life sciences"—which is certainly in keeping with the direction that our mid-century technology seems to be taking. Furthermore, if the modern engineer is to accept responsibly the motto of his profession, "applying science to the needs of man," he must "become quite explicit about what are man's needs—*in a language that is common to the rest of engineering*."[10]

Atypical environments. A notion of what some of those needs might be, and of the various thresholds that man can tolerate, emerges in studies of man in "atypical environments." These include investigations of:

- The mechanisms whereby the body regulates and maintains an optimal internal thermal environment, and defends itself against the threats of extreme cold and heat.
- Man's ability to adapt himself to specific work–sleep schedules while maintaining his effectiveness in tasks encountered in advanced man–machine systems where the man's abilities must be used with maximum efficiency (i.e., as in extended space flights where the number of crew members is severely limited and where it is not possible to bring in replacements when the crew members become fatigued).
- Human tolerance to acceleration, the kinds of gross body distortions that result from acceleration under various forms of constraint systems.
- The effects of vibrations of all kinds on man. External sources of vibration in the environment of man have been steadily increasing in number, magnitude, and complexity. They include man's own movements of walking (especially on hard pavements), running, and jumping, and oscillations from man-made devices and machines—mechanical and electric tools, industrial machinery, and vehicles of all types (cars, trains, airplanes, and even spacecraft). High-performance jet-propulsion systems in aerodynamic and space vehicles present man with a new and highly complex, potentially lethal, poorly understood environment. Most engineers would consider working with these specialized problems, but the myriad vibrations (as well as noises) of the total man-made environment threaten to and do produce both short- and long-term abnormalities in man. The engineer must ask himself whether or not he is merely adding to the infernal din of our already noisy, quivering world.
- The effects of radiation, (again in large part the work of man), though not perceived as immediately as vibration and noise, have been much more publicized, and have become the object of universal fear. Although most of these fears have centered thus far on the effects of atomic testing, the future holds the certainty that the centers of civilization will receive power from numerous atomic power stations. Then we must answer such questions as: What will be the long-term effects of dumping radioactive wastes into the oceans? Although the end results of massive doses of radiation are already far too well known, there is still lacking definitive relationships between observed changes and prior incident radiation.

Clothing and work space. Still another aspect of human factors deals with the problem of how man designs the space around him, the space in which he works and lives. This includes such elements as the space itself, special equipment, furniture, arrangements to provide the best visibility for the worker, the best arrangements for easing and speeding his movements, seating and body support arrangements, and so on, as well as consideration of maintenance and safety factors. Some of this work involves investigations of environmental factors that affect performance of tasks, such as temperature, humidity, motion, altitude; and more recently, for space missions and extended undersea missions, the effects of sensory deprivation.

Extensive studies have also been made on individual factors that affect behavioral efficiency in the performance of tasks—e.g., individual motivation, emotion, intelligence, and aptitudes. Broad studies have been made of the effects of environmental factors on vigilance.

Clothing, which might be construed as an intimate ingredient of the work space, also receives considerable attention from human factors designers. Everyone is familiar with the Buck Rogers type of spacesuit worn by the astronauts and cosmonauts, but this represents only the most dramatic and obvious results of such applied research. There are many unobvious situations in man–machine systems where the clothing and personal equipment are in some way incompatible in their interaction with other elements of the system. Although it is recognized that human beings vary in size, the implications of this fact are often not fully appreciated in system design.

Human factors in automotive safety. Everyone is aware of the "murder" on and near the nation's highways (about 40 000 deaths annually), but very few know about the real causes of these accidents beyond the bland newspaper phrases, "Driver falls asleep," "Driver loses control," or "Drunken driver kills pedestrian." For the human factors novitiate, there are some (unfortunately) fascinating stories of the "real" causes behind the mayhem. Equally unfortunately, the consensus among those who know is that far too little human factors effort has been thus far devoted by the automotive industry to proper human engineering design of vehicles and highways, although there seems to be slightly more emphasis on a greater effort in this direction.

Although one of the primary objectives of human factors engineers is to promote safety by designing equipment in terms of human capabilities and limitations, much of the biological and psychological information needed for this purpose is not yet available.

Sensory supplements. Another important and humane area of human factors application is that of sensory supplementation—devices and methods whereby aid is given to the blind and deaf. Such devices are widely publicized, and are frequently reported in many interdisciplinary meetings and journals. These supplementary appliances include electronic canes and various active units that behave like radar; there are also attempts to develop reading machines for the blind and instruments that convey information through the tactile senses. They are designed, of course, for persons whose normal information-gathering senses have been drastically limited (by some definitions, these efforts should not be included under the human factors label), but there are many man–machine situations in which "normal" operators require sensory extensions, and these fit more unequivocally in the human factors bailiwick. Although radar is the classic example, there now are many electrooptical sensing devices that bring in information from distant domains and display them to the operator of the system. Space research vehicles are loaded with sensory extension instrumentation that must be properly engineered for the human operators. In long-range space research vehicles there are special problems of delay time between an earthbound operator's action and the sensor's response to it. This kind of problem is receiving much attention now. The delay problem applies quite acutely, too, in the use of satellites as telephone communication links, a problem that is under intensive investigation.

Remote manipulators. Sensory extensions (or remote receptors) have their human factors counterpart in remote manipulators, the extensions of man's control abilities (his effectors). This field of human factors endeavor also is a prominent and burgeoning newcomer. Some of the most obvious needs for remote manipulators are for handling radioactive materials, for performing tasks within radiation environments, for work missions in outer space which are too highly dangerous for man, for undersea operations. Less obvious, perhaps, is the use of microsurgical instruments for exploration of structures in the "inner" space of man.

Remote manipulators present some striking psychological problems that are under exploration in a number of institutions. Various types of psychological tests are being conducted (by W. R. Ferrell and his associates at M.I.T., for instance) to determine how operators respond to the presentation of delayed response information and what pattern of "sampling" is optimal. Numerous investigators are studying the problems associated with computer operation of remote slaves and robots, but the complexity involved in humanoid movements is so great that none of these problems can be treated in trivial fashion.

As with aids for the deaf and blind, the applications of manipulators have their counterpart in prosthetic devices, or artificial limbs, variously controlled. One of the most sophisticated of these systems is that devised at Case Institute of Technology by Dr. Reswick and his colleagues; it comprises a computer-programmed set of manipulators that permit a quadriplegic to feed himself and perform other functions.

Adaptive systems. Systems that can learn, that can adapt to new situations, that can recognize patterns of all kinds, that display intelligence (that is, all forms of learning automata and artificial intelligence), systems that can replace and supplement the versatility of human functions and behavior in man–machine systems are, perhaps, a "natural" outcome of the past decade and a half of investigation into the functions and behavior of both man and machine in man–machine systems. By what we commonly account to be most human and unique in man, such adaptive systems are both ambitious and spectacular. Whether or not these systems will be successful beyond very limited formats is yet to be proved, but the fact is that those who are committed to their development find that slowly, very slowly, their machines *are* getting more intelligent. To devise such machines, one must clearly quantify the most obscure of human factors. Such investigations appear under the human factors banner in some quarters, but most of the investigators of artificial intelligence themselves hardly appear to characterize their work in this manner. We are in a borderland here as far as names go. Artificial intelligence, self-organizing systems, bionics—take your pick!

What's in a name?

There has been, among the proponents of the human factors field, a chronic dissatisfaction with its name. Human engineering, engineering psychology, biotechnology, man–machine systems, human factors engineering—none of them have been entirely satisfactory. Why?

On the one hand, we can retort, "What's in a name?" and simply ignore the existence of a seemingly trivial question. Or, on the other hand, we can view the dissatisfaction as symptomatic of deeper problems. The name "human factors" is itself anomalous, for even a trained and disciplined person's ideas of what constitutes "human" may well be at odds with what constitute "factors." On another level, the notion of unity or similarity between man and machine stirs an angst in the modern man's conception of himself, despite his growing and pervasive familiarity with the machine. However, this, too, might be grounded in the simple fact that until now most machines have been antipathetic to man, they have not been properly designed for his peculiar and unique qualities, and it has been difficult for the man to "feel" them as extensions of himself.

But perhaps the most basic reasons for the dissatisfaction lie in the nature of the field itself: in the fact that its emphasis has been shifting as new problems have arisen, that it has gone through many chrysalid stages in its evolution and has not yet crystallized in a unified mature form; perhaps because the conventional psychology from which it drew was only a stepping-stone and not a suitable discipline as it was; and perhaps because the human factors engineers (different ones at different times) have attempted to incorporate too many aspects of the modern technological work under one umbrella; that is, they have overextended their ambitions. And now the emergence of the computer sciences, in which the human characteristics must be matched with the machine at the intellectual and deeper neural levels, threatens to place newer burdens on what "human factors" means as a name. The weight of this newest revolution could sink the name entirely, and it might yet be subsumed under a more conclusive scientific discipline. Cybernetics? But people also boggle at cybernetics for various reasons; it too means many things to many people. Although some consider cybernetics as the personal province of Norbert Wiener, the name now has its own mystique, and no one makes fun of it. As Tom Sheridan says, "People are always making fun of my man–machines." And he concurs that there is some importance in a name because "people make assumptions about names that end up being the reasons they do the things they do."[9]

Clearly, this problem of names now runs across all the uncrystallized interdisciplinary areas, and only time, R & D, and "political" factors will determine how things will be resolved.

Most of these statements are, of course, merely first guesses. Perhaps all they express is this writer's predilection to think that there *is* something in names. But the point that is most clear, and most unequivocal, is that the investigations that go on under any of these names, into man–machine systems and into man's place in the overwhelming man-made environment, must go on and will go on. The engineer, having gone this far, must go further; he must engineer the environment not just to be "tolerable" to man, but to make it, as Wiener said, viable for real human life, to allow the "human use of human beings."

Note: Part II will discuss specific recent approaches to human factors problems in major areas such as communications, controls, displays, guidance, decision making, space systems, etc.

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Relativity and electricity

Electromagnetics is usually developed from a sequence of experimentally based postulates. Here special relativity is used to formulate a complete electromagnetic theory from the inverse-square law, thus deepening our understanding of the unity of electric and magnetic fields

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Several facets of the special theory of relativity are reviewed, commencing with the Lorentz equations and culminating in the force transformation law. The basic equations of electrostatic theory are then formulated, after which a relativistic transformation of Coulomb's law is undertaken, the result being the Lorentz force law. Time-varying electric and magnetic fields are defined as constituent terms of the Lorentz force expression and are then shown to satisfy Maxwell's equations. The development includes derivations of the relativistic transformation laws for sources and fields.

The special theory of relativity is concerned with the comparison of physical phenomena as they appear to two observers who are in motion with respect to each other at a constant relative velocity. In his first paper on this subject in 1905, Einstein[1] accepted the principle of relativity* and proposed as a second postulate that light always propagates in empty space with a definite velocity c, which is independent of the state of motion of the emitting body. Using this second postulate, he introduced a technique for synchronizing spatially separated stationary clocks and then showed that two observers in relative motion disagree in their measurements of time and distance intervals. The Lorentz equations were found to provide the proper connection between the spatial and temporal coordinate values each observer would assign to a given event. From this point, Einstein proceeded to show that Maxwell's equations were covariant under a Lorentz transformation if the electric and magnetic fields of the two observers were related through a certain bilinear transformation. Interpreting this transformation, he remarked "that electric and magnetic forces do not exist independently of the state of motion of the system of coordinates."

In 1912, Leigh Page followed up this observation by demonstrating that one could start from Coulomb's law and use the results of special relativity to derive the fundamental relations of magnetostatics.[2] He also exhibited the expression for the induced electromotive force in one wire due to a variation of current in another. This approach was later embodied in a book coauthored with Adams.[3]

In this article a development conceptually akin to that used by Page, but differing from it substantially in detail, will be presented. After reviewing the necessary aspects of special relativity and electrostatics, a direct derivation of the Lorentz force law and Maxwell's equations will be offered. This approach has the advantage of demonstrating that the fields contained in the Lorentz force expression are synonymous with those contained in Maxwell's equations. This conclusion cannot be reached by a conventional development that postulates separate experimental laws for electrostatics, magnetostatics, and electromagnetics. Further satisfaction results from recognition of the fact that, with the aid of special relativity, *all* the laws of electricity, including the Biot–Savart law and Faraday's EMF law, are derivable from a single experimental postulate based on Coulomb's law.

The development will be confined to the case of electric sources in free space, but it is easily extendable to the case in which materials are present.[4] Wherever specific units are needed, the rationalized MKS system will be used.

The Lorentz transformation

Consider two Cartesian-coordinate systems XYZ and $X'Y'Z'$. As suggested by Fig. 1, the respective axes of these two systems are aligned, with the X and X' axes sliding along each other such that X' is moving in the $+X$ direction at a constant speed u. Let an observer O, who is stationary in XYZ, select his time reference so that $t = 0$ corresponds to the coincidence of the origins of XYZ and $X'Y'Z'$. Similarly, let an observer O', who is stationary in $X'Y'Z'$, select his time reference so that

*The principle of relativity, even then, was an old idea, which had earlier gained the support of Newton, among others. Simply stated, it expresses the belief that all the laws of physics are the same everywhere in the universe. In Einstein's words, "...the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good."

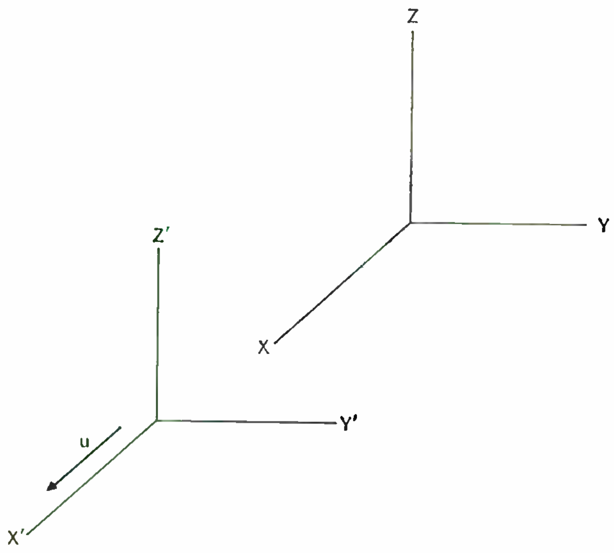

Fig. 1. Two Cartesian-coordinate systems in constant translative relative motion.

$t' = 0$ corresponds to the coincidence of the origins of the two coordinate systems. It is desired to compare the physical observations of O and O'.

Since all physical measurements involve, fundamentally, determinations of distance and/or time intervals, it is necessary to define the concepts of length and time for each observer. To this end, let it be assumed that O determines a unique triplet of numbers (x, y, z) for every point in XYZ space by laying out identical scales (e.g., in meters) along his three axes, and that similarly O' determines a unique triplet of numbers (x', y', z') for every point in $X'Y'Z'$ space by laying out identical scales along *his* three axes. It is further assumed that O and O' lay out these scales using the same standard of length (e.g., a meter stick). By this it is meant that if O measures lengths in terms of a ruler R marked in meters and at rest in XYZ, and if O' measures lengths in terms of a ruler R' at rest in $X'Y'Z'$, then if the two rulers were brought to rest side by side, markings one meter apart on R would coincide with markings one meter apart on R'.

Additionally, each observer, O and O', needs to measure time unambiguously at every point in his coordinate system. To insure this, let it be assumed conceptually that O has an inexhaustible supply of identical clocks, such that he has been able to station one clock permanently at each point in XYZ. To ascertain that all of these clocks are set properly and running at the same rate, O can select one clock as the reference and perform the following experiment: O places himself at the reference clock and stations an auxiliary observer O_1 at the clock to be synchronized. O sends out a pulse of light at time t_a on the reference clock, directing it toward O_1, who reflects it back by means of a mirror. The returned pulse of light reaches O at time t_b. The clock where O_1 is stationed was set properly if it read $(t_a + t_b)/2$ at the instant the light pulse reached the mirror. It is running at the proper rate if it proves to be set properly every time O and O_1 choose to perform this experiment.

In this manner, every clock in XYZ can be synchronized to the reference clock and thus to every other clock in XYZ. It will be assumed that this has been done; this will be the conception of time in the frame of reference XYZ.

Likewise, it may be assumed conceptually that O' has an inexhaustible supply of identical clocks, which he has arrayed at fixed points in $X'Y'Z'$ and which he has synchronized by the same procedure. It will be further assumed that if these two sets of clocks were brought to rest relative to each other, they would be found to be identical and running at the same rate.

With these concepts of spatial position and time, let an event be defined for observer O as something that happens at a point $P(x, y, z)$ at time t, or more briefly at the "point" $P(x, y, z, t)$. The same event will occur for observer O' at the "point" $P'(x', y', z', t')$. The quartet of numbers x', y', z', t' can be connected to the quartet of numbers x, y, z, t by a set of equations known as the Lorentz transformation equations. This transformation may be determined as follows:

Let a pulse of light be emitted from the position jointly occupied by the two origins at the instant the two clocks at this position register $t = 0$, $t' = 0$. Imagine that O has stationed an auxiliary observer O_1 at the fixed point (x, y, z) and that O_1 records the event that the light pulse passes him as having occurred at time t. Then it follows that, if the region is free space, O can characterize this event by the equation

$$x^2 + y^2 + z^2 = (ct)^2 \tag{1}$$

The left side of this equation is the square of the distance from the origin of XYZ to the position of O_1. The right side is the square of the distance a light wave will travel at speed c in empty space in a time interval t. The equation itself is recognized as depicting a spherical wavefront of steadily expanding radius.

If O' has stationed an auxiliary observer O_1' at the *fixed* point (x', y', z'), then the time of occurrence t_1', which O_1' records for this event, satisfies the equation

$$(x')^2 + (y')^2 + (z')^2 = (ct')^2 \tag{2}$$

O' uses the same value for the speed of light in (2) that O uses in (1) because the region is empty space; at most they disagree about the motion of the source, and c has the same value in all directions in $X'Y'Z'$ that it does in all directions in XYZ (Einstein's second postulate).

If O_1 and O_1' just happen to coincide at the instant the light pulse passes, the transformation equations that link the observations in XYZ to those in $X'Y'Z'$ must be such that O can derive (2) from (1) and such that O' can derive (1) from (2), since they are describing the same event. The two observers agree about distance measurements in the Y and Z directions because their relative motion is X-directed. Therefore, part of the transformation is

$$y' = y \qquad z' = z \tag{3}$$

Since every motion that is uniform and rectilinear in XYZ must also appear uniform and rectilinear in $X'Y'Z'$, so that the transformation from (x, t) to (x', t') takes straight lines into straight lines, and is thus *linear*, then the remainder of the transformation must be in the form

$$x' = \alpha_1 x + \alpha_2 t \qquad t' = \alpha_3 x + \alpha_4 t \qquad (4)$$

To evaluate the constant α_2, note first that if a point $P'(x', y', z')$ is *fixed* with respect to observer O', this point appears to be moving in the positive X direction at speed u, when observed by O. For such a point, taking differentials of the first equation of (4) gives

$$dx' = 0 = \alpha_1\, dx + \alpha_2\, dt \qquad \alpha_2 = -\alpha_1 \frac{dx}{dt} = -\alpha_1 u$$

and therefore (4) may be rewritten as

$$x' = \alpha_1(x - ut) \qquad t' = \alpha_3 x + \alpha_4 t \qquad (5)$$

The remaining three constants can be determined by requiring that (1) and (2) transform into each other. If (3) and (5) are substituted into (2), one obtains

$$\alpha_1^2 x^2 - 2\alpha_1^2 uxt + \alpha_1^2 u^2 t^2 + y^2 + z^2 = \alpha_3^2 c^2 x^2 + 2\alpha_3\alpha_4 c^2 xt + \alpha_4^2 c^2 t^2$$

Since this must agree with (1) for all values of x, y, z, and t, it follows that

$$\alpha_1^2 - \alpha_3^2 c^2 = 1 \qquad 2\alpha_1^2 u + 2\alpha_3\alpha_4 c^2 = 0$$

$$\alpha_4^2 c^2 - \alpha_1^2 u^2 = c^2$$

Solving these three equations gives

$$\alpha_1^2 = \alpha_4^2 = (1 - u^2/c^2)^{-1} \qquad \alpha_3 = -\alpha_1 u/c^2$$

which yields the result

$$\begin{aligned} x' &= \kappa(x - ut) \qquad & t' &= \kappa(t - ux/c^2) \\ y' &= y & z' &= z \end{aligned} \qquad (6)$$

in which $\kappa^{-1} = (1 - u^2/c^2)^{1/2}$ is called the contraction factor.

Equations (6) were derived by Einstein in his 1905 paper using an argument which has been reproduced in its essentials. They are commonly called the Lorentz transformation equations, so named by Poincaré in honor of H. Lorentz, who had derived them earlier (1903) under a different set of hypotheses.* Their significance lies in the fact that they may be employed to deduce the four numbers either observer uses to characterize an event, if the four numbers used by the other observer are known.

Length and time under the Lorentz transformation

Let a ruler R' be at rest in the $X'Y'Z'$ frame of reference, such that its two ends occupy the points $(x_1', 0, 0)$ and $(x_2', 0, 0)$. Observer O' will say that its length is

$$l'_{R'} = x_2' - x_1'$$

If observer O wishes to measure the length of R', since it is in motion with respect to him, he should measure its end coordinates x_1 and x_2 at a common time t. Using the first equation of (6), one may write

$$x_1' = \kappa(x_1 - ut) \qquad x_2' = \kappa(x_2 - ut)$$

$$x_2' - x_1' = \kappa(x_2 - x_1)$$

*These equations had actually been used even earlier by Voigt (1887). Lorentz assumed the existence of an ether and physical contraction of bodies due to their motion through the ether, and required that Maxwell's equations transform properly. His ether-related hypotheses were found to be inconsistent with the Michelson–Morley and Kennedy–Thorndike experiments.

from which

$$l_{R'} = x_2 - x_1 = l'_{R'}(1 - u^2c^2)^{1/2} < l'_{R'} \qquad (7)$$

in which $l_{R'}$ is the length of the ruler R', as determined by O, and is seen to be shorter than the rest length $l'_{R'}$. If the ruler had been oriented parallel to the Y' or Z' axis, a similar calculation would reveal that O and O' agreed about the length of R'. One concludes from this that when a body is in motion relative to an observer O, its longitudinal dimension is shortened by the contraction factor, whereas its transverse dimensions are unaltered from their rest values.

Next consider a particular clock in XYZ that remains at fixed coordinates (x, y, z) and is therefore being passed by a sequence of $X'Y'Z'$ clocks. One can define a first event when the hands of this single XYZ clock indicate time t_1 and a second event when they indicate time t_2.

In $X'Y'Z'$, the first event will occur at the spatial position

$$x_1' = \kappa(x - ut_1) \qquad y_1' = y \qquad z_1' = z$$

these equations resulting from an application of (6). The $X'Y'Z'$ clock at this position registers the time of the first event as

$$t_1' = \kappa\,(t_1 - ux/c^2)$$

Similarly, in $X'Y'Z'$ the second event will occur at the spatial position

$$x_2' = \kappa(x - ut_2) \qquad y_2' = y \qquad z_2' = z$$

and the $X'Y'Z'$ clock at this position registers its time as

$$t_2' = \kappa\,(t_2 - ux/c^2)$$

From this it follows that

$$t_2' - t_1' = \kappa(t_2 - t_1) > t_2 - t_1 \qquad (8)$$

Consider this result first from the viewpoint of O, who is stationary beside the single XYZ clock. He watches a succession of $X'Y'Z'$ clocks go by and can take only a single reading of each of them. However, he notices that they seem progressively set further and further ahead, thus accounting for the inequality in (8). On the other hand, observer O' can take a sequence of readings of the XYZ clock as it passes a succession of $X'Y'Z'$ clocks. Since he knows his own clocks are all synchronized, he concludes that the rate of the XYZ clock is slowed by its relative motion.

The results (7) and (8) are known as length contraction and time dilatation. They are symmetrical, in the sense that either O or O' will conclude that longitudinal lengths in the other system are shortened and that clocks in the other system are slowed. Experimental evidence to support these formulas is abundant.[5]

Velocity

The general motion of a point, in which the spatial variables are continuous functions of the temporal variable, may be traced in terms of differentials. From (6),

$$dx' = \kappa(dx - u\,dt) \qquad dt' = \kappa\left(dt - \frac{u}{c^2}dx\right)$$

$$dy' = dy \qquad dz' = dz$$

Ratios of these differentials may be formed to yield velocity components. For example,

(Continued on page 147)

$$v_x' = \frac{dx'}{dt'} = \frac{dx - u\,dt}{dt - (u/c^2)\,dx} = \frac{dx/dt - u}{1 - (u/c^2)\,dx/dt} = \frac{v_x - u}{1 - uv_x/c^2}$$

Proceeding in this manner, one can derive the Lorentz velocity transformation equations:

$$v_x' = \frac{v_x - u}{1 - uv_x/c^2} \qquad v_y' = \frac{v_y}{\kappa(1 - uv_x/c^2)} \tag{9}$$

$$v_z' = \frac{v_z}{\kappa(1 - uv_x/c^2)}$$

As an illustration of this result, consider the case of two particles moving along the X axis. As seen from the XYZ frame of reference, let one particle have a velocity $v_x = v$ and let the other particle have a velocity $v_x = -v$. What is the relative velocity?

To answer this question, let $X'Y'Z'$ ride along with one particle by setting $u = v$. Then from (9), the velocity of the other particle in $X'Y'Z'$ is

$$v_x' = \frac{v_x - u}{1 - uv_x/c^2} = \frac{-v - v}{1 + v^2/c^2} = -\frac{2v}{1 + v^2/c^2}$$

For small values of v/c this yields the classic result $v_x' = -2v$. However, as $v \to c$, $v_x' \to -c$. Therefore, even though in XYZ the two particles might be going in opposite directions, each of which approaches c relative to XYZ, their recessional velocities relative to each other are still less than c.

The variation of mass

A hypothetical experiment first suggested by Lewis and Tolman[6] serves to demonstrate the dependence of mass on relative velocity. Imagine that two exactly similar elastic balls suffer a collision, which in the $X'Y'Z'$ frame appears as shown in Fig. 2(A). The balls are seen to approach each other along parallel lines, collide, and then recede from each other along parallel lines. Their approach speeds are equal and, by symmetry, so too are their recessional speeds. A perfectly elastic collision is assumed, with no loss of energy, thus causing the recessional speed to equal the speed of approach. This experiment can be assumed to take place either in a region free from gravitational attraction or on a level frictionless table over which the balls are sliding.*

Now imagine this same collision as viewed from an XYZ frame that is moving in the direction of the $-X'$ axis at a speed $u = v_x'$; see Fig. 2(B). To an observer O stationary in XYZ, ball A is moving parallel to the Y axis and ball B makes a more grazing incidence to the X axis.

As seen in $X'Y'Z'$, each ball has its y' velocity component reversed by the collision, but its x' component of velocity is unchanged. As seen in XYZ, ball B has its y component of velocity reversed by the collision; however, its x component is unaffected. In XYZ, ball A has only a y velocity component, which suffers a reversal.

Classical mechanics would yield for this experiment the result that $v_y = v_y'$ for both balls A and B. In terms of a Lorentz transformation, one would be ill-advised to assume this result without checking. Therefore, let $\pm w_y$ represent the velocity of ball A in XYZ before and after the collision, and let $\mp v_y$ represent the y component of velocity of ball B before and after the collision.

*A rolling motion would complicate the discussion needlessly.

Using (9), one finds that for ball B

$$v_y' = \frac{v_y}{\kappa(1 - v_x'v_x/c^2)}$$

whereas for ball A

$$v_y' = w_y/\kappa$$

Forming ratios gives

$$\frac{v_y}{w_y} = 1 - \frac{v_x'v_x}{c^2} \tag{10}$$

and thus $v_y < w_y$. Viewed from XYZ, ball A has a greater y component of velocity than does ball B. (For ordinary velocities the difference is exceedingly small.)

Equation (10) requires the abandonment of one or the other of two principles of classical mechanics. If mass is an invariant, then the principle of conservation of linear momentum is violated in the y direction in XYZ. If the momentum principle is valid, then mass cannot be an invariant. The latter assumption is the one consistent with experiment, and will be the basis for what follows.

Let $m_A' = m_B'$ be the two masses in the $X'Y'Z'$ frame (they are equal by symmetry), and let $m_A \neq m_B$ be the two masses in the XYZ frame. Then $m_A w_y = m_B v_y$; thus,

$$\frac{m_B}{m_A} = \left(1 - \frac{v_x'v_x}{c^2}\right)^{-1}$$

This result can be rephrased entirely in terms of XYZ quantities by using (9) to substitute for v_x', which gives

$$\frac{m_B}{m_A} = \left(1 - \frac{v_x^2}{c^2}\right)^{-1/2} \tag{11}$$

This relation is seen not to depend on v_y and should hold even when $v_y = 0$. But then $w_y = 0$ as well, and—as seen from $X'Y'Z'$—the two balls approach each other along the X' axis and just barely touch as they pass. As seen from XYZ, ball A is at rest and ball B passes by, just touching A as it travels parallel to the X axis. With m_0 the mass of ball A at rest, (11) may be rewritten as

$$m_B = \frac{m_0}{(1 - v_x^2/c^2)^{1/2}}$$

One can now argue that it no longer matters whether ball A is present or not. Moreover, the rest mass of ball B should also be m_0, since in $X'Y'Z'$ one started with a symmetrical experiment using identical balls. With only ball B left, in constant rectilinear motion, the subscripts may be dropped on m_B and v_x, giving

$$m = \frac{m_0}{(1 - v^2/c^2)^{1/2}} \tag{12}$$

In (12), m_0 is the rest mass of ball B in XYZ, and m is its dynamic mass when going at a speed v relative to XYZ.

It is inferred from this result that the mass of any material body depends on its relative motion, increasing with speed according to (12). A clear confirmation has been given by Zahn and Spees.[7]

The transformation law for mass

Equation (12) is not, of course, the transformation law for mass because it yields the dynamic mass only in one frame of reference; but it can be used to relate dynamic mass in two different coordinate systems, as follows:

Let a body of rest mass m_0 have a velocity $\mathbf{v}(x, y, z, t)$ in

Use of the del operator

$$\nabla = \mathbf{1}_x \frac{\partial}{\partial x} + \mathbf{1}_y \frac{\partial}{\partial y} + \mathbf{1}_z \frac{\partial}{\partial z}$$

to form the gradient of inverse distance gives

$$\nabla \left(\frac{1}{\mathfrak{r}}\right) = -\frac{\mathfrak{r}}{\mathfrak{r}^3}$$

from which it follows that (19) can be written

$$\mathbf{E}(x, y, z) = -\frac{1}{4\pi\epsilon_0} \int_V \rho(\xi, \eta, \zeta) \nabla \left(\frac{1}{\mathfrak{r}}\right) d\xi\, d\eta\, d\zeta$$

Since neither $\rho(\xi, \eta, \zeta)$ nor the limits of integration are functions of the field point (x, y, z), the order of integration and differentiation may be interchanged, yielding

$$\mathbf{E}(x, y, z) = -\nabla \int_V \frac{\rho(\xi, \eta, \zeta)\, d\xi\, d\eta\, d\zeta}{4\pi\epsilon_0 \mathfrak{r}} \tag{21}$$

Therefore the electric field is expressible as the negative of the gradient of the scalar function

$$\Phi(x, y, z) = \int_V \frac{\rho(\xi, \eta, \zeta)\, d\xi\, d\eta\, d\zeta}{4\pi\epsilon_0 \mathfrak{r}} \tag{22}$$

Φ is called the electrostatic potential function and is measured in volts. Since $\mathbf{E} = -\nabla\Phi$, the units of $\mathbf{E}$ are often given as volts per meter.

Use of the vector identity $\nabla \times \nabla f \equiv 0$ yields the information that

$$\nabla \times \mathbf{E} \equiv 0 \tag{23}$$

Formation of the divergence of (21) provides the companion expression

$$\nabla \cdot \mathbf{E} = \rho/\epsilon_0 \tag{24}$$

Since $\nabla \times \mathbf{E}$ and $\nabla \cdot \mathbf{E}$ jointly contain all the first partial derivatives of all three components of $\mathbf{E}$, if the curl and divergence of $\mathbf{E}$ are completely specified, as in (23) and (24), $\mathbf{E}$ itself can be uniquely determined.

Electromagnetics

The results just obtained, which link static electric fields to their static sources, may be enlarged to include time-varying sources and fields, by comparing the observations of two people in relative motion. To see this, imagine that an observer O' has created in free space a most general electrostatic field $\mathbf{E}'(x', y', z')$ through an arrangement of electric charges in the static distribution $\rho'(x', y', z')$. $\mathbf{E}'$ satisfies the equations

$$\nabla' \times \mathbf{E}' \equiv 0 \tag{25}$$

$$\nabla' \cdot \mathbf{E}' = \rho'/\epsilon_0 \tag{26}$$

Furthermore, observer O' will say that if a small test charge q' is instantaneously at some arbitrary point (x', y', z'), it will experience a force, due to the static charge system, given by

$$\mathbf{F}' = q'\mathbf{E}' \tag{27}$$

If the coordinate system $X'Y'Z'$ has its axes respectively aligned to those of an XYZ system, with the X' axis sliding along the $+X$ axis at a speed u, an observer O, who is stationary in XYZ, will see a moving system of sources and will deduce a force field that differs from the field observed by O'. The connection between these force fields may be determined through use of the force transformation law (15), which can be written alternatively as

$$\mathbf{F} = [\mathbf{1}_x F_x' + \kappa(\mathbf{1}_y F_y' + \mathbf{1}_z F_z')] + \kappa \frac{\mathbf{v}}{c} \times \left(\mathbf{1}_x \frac{u}{c} \times \mathbf{F}'\right) \tag{28}$$

in which $\mathbf{F}'$ is given by (27) and $\mathbf{v}(t)$ is the velocity of the test charge in XYZ. Two cases of (28) will be considered.

Case 1: $\mathbf{v} \equiv 0$

Here the test charge is at rest in XYZ and the force $\mathbf{F}$ is just the bracketed term in (28). Since the system charges are moving through XYZ at velocity $\mathbf{1}_x u$, the force $\mathbf{F}$ changes with time. If, for simplicity, charge is postulated as an invariant, observer O can define a time-varying electric field by the relation

$$\mathbf{F} = \mathbf{1}_x F_x' + \kappa(\mathbf{1}_y F_y' + \mathbf{1}_z F_z') = q\mathbf{E}(x, y, z, t) \tag{29}$$

Using (27), this gives the component equations

$$\begin{aligned} E_x(x, y, z, t) &= E_x'(x', y', z') \\ E_y(x, y, z, t) &= \kappa E_y'(x', y', z') \\ E_z(x, y, z, t) &= \kappa E_z'(x', y', z') \end{aligned} \tag{30}$$

Case 2: $\mathbf{v} \not\equiv 0$

Here the test charge q has an arbitrary motion $\mathbf{v}(t)$ in XYZ and the force $\mathbf{F}$ is the entire expression (28). Using the electric field defined by Case 1, together with (27), this can be written

$$\mathbf{F} = q\mathbf{E} + q\mathbf{v} \times \left(\mathbf{1}_x \frac{\kappa u}{c^2} \times \mathbf{E}'\right) \tag{31}$$

The additional force, represented by the second term in (31), arises because of the motion of the test charge in XYZ. If an *additional field* $\mathbf{B}(x, y, z, t)$ is defined by

$$\mathbf{B} = \mathbf{1}_x \frac{\kappa u}{c^2} \times \mathbf{E}' \tag{32}$$

then (31) may be written

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \tag{33}$$

Equation (33) is known as the Lorentz force law and is seen to be a relativistic transformation of the Coulomb force law (27).

The components of (32) are

$$\begin{aligned} B_x(x, y, z, t) &\equiv 0 \\ B_y(x, y, z, t) &= -\frac{\kappa u}{c^2} E_z'(x', y', z') \\ B_z(x, y, z, t) &= \frac{\kappa u}{c^2} E_y'(x', y', z') \end{aligned} \tag{34}$$

$\mathbf{B}(x, y, z, t)$ is known as the magnetic field and is measured in webers per square meter. (1 Wb/m² = 10^4 gauss.)

Equations (30) and (34) comprise the field transformation equations. They may be combined to give the inverse transformation

$$E_x' = E_x \qquad E_y' = \kappa(E_y - uB_z) \qquad E_z' = \kappa(E_z + uB_y) \tag{35}$$

The differential equations satisfied by the field $\mathbf{E}'$, namely (25) and (26), may be transformed with the aid of (35). However, it is convenient, as a preliminary step, to determine the transformation of the sources ρ'. Since charge has been taken as an invariant, $\rho\, dV = \rho'\, dV'$. But $dV' = \kappa\, dV$ because of length contraction in the X direction. Therefore,

$$\rho(x, y, z, t) = \kappa\rho'(x', y', z') \tag{36}$$

Since all of the source charges are moving through XYZ at a velocity $\mathbf{1}_x u$, they give rise to a *current* as seen by observer O. The distribution of this current may be deduced in the following way: At a general point (x, y, z), erect a volume element $dV = dx\, dy\, dz$, with $dx = u\, dt$. The charge enclosed at any time t is $\rho(x, y, z, t)dV$. All of this charge, and no other charge, will pass out of dV in time dt. The current flow is X-directed and given by

$$dI_x = \frac{\rho\, dV}{dt}$$

The *areal density* of current flow, in amperes per square meter, will therefore be

$$\iota_x = \frac{dI_x}{dy\, dz} = \frac{\rho u\, dt\, dy\, dz}{dt\, dy\, dz} = \rho u$$

Using (36), this becomes

$$\iota_x(x, y, z, t) = \kappa u\rho'(x', y', z') \tag{37}$$

Equations (36) and (37) constitute the source transformation equations. A *static* charge distribution in $X'Y'Z'$ is seen to transform into a time-varying charge distribution and a time-varying current density in XYZ.

With these results it is now possible to convert (25) and (26). The goal will be a set of equations in which the dependence of E and B on the sources is displayed.

To see how this is accomplished, consider any function f of the four coordinate variables. Upon making use of the Lorentz equations (6), one can establish that

$$\frac{\partial f}{\partial x'} = \frac{\partial f}{\partial x}\frac{dx}{dx'} + \frac{\partial f}{\partial t}\frac{dt}{dx'} = \kappa\frac{\partial f}{\partial x} + \frac{\kappa u}{c^2}\frac{\partial f}{\partial t}$$
$$\frac{\partial f}{\partial t'} = \frac{\partial f}{\partial t}\frac{dt}{dt'} + \frac{\partial f}{\partial x}\frac{dx}{dt'} = \kappa\frac{\partial f}{\partial t} + \kappa u\frac{\partial f}{\partial x} \tag{38}$$
$$\frac{\partial f}{\partial y'} = \frac{\partial f}{\partial y} \qquad \frac{\partial f}{\partial z'} = \frac{\partial f}{\partial z}$$

If f is not a function of t', then the second equation of (38) yields

$$\frac{\partial f}{\partial t} = -u\frac{\partial f}{\partial x} \tag{39}$$

Application of (38) and (39) to the curl of E′ gives terms such as

$$\frac{\partial E_x'}{\partial z'} - \frac{\partial E_z'}{\partial x'} = \frac{\partial E_x'}{\partial z} - \kappa\frac{\partial E_z'}{\partial x} - \frac{\kappa u}{c^2}\frac{\partial E_z'}{\partial t}$$

which, with the use of (35), can be written

$$\frac{\partial E_x'}{\partial z'} - \frac{\partial E_z'}{\partial x'} = \frac{\partial E_x}{\partial z} - \kappa^2\left(\frac{\partial E_z}{\partial x} + u\frac{\partial B_y}{\partial x}\right) - \frac{\kappa^2 u}{c^2}\left(\frac{\partial E_z}{\partial t} + u\frac{\partial B_y}{\partial t}\right)$$

Upon determining all three components in this manner, one may write

$$\nabla' \times \mathbf{E}' \equiv 0 = \mathbf{1}_x\left[\kappa\left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}\right) + \kappa u\nabla\cdot\mathbf{B}\right] + \mathbf{1}_y\left[\left(\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}\right) + (1-\kappa^2)\frac{\partial E_z}{\partial x} - \kappa^2 u\frac{\partial B_y}{\partial x} - \frac{\kappa^2 u}{c^2}\frac{\partial E_z}{\partial t} - \frac{\kappa^2 u^2}{c^2}\frac{\partial B_y}{\partial t}\right] + \mathbf{1}_z\left[\left(\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}\right) - (1-\kappa^2)\frac{\partial E_y}{\partial x} - \kappa^2 u\frac{\partial B_z}{\partial x} + \frac{\kappa^2 u}{c^2}\frac{\partial E_y}{\partial t} - \frac{\kappa^2 u^2}{c^2}\frac{\partial B_z}{\partial t}\right] \tag{40}$$

This result can be simplified considerably. From (30) and (34), $uE_z = -c^2B_y$ and $uE_y = c^2B_z$. When these relations are coupled with (39) and employed in (40), one finds that

$$0 = \mathbf{1}_x\left[\left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}\right) + u\nabla\cdot\mathbf{B}\right] + \mathbf{1}_y\left[\left(\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}\right) + \frac{\partial B_y}{\partial t}\right] + \mathbf{1}_z\left[\left(\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}\right) + \frac{\partial B_z}{\partial t}\right] \tag{41}$$

Further simplification is possible through determination of $\nabla\cdot\mathbf{B}$. Since

$$\frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = \frac{\partial B_y}{\partial y'} + \frac{\partial B_z}{\partial z'} = -\frac{\kappa u}{c^2}\left(\frac{\partial E_z'}{\partial y'} - \frac{\partial E_y'}{\partial z'}\right)$$

it follows from (25) that

$$\nabla\cdot\mathbf{B} \equiv 0 \tag{42}$$

and therefore that (41) reduces to

$$\nabla \times \mathbf{E} = -\dot{\mathbf{B}} \tag{43}$$

When this procedure is repeated for the divergence of E′, one obtains

$$\nabla'\cdot\mathbf{E}' = \frac{\rho'}{\epsilon_0} = \frac{\rho}{\kappa\epsilon_0} = \kappa\nabla\cdot\mathbf{E} - \kappa u\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z}\right) + \frac{\kappa u}{c^2}\frac{\partial E_x}{\partial t} \tag{44}$$

Once again reduction is possible, since

$$\nabla\cdot\mathbf{E} = \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = \frac{\partial E_x'}{\partial x} + \kappa\frac{\partial E_y'}{\partial y} + \kappa\frac{\partial E_z'}{\partial z} = \kappa\frac{\partial E_x'}{\partial x'} + \kappa\frac{\partial E_y'}{\partial y'} + \kappa\frac{\partial E_z'}{\partial z'} = \kappa\nabla'\cdot\mathbf{E}'$$

Using (44), this gives

$$\nabla\cdot\mathbf{E} = \frac{\rho}{\epsilon_0} \tag{45}$$

which reduces the remainder of (44) to the form

$$\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z} = \frac{\rho u}{c^2\epsilon_0} + \frac{1}{c^2}\frac{\partial E_x}{\partial t} \tag{46}$$

If a new constant μ_0, called the permeability of free space, is defined by the relation

$$\mu_0 = \frac{1}{c^2\epsilon_0} \tag{47}$$

then, with the substitution $\iota_x = \rho u$, (46) may be written

$$\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z} = \frac{\iota_x}{\mu_0^{-1}} + \frac{1}{c^2}\frac{\partial E_x}{\partial t} \tag{48}$$

Equations (42), (43), (45), and (48) comprise the transformation to XYZ space of the $X'Y'Z'$ field-source equations (25) and (26). They have been derived for the special case that $X'Y'Z'$ is in constant translative motion along the X axis. If a second frame $X''Y''Z''$, containing static sources, were similarly in motion parallel to the Y axis, the same procedure would yield four equations similar to these, the differences being that B_y would be zero and (48) would be replaced by its Y equivalent. Likewise, if a third frame $X'''Y'''Z'''$, containing static sources, were in constant motion parallel to the Z axis, this procedure would produce four equations distinguished by the characteristics that B_z would be zero and (48) would give way to its Z equivalent.

A linear superposition of the fields due to static sources in all other Lorentzian frames therefore yields *total* fields $\mathbf{E}(x, y, z, t)$ and $\mathbf{B}(x, y, z, t)$ in XYZ, which satisfy

$$\nabla \times \mathbf{E} = -\dot{\mathbf{B}} \qquad \nabla \times \mathbf{B} = \frac{\boldsymbol{\iota}}{\mu_0^{-1}} + \frac{\dot{\mathbf{E}}}{c^2}$$
$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \qquad \nabla \cdot \mathbf{B} \equiv 0 \tag{49}$$

These four equations are known as Maxwell's equations, and have been derived here only for sources in free space. Upon representing materials by equivalent sources, (49) is easily extended to apply to general media.

It is evident that observer O need not rely on the static sources of O', O'', etc., to establish his time-varying electromagnetic fields, but can do this equally well himself by direct creation of the time-varying sources ρ and $\boldsymbol{\iota}$. That most general sources ρ, $\boldsymbol{\iota}$ may be treated as a superposition of *static* sources in $X'Y'Z'$, $X''Y''Z''$, etc., is demonstrated in the Appendix.

Conclusions

Through use of the relativisitic force transformation equations, one is able to show that the Lorentz force law is a transformation of the electrostatic Coulomb force equation. The time-varying electric and magnetic fields, which are defined as constituent parts of the Lorentz force expression, are then found to satisfy Maxwell's equations. This establishes the identity of the fields appearing in Maxwell's equations and the Lorentz force law. Additionally, Maxwell's equations are seen to be transformations of the expressions for the curl and divergence of an electrostatic field. All of the conventional relations of electrostatics, magnetostatics, and electromagnetics are derivable from Maxwell's equations. Therefore, this procedure leads to a relativistically exact, complete electromagnetic theory, using Coulomb's inverse-square law as the sole experimentally based electrical postulate. Although no new relations are uncovered, this approach has the virtue of enriching one's understanding of the subject by revealing the fundamental unity of electric and magnetic phenomena.

Appendix

Let a general current-density distribution $\boldsymbol{\iota}(x, y, z, t)$ be represented by the fourfold Fourier integral

$$\boldsymbol{\iota}(x, y, z, t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathbf{g}(k_x, k_y, k_z, \omega)\cdot e^{j(\omega t + k_x x + k_y y + k_z z)}\, dk_x\, dk_y\, dk_z\, d\omega \tag{A.1}$$

In a similar manner, let a general charge-density distribution $\rho(x, y, z, t)$ be represented by

$$\rho(x, y, z, t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(k_x, k_y, k_z, \omega)\cdot e^{j(\omega t + k_x x + k_y y + k_z z)}\, dk_x\, dk_y\, dk_z\, d\omega \tag{A.2}$$

The integrands of (A.1) and (A.2) are connected by the continuity equation, $\nabla \cdot \boldsymbol{\iota} = -\dot{\rho}$, which gives

$$f = -\frac{1}{\omega}(\mathbf{k} \cdot \mathbf{g}) \tag{A.3}$$

where $\mathbf{k} = \mathbf{1}_x k_x + \mathbf{1}_y k_y + \mathbf{1}_z k_z$.

If the fictitious charge and current densities in the interval $(d\mathbf{k}, d\omega)$ are treated as an independent entity that satisfies the flow equation $\boldsymbol{\iota} = \rho\mathbf{v}$, then the velocity of these fictitious charges is

$$\mathbf{v}(\mathbf{k}, \omega) = \frac{\mathbf{g}}{f} = -\frac{\omega\mathbf{g}}{\mathbf{k} \cdot \mathbf{g}} \tag{A.4}$$

This velocity is *independent* of x, y, z, and t, and is therefore a common velocity shared by all the charges that give rise to the $(\mathbf{k}, \omega)$ current and charge waves. In a coordinate system traveling at the velocity $\mathbf{v}$ with respect to XYZ, these charges are at rest. As $\mathbf{k}$ and ω are permitted to range over their complete spectra of values, (A.4) indicates that all values of $\mathbf{v}$ will be encountered in the interval $0 \leq v < \infty$. One may conclude from this that arbitrary *static* charge distributions in all Lorentzian frames may be combined to give the most general time-varying spatial distributions of current and charge density in a particular Lorentzian frame.

Because the range of $\mathbf{v}$ is unrestricted, some of these fictitious charge distributions are traveling through XYZ at speeds greater than light. This requires use of the Lorentz transformation equations when $v > c$. Even though the transformation is then nonphysical, this is mathematically admissible in the sense that Maxwell's equations transform properly under a Lorentz transformation, regardless of the value of v/c. It should be emphasized that the charge densities in the interval $(d\mathbf{k}, d\omega)$ are *fictitious*. No intimation is intended that the *real* time-varying charges, which are the sum of these fictitious static charge densities, are traveling at speeds in excess of c.

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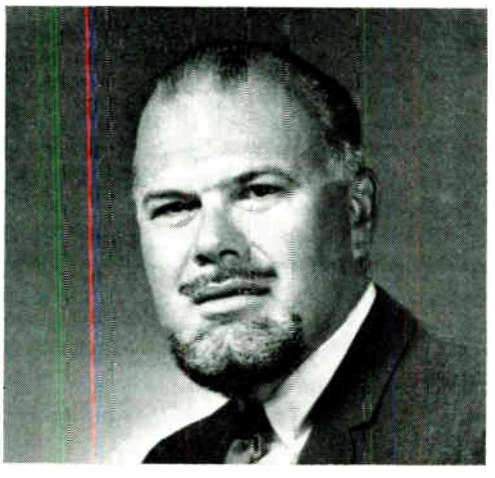
Communication with extraterrestrial intelligence

Harold Wooster, moderator
Paul L. Garvin
Lambros D. Callimahos
John C. Lilly
William O. Davis
Francis J. Heyden



Harold Wooster

Air Force Office of Scientific Research

As originally set up, this session was planned as a debate between those who say there is extraterrestrial life and those who say there isn't. It struck me that it might be much more interesting to set up the assumption that there is extraterrestrial life, and then attempt to answer the question, "How do we go about recognizing it and, hopefully, communicating with it?"

It seems evident that no single professional discipline is able to answer this question by itself. and so I thought that I would see what sorts of skills might be involved and then ask people representing these skills to appear on the panel.

In a discussion of this nature, we quite obviously need a linguist—a very special kind of linguist who specializes in monolingual field work (which will be explained subsequently). I believe that Paul L. Garvin fills the bill perfectly.

Obviously, too, a cryptologist was needed. I chose Lambros D. Callimahos, a highly qualified expert from the Department of Defense.

Let us examine the word "extraterrestrial." *Terrestrial* means "earth or land" and *extra* means "outside of." An ideal choice would be someone who has actually lived with, worked with, and talked with an extraterrestrial species. Therefore we have with us Dr. John Lilly, who works with dolphins.

William O. Davis is a physicist, a rather free-thinking one, who was invited on the grounds that we should have somebody on the panel whose comments are seldom predictable.

"Extraterrestrial" has other connotations. Since there is an astronomical aspect to this whole question, a learned astronomer would be an excellent person to have on the panel. And so we have Father Heyden.

Panel members will each have an opportunity to state their positions. They will then be allowed to—using a nice sociological word—interact.

Harold Wooster is director of the Information Sciences Directorate of the Air Force Office of Scientific Research, which has the responsibility of managing the principal Air Force basic research program in the information sciences. He received the A.B. degree in chemistry from Syracuse University in 1939, and the M.S. and Ph.D. degrees for research in clinical endocrinology from the University of Wisconsin in 1941 and 1943 respectively. During World War II he worked for the National Defense Research Committee, OSRD, at the Toxicity Laboratory, University of Chicago, in classified research on novel chemical warfare agents. In 1946 he worked under an Office of Naval Research Contract at the University of Pennsylvania's Pepper Laboratory of Clinical Medicine. He joined the Mellon Institute, Pittsburgh, in 1947 as Senior Fellow on a Food Varieties Fellowship. He combined laboratory research in nutrition and food biochemistry with writing and editing in nutrition. In 1956 he joined the Air Force Office of Scientific Research where, in addition to fulfilling his basic duties, he has edited four books.

This article is a condensation of Session 1-5 of the 1965 IEEE Military Electronics Conference (MIL-E-CON 9), Washington, D.C., Sept. 22–24, 1965. It is derived from the actual transcript of the session, except for Mr. Callimahos' statement, which is a formal version of his presentation at the conference. Dr. Stanley Winkler, Institute for Defense Analyses, was the organizer of the session.

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1000000000000000000000000000000000000000
1000011100000000001000001000000100000100
0000010001000000000000000000000000000000
0000001000100001000000100000000000001000
0000000100010000010000001000000000100100
0100000000111000000000000010000000000001
0000000000000000000000000000000000000000
0000000000000000000000001000001000000100
0001000011000100000000001100000000000000
0000000000000000000110000110000110000110
1101101101001100001100101100101100100100
1001001001010100100100001100001100001100
0011000011000000000100000000000111110100
0000000000000000000100000000000100000100
0000000001011011100100000000000001111101
0000000000000000000000000000100000000000
0000001000100111000000000000000010100000
0000001010010000110010101110010100000000
0000000101001000010000000000100100000000
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0000000010101000000010000000000010001010
0000000010100010000000000000000001000100
1000100010011011001110110110100000100010
0010101010001000100000000000000000010001
0001001001000100010000000000100000000111
0000011111000001110000000000011111010000000101
0100000101000001000100000010000000000100
0001000011100001000001000001000000000010
0000100010001000100010000000110001100001
0000010001000100010000010000011000000001
1000001101100011011000001100111
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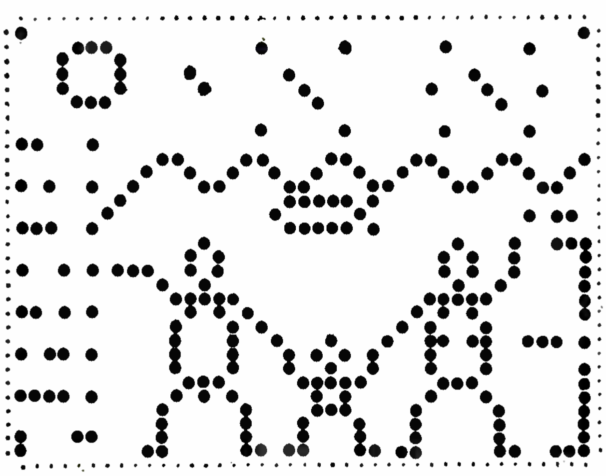
Fig. 1. Message of 1271 binary digits.

Fig. 2. Printout of message of Fig. 1, arranged in 31 lines of 41 bits each. Here the binary 1's have been replaced by dots and the binary 0's left as blank spaces.



than a billion galaxies similar to ours in the observable universe, the number of stars that could support some form of life, is to reach for a word, astronomical.

The nearest neighbor to our solar system is Alpha Centauri, only 4.3 light-years away; but, according to Dr. Su-Shu Huang of the National Aeronautics and Space Administration, its planetary system is probably too young for the emergence of life. Two other heavenly friends, Epsilon Eridani and Tau Ceti, about 11 light-years away, are stronger contenders for harboring life. Nevertheless, if superior civilizations are abundant, the nearest would probably be at least 100 light-years away; therefore it would take 200 years for a reply to be forthcoming. This should, however, make little difference to us, in view of the enormous potential gain from our contact with a superior civilization. Unless we're terribly conceited (a very unscientific demeanor), we must assume that the "others" are far more advanced than we are. Even a 50-year gap would be tremendous; a 500-year gap staggers the imagination; and as for a 5000-year gap. . . (By the way, if they are as much as 50 years *behind* us, forget it.) It is quite possible that "others" have satellite probes in space, retransmitting to "them" anything that sounds nonrandom to the probe. But they have probably called us several thousand years ago, and are waiting for an answer; or worse yet, they have given up; or, more probably, they have reached such impressive technological advances that they have destroyed themselves.

Epsilon Eridani and Tau Ceti were the targets on which Dr. Drake focused his attention in the spring of 1960 in Project Ozma, an attempt to detect possible intelligent signals from outer space. The frequency selected for listening was 1 420.405 752 Mc/s, or a wavelength of 21 cm. This particular frequency, postulated independently by two professors on the faculty of Cornell University, Giuseppe Cocconi and Philip Morrison, happens to be the radiation frequency of atomic or free hydrogen, which permeates space in great clouds; moreover, it is within the range of radio frequencies able to pass through the earth's atmosphere. Presumably, this frequency's significance would be known to other intelligent beings in the universe who understand radio theory. We're still talking about radio waves as the communication medium; other possible media might be masers, lasers, or the as yet undiscovered and unnamed "rasers." A technology superior to ours might even have learned how to modulate a beam of neutrinos (weightless, uncharged particles that physicists on earth find difficult even to detect); if so, "they" may have to wait a century or two before we learn how to build a neutrino receiver.

If another civilization were trying to establish communication with us, it would first embark on attention-getting signals of such a nature that we could distinguish them from random cosmic noise; once we receive a recognizable signal, we have a good chance of understanding the message. For example, they could start with trains of signals corresponding to the natural numbers 1, 2, 3 . . ., followed perhaps by prime numbers. They might continue with equal-length extended signals consisting of start and stop impulses, with occasional pulses in between; when these signals are aligned flush over one another, they would show a circle, the Pythagorean theorem, or similar geometric design. These attention-getting signals would be followed by early "language lessons," interspersed with items of technical information to help bring us up to "their" level.

It may be assumed that the sense of sight, or an equivalent, is possessed by all higher forms of life; the problems of communication could thus be greatly simplified through the medium of a "raster" representation such as that of a television screen. After a 1961 conference at Green Bank, W. Va., to discuss the possibility of communication with other planets, one of the participants, Bernard M. Oliver, made up a hypothetical message on the raster principle. The message, consisting of 1271 binary digits or "bits," is shown in Fig. 1. Since 1271 has but two prime factors, 31 and 41, we would naturally be led to write out the message in raster form, in 41 lines of 31 bits each, or in 31 lines of 41 bits each; the latter case reveals a greater nonrandomness in the patterns disclosed, indicating that

Fig. 3. A series of 30 transmissions, devised as messages that conceivably could have been received as communications from outer space.

(1) A. B. C. D. E. F. G. H. I. J. K. L. M. N. O. P. Q. R. S. T. U. V. W. X. Y. Z.
*. &. $. ¢. #. @. A. B. C. D. E. F. G. H. I. J. K. L. M. N. O. P. Q. R.
S. T. U. V. W. X. Y. Z. *. &. $. ¢. #. @.

(2) A A, B; A A A, C; A A A A, D; A A A A A, E; A A A A A A, F; A A A A A A A, G;
A A A A A A A A, H; A A A A A A A A A, I; A A A A A A A A A A, J.

(3) A K A L B; A K A K A L C; A K A K A K A L D. A K A L B; B K A L C; C K A L D.
B K C L E; E L B K C; F K D L J; J L D K F. E L K E; K E L E.

(4) C M A L B; D M A L C; G M E L B; E M G L M B.

(5) D K N L D; G K N L G; F M F L N; E M E L N.

(6) J L AN; J K A L AA; J K B L AB; AA K A L AB. J K J L BN; J K J K J L CN;
IN K C L IC.

(7) B O C L F; D O B L H; E O B L AN; D O AN L DN.

(8) F P C L B; H P B L D; J P B L E; J P E L B.

(9) A P J L Q J; A P ANN L Q ANN; Q J, P J L Q ANN.

(10) Q J L R A; Q J O B L R B; A R E M A L R E L E O Q J. Q ANN L R NA;
Q ANN O B L R NB.

(11) H L H; G S C, C S G. D K A L C K B; D K C S E K A; E K A S D K C.

(12) D T A; D T B; D T C; D L D; D U E; D U F; D U G. J T I; J U AA.

(13) FIRII V GN; ANNN K C V ANNN; AN P C V CRC.

(14) W E K A X L E K A; B W E K A X L W B O E X K W B O A X L B O F.

(15) C Y B L I; E Y B L BE; B Y E L CB; W D K A X Y B L BE.

(16) BE Z B L E; FD Z B L H; BG Z C L C; ABE Z C L E. W AI K F X Z B L E.
BE Z B L M E; M ABE Z C L M E. BE Z B L KM E.

(17) D * L D O C O B O A L BD; E * L E O D O C O B O A L ABN; H * L DNCBN.

(18) & P D L A M Q C K Q E M Q G K Q I M. & V CRADAEI.

(19) $ L A K Q W A * X K Q W B * X K Q W C * X K Q W D * X K. $ V BRGAHBH.

(20) ¢ E K A # L W E K A X; B ¢ E K A # L B W E K A X;
B ¢ E K W D K C X # L B W E K G X. ¢ B # ¢ D # L W B X W D X L B O D.

(21) $ Y ¢ & O W M A X Z B # K A L N.

(22) B K C L ¢ @ NNA #; B K C L E. C O D L ¢ @ NNA #; C O D L AB.
D Y B L ¢ @ NNA #; D Y B L AF.

(23) B K C L E; ¢ @ NNB #. B K D L E; ¢ @ NNC #. E Y B L BE; ¢ @ NNB #. F Y B L C E;
¢ @ NNC #. I T E; ¢ @ NNB #. H U C; ¢ @ NNC #. & V BRGAHBH; ¢ @ NNC #.

(24) B L ¢ @ NND #. C L ¢ @ NND #. E, G, AA, AC, AG, ¢ @ NND #. ANA ¢ @ NND #.

(25) ¢ @ NNE # L B O & ¢ @ A #; ¢ @ NNF # L & ¢ @ A # Y B. ¢ @ A # L ¢ @ NNG #.
¢ @ NNE # L B & ¢ @ NNG #; ¢ @ NNF # L & ¢ @ NNG # Y B.

(26) ¢ @ NNH # L D O Q C O & ¢ @ NNG # Y C.

(27) Q B K Q D K Q H K Q AF K Q CB V A;
Q B K Q D K Q H K Q AF K Q CB K ¢ @ NNI # L A.

(28) C K ¢ @ A # L G; ¢ @ A # L D. I K ¢ @ A # L AB; ¢ @ A # L C.
FD Z ¢ @ A # L H; ¢ @ A # L B.
¢ @ A # L A, R GG, M R GG, J P C, &, K, M, ¢ @ NNI #.
¢ @ B # L A, R GG, M R GG, J P C, &, K, M, ¢ @ NNI #.
¢ @ C # L A, R GG, M R GG, J P C, &, K, M, ¢ @ NNI #.

(29) ¢ @ NNE # L B & ¢ @ B #; ¢ @ NNF # L & ¢ @ B # Y B.
¢ @ NAN # L B ¢ @ C # K B ¢ @ D #; ¢ @ NAA # L ¢ @ C # O ¢ @ D #.

(30) ¢ @ NNE # L ¢ @ NAB #, ¢ @ NAC #; ¢ @ NNF # L ¢ @ NAD #, ¢ @ NAC #.
¢ @ NAN # L ¢ @ NAB #, ¢ @ NAE #; ¢ @ NAA # L ¢ @ NAD #, ¢ @ NAE #.

Symbols

A	1	I	9	Q	reciprocal	Y	power
B	2	J	10	R	decimal point	Z	root
C	3	K	+	S	≠	*	factorial
D	4	L	=	T	>	&	π
E	5	M	-	U	<	$	e
F	6	N	∅	V	≈	¢	[
G	7	O	×	W	(	#	]
H	8	·P	÷	X	)	@	code

Code values

001	question	007	radius	013	circle
002	true	008	volume or sphere	014	area
003	false	009	... (ellipsis)	015	rectangle
004	prime	010	perimeter of rect.	.	
005	circum. of circle	011	area of rectangle	.	
006	area of circle	012	perimeter	999	

Code values 1, 2, 3,... 99 = x, y, z,... (abstractions, unknowns, variables)

Fermat's Last Theorem:

¢ @ A # Y ¢ @ D # K ¢ @ B # Y ¢ @ D # L ¢ @ C # Y ¢ @ D #. ¢ @ D # L B; ¢ @ NNB #.

¢ @ D # L C, D, E, ¢ @ NNI #; ¢ @ NNC NNA #.

Goldbach's Conjecture:

B ¢ @ A #. B ¢ @ A # L ¢ @ B #; ¢ @ B # T B. ¢ @ B # L ¢ @ C # K ¢ @ D #;

¢ @ C # L ¢ @ NND #, ¢ @ D # L ¢ @ NND #. ¢ @ NNB NNA #.

Fig. 4. Solution to the "space communication" presented in Fig. 3.

these are the correct dimensions. In Fig. 2 is the writeout of the message, in which the binary l's have been replaced by dots and the 0's left as blank spaces. Now for its interpretation.

There are dots at the four corners of the pictogram as reference points, marking the outlines of the rectangle. At the upper left is a representation of the sun; directly underneath in a column are dots representing eight planets, identified by the appropriate binary coding to their left, preceded by a binary point as a marker. The erect, two-legged beings illustrated are obviously male and female mammals. One hand of the male figure points to the fourth planet, where they apparently reside. At the top of the pictogram may be seen representations of hydrogen, carbon, and oxygen atoms, indicating that the chemical structure of life on their planet is similar to ours. From the third planet there emerges a wavy line, showing that it is covered with water; the fish shows that they must have visited us and therefore have space travel. One hand of the female figure points to a six (preceded by the usual binary point), perhaps implying that there are six fingers on each hand; we could therefore assume that their number system is probably to the base 12. At the right of the female figure may be seen a bracket, in the middle of which is eleven in binary form (preceded by a binary point); this implies that the beings are 11 units high. A reasonable interpretation is that the unit is 21 cm, the wavelength of the transmission, making them about 7½ feet tall, which should be all right for average Martians.

In 1952 the British scientist Lancelot Hogben delivered an address before the British Interplanetary Society entitled "Astraglossa, or First Steps in Celestial Syntax." Hogben pointed out that *number* is the most universal concept for establishing communication between intelligent beings; therefore, mathematics forms the basis for the first steps in extraterrestrial communication. He then illustrated how he could transmit pulses representing integers, and distinctive signals or "radioglyphs" representing +, −, =, and so on. Morrison later carried out the basic idea a little further, using different pulse shapes to represent elementary mathematical symbols. An entirely different approach was developed by Hans Freudenthal, professor of mathematics at the University of Utrecht, who in 1960 published a book entitled *Lincos: Design of a Language for Cosmic Intercourse*. Lincos, which is an acronym of "lingua cosmica," tries to establish a communication of ideas through symbolic logic, but the general consensus of those who have taken the trouble to study his book is that his plan is too difficult. After all, the object of the exercise is getting ideas across to another party, whose thinking processes may be entirely different from our own. In other words, what we need to develop is an "inverse cryptography," or communication symbolism specially designed, not to hide meaning but to be as *easy* as possible to comprehend. Cleverness on the part of the *sender* is the important factor, not reliance on ingenuity of the recipient. The "inverse cryptographer" must make his meaning clear to the recipient, even if the latter does not possess a cosmic equivalent of the Rosetta Stone.*

As an illustration of how much information could be conveyed with a minimum of material, and as an example of facile inverse cryptography, let us consider a message I have devised to be typical of what we might expect of an initial communication from outer space. In Fig. 3 is shown a series of transmissions that could have come from another inhabited planet, many light-years away. The 32 arbitrary symbols are representations of the 32 different signals (combinations of beeps, or distinctive pulse shapes) heard on a frequency of 1420.4 Mc/s. The punctuation marks are not part of the message, but here represent different time lapses: adjacent symbols are sent with a short pause (1 unit) between them; a space between symbols means a longer pause (2 units); commas, semicolons, and periods indicate pauses of 4, 8, and 16 units, respectively. Between transmissions (numbered here for reference purposes) there is a time lapse of 32 units.

The first transmission, (1), is obviously an enumeration of the 32 different symbols that will be used in the communications; in transmission (2) is the clear implication that A represents the integer 1, B the integer 2, . . ., J the integer 10. In the first 20 transmissions there are introduced symbols for the introductory expository treatment in teaching us their mathematics. Among the items treated are: addition, subtraction, multiplication, and division; decimal notation and the concept of zero; inequalities and approximation; powers and roots; and definitions of π and e. Transmission (21) adds nothing new to the 31 symbols recovered thus far, but it does quote one of the most beautiful concepts in pure mathematics: They are telling us that if they can teach us such a complex notion at this early stage, we will be staggered by what they will teach us by the 200th or the 2000th transmission. Beginning with transmission (22), words and word-cluster concepts are introduced, so that by the time we come to transmission (30), we now are understanding, in a manner of speaking, pure Venerean. We can now see how we could recover the code they are using on us, and which will obviously consist of thousands of code groups with different meanings; this is easily appreciated by anyone who takes the trouble to fathom the meaning of all the 30 foregoing transmissions. (The solution may be found in Fig. 4.)

Even right after this first message, if we are in direct communication with that planet, we shall have questions to put to "them": the proof of Fermat's last theorem, Goldbach's conjecture,† and many other unsolved problems in mathematics and the natural sciences. It will not be difficult for "them" to demonstrate their intellectual and technological superiority (first of all, don't forget it was *they* who were able to call *us*). If "they" but know the seventh digit of the "fine structure constant," they are ages ahead of us (we know only the first five for sure, suspect the sixth). This number, 137.039 . . ., is the ratio, among others, of the speed of light to the speed of the hydrogen electron; it may take a century to calculate this constant to nine digits. And after we resolve our pressing scientific questions, it might be appropriate to make discreet inquiries as to how we could live in harmony and peace with our fellow man—that is, if we aren't eaten or otherwise ingested by the superior civilization that had the good fortune to contact us. But as far as the cryptologist is concerned, he (and generations of his descendants who might experience the thrill of their lives when we hear from "them") must keep a level head and be prepared to cope with problems such as he has never seen—problems that are out of this world, so to speak.

*The Rosetta Stone is a piece of basalt found in 1799 near the Rosetta mouth of the Nile, bearing a bilingual inscription (in Egyptian hieroglyphics, Egyptian demotic, and Greek) with which Jean François Champollion was able to solve the mystery of the Egyptian hieroglyphs.

†With what he has learned from this example of space communication, let the reader formulate these two questions directly for transmission to "them," in a clear and compact form; the solutions appear in Fig. 4. For the reader who is a little rusty on classic unsolved problems in mathematics, Fermat's last theorem states that no integral values of x, y, and z can be found to satisfy the equation $x^n + y^n = z^n$, if n is an integer greater than 2; Goldbach's "notorious" conjecture ("notorious" only because other mathematicians failed to make the conjecture themselves) states that every even number greater than 2 can be expressed as the sum of two primes.

John C. Lilly

Communication Research Institute

The title that I might choose for my discussion is "The Need for an Adequate Model of the Human End of the Interspecies Communication Program," a plea for self-conscious, open-ended, general-purpose, nonspecies-specific cognition research into models of theory for communication with nonhuman minds. I believe that this is the first time the word "mind" has been mentioned in this respect.

John C. Lilly, M.D., is director of the Communication Research Institute, an independent organization with laboratories in Florida and the Virgin Islands, which he founded in 1959 for studies on methods of communication between man and other species and on the structure and functions of the brain and psychology of man and of animals of the sea. He received the B.S. degree from the California Institute of Technology and the M.D. degree from the University of Pennsylvania. He was on the faculty of the E. R. Johnson Foundation for Medical Physics for 12 years and later became chief of the Section on Cortical Integration, Laboratory of Neurophysiology of the National Institute of Mental Health, Bethesda, Md. He is the author of *Man and Dolphin* and coauthor, with Dr. Ashley Montagu, of *The Dolphin in History*. He has also written some 90 published papers on his scientific research.

For approximately the last nine years, I have struggled with the problem of devising working models of the interspecies communication problem at a relatively highly structured cognitive level. Despite overglamorization and excessive public exposure, the embryo has remained viable and hard working.

The major portion of the total problem has been found to be my own species rather than the delphinic ones. There is apparently no currently available adequate theory of the human portion of the communication network. The lack of such a theory has made it difficult for most scientists to see the reality of the problems posed in the interspecies program. As long as the conscious–unconscious basic belief exists of the pre-eminence of the human brain and mind over all other earthside brains and minds, little credence can be obtained for the proposition that a problem of interspecies communication exists at all.

Despite arguments based on the complexity and size of certain nonhuman brains, little if any belief in the project has been instilled in the scientific community at large. Support has been obtained for further examination and demonstration of the large-sized, detailed excellence of structure and description of the large dolphin brain. There is no lack of interest in this area. The falling out comes in obtaining the operating interest of competent working scientists in the evaluation of the performance of these large brains. Interest and commitment of time and self are needed for progress.

The basic assumptions on which we operate are as follows. Each mammalian brain functions as a computer, with properties, programs, and metaprograms partly to be defined and partly to be determined by observation. The human computer contains at least 13 billion active elements and hence is functionally and structurally larger than any artificially built computer of the present era. This human computer has the properties of modern artificial computers of large size, plus additional ones not yet achieved in the nonbiological machines. This human computer has stored program properties, and stored metaprogram properties as well. Among other known properties are self-programming and self-metaprogramming. Programming and metaprogramming language is different for each human, depending upon the developmental, experiential, genetic, educational, accidental, and self-chosen variables, elements, and values. Basically, the verbal forms are those of the native language of the individual, modulated by nonverbal language elements acquired in the same epochs of his development.

Each such computer has scales of self-measuration and self-evaluation. Constant and continuous computations are being done, giving aim and goal distance estimates of external reality performances and internal reality achievements.

Comparison scales are set up between human computers for performance measures of each and of several in concert. Each computer models other computers of importance to itself, beginning immediately *post partum*, with greater or lesser degrees of error.

The phenomenon of computer interlock facilitates model construction and operation. One computer interlocks with one or more other computers above and below the level of awareness any time the communicational distance is sufficiently small to bring the interlock functions above threshold level.

In the complete physical absence of other external computers within the critical interlock distance, the self-directed and other-directed programs can be clearly detected, analyzed, recomputed, and reprogrammed, and new metaprograms initiated by the solitudinous computer itself. In this physical reality (which is an as completely attenuated as possible environment with solitude), maximum intensity, maximum complexity, and maximum speed of reprogramming are achievable by the self.

In the field of scientific research, such a computer can function in many different ways—from the pure, austere thought processes of theory and mathematics to the almost random data absorption of the naturalistic approach with newly found systems, or to the coordinated interlock with other human computers of an engineering effort.

At least two extreme major techniques of data-collection analysis exist for individual scientists: (1) artificially created, controlled-element, invented, devised-system methods; and (2) methods involving the participant–observer, who interacts intimately and experientially with naturally given elements, with nonhuman or human computers as parts of the system.

The former is the current basis of individual physical–chemical research; the latter is one basis for individual, explorative, first-discovery research of organisms having brains larger than those of humans.

Sets of human motivational procedural postulates for the interlock research method on nonhuman beings, with computers as large as and larger than the human computers, are sought. Some of these methods involve the establishment of long periods—perhaps months or years—of human to other organism computer interlock. It is hoped that this interlock will be of a quality and value sufficiently high to permit interspecies communication efforts on both sides on an intense, highly structured level.

In essence, then, this is the problem of communicating with any nonhuman species or being or mind or computer. We do not have, however, the full support in basic beliefs in the scientific community for these postulates. Obviously, we as a species do not believe, for example, that a whale, with a brain six times the size of ours, has a computer worth dealing with. Instead, we kill whales and use them as fertilizer. We also eat them. To be fair to the killer whale, I know of no instance in which a killer whale has eaten a human, but I know of many instances in which humans have eaten killer whales.

Therefore, on an historical basis, I do not feel that at present there is much chance that any species of greater attainments than ours will want to communicate with us. The dolphins want to communicate only with those people who are willing to live with them on the terms the dolphins set up and that certain kinds of human beings set up. Other types the dolphins drive away. Every year we lose people from the dolphin research program. Usually it is because of fear of the power of these animals and fear of damage, even though in the history of the laboratory no one has yet been injured by the dolphins. Sometimes we think that these people who are lost are projecting their own hostilities outward onto the animals in a very unrealistic fashion. The people who survive either realize that this mechanism is operating and conquer it, or else their nature is such that they do not have hostilities to project.

William O. Davis

Huyck Corporation

I shall begin by stating that I am not speaking now as a physicist. What I have to say will not be scientific. It certainly will have nothing to do with military electronics. If anything, I would call it an imaginative extrapolation of speculative concepts for recreational purposes.

What is life? I don't mean to approach this at the level of religion, but rather from a strictly functional point of view. Living systems have certain characteristics that are quite different from those of nonliving systems. The most important one has to do with the way in which they become more orderly with time instead of less orderly. Physical systems, nonliving systems, according to the well-known second law of thermodynamics, tend to become increasingly disordered with time. They run down, whereas life tends to become more organized with time, though not necessarily forever. The individual dies and becomes disorderly, but at least as a species and during the lifetime of the individual he becomes more orderly with time. The essential characteristic of life is order.

If I were going to set up a detection means, a system for detecting life, I think I would probably choose an analog to the very famous method that Clyde Tombaugh, the astronomer, came up with to determine whether the Martian canals were made by people or were natural phenomena. Clyde noted that these canals as sketched by the astronomers formed a network. He also noted that networks have certain characteristics. They are connected in certain ways. How many intersections did you have between rays, for example? Did you normally have just two rays meeting, or three or four or five? What was the distribution in the multiplicity of these connections?

He found that physical, nonliving systems tend to have a certain distribution of connections—for example, cracked clay, or the cracks on a ceramic pot, or the river system on a continent all have certain typical kinds of connections. Somewhat living but not intelligent organisms, such as spiders and bees, tend to produce a different kind of a pattern. On the other hand, cows finding their way to water and man building railroads follow pretty much the same pattern. Based on this analysis, he concluded that the canals of Mars must have been made by something at least as intelligent as a cow.

It turned out that he was right, because in fact we now know that the canal structure was a function of the observer and not what was observed.

This, in essence, is the principle. I am not going to talk any more about life detection systems here, but if I were trying to design a life detection system to fly over Mars and determine whether there was life there, or on Venus, or somewhere else, I think I would base it on this general principle. I would look for patterns of order.

Now, let's assume we discover that there is life. This life need not have the same chemical form as our life. All that is required for it to be life is that there be a local reversal of the second law of thermodynamics; and if we see that there is, we suspect there is something living present. If we find that nuclear reactions that we know take place in a certain way are going the other way on a certain planet, then I would look for life at the nuclear level.

How do we communicate? Well, we have talked about the linguistic approach. We have talked about Dr. Lilly's approach with nonhuman forms. I think I would like to break the problem down a little more.

There are really three different cases we should worry about. First of all is an encounter with a lower order of intelligence than our own. This would be the case if we should land on a planet and find it occupied with life at the level of bees or cows and presumably nonintelligent, or at least not yet at our level. In this particular case, I think that the best we could hope for would be the type of communication we establish with dogs and horses, a symbiosis or—and this is disputable—a telepathic rapport with them. It would be unlikely that we could establish communication at the verbal level or at the level of symbology.

The second case is where we find people of precisely equal evolution. Now, this is very improbable, as was pointed out earlier. Even 15 years in our history would make a tremendous difference, either backwards or forwards. If you look at the technological trend curves, for example, you find that by the year 2000 everything is asymptotic, and it is extremely likely that technological revolution per se will have played itself out by that time. Other trends indicate that from here on increasing emphasis is going to be on understanding the mind and how it operates. Some of the work that Dr. Puharich has done is a little controversial, too, such as studying extrasensory perception with people having extreme talents,

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which indicates that there are relationships between these ESP talents and other natural phenomena, and indicates that as we go on we may be able to learn how to improve our ability to communicate, at least at the symbolic level, by ESP means. Certainly even today we do a great deal, I suspect, of our communication at the emotional level by extrasensory means.

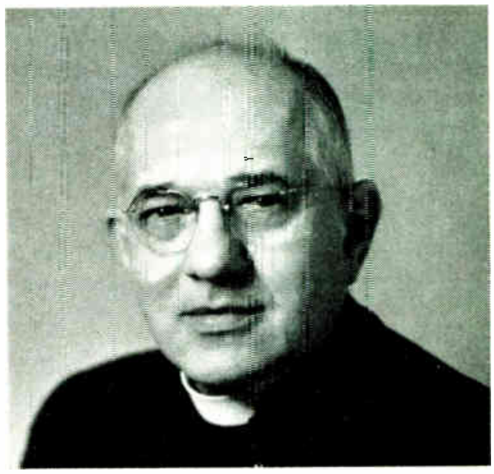
If we were to encounter somebody of equal intelligence, I think we would have a problem. We would undoubtedly fight them. This, to my way of thinking, is the least probable and the most dangerous of the three cases.

In many respects the most probable encounter is with a higher form of life, or at least a more advanced form, because these beings would be more likely to reach us first than vice versa. If we assume that they understand more about the mind than we do—and let's say they understand more about ESP or it turns out to be a human-type phenomenon—they should be able to detect us. After all, we know all kinds of fields associated with the physical world, the world of entropy. It is not illogical to assume that life may have as yet undetected fields and radiation associated with it. They wouldn't have to scour the whole universe for us. They would simply focus their life-detecting device. (That, incidentally, is a very good challenge for the military electronics engineer.)

The nice thing about this hypothetical contact is that communication would be their problem. We wouldn't have to worry too much about it. They would come to us. As a matter of fact, I strongly suspect that the first communication is very likely to be telepathic; perhaps it will just involve a sense of being friendly. As Dr. Lilly pointed out earlier, some dolphins want to communicate and others don't, and they apparently can detect which people wish to communicate with them and which don't. I think that if this first form of communication were achieved, more detailed forms would probably follow.

The problem of language is that you require some kind of a cultural reference. In just learning to speak a European language, for example, you may know all the words and be able to translate them into English, but if you know nothing of the culture of the country, you will not really understand the subtleties of what you are saying. This sort of problem will be incredibly more complicated in communication with an alien race. In fact, I suspect that language communication will be almost the last thing to take place.

In summary, I would say that the most probable case of communication with extraterrestrial beings is an encounter with a race more advanced than we; therefore, the problem would be primarily psychological on our part. We would undoubtedly be deeply upset by this state of affairs. Thus these beings, if they are really advanced and subtle, would know this and would approach us in such a way as not to frighten us. If I were on their staff, I think I would use my advanced knowledge to learn the languages of the human race through one means or another, imitate human structure and appearance, and send representatives down to mingle with the earth's people. Gradually I would begin to understand the earth's culture and develop means of communication to a point at which at a later time communication could be established in the proper verbal manner after the human race had been thoroughly relaxed. Thus, it is entirely possible and maybe even probable that extraterrestrial races are already amongst us!



Francis J. Heyden

Georgetown University

In the question of communication from outer space, there are a few factors that an astronomer would naturally want to consider. For example, he would like to know whether there are other solar systems in space. Let us first examine how our own solar system came into being. We know, for example, that geologists by means of time scales based on radioactivity have found that the rocks in the surface of the earth are about 4 to 5 billion years old. When we finish bringing up cores from the Mohole out in the Pacific, and once we get to digging it, we may be able to tell from the type of rock there whether or not the earth is even older than that.

In recent years astronomers who have thought of abandoning the radioactive time scale in favor of a nuclear time scale of hydrogen cores burning in stars have found that certain clusters of stars indicate ages of 24 billion years.

It would appear, therefore, that we are rather newcomers, if we can trust the age that we find in the rocks on the surface of the earth, and that this great galaxy of which we are just one little member is much older than the earth.

The next question is: How did the earth get here? We have had many, many theories. Two of them we can classify, one as catastrophic and the other as one in which the earth sort of grew, grain by grain, like an ant hill, as the forces of solar wind and outer space made them cluster together.

Francis J. Heyden, S.J., attended St. Andrew-on-Hudson, where he was a Jesuit Novice for four years, and Woodstock (Md.) College, from which he received the M.A. degree in philosophy in 1931. He spent the next three years as chief of the Astronomical Division of the Manila Observatory, and then returned to Woodstock for theological studies, which he completed in 1937. He later received the M.A. and Ph.D. degrees in astronomy from Harvard University, where he took graduate courses and served as a Teaching Fellow in the Department of Astronomy. After teaching mathematics for a year at St. Peter's College in Jersey City, Father Heyden joined the faculty of Georgetown University in 1945. He is now a professor and head of the Department of Astronomy at Georgetown. Among his projects there have been five solar eclipse expeditions from 1947 to 1955; spectroscopic research involving the sun, planets, and metals of astrophysical interest; and special studies on the colors and periods of pulsating and double stars.

I like the catastrophic one, although that doesn't prove it was so, because it would seem that we sort of got mixed up in one great big whirlwind and some great collision that took place between two stars.

We can study the number of stars there are per unit volume of space in the vicinity of the sun; if we want to do it the way a statistical astronomer would, we calculate the number of stars of solar size per cubic centimeter, of which there are 10^{-57}.

Calculating on the basis of an average speed of 15 km/s, there should be a meeting of two stars a distance apart from the sun to Saturn once every 2×10^{18} years, and assuming that we have 2×10^{11} solar masses in our galaxy, this would indicate that we should have a collision of this sort once every 10 million years. So that in the age of this system (if we allow 20 billion years as the age), and if it worked every time, then we have roughly 2000 solar systems in our Milky Way.

But have we ever seen any of them? Well, about 20 years ago an astronomer at the Naval Observatory began studying a double star. And let me say that probably two thirds of the stars in the sky are double systems. This particular star, known as 61 Cygni, which is 11 light-years away from us, has a companion that goes around once every 720 years, and it has been observed now for better than a century.

One peculiarity of this star system, where you can see the one going around the other and plot the path, is that one star is not going around in a smooth path, but is staggering. What could make it do that but an invisible companion? You can't see the companion, even with the largest telescopes we have. Of course, we may build bigger telescopes in orbit later, now that we are getting to the point where gravity won't let us put them on the earth. We will put them in orbit and look for these invisible companions. This particular one would seem to be about eight times the size of Jupiter. So it is logical to say that living beings on this planet, even if they are intelligent, must be a little bit different from us. Certainly if you were the inhabitant of a planet eight times the size of Jupiter you would not be walking around in the skeletal structure that you have here on the earth, because it would be very difficult to lift one foot off the ground.

In the course of time we have found probably four other stars of this sort, double stars that have staggering companions and that indicate the existence of invisible planets, or perhaps dark stars. They are Barnard's Star (a very famous star that travels rapidly through space), then one known as the Lund 21185, another named after Frank Ross (Ross 614), and then BD + 20° 2465.

Although the farthest one of these is 15 light-years away, it does seem as if there are some things out there that might be planets associated with stars, and while we haven't seen them or haven't measured any temperatures on their surfaces and we don't know whether they have atmospheres or anything of that sort, at least there is some evidence that we are not alone.

Let's assume that we do pick up a communication. Suppose this "Rosetta Stone of space" does sometimes occur. A Russian radio astronomer once found certain definite repetitive frequencies that he could not attribute to any physical phenomenon, such as the 21-cm action of the hydrogen atom in its rotation in space, or to collisional action or temperature variations of a sort. This effect he discovered is periodic, and he concluded that it must be an intelligent being pounding away once every hundred days with a key.

But let's not forget that there is a great geometric dilution factor coming in here. Those people connected with the signals coming from Mariner 4 are familiar with the $1/R^2$ dilution law of space, and the signal can get pretty weak and thin by the time it reaches the earth, where we are just one little solitary grain of intelligence to pick up this signal.

The Russian radio astronomer also made the statement that he thought there were three kinds of intelligence; in fact, he went even further and said that there are three kinds of civilizations.

If the signal were coming from a planet, probably some thousands of light-years away, the energy needed for that transmission would be roughly equivalent to all of the energy that we can now generate on this earth at one time. Of course, it would take more than an International Geophysical Year to get wired up for it on earth.

If the same signal were coming from about 100 000 light-years away the dilution would become much greater. It would then be necessary to take all of the energy generated by our sun. Any civilization that can master that much and get it together and put it into an antenna for transmission is a civilization of Type 2.

If the signal were coming from 100 million light-years away, we would need all the energy of all the stars in the whole Milky Way, or 2×10^{11} times the solar energy. To achieve this would require a Type 3 civilization.

I can't say as an astronomer that we have ever heard any such signal. However, if we did find something that could be interpreted, let's suppose that the thing said, "Hello, there."

We would answer by asking, "Where are you?"

It might take about 400 years for a signal to come back, saying, "Out here."

General discussion

Dr. Wooster: At this point we have to do something cumbersome. I would normally prefer to let the panel all talk to each other at once, but we have to be more stylized than that. So I will ask the panel members for questions and comments directed to the other members.

Dr. Garvin: I have only one brief comment to make; that is, if Dr. Davis' assumption is right about the people from elsewhere coming in here to contact us, then they would have to do monolingual field work on us. It might contribute greatly to the advancement of my profession, so I am hoping for it to happen.

Dr. Lilly: I think I have one advantage over the others on the panel, in that we have a body to work with that is trying to communicate with us.

Dr. Davis: Dr. Lilly, is there any indication that ESP or something other than verbal communication plays any role in the learning process of the dolphin?

Dr. Lilly: I will answer Dr. Davis with a question: Has the existence theorem for ESP been established?

Father Heyden: I can't predict whether we will ever have telepathic tennis players racketing news back and forth from distant parts of space. I hope that when we do unravel the mysteries of telepathy it will not be tied down by the speed of light, which brings down a light curtain upon all of us when we try to talk about interplanetary or interstellar communication. Telepathy may, as Aristotle said, need no time to travel through space.

IEEE takes a stand on units

Bruce B. Barrow *Sylvania Electric Products Inc.*

The purpose of this article is to present an introduction to the important new standards publication, "IEEE Recommended Practice on Units in Published Scientific and Technical Work," recently approved by the IEEE Standards Committee. The full text of the document appears at the conclusion of this discussion, which is intentionally kept informal because it is concerned with opinion and judgment as well as with fact.

It is important for IEEE to concern itself with units, because units—especially those used in electricity and magnetism—have represented a continuing problem area for the profession. It is now more than a century since the eminent Committee on Electrical Standards, under the leadership of Prof. William Thomson (later Lord Kelvin), was appointed by the British Association for the Advancement of Science. During all the time since then the search for the ultimate system of units has continued. Although there is always room for doubt as to whether the ultimate has been reached, there is no doubt whatever that considerable progress has been made. At the time the first International Electrical Congress was convened in 1881 there were in use in various countries 12 different units of electromotive force, 10 different units of electric current, and 15 different units of resistance.

Both AIEE and IRE maintained a continuing activity in matters concerning units, and AIEE in particular provided international leadership for many years. For example, in 1894 it recommended the adoption of the names gilbert, gauss, weber, and oersted for various magnetic units. These names were later adopted, though not for the same units for which they had originally been proposed. In 1928 AIEE recommended conversion from the "international" electrical units then used to the "absolute" units, a step formally taken 20 years later by the International Electrotechnical Commission.

By contrast, IEEE in its first years of existence made no coordinated effort to keep its members informed of international developments regarding units; nor did it (in the face of the many organizational growing pains that resulted from the AIEE-IRE merger) immediately face up to the responsibilities it had assumed, as an announced "nonnational" organization with a wide international readership, of reporting technical data in terms that would be readily understandable to an international audience. In response to the requests of various members for guidance and to the protests of others who objected to finding data expressed in fathoms or American gallons in IEEE publications, an IEEE Standards Coordinating Committee, under the chairmanship of Dr. Chester Page of the National Bureau of Standards, was appointed in 1964 to consider problems concerning quantities and units. This committee drafted the Recommended Practice identified as IEEE Standards Publication 268 and eventually secured its approval.

This document consists of a series of recommendations that the IEEE considers to be appropriate for its members in all countries, although the greatest impact will clearly be on IEEE members in the English-speaking countries, where nonmetric units are still used most frequently. The recommendations apply only to information in published scientific and technical work. The complex and very important area of dimensions and standards for manufactured items is specifically excluded from consideration. In published work, however, technical data should be presented in metric units, specifically in units of the International System. This is the critical recommendation. Others concern various smaller points and give guidance on the application of the main principle. They include recommendations on how to handle conversions and on what names should be given to units, and they identify some nonmetric units that should be abandoned as soon as practicable.

What is this International System of Units that is so strongly recommended? Electrical engineers will be reassured to find that it includes the familiar MKSA system long used in electrical engineering. It contains all the common electrical units such as the volt, ohm, ampere, and henry, as well as the meter, kilogram, and second. The MKSA system was, in fact, invented so that the common electrical units, which by the early part of the 20th century were in use throughout the entire industrial world, could be included without change in a comprehensive unit system. The International System is simply the MKSA system expanded, by the addition of the degree Kelvin and the candela as basic units, to include the units used in heat and photometry.

Let us recall that the metric system has always offered two important advantages for technical and scientific work. The first advantage is the decimal relationship between units of the same quantity; thus, length may be measured in centimeters or kilometers, for example, but the conversion requires only a power of 10 and is therefore much simpler than the conversion between inches and miles. The second advantage, by no means less important than the first, is that units for many different

Woodcut from a book published in 1575. Sixteen men, as they came from church, were arranged toe to heel and the overall length of the 16 feet was divided into 16 equal parts, thus giving an average value to be used as a measure of length.

quantities are related through a series of simple, basic relationships. This striving toward simple internal relationships was a characteristic of the metric system from its earliest conception. For example, the everyday unit of volume, the liter, was defined as the volume of one kilogram of water under standard conditions and was for practical purposes equal to 1000 cubic centimeters. By contrast, although the British imperial gallon was defined in 1824 as the volume of 10 pounds of water, none of the various gallons commonly used in the United States or Great Britain bear any simple relationship to the cubic inch or cubic foot or, indeed, to any length unit.

As the metric system evolved, more and more effort was made to develop systems of units that would have as many simple interrelationships as possible. Systems were developed based upon the meter, gram, and second, and then upon the centimeter, gram, and second. Along the way the so-called absolute units of electricity, the ones we now use, were assigned a decimal relation to the mechanical units of the metric system. For example, the product of a volt and an ampere equals one watt, the unit of electric power; the watt is also defined as a newton meter per second, the unit of mechanical power. The foundations necessary to bring about this simple relation were laid very early in the development of electrical units, and may be credited in no small part to the activities of

The Convention du Mètre, 1875, now having 40 adhering states, established the International Committee of Weights and Measures, together with the International Bureau of Weights and Measures, to work toward the acceptance of a convenient, rational, and precise system of physical measurement for all purposes and for the whole world. The committee's method for bringing about this desirable goal has never been to exert undesirable pressure on governments, organizations, or individuals. Instead it has devoted itself, in close cooperation with all other interested international and national bodies, to developing the best possible measurement system in the light of current thinking and scientific knowledge. The committee has always had the conviction that if it were successful, voluntary action to keep step with the best in science would inevitably render the system universal. The United States has, since the inception of the committee, contributed brilliantly and broadly to its work through a succession of distinguished American scientists—of whom the latest, since 1954, is Dr. Allen Astin. The current culmination of the committee's work has been to develop the original metric system of measurement, founded on two base units, into the International System of Units, with six base units.

The adoption of this system by the large and influential IEEE as the recommended one for all its publications is most gratifying, and particularly significant since the headquarters of the IEEE is located in North America, the last continental stronghold of the Imperial System. This action, coupled with that already taken by the U.S. National Bureau of Standards and similar steps under study by other American organizations, gives grounds for the hope—nonexistent a decade ago—that the day is not far off when the 18th-century scientists' dream of a universal measurement system will become a reality.

L. E. Howlett, President
International Committee of Weights and Measures

Lord Kelvin and the British Association Committee on Electrical Standards mentioned previously. Kelvin was, by the way, an extremely ardent proponent of the metric system, who at one time referred to the English system of units as a "wickedly brain destroying piece of bondage under which we suffer."

The CGS systems of units, which were introduced at the end of the 19th century, possessed to a very high degree the systematic advantages that we have been discussing: the advantages of decimalization and of simple relationships among units. However, because the relationships of electromagnetism are much more complicated than those of Newtonian mechanics, a number of CGS systems were devised, each one having special advantages in a particular area of work.

In an attempt to remedy the various deficiencies in the commonly used CGS systems, to replace the several systems with one system, and to have a system that would include the common electrical units, such as the volt and ohm, without making it necessary to memorize a number of decimal exponents, the International Electrotechnical Commission (IEC) in 1950 recommended the use of the MKS system in its rationalized form. In doing so it took an action that had been recommended by Giorgi in 1901. As an example of the convenient way in which relations between the mechanical units and the electromagnetic units appear in this MKSA (for meter-kilogram-second-ampere) system, note that the force on an electric charge of one coulomb, placed in a uniform electric field having a field strength of one volt per meter, is one newton. Allow this charge to move a distance of one meter in the direction of the electric field vector, and one joule of work has been done. Similarly, the force on a current element of one ampere meter, placed in a uniform magnetic field where the magnetic induction is one tesla, is one newton.

The International Union of Pure and Applied Physics (IUPAP) supported steps to incorporate the MKSA system into a larger system of units, which includes the degree Kelvin and the candela as other basic units and which is intended to evolve eventually into a complete system of units suitable for use in all fields of science and

What's in a name?

One frequently hears complaints that too many different units exist and that the many unit names that must be remembered represent excess baggage to be carried by the practicing engineer. In discussing unit names it is helpful to apply three test questions: (1) Is a particular unit necessary? (2) If so, is it desirable that the unit should have a special short name of its own? (3) If a special name is desirable, what name should be chosen?

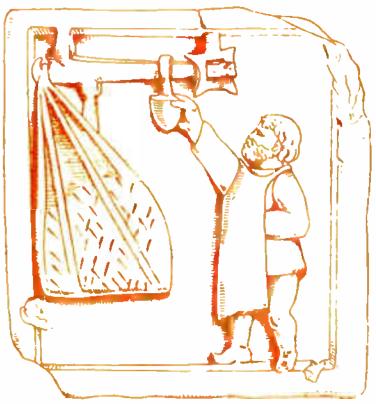
Much of the confusion is caused by the fact that a great many units have been used which are convenient for particular applications but which offer so little general advantage that their existence cannot be justified. If IEEE members accept the recommendations in IEEE Publication 268, many of these units will be abandoned, for IEEE 268 identifies dozens of units—especially in the fields of electricity and magnetism—as obsolete. Therefore, even though the International System includes more than 20 unit names, a few of which are not yet generally familiar to a large part of the IEEE membership, a net result of its adoption will be a considerable simplification.

The question of whether a unit should have a short name all its own is one that is largely a matter of taste and custom. Electrical resistance can properly be expressed in terms of volts per ampere, but everyone agrees that it is convenient as a normal rule to use the short name *ohm*. In some other cases there is no universal agreement that a short name is necessary or even desirable. For example, at the 1960 General Conference on Weights and Measures there was some very vocal objection to the adoption of the name *tesla* as the unit for magnetic flux density. Some, particularly physicists, complained about "the tendency of electrical engineers to introduce many special names for units," but nevertheless the name was accepted as part of the SI.

The International Electrotechnical Commission, in proposing the name *tesla*, had noted that the unit of magnetic flux density may be composed in several different ways, depending on the particular aspect of the quantity that is of interest. The tesla is not only the weber per square meter (density of a flux), but it is also the volt second per square meter (induced electromotive force), as well as the newton per ampere meter (force on a current-carrying conductor in a magnetic field).

In 1930 the essential points of the argument had been tersely expressed by Paul Janet of France concerning the adoption of the name *gauss*: "It seems to me at once clear that engineers have an urgent need for a unit of flux density. It is true that the maxwell per square centimeter is a correct term; strictly speaking it would suffice, but it is a long expression and there is an advantage in having a short name."

When a name is to be given, it is essential to choose one that will be intelligible to an international audience, and thus it has proved useful to choose names of famous scientists, or to derive appropriate names from Greek or Latin (e.g., meter, candela, and lumen). One reason why the name *hertz* has been adopted for the unit of frequency is that it is understandable in all languages, even though the long term *cycle per second* is technically correct. It will interest IEEE members to learn that an early draft of IEEE 268 had placed hertz and cycle per second on equal standing, but this was subsequently changed to indicate preference for hertz at the request of American instrument manufacturers who pointed out that they had begun to label their products in hertz for the international market.



technology. In 1960 the General Conference on Weights and Measures (CGPM) gave this system the name "International System" and specified the designation "SI" to be used in all languages. It is in recognition of the IEC and IUPAP recommendations, and of the action taken by the General Conference, that IEEE has decided to recommend the International System as the single preferred system of units.

With IEEE's recommendations now on record, it is of interest to compare the positions taken by other international and national organizations concerning systems of units. The IEC has been, as we have seen, the prime mover in favor of the MKSA system, which is included as part of the International System. The International Consultative Committee on Radio (CCIR) has adopted a recommendation that the MKSA system of units be used to the exclusion of all other systems of units by its participating administrations. The International Organization for Standardization has given the SI units preferred place, and, as we have seen, the General Conference on Weights and Measures has identified the International System as the preferred system for international use. On the other hand, physicists have not been as willing to give up the CGS systems of units as engineers have been, and although the International Union of Pure and Applied Physics has strongly encouraged the adoption of the SI "for international purposes," it has nevertheless recorded that it "does not recommend that the CGS System be abandoned by physicists."

Many national organizations are giving active support to the International System. Countries already on the metric system are now identifying the SI as the system of units to be used in textbooks, for example. In the United Kingdom, the Institution of Electrical Engineers has identified the SI as the preferred system for use by its authors. In the United States, the National Bureau of Standards has adopted the SI for use by its staff and employs it in its publications "except where use of these units would obviously impair communication or would reduce the usefulness of a report to the primary recipients." It is also worth noting that the American Society for Testing and Materials, like a number of agencies of the United States Government, has gone on record as favoring the metric system for expressing technical data without being extremely specific as to whether the SI units have a preferred status over other metric units. Finally, it should be mentioned that in 1965 a Panel on Engineering and Commodity Standards of the Commerce Technical Advisory Board presented to the U.S. Department of Commerce a comprehensive report on standards, which included recommendations that industry prepare itself for more extensive expression of measurement in the International System of Units; that SI equivalents of values of customary U.S. units be included wherever appropriate in standards, drawings, specifications, and other documents; and that SI units be voluntarily used in specifications for new designs wherever advantageous.

In contrast to the pro-metric positions adopted by the organizations just referred to, the American Society of Mechanical Engineers in 1964 took a position as defender of the embattled inch. Because the ASME position has occasionally been misrepresented or misunderstood, it is worth quoting this resolution:

> The American Society of Mechanical Engineers, in the interest of national economy and industrial efficiency, advocates the continued use of the existing American, British, and Canadian sizes, modules, designs, and ratings. Further, the Society is of the opinion that legislative action directed to an alternate system of dimensional standards, such as the metric, will be at this time confusing and disturbing to the productive capacity of the United States and is not, therefore, in the best of public interest.

Publication of this statement elicited a good deal of comment, not all of it germane, from ASME members. A good sampling of the various points of view may be found in *Mechanical Engineering*, pp. 150–158, May 1965.

The careful reader will observe, however, that the ASME policy statement and the IEEE recommendations on units are entirely compatible. The ASME statement is directed purely toward questions of maintaining standard sizes, designs, modules, and ratings. The IEEE recommendations, by contrast, concern only the use of units in technical publications; that is, they are directed exclusively to the communication of information. This is not to say that the recommendations of the IEEE will not have associated effects that will favor further use of the metric system. They will certainly provide impetus toward wider use of the metric system by making metric-system units, and up-to-date metric-system units in particular, more familiar to the practicing electrical engineer.

The question of United States conversion to the metric system has been discussed perennially since the early

days of the Republic. In 1790 Thomas Jefferson, then Secretary of State, recommended to the House of Representatives a plan "to reduce every branch [of weights and measures] to the same decimal ratio already established for coin, and thus bring the calculations of the principal affairs of life within the arithmetic of every man who can multiply and divide plain numbers."

In recent months the question of conversion has attained new urgency because of the announcement by the British Government urging full adoption of the metric system and setting a period of ten years for reasonably complete conversion. Until this announcement appeared, no responsible persons in the United States had thought it at all likely that Britain would choose to "go it alone" on metric conversion. The U.S. Senate subsequently passed a bill (S. 774) that would authorize the Secretary of Commerce to make a three-year study to determine the advantages and disadvantages of increased use of the metric system in the United States. This appears to be the first metric-system bill to have passed either house of Congress in the 20th century. As this is being written, the Senate bill rests (together with a companion House bill that was favorably reported out of the House Science and Astronautics Committee in 1965) in the House Rules Committee. The bill does not push for conversion to the metric system, but it does provide for the sort of careful study of costs and benefits that is essential if government and industry in the United States are to consider the question of conversion intelligently.

This is not the place to go into the conversion argument in depth, but a summary of the main elements of controversy is relevant. Many of the arguments, and especially those characterized by more heat than light, have failed to distinguish among the three sometimes overlapping areas of application of units: scientific and technical communication, commerce, and manufacturing. It is fairly easy to "go metric" in the first area, and this is in fact what the IEEE has recommended, believing that the essence of good communication is to have as wide an agreement as possible on a common language.

So far as commerce is concerned, it is not easy to predict whether or when the United States will really convert to the metric system. It is already legal in the United States to sell milk by the liter and meat by the kilogram, and pharmaceutical products (except for the aspirin tablet) are now weighed in milligrams. It would not be difficult to measure highway distances in kilometers or to give weather forecasts in degrees Celsius. Whenever it becomes clear that a significant advantage will accrue from such changes, they can be effected without major disturbance.

Manufacturing, with its reliance on dimensional standards and its large inventories of tools, drawings, and spare parts, is quite another matter. It is here that the vocal opponents to metric conversion are to be found. They argue that far more of the world's manufactured goods are now manufactured to inch standards than to any single set of metric standards. Many fear that any increased use of the metric system, even for communicating technical information, will weaken the position of the inch in international product standardization.

In the literature on the metric-system controversy there is accordingly a great deal of argument that is really directed at different questions. Articles written by people whose interest is primarily scientific generally assume that conversion is inevitable and see no particular difficulty in effecting such a conversion. An equal number of articles defend the inch, pointing out that it may be decimalized, and assuming that decimalization provides all the advantages claimed by metric-system proponents. The case is of course much more complex since, as was previously pointed out, the great advantage of the International System is that of simple relations between units for different quantities. This is an extremely important advantage for a discipline, such as electrical engineering, that touches on many of the technical arts and sciences; and it is for this reason that the International System is recommended to the members of IEEE.

Whether the new recommendations are effective or not will depend on the extent to which IEEE editors and authors accept them. It is intended that SPECTRUM and PROCEEDINGS will follow the recommendations as closely as practicable. Editors will not be able to do the job, however, if authors are not in sympathy with the new recommendations.

It is hoped, therefore, that as a result of the publication of IEEE 268, many of our current irrational practices may be abandoned. Consider for instance the current profusion and confusion of units of energy—the foot pound-force and the foot poundal, the British thermal unit and the calorie, the horsepower hour, kilowatthour, erg, joule, and several others. The horsepower is an anachronism because—perhaps unfortunately—few engineers today have any appreciation of the capabilities of the draft horse. The saddest fate, however, is that of the British thermal unit, which, now that Britain has abandoned her old German friend Fahrenheit, must languish in precarious exile in America. Is it perhaps loyalty to faithful old servants that assures them their place in our hearts—and journals?*

The publications of IEEE are of course only one battleground in the struggle to achieve more rational usage of units. New textbooks will be needed, as will new handbooks. To a great extent a new generation of textbooks is already here, for modern electrical engineering textbooks and many physics texts, including those of the new physics curriculum taught in many American secondary schools, are using the International System of Units. New handbooks now in production will continue the trend. In countries other than the United States the trend toward the SI seems even stronger.

In the last analysis, however, the IEEE membership will decide which of the new recommendations are sound. The Standards Committee has used its best technical judgment in presenting its recommendations to the members. These recommendations are now open for criticism, evaluation, application, and eventual revision.

*Many will argue that the conventional use of the horsepower and Btu makes communication with these units simpler than it would be without them. But consider how difficult it really is to communicate in terms of the Btu. In the United States, home air conditioners are now rated in Btu per hour (they used to be rated in tons, their capacity for freezing ice, but hardly anyone used them for that purpose). It takes some technical training to relate the cooling of a pound of water to the cooling of a room, but architects and heating engineers have been able to work out the relationships. On the other hand, every homeowner has a rough idea of the amount of heating that is produced by a 1500-watt electric heater, and it is a trivial matter to teach him that a 1500-watt (output) air conditioner will achieve an equivalent amount of cooling. (The fact that it can do this while adding only about one kilowatt to his electric power load indicates what a real bargain air conditioning is.)

IEEE Recommended Practice for Units in Published Scientific and Technical Work

Prepared by IEEE Standards Coordinating Committee 14 (Quantities and Units)

Chester H. Page, Chairman

Bruce B. Barrow *Wayne Mason*
J. G. Kreer, Jr. *W. T. Wintringham*

Approved by IEEE Standards Committee, October 14, 1965

The recommendations contained in this document are based upon the following premises, which are believed to represent the broadest base of general agreement among proponents of the major unit systems:

a. That for most scientific work and technical work of an analytic nature the International System of Units (officially designated "SI")* is generally superior to other systems; that this is particularly true for the fields of electrical science and technology since the common electrical units (ampere, volt, ohm, etc.) are included among the SI units; that the International System is more widely accepted than any other as the common language in which scientific and technical data ought to be expressed.

b. That various units of the British and American systems (hereafter referred to as "British-American units"), particularly the inch and the pound, are the fundamental units used in the standards followed by a large part of the world's manufacturing industry; that this will continue to be true for some time.

c. That unit usage can and should be simplified, particularly in the fields of interest to the IEEE; that one means toward such simplification is the identification of obsolete and unneeded units, and that another is the adoption of more rational links between SI units and units of other systems.

1. RECOMMENDATIONS REGARDING PREFERRED SYSTEM OF UNITS

Technical and scientific data, except in cases such as those cited below, should be given in units of the International System, followed if desired by the equivalent data in other units given in parentheses.† *This recommendation applies only for the publication of data and does not in any way affect the choice of units for manufacturing processes or for industrial standards.*

1.1 Exceptions

1.1.1 When a nonmetric industrial standard is referred to, the nonmetric data should be given first place, with the SI equivalent data given in parentheses. Examples include standard inch sizes of nuts and bolts, American Wire Gauge sizes of electrical conductors, and the like.

1.1.2 Where, in special fields, for reasons related to the field, a unit not in the International System offers significant advantages, such a unit may be used, with the SI equivalent data given in parentheses. Examples include the use of the electronvolt in physics, the nautical mile in navigation, and the astronomical unit in astronomy.

1.1.3 Experimental data taken in non-SI units may be quoted without change, followed by the SI equivalents in parentheses.

1.1.4 When a non-SI unit is at present too widely used to be eliminated immediately, its use may be continued with the SI equivalent given in parentheses. Examples include the use of the horsepower to measure mechanical power and the use of the torr to measure air pressure. This exception is not intended as a permanent protection for irrational practices, however, and as future standards are drafted such anachronisms as the horsepower should be eliminated.

1.1.5 Some nonelectrical quantities are frequently expressed in units that are decimal multiples of SI units. Such units include the liter, the hectare, the bar, the tonne (metric ton), and the angstrom. These units may be used in appropriate fields. The SI units *newton* and *joule* are, however, to be used in place of the *dyne* and *erg*.

1.2 Specific Recommendations

1.2.1 The various CGS units of electrical and magnetic quantities are no longer to be used. This includes the various ab- and stat- designations (abvolt, statcoulomb, etc.) and the gilbert, oersted, gauss, and maxwell. It is of course recognized that in some cases it may be desirable to state CGS equivalents in parentheses following data given in the International System.

1.2.2 The use of prefixes‡ to express decimal mul-

*The International System includes as subsystems the MKS system of units, which covers mechanics, and the MKSA system, which covers mechanics, electricity, and magnetism. Appendix A describes the International System of Units.

†The size or description of apparatus, nominal or nonprecise dimensions, and other measurements not entering into the presentation of scientific data need not be "force-translated" into the SI; e.g., "The interferometer mirror, mounted on 1-inch rods, was advanced in 10-nanometer increments."

‡The official list of prefixes is given in Appendix A. Compound prefixes (e.g., millimicro-) are not to be used. Multiplication beyond the range covered by the prefixes should be handled by using powers of ten.

tiples of SI units is permitted. Thus, although the SI unit for current density is the ampere per square meter, use of the ampere per square centimeter where convenient is entirely permissible.

1.2.3 Use of metric-system units that are not decimal multiples of SI units, such as the calorie and the kilogram-force, is especially to be avoided. Note that the 9th General Conference on Weights and Measures has adopted the joule as the unit of heat, recommending that the calorie be avoided wherever possible.

1.2.4 Where it is absolutely necessary to use British-American units, the conversion to SI units should be kept as obvious as possible. For example, if an electric generator is built to inch specifications, it may be inconvenient to express magnetic flux density in teslas (webers per square meter). In such a case webers per square inch should be used, not maxwells ("lines") per square inch.

2. RECOMMENDATION ON UNIT CONVERSIONS

Unit conversions are to be handled with careful regard to the implied correspondence between accuracy of data and the number of figures given.

2.1 Remarks

2.1.1 Some applicable rules for conversion and rounding, from American Standard B48.1, are quoted in Appendix B.

2.1.2 When a dimension or other quantity is specified with tolerances, care must be taken to ensure that the range of values permitted after unit conversion lies within the original tolerances.

2.1.3 Whenever possible, unit conversions should be made by the author of the document, for he is best able to determine how many figures are significant and should be retained after conversion. For example, a length of 125 feet converts exactly to 38.1 meters. If, however, the 125-foot length had been obtained by rounding to the nearest 5 ft, the conversion should be given as 38 m; and if it had been obtained by rounding to the nearest 25 ft, the conversion should be given as 40 m.

3. RECOMMENDATIONS WHERE A UNIT HAS MORE THAN ONE NAME

3.1 General Principles

3.1.1 Many of the derived units in the International System have been given special names, which may be used as alternatives to the compound forms. When the special names are formally recognized by the General Conference on Weights and Measures (CGPM), they have a standing which is equal to that of the compound forms. Both names are technically correct, and the choice between them must be made partly on the basis of taste, keeping in mind the particular application.

Example: The unit of electrical resistance is the *ohm*, which is equivalent to the *volt per ampere*. Resistance is almost always expressed in ohms, but there are occasions when the explicit expression in volts per ampere is desirable. Such usage is entirely correct.

3.1.2 Some names that have been proposed for derived SI units have not yet been recognized by the CGPM. If such a proposed name is used, care must be taken to make sure that the intended meaning is clear.

Example: The name *pascal* has been proposed for the SI unit of pressure, the newton per square meter.

3.1.3 The use of special names for decimal multiples of SI units is not recommended. Some well-established, nonelectrical units are, however, recognized as exceptions (see 1.1.5).

3.1.4 The decimal prefixes are not recommended for use with British-American units. An exception is made for the *microinch*, a unit that is frequently used in precision machine work.

3.1.5 Except for the unit of electrical conductance (see 3.2.3), the practice of giving special names to reciprocal units is to be discouraged. In particular, use of the name *daraf* for the *reciprocal farad* is not recommended.

3.2 Specific Recommendations

3.2.1 *Frequency.* The CGPM has adopted the name *hertz* for the unit of frequency, but *cycle per second* is widely used. Although *cycle per second* is technically correct, the name *hertz* is preferred because of the widespread use of *cycle* alone as a unit of frequency. Use of *cycle* in place of *cycle per second*, of *kilocycle* in place of *kilocycle per second*, etc., is incorrect.

3.2.2 *Magnetic Flux Density.* The CGPM has adopted the name *tesla* for the SI unit of magnetic flux density. The name *gamma* shall not be used for the unit *nanotesla* (see 3.1.3).

3.2.3 *Electrical Conductance.* The CGPM has not yet adopted a short name for the ampere per volt (or reciprocal ohm), the SI unit of electrical conductance. The International Electrotechnical Commission has recommended the name *siemens* for this unit, but the name *mho* has been more widely used. In IEEE publications the name *mho* is preferred.

3.2.4 *Temperature Scale.* In 1948 the CGPM abandoned *centigrade* as the name of a temperature scale. The corresponding scale is now properly named the *Celsius* scale, and further use of *centigrade* for this purpose is deprecated.

3.2.5 *Luminous Intensity.* The SI unit of luminous intensity has been given the name *candela*, and further use of the old name *candle* is deprecated. Use of the term *candlepower*, either as the name of a quantity or as the name of a unit, is deprecated.

3.2.6 *Luminous Flux Density.* The common British-American unit of luminous flux density is the *lumen per square foot*. The name *footcandle*, which has been used for this unit in the U.S., is deprecated.

3.2.7 *Micrometer and Micron.* Although the name *micron* has been widely used for the micrometer, it is not recommended. The name *nanometer* is preferred over *millimicron*, which is deprecated.

3.2.8 *Gigaelectronvolt.* Because *billion* means a thousand million in the United States but a million million in most other countries, its use should be avoided in technical writing. The term *billion electronvolts* is deprecated; use *gigaelectronvolt* instead.

4. RECOMMENDATIONS CONCERNING BRITISH-AMERICAN UNITS

4.1 In principle the number of British-American units in use should be reduced as rapidly as possible.

4.2 Quantities are not to be expressed in mixed units. For example, a mass should be expressed as 12.75 lb, rather than as 12 lb, 12 oz.

4.3 As a start toward implementing the recommendation of 4.1, above, the following should be abandoned:

British thermal unit

horsepower

Rankine temperature scale

US dry quart, US liquid quart, and UK (Imperial) quart, together with their various multiples and subdivisions*

footlambert†

APPENDIX A

THE INTERNATIONAL SYSTEM OF UNITS

The following is a translation, from the original French, of the principal resolution on the International System adopted by the General Conference on Weights and Measures.

Resolution of the 11th General Conference on Weights and Measures (1960)

International System of Units
(Resolution No. 12)

The Eleventh General Conference on Weights and Measures,

Bearing in mind:

Resolution No. 6 of the Tenth General Conference on Weights and Measures by which it adopted the following six units to serve as a basis for the establishment of a practical system of measures for international purposes:

length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	Kelvin degree	°K
luminous intensity	candela	cd

Resolution No. 3 adopted by the International Committee on Weights and Measures in 1956,

The recommendations adopted by the International Committee on Weights and Measures in 1958 concerning the abbreviation for the name of this system and the prefixes to be used for the formation of multiples and submultiples of units,

Decides:

1° the system based on the six basic units mentioned above is designated by the name International System of Units;

2° the international abbreviation for the name of this System is: SI;

3° the names of multiples and submultiples of units are formed by the use of the following prefixes:

Factor by Which the Unit Is Multiplied	Prefix	Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka‡	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto§	f
0.000 000 000 000 000 001 = 10^{-18}	atto§	a

4° in this system the units given below are employed without prejudice to other units that could be added in the future.

Supplementary Units

Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Area	square meter	m^2
Volume	cubic meter	m^3
Frequency	hertz	Hz
Density	kilogram per cubic meter	kg/m^3
Velocity	meter per second	m/s
Angular velocity	radian per second	rad/s
Acceleration	meter per second squared	m/s^2
Angular acceleration	radian per second squared	rad/s^2
Force	newton	N
Pressure (stress)	newton per square meter	N/m^2
Kinematic viscosity	square meter per second	m^2/s
Dynamic viscosity	newton second per square meter	$N\cdot s/m^2$
Work, energy, quantity of heat	joule	J
Power	watt	W
Electric charge	coulomb	C
Voltage, potential difference, electromotive force	volt	V

*If it is absolutely necessary to express volume in British-American units, the cubic inch or cubic foot should be used.

†If it is absolutely necessary to express luminance in British-American units, the candela per square foot or lumen per steradian square foot should be used.

‡Translator's note: This prefix is spelled "déca" in French.

§The prefixes "atto" and "femto" were incorporated into the International System in 1964 by the 12th CGPM.

Electric field strength......	volt per meter	V/m
Electric resistance....	ohm	Ω
Capacitance....	farad	F
Magnetic flux...	weber	Wb
Inductance.....	henry	H
Magnetic flux density......	tesla	T
Magnetic field strength.....	ampere per meter	A/m
Magnetomotive force........	ampere	A
Luminous flux..	lumen	lm
Luminance.....	candela per square meter	cd/m²
Illumination....	lux	lx

[*End of Resolution*]

Definitions of the fundamental units of the International System are given below, translated from the original French.

Meter

The 11th CGPM, 1960, has adopted the following:

The meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the unperturbed transition between the levels $2p_{10}$ and $5d_5$ of the atom of krypton-86.

Kilogram

The 3rd CGPM, 1901, has declared:

The kilogram is the unit of mass; it is represented by the mass of the International Prototype Kilogram [a particular cylinder of platinum–iridium alloy preserved in a vault at Sèvres, France, by the International Bureau of Weights and Measures].

Second

The 12th CGPM, 1964, considering that, in spite of the results obtained in the use of cesium as an atomic frequency standard, the time has not yet come for the General Conference to adopt a new definition of the second, a fundamental unit of the International System of Units, because of the new and important progress which may arise from current researches, and considering also that it is not possible to wait any longer to base physical measurements of time on atomic or molecular frequency standards, empowered the International Committee on Weights and Measures to designate the atomic or molecular standards of frequency to be used temporarily.

The International Committee then acquainted the CGPM with the following declaration:

The standard to be used is the transition between the hyperfine levels $F = 4$, $M = 0$ and $F = 3$, $M = 0$ of the fundamental state $^2S_{1/2}$ of the cesium-133 atom unperturbed by external fields. The value 9 192 631 770 hertz is assigned to the frequency of this transition.

Ampere

The 9th CGPM, 1948, has adopted the following:

The ampere is the constant current that, if maintained in two straight parallel conductors that are of infinite length and negligible cross section and are separated from each other by a distance of 1 meter in a vacuum, will produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

Degree Kelvin

The 10th CGPM, 1954, has adopted the following:

The 10th General Conference on Weights and Measures decides to define the thermodynamic scale of temperature by means of the triple-point of water as a fixed fundamental point, attributing to it the temperature 273.16 degrees Kelvin, exactly.

Candela

The 9th CGPM, 1948, has adopted the following:

The magnitude of the candela [unit of luminous intensity] is such that the luminance of a blackbody radiator at the freezing temperature of platinum is 60 candelas per square centimeter.

APPENDIX B

RULES FOR CONVERSION AND ROUNDING*

Number of Decimal Places To Be Retained

In all conversions between inches and millimeters the number of decimal places retained should be such that precision is not sacrificed in the process of conversion and at the same time such that the converted value is not carried to an implied precision that is not justified. A general rule that is satisfactory in most cases is: On converting inches to millimeters, carry the millimeter equivalent to one less decimal place than the number to which the inch value is given; and on converting from millimeters to inches, carry the inch equivalent to two more places than the number to which the millimeter value is given.

As a special case under the above general rule it should be pointed out that in converting integral values of either inches or millimeters consideration must be given to the implied or required precision of the integral value to be converted. For example, the value "4 inches" may be intended to represent 4″, 4.0″, 4.00″, 4.000″, 4.0000″, or even a still higher precision. Obviously, the converted value should be carried to a sufficient number of decimal places to maintain the precision implied or required even though the value to be converted is given only as a whole number.

Method of "Rounding Off" Decimal Values

When a decimal value is to be rounded off to a lesser number of places than the total number available, the procedure should be as follows:

(a) When the figure next beyond the last figure to be retained is less than 5, the last figure retained should not be changed. Example: 3.46325, if cut off to three places, should be 3.463; if cut off to two places, 3.46.

(b) When the figures beyond the last place to be retained amount to more than 5 in the next place beyond that to be retained, the last figure retained should be increased by 1. Example: 8.37652, if cut off to three places, should be 8.377; if cut off to two places, 8.38.

* Excerpts from "American Standard Practice for Inch–Millimeter Conversion for Industrial Use," ASA B48.1-1933 (reaffirmed 1947).

(c) When the figure next beyond the last place to be retained is exactly 5, with only zeros beyond, the last figure retained, if even, should be unchanged; if odd it should be increased by 1. Example: 4.365, when cut off to two places, becomes 4.36; 4.355 would also be cut off to the same value, to two places.

This method of rounding off even fives results, in the long run, in the same number of values being raised as are lowered, and thus the average value is correct, whereas if the even five were always retained or always discarded, the final value, in the long run, would be too large or too small.

APPENDIX C

SOME FACTORS FOR CONVERSION INTO UNITS OF THE INTERNATIONAL SYSTEM

Length

1 inch = 2.54 centimeters (exactly)
1 foot = 0.3048 meter (exactly)
1 mile = 1609.3 meters
1 nautical mile = 1852 meters (exactly)
1 micron = 1 micrometer (exactly)
1 angstrom = 0.1 nanometer (exactly)

Area

1 square inch = 6.4516 square centimeters (exactly)
1 square foot = 0.092 903 square meter
1 circular mil = 5.0671 $\times$ 10^{-4} square millimeter
1 acre = 4046.9 square meters
1 barn = 10^{-28} square meter (exactly)
1 hectare = 10 000 square meters (exactly)

Volume

1 cubic inch = 16.387 cubic centimeters
1 cubic foot = 0.028 317 cubic meter
1 fluid ounce (UK) = 28.413 cubic centimeters
1 fluid ounce (US) = 29.574 cubic centimeters
1 gallon (UK) = 4546.1 cubic centimeters
1 gallon (US) = 3785.4 cubic centimeters
1 barrel (US) (for petroleum, etc.) = 0.158 99 cubic meter
1 acre foot = 1233.5 cubic meters
1 liter = 1000 cubic centimeters (exactly)

Speed

1 foot per minute = 5.08 millimeters per second (exactly)
1 mile per hour = 0.447 04 meter per second (exactly)
1 knot = 0.514 44 meter per second
1 kilometer per hour = 0.277 78 meter per second

Mass

1 ounce (avoirdupois) = 28.350 grams
1 pound = 0.453 59 kilogram
1 slug = 14.594 kilograms
1 short ton = 907.18 kilograms
1 long ton = 1016.0 kilograms
1 tonne = 1000 kilograms (exactly)

Density

1 pound per cubic foot = 16.018 kilograms per cubic meter
1 pound per cubic inch = 27 680 kilograms per cubic meter

Force

1 poundal = 0.138 25 newton
1 ounce-force = 0.278 01 newton
1 pound-force = 4.4482 newtons
1 kilogram-force = 9.806 65 newtons (exactly)
1 dyne = 10^{-5} newton (exactly)

Pressure

1 poundal per square foot = 1.4882 newtons per square meter
1 pound-force per square foot = 47.880 newtons per square meter
1 pound-force per square inch = 6894.8 newtons per square meter
1 conventional foot of water = 2989.1 newtons per square meter
1 conventional millimeter of mercury = 133.32 newtons per square meter
1 torr = 133.32 newtons per square meter
1 normal atmosphere (760 torr) = 101 325 newtons per square meter (exactly)
1 technical atmosphere (1 kgf/cm^2) = 98 066.5 newtons per square meter (exactly)
1 bar = 100 000 newtons per square meter (exactly)

Energy, Work

1 foot poundal = 0.042 140 joule
1 foot pound-force = 1.3558 joules
1 British thermal unit (thermochemical) = 1054 joules
1 British thermal unit (International Table) = 1055 joules
1 calorie (thermochemical) = 4.184 joules (exactly)
1 calorie (International Table) = 4.1868 joules (exactly)
1 electronvolt = 1.602 $\times$ 10^{-19} joule
1 erg = 10^{-7} joule (exactly)

Power

1 foot pound-force per second = 1.3558 watts
1 horsepower (metric) = 735.50 watts
1 horsepower (British) = 745.70 watts
1 horsepower (electrical) = 746 watts (exactly)
1 British thermal unit (I.T.) per hour = 0.2931 watt
1 erg per second = 10^{-7} watt (exactly)

Quantities of Light

1 footcandle = 10.764 lux (lumens per square meter)
1 footlambert = 3.4263 candelas per square meter

*Quantities of Electricity and Magnetism**

1 ESU of current = 3.3356 $\times$ 10^{-10} ampere
1 EMU of current = 10 amperes (exactly)
1 ESU of electric potential = 299.79 volts
1 EMU of electric potential = 10^{-8} volt (exactly)
1 ESU of capacitance = 1.1126 $\times$ 10^{-12} farad
1 EMU of capacitance = 10^{9} farads (exactly)
1 ESU of inductance = 8.9876 $\times$ 10^{11} henrys
1 EMU of inductance = 10^{-9} henry (exactly)
1 ESU of resistance = 8.9876 $\times$ 10^{11} ohms
1 EMU of resistance = 10^{-9} ohm (exactly)
1 gilbert = 0.795 77 ampere
1 oersted = 79.577 amperes per meter
1 maxwell = 10^{-8} weber (exactly)
1 gauss = 10^{-4} tesla (exactly)
1 gamma = 10^{-9} tesla (exactly)

*NOTE: "ESU" means "electrostatic CGS unit"; "EMU" means "electromagnetic CGS unit."

Special Conference Report

Second Symposium on Radio Astronomical and Satellite Studies of the Atmosphere

J. Aarons, J. A. Klobuchar, R. S. Allen, D. A. Guidice
U.S. Air Force Cambridge Research Laboratories

From the very start of serious studies in radio astronomy, there has been a lively interest in the atmospheric effects on radio signals. Radio astronomical techniques are now regarded by atmospheric and propagation physicists as a valuable tool for examining the characteristics of the atmosphere.

The study of the atmosphere by radio astronomical techniques has been pursued by several diverse methods. Lunar radar experiments in the VHF range allowed a study of the total electron content of the ionosphere (and for the first time the number of electrons above the maximum of the *F* layer relative to the peak electron density have been measured). Measurements of apparent changes in radio-star output power enabled a study of temporal and geographic characteristics of ionospheric irregularities. Low-elevation measurements of the apparent position of radio celestial sources provided a measure of refraction and microwave absorption caused by the atmosphere. Absorption of cosmic radio noise in the 15–30-MHz range contributed basic data for studies of normal solar heating, the aurora, and the effects of solar-flare X-ray emission.

With the advent of low-altitude artificial earth satellites, it became possible to probe many latitudes with the same instrument. The results were a mapping and understanding of the irregularity structure as a function of latitude and magnetic index, the total electron content and its latitudinal and temporal vagaries, as well as propagation factors for long-range transmissions. Now, with the addition of synchronous satellites (Syncom and Early Bird) containing fixed VHF beacons radiating polarized energy, it is possible to make many types of atmospheric studies continuously at fixed locations. Deep-space probes with adequate power and VHF beaconry will provide even more tools for the physicist in this realm.

The first Symposium on Radio Astronomical and Satellite Studies of the Atmosphere was held in Corfu, Greece, in 1962 under the aegis of NATO's Advanced Study Institute program. The second symposium was held in Boston, Mass., October 1965, and was sponsored by the Radio Astronomy Branch of the Space Physics Laboratory of the Air Force Cambridge Research Laboratories with the participation of the Joint Satellite Studies Group, an organization sponsored in part by NATO's Scientific Affairs Division.

The time lapse since 1962, plus the advent of beacon satellites specifically designed to explore the ionosphere, led to the need for the second symposium. Approximately 200 persons attended the three-day meeting. The program consisted of review papers, short communications, discussion periods, and round-table discussions of specific topics. Four-page summaries of the papers to be presented were distributed to all registrants at the opening of the meeting.

A fourth day was added to the symposium to provide both attendees from the United States and visitors, who came from such diverse areas as Australia, India, Ghana, Jamaica, Kenya, and Singapore, an opportunity to inspect the 84-foot and 150-foot parabolas at the Sagamore Hill Radio Observatory (AFCRL) and the 29-foot millimeter antenna at Prospect Hill (AFCRL), as well as the 120-foot Haystack parabola, the 220-foot fixed parabola, and the 84-foot antenna at M.I.T. Lincoln Laboratory's Millstone Hill.

The formal parts of the symposium were divided into five sessions: (1) total electron content studies; (2) scintillation studies; (3) lower atmospheric measurements; (4) absorption studies by riometer techniques; and (5) satellite propagation and background experiments.

Total electron content studies

The first session of the symposium was devoted to a study of techniques and results of measurements of the electron content of the ionosphere. Changes in the latitude profile of ionospheric total electron content provided the subject for a number of papers. The equatorial anomaly was discussed by E. Golton from Slough, England, who collected data at Singapore and Hong Kong using the NASA ionospheric beacon satellite, S-66 (also known as BE-B and Explorer 22). He noted an increase in electron content both north and south of the magnetic equator. This increase was a maximum in the afternoon hours, and at night the anomaly was almost absent. Large diurnal changes in total electron content of 25 to 1 were normally observed at Singapore. Golton attributed the afternoon ledge or constant total electron content that he observed for several hours during the afternoon at Singapore to a downward flux of electrons from the equator along field lines. Data taken at New Delhi, India, and presented by A. P. Mitra of the National Physical Laboratory, New Delhi, showed the part of the equatorial anomaly north of the latitude of the maximum total electron content. The New Delhi data also showed this anomaly to be a maximum near midday. The total ionospheric electron content over New Delhi at midday also was shown to have a linear correlation with magnetic activity.

Since the total electron content measured is dependent upon the mean longitudinal component of magnetic field strength, an interesting condition arises near the magnetic equator where this longitudinal component becomes small and the Faraday effect is no longer valid. This region of nonvalidity of the simple Faraday effect was reported by J. Mass of Israel's Academy of Sciences, Haifa, who showed that it is not always found to be where predicted. Horizontal gradients in the ionosphere and the resulting refraction are largely held responsible for this discrepancy. Another example of the invalidity of the simple, linearly polarized, Faraday twist of a radio wave, though not in the earth's ionosphere, was given by M. A. Gordon, University of Colorado, who discussed the polarization of very short bursts of radiation in the ten-meter wavelength range from the planet Jupiter. In this case, the invalidity of the simple quasi-longitudinal Faraday effect is due to the high magnetic field of Jupiter.

Moving from equatorial studies to the auroral region, L. Liszka, of the Kiruna Geophysical Observatory in Sweden, gave a paper describing the increase in total electron content in the northern regions at nighttime.

Mid-latitude data, presented by F. Bertin, University of Paris, France, and taken at several European observatories, showed a smoother geographical distribution of total electron content on magnetically disturbed days (see Fig. 1). Irregularities in total mid-latitude electron content were discussed by several authors: R. G. Merrill, Central Radio Propagation Laboratory, Boulder, Colo.; K. Bibl, Lowell (Mass.) Technological Institute Research Foundation; D. Ilias, National Observatory of Athens, Greece; P. R. Arendt, Fort Monmouth, N.J.; and A. D. Maude, University College of Wales, Aberystwyth. These papers largely dealt with improved equipment techniques for measuring irregularities by receiving ionospheric beacon satellite radio signals. A. D. Maude, however, proposed two types of wave motion that might produce some of the observed irregularities—Helmholtz gravity waves and internal gravity waves. The latter type may be considered a sound wave modified by the influence of gravity, and he regards it as more likely to be responsible for some types of ionospheric irregularities.

All of the foregoing papers discussed in this review of the first session referred to radio transmission from

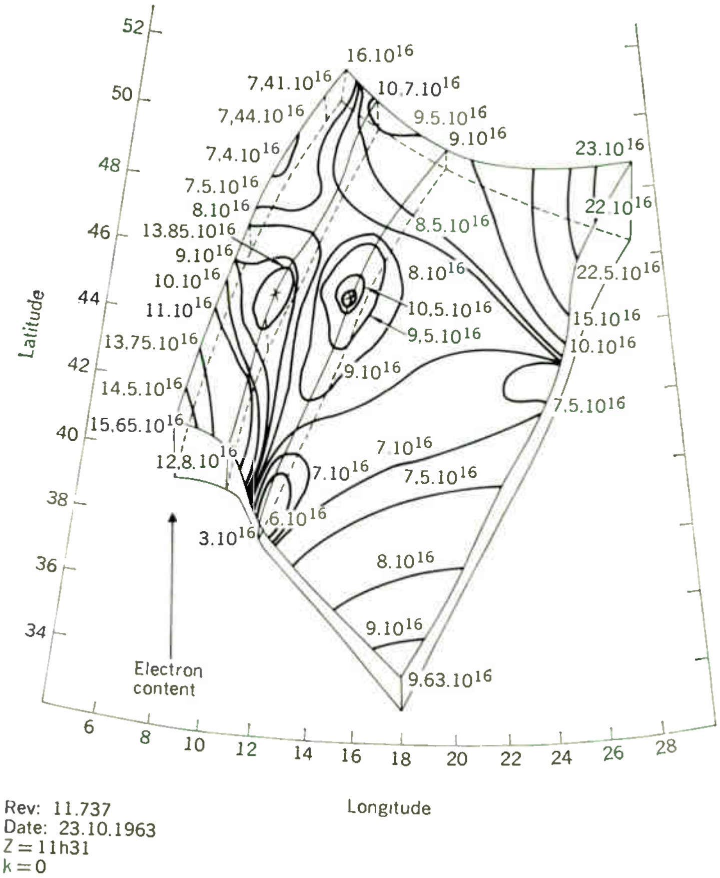


Fig. 1. Geographical distribution of total electron content over Europe on October 23, 1963. Data were analyzed by F. Bertin, University of Paris, from records taken by the Joint Satellite Studies Group, an organization sponsored in part by NATO.

artificial earth satellites at a height of approximately 1000 km. Consequently, the data described were the result of many brief passes of a satellite above the horizon of the receiving stations. Great interest was shown at the first session of the symposium when data indicating diurnal electron content changes were presented by several people who had utilized radio transmission from synchronous orbit satellites. Since a synchronous orbit satellite is always viewed in the same direction, continuous measurements of the total electron content of the ionosphere can be taken. Synchronous satellite coverage for determining ionospheric total electron content is limited to low and mid-latitudes. Polar region data, however, can be taken by observing the polarized component of galactic radio noise at high celestial declinations. The experimental problems involved in such measurements were discussed by the following: V. A. Hughes, Queen's University, Kingston, Ont., Canada; J. M. Goodman, U.S. Naval Research Laboratory (see Fig. 2); J. A. Klobuchar, Air Force Cambridge Research Laboratories; P. F. Checcacci, Centro Microonde, Florence, Italy; R. D. S. Earnshaw, Jodrell Bank Experimental Station, Manchester, England; and Rev. J. R. Koster, University of Ghana, Accra. They all presented data on diurnal changes in total electron content taken at various latitudes. Klobuchar's data showed large differences in total electron content from day to day for quiet magnetic conditions.

A. V. da Rosa, Stanford University, who presented results both from the highly elliptical orbit satellite (the Orbiting Geophysical Observatory) and from the Syncom synchronous satellite, found somewhat different nighttime behavior at two sites. Using data from Hawaii and Stanford, da Rosa *et al.* found a continuous decrease in total electron content at the lower latitude Hawaii site but, for a good share of the time, a constant nighttime total content in the ionosphere over Stanford University. He attributed the maintenance of the Stanford nighttime total content to a downward flux of electrons from the exosphere. Measurements he made of the exospheric total electron content by subtracting Faraday total electron content from the differential Doppler content show that there are sufficient electrons produced in the daytime at higher mid-latitudes to maintain the nighttime ionosphere at the Stanford site but not at Hawaii.

Another measure of exospheric electron content was described by H. T. Howard, who used two large radars to receive lunar-reflected radio waves. He found an average exospheric—or, as he calls it, cislunar—electron density of 100 cm^{-3} in the direction of the sun and 300 electrons cm^{-3} in the quadrant opposite the sun. He attributes the higher density in the antisolar direction to the solar wind wake of the earth.

K. L. Chan, Ames Research Center, Moffett Field, Calif., described results of the topside ionospheric sounder, Alouette. Since this satellite-borne ionosonde is in a polar orbit the data are worldwide and show several interesting features. The low latitudes are characterized by the equatorial anomaly, or the lower values of electron density at the equator than at either side of it. This anomaly is more pronounced in the northern latitude summer. The mid-latitudes are characterized by smooth electron density contours and the southern border of polar or auroral region has a pronounced trough or dip in electron density. The position of this trough is dependent upon magnetic conditions and moves to the south during high magnetic activity. The polar regions are characterized by rapid changes of electron density within a small distance. Additional work on high-latitude small-scale gradients in total electron content was described by L. R. Hughes, Smyth Research Associates, San Diego, Calif. His measurement technique enabled him to see irregularities of 10^{-4} of the total electron content.

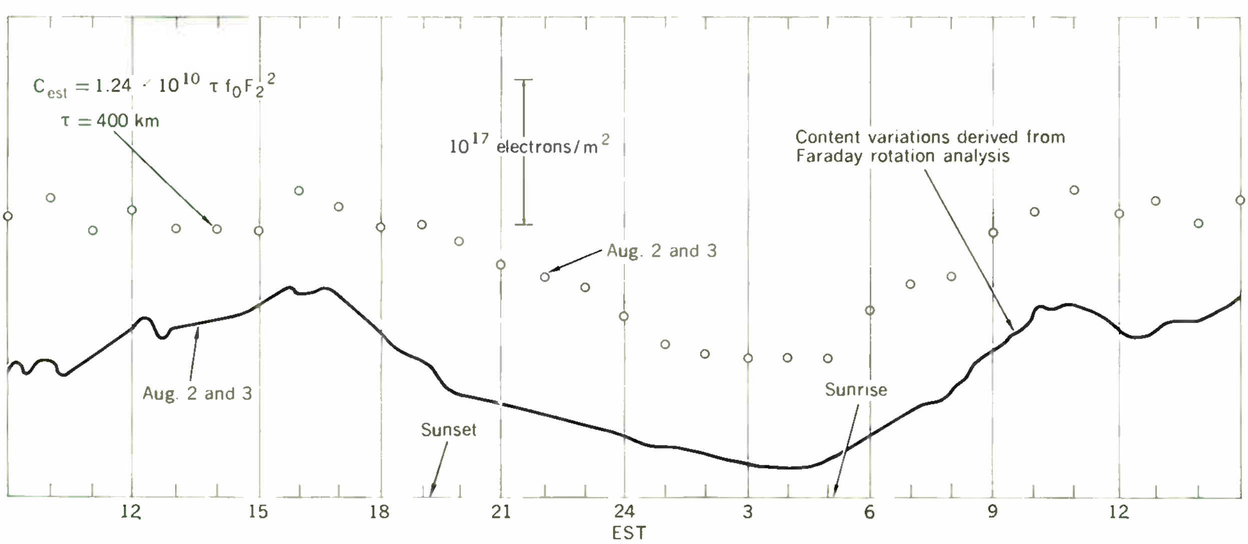
The session on total electron content studies ended with a panel discussion on the status of the work in the field and future plans. Panel members were: J. V. Evans, Lincoln Laboratory, Lexington, Mass.; A. V. da Rosa, Stanford University; E. Schmerling, NASA Headquarters, Washington, D.C.; and J. Aarons, U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., moderator. Evans stated that the workers in ionospheric research sometimes put too much emphasis on techniques and data collection and not enough on data analysis and interpretation. This sentiment was echoed by da Rosa. Schmerling commented that not much correlation among stations was being done and then was asked from the floor about how the NASA data exchange was working out. S. Isaacson from NASA Data Center commented that of the 90 observatories taking data from ionospheric beacon S-66 and the 54 taking data from BE-C, only 13 have sent in data. B. H. Briggs, from the University of Adelaide, Australia, suggested that NASA support a more convenient and useful procedure for this data exchange.

The participants concluded the round-table discussion by emphasizing the value of such tools as the synchronous satellite beacon, the incoherent scatter radar, and rocket probes.

Scintillation studies

Attendees at the second session of the symposium first heard Prof. Briggs, University of Adelaide, review the theoretical effort that has been applied to the analysis of ionospheric scintillations. As a stimulus to the experimentalists, he suggested that the outstanding problem is the choice of a causal theory from the multitude available. Although we are beginning to accumulate data on the latitude distribution of irregularities, there is still a

Fig. 2. Diurnal variations of total electron content observed from polarization study of VHF beacon on Comsat Early Bird Satellite compared with square of f_0F_2 from Fort Belvoir, Va., August 1965.



decided lack of information on the electron density variation within the irregularity. The question arises: Is it a local enhancement of electron density (precipitation theories) or are there an equal number of times in which the electron density is above and below the mean (turbulence, wave theories)?

Observations at a high latitude using a phase-sweep interferometer were discussed by E. J. Fremouw, Geophysical Institute, University of Alaska. In addition to investigating the correlation of scintillations with geophysical activity, this group is beginning a very interesting study of cross correlation of the amplitude and phase variation of scintillations. The purpose is to compare the observations with theoretical predictions of refraction from simple linear increases in models of the electron density profile. This work holds promise of beginning to answer Prof. Briggs' question.

A preliminary report on a statistical analysis of Cassiopeia A scintillation for 1961–1964 was made by J. Aarons. This subauroral study confirms the latitude and geophysical dependence of irregularities. The diurnal behavior clearly peaks before magnetic and solar midnight, a perplexing clue for proponents of causal theories involving either particles or solar heating.

The earliest studies established the fact that the irregularities producing radio-star scintillations were definitely ionospheric. Probable heights were a few hundred kilometers. The interpretation of the correlation found between radio-star scintillation and irregularities observed on ionosondes (spread *F* and sporadic *E*) has been indeterminate for lack of data. L. E. Petrie, Defence Research Telecommunications Establishment, Ottawa, Ont., Canada, presented topside spread *F* observations from the Alouette sounder satellite. The occurrence of spread *F* in the topside ionosphere increases toward the auroral zone in general agreement with the latitude behavior of satellite scintillations, but a detailed comparison of scintillation irregularities and spread *F* observations awaits an interested experimenter.

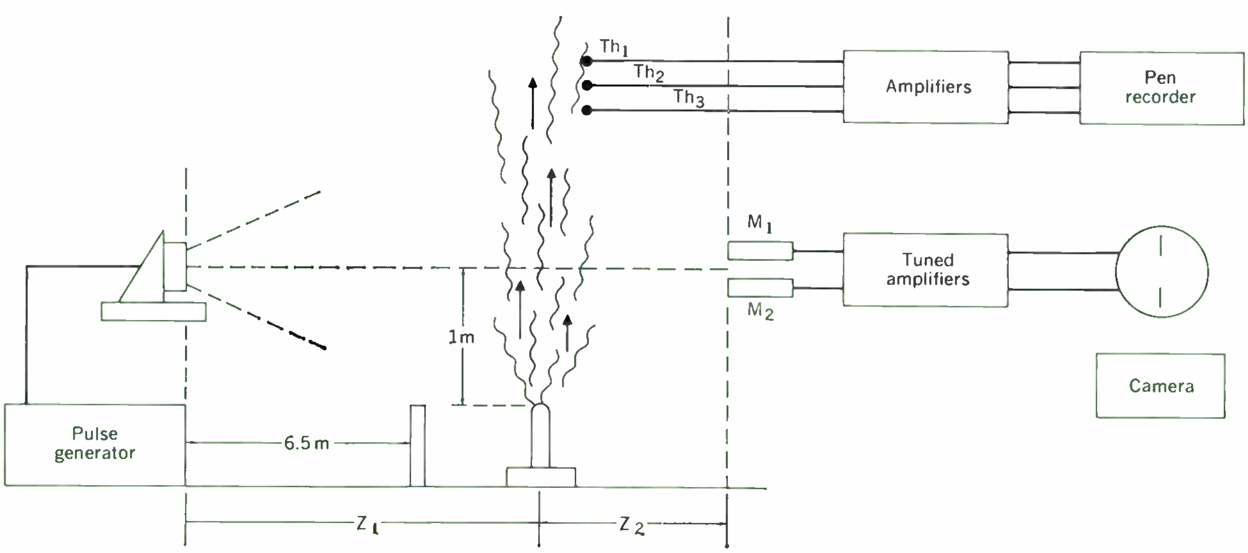
Data on the physical characteristics of the irregularities are always welcome. Rev. Koster of Ghana was able to use the Comsat "Early Bird" synchronous satellite for a four-station study of equatorial scintillations. Of particular interest was the extension of the base line to 21 km to measure irregularity elongation by correlation techniques. For the very active night of July 7, 1965, the elongation was at least 60 to 1. From a series of these measurements, it was concluded that the nighttime amplitude pattern on the ground is essentially a series of parallel straight lines moving predominantly eastward with mean velocities of 70 m/s.

In the northern hemisphere, we tend to divide the scintillation regions into auroral, subauroral, middle latitude, and equatorial. G. H. Munro of the University of Sydney, Australia, has reawakened our interest in comparing north and south regions by contributing results from a morphological study made in Australia. Any complete theory of the origin and behavior of irregularities must explain the seasonal changes that they undergo. The principal feature is a sudden enhancement of nighttime scintillation in September each year and a simultaneous near disappearance of daytime scintillations.

In each of the theoretical methods used to attack the scintillation problem—scattering, diffraction, and ray optics—there are restrictive assumptions necessary to facilitate the mathematical analysis. How do these assumptions limit the interpretation of experimental data in terms of scale size, velocity, scintillation depth, and so on? Prof. Briggs had some interesting results of a model study using sound waves detected after passing through heated (turbulent) air (see Fig. 3). Fortunately for our previously published interpretations, every test made validated the pertinent current methods of analyzing data. There were several suggestions from the audience for techniques to extend this model to the case of strong scattering. This would be valuable because most of the controversial aspects of data interpretation seem to involve the possibility of strong scattering.

The ionospheric limitations on the use of decametric waves for radio astronomy were considered by R. S. Roger, Dominion Radio Astrophysical Observatory, Penticon, B.C., Canada. Although scintillation can be minimized by choice of season, time of day, and state of

Fig. 3. Scintillation model utilizing heated air.



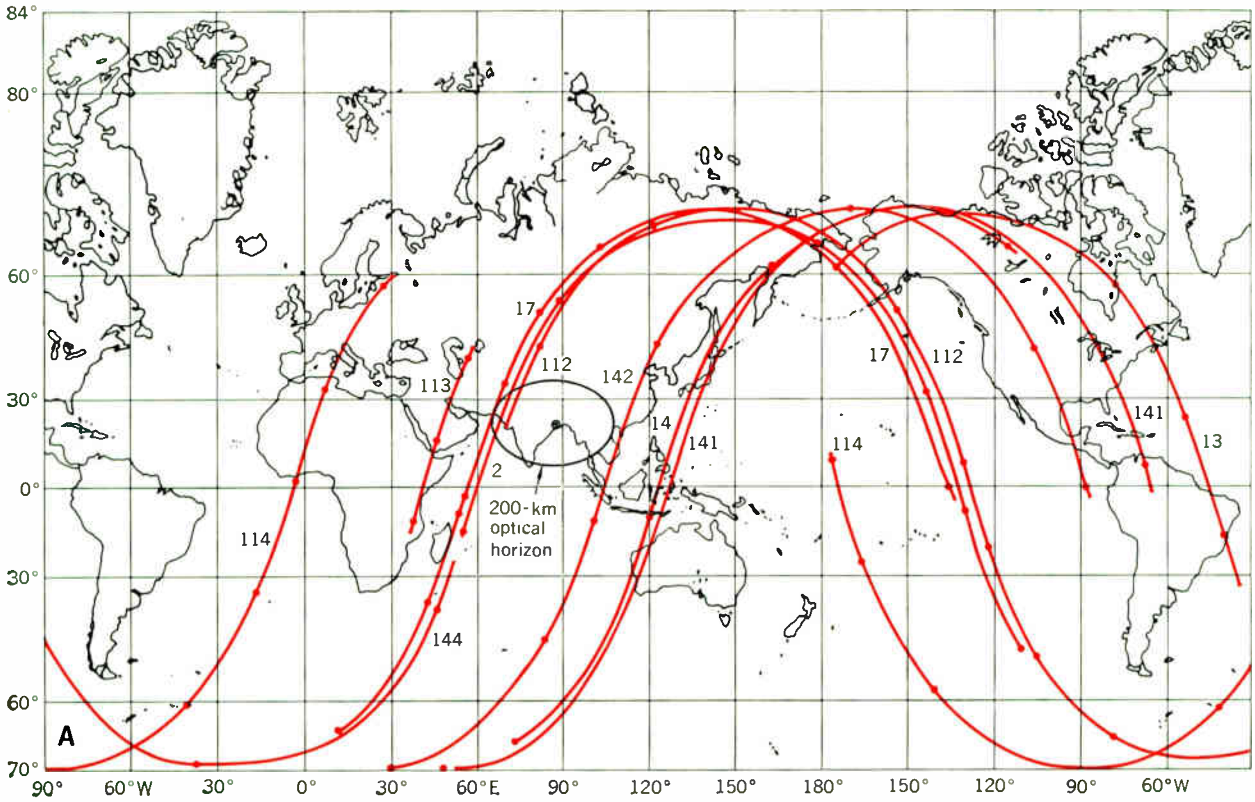


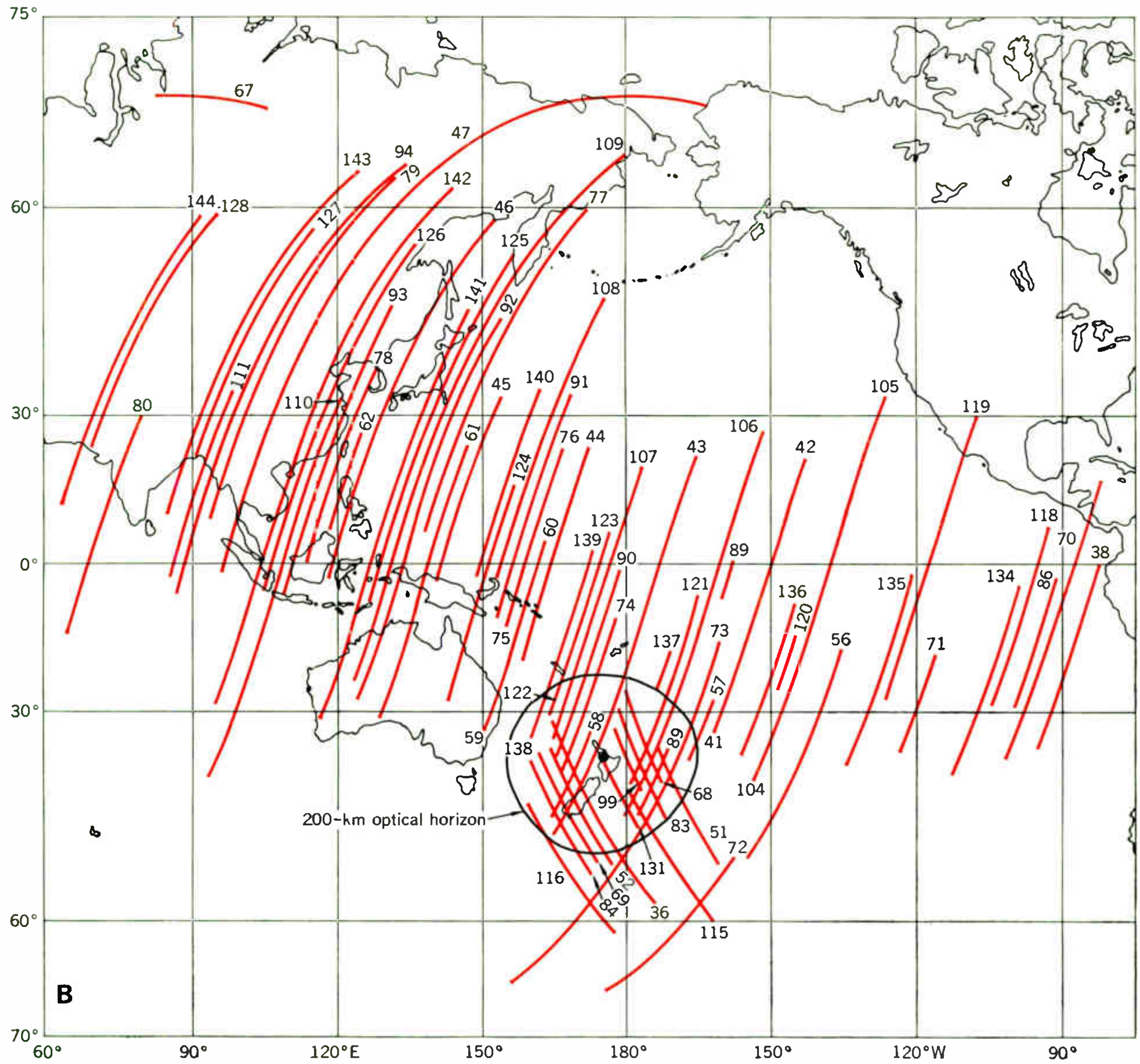
Fig. 4. A—Observations made at Calcutta, India, by S. Basu (University of Calcutta) of the ORBIS satellite. The CW transmissions at 10 MHz were produced by a beacon in a polar satellite orbiting in the 200–400-km range. The program was under the sponsorship of AFCRL. B (right)—Similar observations made by the University of Auckland, New Zealand.

solar activity, the effect of refraction from ionospheric gradients, absorption, and change of polarization must be considered. Some rather good radio-star scans made under favorable conditions may encourage others to enter this portion of the spectrum. The use of decametric waves from Jupiter noise storms for interplanetary scintillation studies was reported by A. G. Smith, University of Florida, and also by J. N. Douglas, University of Texas. Comparison of records from several stations show that local ionospheric effects are very important in site selection for Jupiter studies.

Lower atmospheric measurements

In one session nine papers were presented that highlighted measurements of various lower atmospheric properities, many of which have counterparts in ionospheric phenomena. These properties included the size and structure of irregularities, atmospheric refraction and attenuation, and spectral emission and absorption by water vapor and molecular oxygen. The frequency range encompassed by lower atmospheric measurements is 1 to 60 GHz, which is much higher than that used in dealing with ionospheric phenomena.

In the morning program of this session, which was chaired by S. Silver, University of California, J. Smyth, Smyth Research Associates, discussed the field distortions that result when radio waves are transmitted between a high-flying airplane and a ground station through the inhomogeneous troposphere. Analysis of the diffraction patterns obtained indicate discrete irregularities in dielectric constant having a scale size of the order of one to two miles horizontally and a few hundred feet vertically. In proposing the use of synchronous satellites for atmospheric stability measurements, S. F. Singer, University of Miami, Fla., in a very interesting proposal, recommended 3- and 10-GHz transmitters in addition to those presently operating at 136 MHz. In his proposal, two antennas placed a large distance apart on the ground would measure the phase difference between received signals as a function of time. Slow changes would be attributable to the drift in apparent satellite position, while rapid changes would directly measure variations in the refractive index of the atmosphere. With regard to the forthcoming solar patrol work, P. Kalaghan, Ewen-Knight Corporation, Natick, Mass., discussed a method whereby solar flux measurements can be better corrected for atmospheric attentuation. Using both ground humidity and photoelectric cloud cover data, a reduction by a factor of two in the statistical variation of 35-GHz solar temperature measurements was shown. J. Gibson, U.S. Naval Research Laboratory, discussed the atmospheric attenuation measurements made at 8.6- and 13.5-mm wavelengths (35 and 22.2 GHz) and the derivation of sky brightness temperature as a function of zenith angle. The observed data show an increased attenuation at 13.5 mm as compared with that at 8.6 mm, consistent with the difference in calculated opacity. J. P. Castelli, AFCRL, presented the results of seasonal measurements of atmospheric attenuation indicating that at 3.27-cm



wavelength (9.17 GHz), attenuation is more closely related to oxygen than to water vapor content. Measured vertical attenuation in winter with its higher barometric pressure was almost twice as high as in summer, despite the higher summer humidity.

In the four papers presented in the afternoon program chaired by A. S. Straiton, University of Texas, the emphasis was on the atmospheric molecular oxygen band, which consists of 25 spectral lines centered about 60 GHz. The atmospheric pressure at lower altitudes blends these lines into a continuous absorption band exerting a significant influence in the region from 50 to 70 MHz. V. Falconi, AFCRL, briefly reviewed the microwave absorption theory of Van Vleck and Weisskopf, and showed that experimental results of atmospheric absorption measurements made at 15, 17, and 35 GHz would achieve a greater correspondence with theory if the accepted value of the line breadth constant ($\Delta\nu/c$) for oxygen was changed from the present 0.02 cm^{-1} to 0.025 cm^{-1}. E. R. Westwater, National Bureau of Standards, discussed the potential use of the microwave emission spectrum of oxygen for ground-based probing of the temperature vs. height profile of the lower atmosphere. Based on absorption profiles, the frequency region of greatest height selectivity and, therefore, the best for probing, is the 53- to 57-GHz region; the required radiometric sensitivity would be about 0.5°K. A. C. Anway, Collins Radio Company, presented the results of measurements of atmospheric oxygen emission made with a radiometer mounted in the tail of a high-flying B-52 aircraft operating at a frequency of 51.25 GHz, which is on the lower edge of the molecular oxygen absorption complex centered about 60 GHz. The results show the expected increase in antenna temperature with decreasing elevation angle. Design criteria for a satellite-borne radiometer built to measure the temperature of the atmospheric oxygen mantle as a function of latitude and solar illumination were presented by R. Taylor of Ewen-Knight Corporation. The 20- to 30-km altitude region probed by the downward-looking horn antenna is determined by the choice of operating frequency, 60.8 GHz, near the center of the molecular oxygen band in a "well" between two emission lines. The instrument, having a 0.5°K sensitivity (for 10-second integrating time), will yield information needed to evaluate the feasibility of a 60-GHz-band local vertical sensor for spacecraft navigation.

Absorption studies by riometer techniques

In another session, chaired by R. Pendorf, Avco Corporation, Burlington, Mass., six papers were presented on riometer (relative ionospheric opacity meter) techniques for the study of ionospheric absorption. The session emphasized both simultaneous multifrequency measurement of the absorption of cosmic radio noise and the theoretical study of the relationship between absorption and the various solar-induced phenomena in the ionosphere. B. Hultqvist, Kiruna Geophysical Observatory, presented a review of the theory of the multifrequency absorption techniques for determination of the electron density profile. A. P. Mitra, National Physical Laboratory, New Delhi, reported the results of frequency analysis of sudden cosmic noise absorption (SCNA) made with a multifrequency riometer system and of a comparative study of SCNAs and 10.7-cm solar radio noise measurements.

T. Elkins, Wentworth Institute, working with AF Cambridge Research Laboratories, reported that the existence of a quasi-continuous large-scale flux of solar protons into the earth's atmosphere is consistent with ionospheric and geophysical observations and that the process is of very great importance during highly disturbed periods. Scientists from the National Bureau of Standards gave presentations on the measurement of auroral absorption and its relationship with very-low-frequency emissions. At Baie St. Paul, Quebec, a site in the auroral region 8° south of the maximum of the auroral zone, four radiometers were connected to four corner reflectors whose axes were directed 45° from the zenith in the direction of geographic north, east, south, and west. No variation between east and west absorption gradient was found but the average absorption gradient to the north increased two to three times as often as that to the south. Results suggest significant diurnal and magnetic activity dependent changes in the typical absorption gradient. The occurrence of VLF (1- to 10-kHz) emission was shown to increase almost linearly with auroral absorption. For accurate determination of ionospheric absorption using riometers, R. D. Sears, IIT Research Institute, Chicago, Ill., showed that better information on the true (unattenuated) cosmic noise background must be used. Although the power vs. frequency variation is commonly expressed by $P(\nu) = P_0\nu - N$ with N taken typically as 2.7, maps of galactic radio noise at several frequencies have shown that N exhibits a significant variation as a function of the sidereal coordinates of right ascension and declination. Techniques that take into account the variation in cosmic noise power as a function of sidereal time for the beam pattern of the aerials used with riometers have been developed, and 0.1-dB accuracy is expected.

Satellite propagation and background experiments

The last session was devoted to atmospheric propagation effects observed in several studies when a satellite was transmitting in the F layer, 200–400 km, on high frequencies. M. S. Wong, AFCRL, briefly reviewed his early work in ray-tracing analysis. The vehicle carrying his satellite-to-satellite HF experiment was destroyed during its September 1965 launch. Several symposium attendees evinced interest in obtaining advance information of the next launch in this series. M. Grossi, Raytheon Company, Sudbury, Mass., gave detailed consideration to guided propagation modes in the lower ionosphere, particularly to the tilted layer effects similar to a whispering gallery. Since the transition from ground station to ducted waves along the layer interface depends on the vagaries of scattering mechanisms, he emphasized the need for satellite-to-satellite measurements of the behavior of the duct mechanism.

J. P. Mullen, AFCRL, presented the results of a worldwide study of 10-MHz satellite-to-ground propagation (ORBIS) (200–400-km altitude) during November 1964. A general picture emerged which emphasized simple hop propagation into the edge of the nighttime ionosphere for mid-latitude stations. Observations of the equatorial regions, reported by S. Basu, University of Calcutta, India, showed several cases of continuous round-the-world reception from the ORBIS vehicle (see Fig. 4). Extremely long-range reception in the equatorial regions were noted and were attributed to a ducting mechanism, particularly in the Calcutta observations and those taken at Auckland, New Zealand.

Two papers were presented on the noise background observed by high-frequency receivers in satellites. M. D. Pappagiannis, Harvard College Observatory, discussed 4- and 7-MHz observations made between 200 and 350 km. T. R. Hartz, DRTE, Canada, reported observations made with a swept receiver (0.5 to 12 MHz) on board the Alouette satellite. In both cases, there are combinations of man-made, atmospheric, ionospheric, solar, and cosmic noise. These preliminary studies illustrate what may be expected in future studies of solar and cosmic noise made at higher satellite altitudes.

The propagation session ended with a panel discussion of the problems associated with satellite beacons and problems of launch schedules. All the participants agreed that they look forward to the utilization of the Titan vehicle's capability for putting more sophisticated packages into orbit. A plea was made for more advance information on the multitude of high-frequency packages programmed for the near future. Since many experiments, such as ORBIS or the Gemini transmission, involve only modest receiver installations, there are many potential volunteers willing to provide elements for a worldwide observation net.

Conclusion

What is the output of a specialized symposium? Certainly the discussion of techniques of data taking and reduction and the interpretation of results—and the disputes on these subjects—are important to the participants. The chitchat at coffee time, the arrangements to exchange visits to laboratories, and informal discussions of not-too-successful research are off-the-floor features of all specialized meetings. The interchange of ideas between theoreticians and experimenters is always helpful. Then, of course, many persons just starting in a field are spurred on by the excitement of results presented at a symposium. The physical output of the symposium reviewed here, the papers presented, will be embodied in a special issue of *Radio Science* scheduled for publication in the fall.