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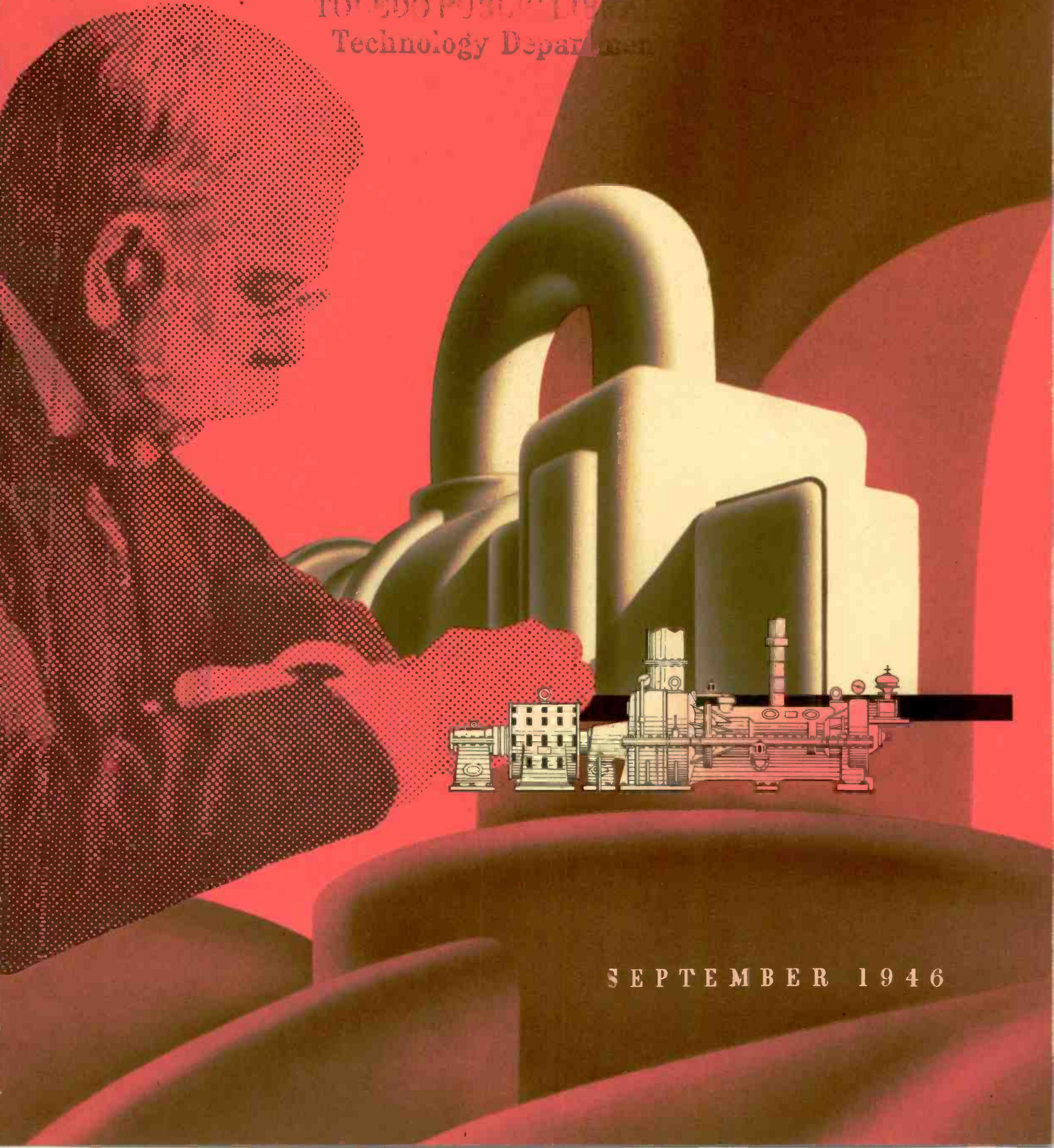

SEPTEMBER 1946

Limits without Limit

According to the narrow view, engineers are always working themselves out of jobs. They devise a machine to save labor. They create a process and then turn it over to operating personnel not technically trained to run it. They provide automatic controls that do the work of technicians. Paradoxically, however, there is always more engineering work to do than before. That's the way it is with technical exploration and exploitation. Each new technical accomplishment only proves that the field is limitless, just as, with each increase in telescope power, astronomers find more uncharted heavens than they had previously explored.

One need not look far for interesting cases of the new opportunities continually being uncovered by scientists and engineers. Every issue of a technical journal carries some; this one, for example.

The known regions of the electromagnetic spectrum are really little more than fairly narrow and widely separated bands, so much so that the continuity has not been too clearly appreciated. The power engineer, working at 60 cycles, does not feel close kinship to the radio engineer working with hundreds of kilocycles or the electronics engineer dealing with many megacycles. As pointed out by Dr. Hill (p. 134) one set of laws is applicable to them all. The empty regions in the spectrum are gradually being explored and brought to a stage of usefulness.

Before the war, television appeared as an attractive but expensive and somewhat distant possibility. Now television is not only proved practical and an accomplished fact in a limited area but also television pictures in full color and good quality are possible by the method discussed by D. L. Balthis (p. 155). The physical limits of human sight are being swept aside.

In the field of steam power plants the ceilings of total rating, pressure, and temperature have been slowly pushed upward by dint of painstaking research and development. The planners of the new Sewaren generating station of the Public Service and Gas Company of New Jersey tried to reach out into the future. They succeeded in taking another upward hitch in ratings. The first unit for that station (described on p. 130) is a high-speed machine with a 100 000-kw output, developed from steam at 1050 degrees F and 1500 pounds. This represents by 50 degrees a new undertaking in temperature. Also, the pressure, while not the highest employed, is a marked advance over the 1250 pounds considered top standard. It is also the first 3600-rpm machine to produce 100 000 kw, yet only 16 years ago 10 000 kw was the top. The result is a new mark in fuel economy and again better use of materials — both continually sought as engineering objectives.

It is clear-cut engineering thinking that can conceive of an electric motor as a horizontal track for a moving car with the "rotor" used as an airplane launching device (p. 160). Also, important but less spectacular, is a tall high-voltage lightning arrester that can stand alone without mechanical bracing (p. 164). It is an example of the more common form of progress—improvement of detail that results in simplication and a better use of materials.

The ability to recognize limits and then push beyond them is the mark of a great engineer, such as was George Westinghouse whose one hundredth birthday is being celebrated next month. This is illustrated by the outstanding events of his life—alternating current, geared-turbine ship drive, and the air brake (p. 145). It is the kind of thing that distinguishes the great men of electrical engineering, whose life spans and accomplishments are graphically presented in the chart p. 146. Before the engineer there are endless frontiers —limits without limit.

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VOLUME SIX SEPTEMBER, 1946 NUMBER FIVE

On the Side

The Cover—The stalwart figure of George Westinghouse, born one hundred years ago next month, stands in the background of many of industry's present-day technical developments. It is fitting that this issue, which pays tribute to Westinghouse, also describes (p. 130) another milestone in power generation, the establishment of which he so greatly aided.

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Atomic-Power Development — What is probably the first university of the "atomic age" will open its doors this fall in Oak Ridge, Tenn., to a selected group of scientists and engineers from the nation's research laboratories, industrial plants, and colleges. Called the Institute of Nuclear Studies and sponsored by a group of southeastern universities, the new school will attack chiefly the problems of peacetime application of atomic power. Research will be carried out in the fields of physics, chemistry, biology, medicine, and engineering. Nine men will represent Westinghouse in this important project. They are Dr. E. B. Ashcraft, Dr. S. Siegel, Dr. J. E. Hill, and Dr. L. P. Hunter, all from the Research Laboratories; J. W. Simpson and A. H. Toepfer from the engineering department of the East Pittsburgh Works; and N. J. Paladino and E. F. Miller from the Steam Turbine Division at South Philadelphia, Pa.

Underwater Rocket—Had the Japs prolonged the fight a few more weeks they would have felt the sting of a new weapon, just now announced. It is a hydro-bomb, or aerial torpedo launched from a fast-flying airplane. Striking the water it is propelled by the jet reaction of expelled hot gases.

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In This Issue

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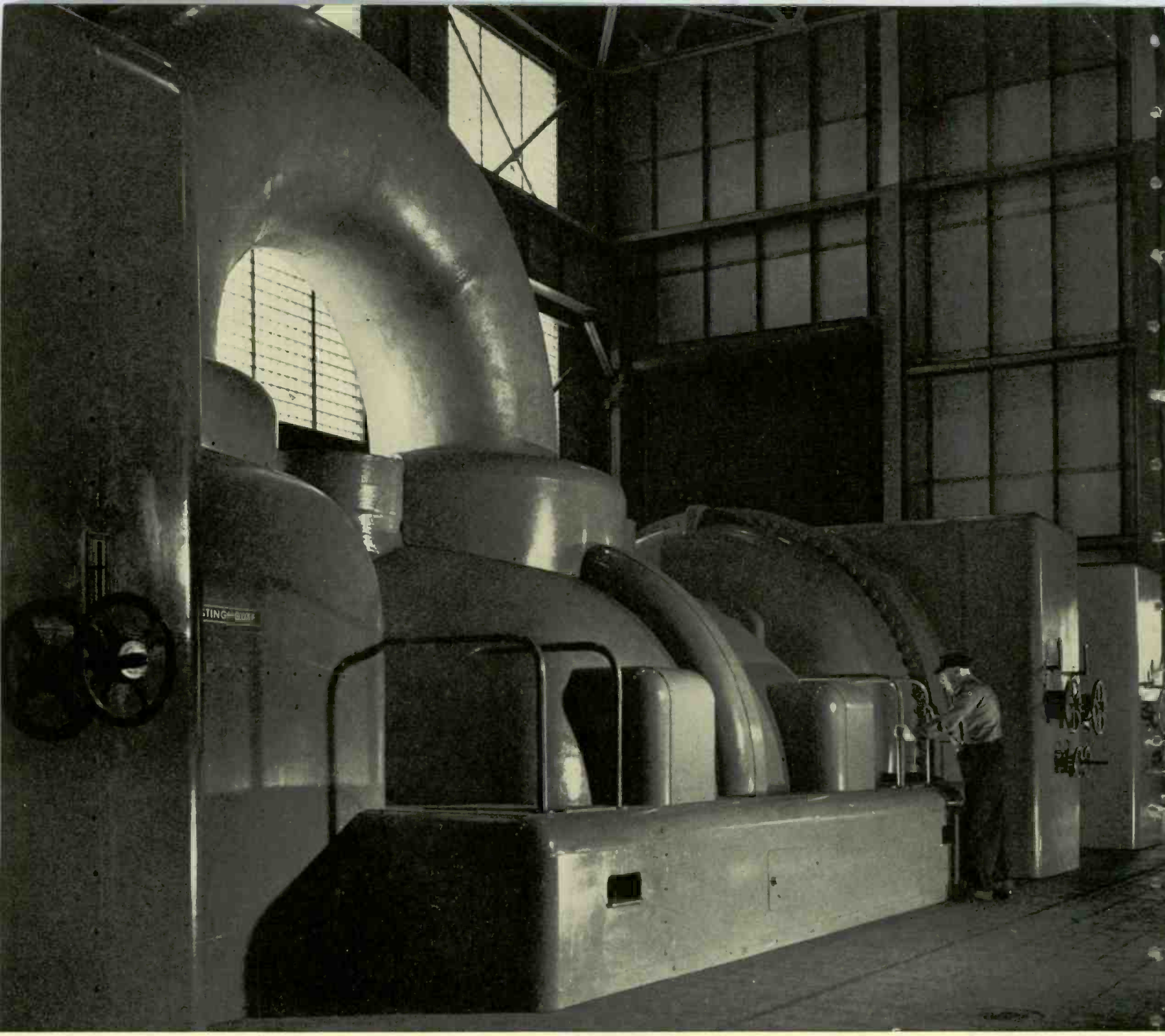


Most growth is an uneven series of plateaus, not a smooth upward curve. Certainly this has been true of progress in high-speed generating units. Just recently new upward steps have been taken in steam temperature, pressure, kilowatt rating and last-row blade length. The first machine for the new Sewaren Station will take steam at 1050 degrees, 1500 pounds, and develops more than 100 000 kw. At 3600 rpm the tips of its 23-inch exhaust blades travel nearly 1400 feet per second.

Limits to 3600-Rpm Generating Units Raised

In the brief period of ten years the 3600-rpm turbine generator has so grown in ratings that it has in effect driven the slower speed, four-pole generating unit from the central-station field except for the largest capacity installations. But here, too, the death knell is being sounded by the construction of a 100 000-kw, 3600-rpm unit for the Sewaren Station of the Public Service Electric & Gas Company of New Jersey that will operate with steam at 1500 psig and 1050 degrees F, the highest inlet temperature yet attempted. Although other stations operate with higher initial steam pressure, the 1500 pounds of the Sewaren unit represent a material advance in pressure over the 1250 pounds that have otherwise been the top for power-station use.

The steam turbine, a tandem-compound unit with a double-flow low-pressure element, is capable of driving a 95 000-kw main generator and a 7500-kw house generator. The main generator is rated at 85-percent power factor; the house generator, at 80-percent power factor.

The machine is about 80 feet long, 18 feet wide, and 15 feet high, and thus will require less floor space than an 1800-rpm unit of comparable rating.

As might be expected with such a large machine, the problems of design are involved and numerous, but none is more dependent on past metallurgical improvements than the high inlet temperature. Operating temperatures have risen quite sharply in the past 15 years as Fig. 1 shows. With the early 1930's, condensing turbines generally were limited to throttle conditions of 400 psig and 750 degrees F. Although thermal studies indicated that the use of increased pressures and temperatures would result in operating economies, the cast-carbon-steel materials for the cylinder limited the upper temperature to approximately 750 degrees F, and it was possible to utilize only the increase in pressure. With high pressure and low temperature went excessive moisture at the exhaust end, and consequent erosion of the blading. Experience led to the establishment of an arbitrary limit of 12-percent moisture at exhaust, which meant that for any specific temperature there was a definite limit of pressure. This was overcome in some plants which were designed to provide interstage reheating. Some stations adopting this principle were highly successful and economical, as evidenced by the drop in heat rate at this period. However, although interstage reheating provided better overall thermal efficiency there was another limiting factor, namely, the ability of the exhaust blading to pass any increase in steam flow efficiently. Given a steam inlet temperature and pressure, the rating of any condensing turbine can be increased only by increasing the ability of the last row of blading to pass the larger steam flow without prohibitive leaving loss. With a given speed and acceptable amount of energy that can be permitted in the steam as it goes to the condenser, this means a larger last-row annulus area, i.e., longer blades. The limit to exhaust blade length is set by the ability to design a blade of such reasonable proportions and of such material that it, as well as the rotor, can withstand the high peripheral forces involved. These forces really become tremendous. For example, the root structure of the 23-inch blade on the Sewaren machine must resist a force of greater than 80 000 pounds tending to lift them out of the spindle, or the disc must resist a total pull, from all blades, of 10 million pounds.

In 1929, Westinghouse engineers designed a 17-inch blade, for 3600-rpm machines. This meant an increase of 141 feet per second tip speed over the previous 12-inch blade and a 60-percent increase in centrifugal force. This was a noteworthy accomplishment, because it increased the economical capacity of a single-case machine.

Progress in steam-turbine developments is closely linked with improvements in low-pressure exhaust blading. The tendency has been to design a larger blade and gain operating experience with the machine before again venturing further. In the meantime, increased capacity can be obtained by going to tandem-compound units. For example, 10 000 kw was the maximum that could be gotten from a single-case machine for 17-inch exhaust blading in 1929. This first unit, built for Peoples Gas and Electric Company at Mason City, Iowa, was rated with steam conditions of 400 pounds, 700 degrees F. But Virginia Public Service wanted more capacity for their Bremo Bluff station and purchased a 15 000-kw tandem-compound machine. Because the exhaust steam was split into two paths, even this did not represent the limit, 20 000 kw being possible, but not required at the time.

The generator then became the limiting factor, and remained so until 1936 when rapid advances were made both in generator and turbine engineering. Generator capacity was boosted by improved rotor end-turn ventilation, by a better method of dynamic balancing, and by improvements in forgings for the generator shaft. Changes in the rotor forging in the past 20 years have permitted a 70-percent increase in allowable working stresses without any reduction in the factor of safety. In addition, improvements in design, materials and inspection have increased the maximum rotor diameter approximately 50 percent, and increased the length of the body with respect to the diameter.

Most important of all generator improvements during this period, however, was hydrogen cooling, as it has been the means of obtaining an increase in rating from a given size of generator. Not only does it give a higher rate of heat transfer, but accounts for a reduction in windage loss over that obtained in air, which means better efficiency and a reduction in the temperature rise of the rotor.

At this time, too, came a host of turbine advances in turbine engineering. Exhaust-end blade lengths were increased to 20 inches and blade tip speeds increased to 1257 feet per second, slightly greater than sea-level sonic velocities. The blade root was redesigned to hold the blades under these higher stresses, and a new class of steels became available for turbine casings, indicating that the same degree of safety could be worked into the design of units operating with temperatures of 925–950 degrees F as had previously existed for carbon steels at temperatures of 825 degrees F. Carbon-molybdenum steels were used for castings, nickel-chromium-molybdenum steels for forgings, and 12-percent chrome iron for blading. In addition, the use of stellite shields on the blade inlet edges of water catchers effectively reduced erosion.

This story on the development of the high-speed generating unit is based on Westinghouse experience but closely parallels the industry as a whole. It has been prepared by Val Laughner from information supplied by C. C. Franck, F. K. Fischer, John Carlson, and J. W. Batchelor of the Westinghouse steam-turbine and generator engineering departments.

From Sixty Cycles to Super-Frequencies

DR. J. E. HILL, *Westinghouse Research Laboratories*

THE behavior of microwaves and of the ultra-high and hyper-frequency* currents associated with them appears almost incomprehensible when these phenomena are compared with sixty-cycle and ordinary radio-frequency phenomena. Actually the same basic physical laws that apply to power and broadcast radio frequencies serve also to describe the effects of frequencies all the way up the radio-frequency spectrum and serve equally well to explain many of the phenomena in the infrared and optical regions.

Many of the properties of hyper-frequency oscillations and their circuits appear strange only because isolated regions, widely separated in frequency, have been utilized suddenly and independently, without the development of large intervening regions of the frequency spectrum. Thus the smooth continuity of changes that prevail as we proceed up the electromagnetic frequency scale has not been apparent.

The electromagnetic spectrum might seem like a crossword puzzle, loose-jointed and uncoordinated. Actually it is more like a fine mosaic. Some pieces are still missing—not so many as only a few years ago—but enough have been filled in to show the orderliness of the spectrum from direct current, through 60 cycles, and on past radio and microwaves. The power engineer is gratified to find that cycles and megacycles obey the same fundamental laws. Only the emphasis on the qualities varies as one traverses the frequency scale.

Not only is there an essential continuity within the radio-frequency spectrum, but also this continuity exists throughout the whole gamut of the complete electromagnetic waves. With the discovery of radio, infrared, ultraviolet, x-ray, gamma, and cosmic radiations—varying in frequencies from a few kilocycles (say 10 000 cps for long-wave radio) to a million billion billion (10^{24} cps for the electromagnetic components of cosmic rays)—the whole continuous sweep of the spectrum has been mapped.

All of these radiations have in common the fact that they are propagated in empty space as electromagnetic waves of constant velocity ($c=3\times10^{10}$ cm per second or 186 000 miles per second). Moreover, a particular wavelength is associated with each frequency such that the product of the frequency and the wavelength equals this velocity of propagation, i.e., $c=f\lambda$.

Wherever these radiations interact with matter, energy is transferred to the material particles only in packets of finite size or quanta equal to the product of a universal constant (Planck's constant $h=6.55\times10^{-27}$ erg-sec) and the frequency f: Each such quantum of energy has the momentum hf/c. The correlation of frequency, wavelength, and the quantum energy for different types of electromagnetic radiation is shown in Fig. 1.

Numerical values of some extreme limits in Fig. 1 are of interest. At the low-frequency end of the spectrum, say 60 cps, the wavelength is 5×10^{8} cm or 3100 miles. This is too long for practical use in radio transmission, for a quarter-wave antenna would be 775 miles long.

The quantum energy at 60 cycles is 2.46×10^{-13} ev, an energy so small compared with the binding energies holding characteristic material particles together, that large numbers of quanta are included in any energy measurement possible in the laboratory. This means that any absorption of electromagnetic energy at this frequency is a continuous process as far as is detectable by experiment. This condition continues well into the radio-frequency region and it is only at hyper-frequencies that strictly quantum effects can be observed, when the electromagnetic radiations interact with matter. For example, at 30 000 megacycles where the wavelength is 1 cm, the quantum energy is 1.2×10^{-4} electron volt or a half billion times greater than at 60 cycles. Resonance absorption by gas molecules of electronically generated electromagnetic waves has recently been observed at these frequencies, thus demonstrating the existence of distinct quantized energy states in molecules separated by these small energy values.

At the other extreme, the electromagnetic waves that form a secondary component of cosmic rays (not the actual primary rays themselves) have energies of billions of ev or frequencies of approximately 10^{24} or a million, billion, billion cycles/sec and wavelengths of 10^{-14} cm. An idea of the magnitude of this wavelength is indicated by the fact that the smallest length visible in best microscopes is approximately 10^{-6} cm. Such radiation—10^{-14} cm—is produced by charged particles (primary cosmic rays) with enormous velocities on colliding with other particles of matter. Their true origin is yet unknown.

The radio-frequency spectrum now extends from frequencies less than 10^{5} cps used for long-wave transatlantic commercial radiophone and radio-telegraphic communications, to almost 10^{11} cycles, used for microwave radar—i.e., from 100 kilocycles to almost 100 000 megacycles. This is a small portion of the entire electromagnetic spectrum, but comprises the greater portion of the spectrum from power frequencies down to the heat or infrared radiation. The radio-frequency spectrum, shown in Fig. 2, now comprises almost 20 octaves (a change of one octave doubles the frequency), whereas the spectrum of visible light occupies only a little over one octave.

The phenomena encountered in the radio-frequency portion of this electromagnetic spectrum—from direct current upward to the infrared—can all be explained by Maxwell's electromagnetic theory, which is summarized by a set of equations known as Maxwell's electromagnetic field equations. These are summarized in table I, both in integral and derivative form. Any treatment of the radio spectrum would be incomplete without mention of their physical meaning and a discussion of their predictions, which account for the wide

*What has been high frequency to some engineers is low frequency to others. To bring some order out of this chaotic nomenclature, a suggested standard terminology for the different frequencies, given in Fig. 2, is used in this article.

	FREQUENCY		WAVELENGTH CM	WAVELENGTH ENGLISH UNITS	QUANTUM ENERGY ERGS
	0		INFINITY	INFINITY	0
Electric Power	10	Cycles	3×10^{9}		6.5×10^{-26}
	60	Cycles	5×10^{8}	3120 miles	2.1×10^{-25}
	100	Cycles	3×10^{8}	1865 miles	6.5×10^{-25}
Sound	1 000	Cycles	3×10^{7}	186.5 miles	6.5×10^{-24}
	10	Kilocycles	3×10^{6}	186.6 miles	6.5×10^{-23}
Radio frequency: Long	100	Kilocycles	3×10^{5}	1.8 miles	6.5×10^{-22}
	1 000	Kilocycles	3×10^{4}	984 feet	6.5×10^{-21}
Radio frequency: Short	10	Megacycles	3×10^{3}	98.4 feet	6.5×10^{-20}
	100	Megacycles	3×10^{2}	9.8 feet	6.5×10^{-19}
Microwaves	1 000	Megacycles	30	11.8 inches	6.5×10^{-18}
	10 000	Megacycles	3	1.18 inches	6.5×10^{-17}
Heat	10^{12}	Cycles	3×10^{-2}	0.01 inches	6.5×10^{-15}
Light	10^{14}	Cycles	3×10^{-4}		6.5×10^{-13}
Ultraviolet	10^{16}	Cycles	3×10^{-6}		6.5×10^{-11}
Xrays	10^{18}	Cycles	3×10^{-8}		6.5×10^{-9}
	10^{20}	Cycles	3×10^{-10}		6.5×10^{-7}
Gamma rays	10^{22}	Cycles	3×10^{-12}		6.5×10^{-5}
Cosmic rays	10^{24}	Cycles	3×10^{-14}		6.5×10^{-3}

←

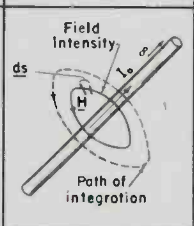
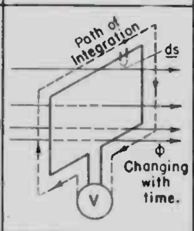
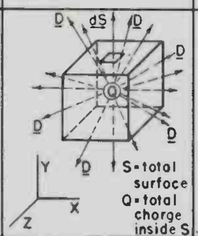
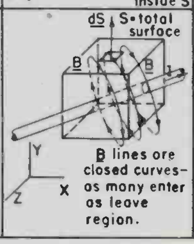
Fig. 1—The electromagnetic frequency spectrum showing the relationship of frequency, wavelength, and quantum energy. The different types of energy are shown in the approximate positions. Their boundaries overlap, however, and are by no means as well defined as indicated here. Sound, although not an electromagnetic phenomenon, is included to show the frequency relationship. One reason for the great interest in cosmic rays is the size of their quanta—some ten thousand billion billion times greater than quanta of power-frequency radiation and even a billion times larger than light quanta. Such energy may be useful in atom smashing.

10 kc		
	Very low frequencies	
30 kc		10^{6} cm (10 000 meters)
	Low frequencies	
300 kc		10^{5} cm (1 000 meters)
	Medium frequencies (Broadcast band 550 kc – 1 500 kc)	
3 000 kc (3 mc)		10^{4} cm (100 meters)
	High frequencies	
30 mc		10^{3} cm (10 meters)
	Very high frequencies	
300 mc		10^{2} cm (1 meter)
	Ultrahigh frequencies	
3000 mc		10 cm
	Super high or hyper frequencies	
30 000 mc		1 cm

Fig. 2—The high-frequency sections of the electromagnetic spectrum and a proposed nomenclature.

TABLE 1—SIMPLIFICATION OF MAXWELL'S FOUR BASIC EQUATIONS OF ELECTRICITY AND THEIR MEANINGS.

MAXWELL'S EQUATIONS (VECTOR FORM) (MKS UNITS)

STATEMENT OF BASIC LAW	DIAGRAMMATIC SKETCH	INTEGRAL FORM	DERIVATIVE FORM (GENERAL)	DERIVATIVE FORM (STATIC CASE)	DERIVATIVE FORM (STEADY STATE)	DERIVATIVE FORM (QUASI-STEADY STATE)	DERIVATIVE FORM (FREE SPACE)
1 The work required to carry a unit magnetic pole around any closed path is equal to the total current (conduction + displacement) linking that path, that is the total current passing through any surface which has that path for its periphery.		$\int_o \underline{H} \cdot \underline{ds} = I_{total}$ ($I_{total} = I_{conduction} + I_{displacement}$) Where $\int_o$ indicates a line integral around any closed path and ds is a vector element of length along that path. H is the vector magnetic field intensity.	$\nabla \times \underline{H} = \underline{j}_c + \frac{\partial D}{\partial t} = \underline{j}$ (total) $\underline{j}_c = \sigma \underline{E}$ ($\nabla = \bar{i}\frac{\partial}{\partial x} + \bar{j}\frac{\partial}{\partial y} + \bar{k}\frac{\partial}{\partial z}$ is a vector operator), $\nabla \times \underline{H}$ is the vector product of ∇ and H, and j is the total current density (conduction+displacement.)	$\nabla \times \underline{H} = 0$ All time derivatives are 0 and charges stationary, that is $\underline{j}_c + \frac{\partial \underline{D}}{\partial t} = 0$	$\nabla \times \underline{H} = \underline{j}_c$ Conduction current exists but both the time derivatives of electric and magnetic induction are zero.	$\nabla \times \underline{H} = \underline{j}_c$ $\frac{\partial \underline{D}}{\partial t}$ while not zero is very small and can be neglected except in condensers. (As in AC at power frequencies.)	$\nabla \times \underline{H} = \frac{\partial \underline{D}}{\partial t} = \epsilon_0 \frac{\partial \underline{E}}{\partial t}$ jc = 0 (no conduction current.) Note $\underline{D} = \epsilon_0 \underline{E}$ where ϵ_0 constant in free space.
2 The emf induced in any fixed closed loop is equal to minus the time rate of change of the magnetic flux ϕ through that loop by emf is meant the work required to carry a unit charge around the loop.		$\int_o \underline{E} \cdot \underline{ds} = -\frac{\partial \Phi}{\partial t}$ $\int_o$, and ds have the same meaning as in 1. The time rate of change of ϕ is written as a partial derivative to indicate that the loop does not move (x,y,z of each point of the loop remain fixed during integration) E is the vector electronic field intensity.	$\nabla \times \underline{E} = -\frac{\partial \underline{B}}{\partial t}$ Where B is the vector magnetic flux density.	$\nabla \times \underline{E} = 0$ (See above)	$\nabla \times \underline{E} = 0$ (See above)	$\nabla \times \underline{E} = -\frac{\partial \underline{B}}{\partial t}$ (Same as general case since $\frac{\partial \underline{B}}{\partial t} \gg 0$)	$\nabla \times \underline{E} = -\frac{\partial \underline{B}}{\partial t} = \mu_0 \frac{\partial H}{\partial t}$ ($\underline{B} = \mu_0 \underline{H}$ and μ_0 = constant in free space.)
3 The total flux of electric field diverging from a charge Q is equal to Q in magnitude.		$\int_S \underline{D} \cdot \underline{dS} = Q$ Where S is here any closed surface, dS is a vector element of S, D is the vector electric flux density, Q is the net charge within S, and the integral indicates that $\underline{D} \cdot \underline{dS}$ is to be calculated for each element of S and summed.	$\nabla \cdot \underline{D} = \rho$ Where $\nabla \cdot \underline{D}$ is the scalar product of ∇ and D, and ρ is the charge density (charge per unit volume) the equation states that at each and every point the electric flux diverging from a unit volume is equal to the charge in that volume.	$\nabla \cdot \underline{D} = \rho$ (No change from general case.)	$\nabla \cdot \underline{D} = \rho$ (No change from general case.)	$\nabla \cdot \underline{D} = \rho$ (No change from general case.)	$\nabla \cdot \underline{E} = 0$ $\rho = 0$ that is no charges since $\underline{D} = \epsilon_0 \underline{E}$ where ϵ_0 = constant in free space E can replace D.
4 Magnetic flux lines are continuous, that is, closed loops. There are no sources or sinks of magnetic flux.		$\int_S \underline{B} \cdot \underline{dS} = 0$ Where S, ds, and the integral have meanings as for 3 and B is the vector magnetic flux density.	$\nabla \cdot \underline{B} = 0$ Which states that at any and every point the net outward flux of B from a unit volume is zero (as much enters as leaves.)	$\nabla \cdot \underline{B} = 0$ (No change from general case.)	$\nabla \cdot \underline{B} = 0$ (No change from general case.)	$\nabla \cdot \underline{B} = 0$ (No change from general case.)	$\nabla \cdot \underline{H} = 0$ ($\underline{B} = \mu_0 \underline{H}$ and in free space μ_0 = constant.) ∴ H can replace B

variation in behavior of oscillations at 60 cps and at, say, 3×10^{10} cps. Maxwell's field theory comprises four basic differential equations. One of these relates a function of the space rate of change of the magnetic field to the time rate of change of the electric field and the electrical constants of the media (dielectrics and conductors). A second relates the same function of the electric field to the time rate of change of the magnetic field and the magnetic characteristics of the media involved (permeability). A third equation states that another function of the space rate of change of the magnetic induction is equal to zero, and the last equation says that this same function of the electric induction is proportional to the electric charges in the region considered. These four equations summarize, in precise mathematical language and in a very general way, the basic experimental discoveries of electrostatics and electrodynamics. Because they are differential equations, the solutions satisfying these equations with the initial conditions of the particular problem must be obtained to determine the actual magnetic and electric fields or the associated currents and voltages as a function of both position and time.

Maxwell was able to deduce from these fundamental equations that at sufficiently high frequencies (say about 15 kc) electromagnetic energy in a high-frequency circuit becomes detached and travels into space as an electromagnetic wave with a velocity equal to that of light. In fact, Maxwell calculated the velocity of these electromagnetic waves to be equal to the ratio of the electromagnetic unit of current to the electrostatic unit of current. This calculated velocity of electromagnetic waves turned out to be identical to the measured velocity of light. Maxwell thereupon stated that light itself was indeed electromagnetic radiation of short wavelength. About 25 years after Maxwell's predictions, Hertz generated electromagnetic waves in the laboratory and demonstrated their properties to be as predicted by Maxwell. In so doing Hertz laid the foundations for the science of radio.

Maxwell's electromagnetic field theory is completely adequate to explain the whole range of electrical phenomena from d-c to say 10^{11} cycles (100 000 megacycles). Generators and detectors of higher frequencies consist of atomic and molecular systems, and many of the phenomena require quantum theory for their description. Power and audio-communication frequencies are adequately treated by defining circuit elements of inductance, capacitance, and resistance and working with current and voltage measurements. This procedure essentially eliminates the necessity of considering electric and magnetic fields in the description of the electrical phenomena involved: once the definitions of resistance, inductance, and capacitance are stated, attention may be focussed on the circuit and the current and voltage distribution therein. Once the circuit constants are defined, what transpires in the space surrounding the circuit is ignored. This so-called "lumped constant" treatment can be extended well into the radio-frequency region if proper precautions are taken in the design of the circuit elements, in the shielding and arrangement of these elements, and by introducing such concepts as radiation resistance of antennas, etc.

When dealing with the microwave region, however, these methods are of little use. The electric and magnetic fields are now of prime importance. Instead of resonant circuits consisting of inductance, capacitance, and resistance, resonant cavities operating in specific modes or field configurations are encountered. Transmission lines become hollow pipes, not parallel wires or twisted pairs. Their very name — waveguides —emphasizes that their prime function is to contain and guide the electric and magnetic fields that constitute these "guided waves." Antennas begin to look more like searchlight reflectors than the familiar wire arrays of long-wave radio antennas.

The quantities measured are likewise different. At low frequencies, currents, voltage, inductance, capacitance, resistance, and frequency measurements are of prime importance. In microwave measurements power, attenuation, wavelength, standing wave ratio and position are the quantities sought.

Three phenomena that can be calculated from Maxwell's theory are of fundamental importance in predicting these changes as the frequency is increased, and are the determining factors in all design and analysis considerations:

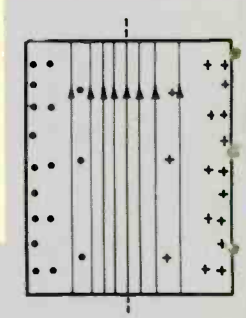
1—Radiation of energy by the circuit in the form of electromagnetic waves increases as the frequency increases unless special precautions are taken to prevent this energy loss.

2—Skin effect confines the currents to ever thinner lamina near the boundaries of the conductors as the frequency increases. Finally, current becomes a surface phenomenon.

3—The dimensions of circuits become larger and larger in proportion to the wavelength as the frequency increases, so that all portions are not simultaneously in phase. At megacycle frequencies dimensions become limiting.

Radiation

For a radio antenna the electromagnetic energy radiated with a fixed exciting voltage increases as the fourth power of the frequency, other things being equal. The radiation is also increased as the antenna length increases to a point where it is an



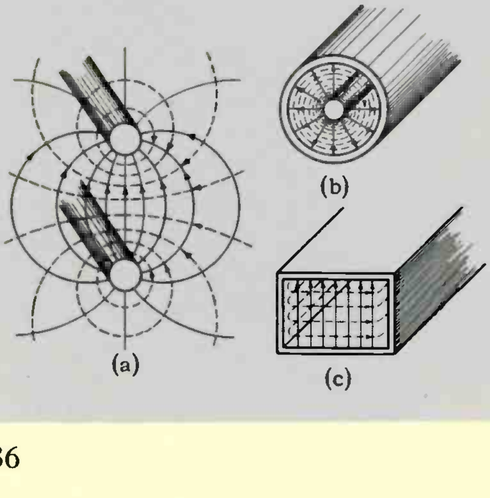


Fig. 3—Electric and magnetic fields for (a) two-wire transmission systems, (b) coaxial line, and (c) for hollow waveguide.

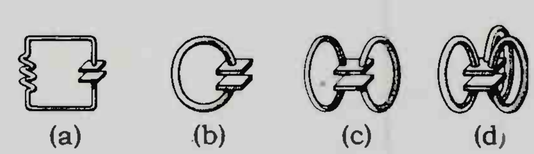


Fig. 4—The cavity-type resonator can be considered as the ultimate result of the progressive extension of the idea of a resonant circuit consisting of a coil and condenser in series, (a), to a single-turn coil and condenser (b), and finally beyond (c) and (d) to a single-turn solid conductor with a "nosed-in" section.

appreciable fraction of a wavelength long. From these considerations it is clear that to make more efficient use of transmitter power one should go to higher frequencies. This is certainly true within the limitations of propagation phenomena connected with the Heaviside layer and atmospheric absorption. Also, because the antenna should be a reasonable fraction of a wavelength long for efficient radiation, frequencies less than 50 to 100 kc are usually impractical just on the basis of antenna length alone.

On the other hand, at frequencies above 50 mc (wavelength about 6 meters or 20 feet) circuits and circuit components begin to attain sizes of the order of the wavelength. Indeed, in the microwave region (300 to 30 000 mc), they are usually many wavelengths in physical dimensions. Under these conditions unwanted radiation from resonant elements, transmission lines, etc., becomes so serious that special design is necessary to make such circuit elements self-shielding. Coaxial lines and waveguides must replace open-wire transmission lines; resonant cavities must be used in place of resonant *LC* circuits; and in most cases oscillator tubes must be built as an integral part of these resonant cavities instead of being a circuit component, the function of which can be largely regarded as an electronic switch.

Figure 3 shows how the fields are confined in coaxial lines and rectangular waveguides in contrast with an open-wire transmission line, thus directing the high-frequency energy to the desired destination without coupling to other objects or radiating into space.

A resonant-cavity klystron, as shown in Fig. 4,* is an example of combined electronic and resonant elements in a self-shielding oscillator unit. The structure can be regarded very loosely as the coupling together of several units, consisting of a small loop inductance and a single-section condenser, to form a closed self-shielding cavity as indicated. This, however, is an oversimplification, for not all the inductive effect can be confined to the outer part of the cavity nor can all the capacity effect be limited to the "noses" of the "nosed-in" cavity. In fact the design of such a cavity to a specified resonant frequency requires a calculation of the electric and magnetic fields rather than *LC* circuit calculation. The field configurations in such a cavity are shown in Fig. 5.

Fig. 5—The electric (solid lines) and magnetic fields (dots and crosses representing entering and leaving field lines) within a hollow cylinder.

Skin Effect

The phenomenon of skin effect, by which the resistance of a given conductor becomes greater the higher the frequency, is known to every worker with alternating current. Even at power frequencies it is significant and is taken into account in the design of power-transmission lines. Maxwell's theory shows that the rapidly oscillating fields tend to decrease the current density in the body of a conductor and increase it at the boundary surfaces, in contrast to uniform current distribution throughout the volume of the conductor at d-c or very low frequencies. This condition becomes more and more pronounced as the frequency increases until at the super-high or hyper-frequencies only a surface layer, fractions of a thousandth of an inch thick, carries the entire current, as Fig. 6 indicates.

Clearly, conductors of annular cross section are just as good conductors as solid ones at quite moderate frequencies. This fact is used to reduce conductor costs and weight in radio circuits. At microwave frequencies, a thin layer of electroplated silver is often used on some stronger and less expensive metal. Silver's superior conductivity and the fact that at these frequencies skin effect confines the currents to a thin surface layer make the cost acceptable. A recent practice is literally to print circuits on an insulating surface, such as porcelain, using conducting heat-set inks.

Another consequence of this extreme skin effect at microwave frequencies is the fact that relatively large voltage differences may exist between opposite boundaries of very thin layers of conducting materials. For example, a potential difference of thousands of volts may exist between the inner and outer surfaces of a waveguide only a few thousandths of an inch thick, as shown in Fig. 7. A high-frequency, voltage-sensitive device connected between the top and bottom inner surfaces of the guide measures a high voltage; but the same device connected to the outer top and bottom surfaces, and nowhere linking the fields inside, indicates nothing. This may surprise those accustomed to thinking of a conductor as being an equipotential surface as in electrostatics and low-frequency circuits. It is readily understood, however, on considering that the fields and currents penetrate only slightly into the metal; consequently the exterior of the guide is completely free of fields or currents, although the distance from the inner surface carrying the currents is only a small fraction of a wavelength length.

Finite Field Propagation Times

Power engineers, except those dealing with long transmission lines, are accustomed to thinking of the changes in fields and currents as occurring simultaneously with the motivating causes. At low frequencies the rates of changes are slow enough compared with the rapid propagation of electromag-

*The principles of resonant-cavity devices, such as magnetrons and klystrons will be discussed in articles in later issues of the *Westinghouse ENGINEER*.

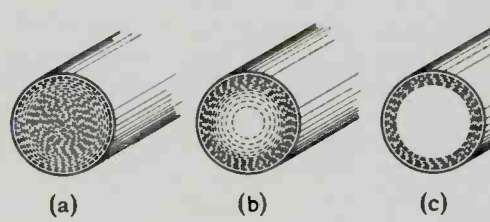


Fig. 6—As frequency increases, current distribution ceases to be uniform. The condition in (a) represents the direct-current condition. As frequency rises further current crowds to the surface, (b), until at high frequencies, (c), the current is confined to the outer layers of the conductor, and finally to the surface itself. The conductor can be hollow.

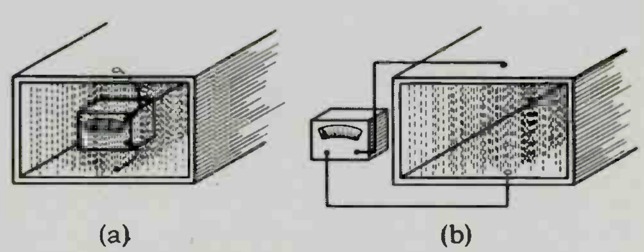


Fig. 7—An instrument connected to the inner surface of an energized waveguide would show a potential as in (a). If the connections were made to the outer surface the instrument would not indicate the presence of any magnetic flux.

netic effects (the speed of light) that the effect can usually be assumed to appear simultaneously with the cause. The speed of light, while fast, is not infinite. Hence at ultra-high or hyper-frequencies the rates of change are so high that the finite speed of propagation cannot be ignored. Difficulties are encountered because of the difference in phase between various parts of the equipment.

One effect is the production of standing waves by any reflections in the system as shown in Fig. 8. This becomes a problem of major proportions in the microwave region. For example, a standing wave introduces abnormally high voltages at the maximum points for a given power level in the system, thereby limiting the maximum power that can be used without dielectric breakdown. As a consequence the art of "matching"—i.e., design of ultra-high-frequency components free of standing waves—is one of the principal problems in systems operating at frequencies above, say, 300 mc. It requires consideration even at power frequencies where power lines hundreds of miles long are encountered.

Another aspect of the matching problem, important in the microwave spectrum, arises from the fact that any reflections introduced into the equipment vary in phase and magnitude as the frequency is changed. Because it is often necessary to use a given system over a range of frequencies, rather than at a specific predetermined frequency, an arrangement must be achieved that yields a matched condition over the required frequency range. This can be done by introducing elements that produce compensating changes of reflection as the frequency is changed. The procedure, known as "broad banding," is much used in the microwave art.

The criterion for the circuit size attained before these propagation times become important is not an absolute one, but merely that the physical dimensions be large compared with the wavelength at the frequencies involved. Thus, whenever the wavelength becomes as short as a few centimeters, problems similar to those just discussed with components of practical dimensions are encountered.

A related difficulty at ultra- and super-high frequencies is experienced in the design of electronic-tube components for use as oscillators, amplifiers, switches, etc. This relates to the time required for electrons to move from the cathode to other tube elements (transit time), which becomes appreciable relative to the period of oscillation. The same is true for the time required for changes in the field produced by the grid to propagate to the space-charge region near the cathode and produce a change in plate current.

For a simple calculation, assume the plate voltage to be 100. This corresponds to an electron velocity of approximately 6×10^8 cm (3750 miles) per sec.* If the electrode spacing is 1 cm then the transit time is 1.6×10^{-9} sec. or nearly two thousandths of a microsecond. This is equal to the time of one cycle of a 625-mc wave. Even the time needed for a change in field strength at the grid to be propagated to the space charge around the cathode is about a thousandth of a microsecond (10^{-9} sec.). These difficulties can be overcome only by some scheme that adjusts the distances and voltages in the tube to give a synchronization with oscillations occurring at some predetermined fraction of a period later, as in the so-called transit-time oscillators.

This transit time or the time required for an electron to move a given distance under the influence of a potential difference is of no concern at power frequencies. Engineers dealing even with long-wave radio devices are not much concerned by it. But at still higher frequencies it becomes a nuisance to be avoided and finally in the microwave region it can actually be put to good use as the basis of a generator of hyper-frequencies. In the klystron, for example, a drift space between two resonant cavities allows bunching of the electrons. That bunching occurs can be seen by the fact that those electrons passing through the cavity when the voltage is in such a direction as to slow them down, enter the drift space at relatively low velocity. Those entering a half cycle later are accelerated and overtake the slow group if the drift space is long enough. There is a series of drift lengths for a given frequency of the oscillating field in the buncher cavity that give optimum bunching of the electrons in the beam. This bunched beam consisting as it does of uniformly spaced clouds of moving electrons in turn induces oscillations in the catcher cavity. By external high-frequency coupling between the two cavities a regenerative action is obtained and the tube operates as a self-excited oscillator to convert direct current into ultra-high-frequency energy, the frequency being determined mostly by the resonant frequency of the buncher and catcher cavities. This action is indicated in Fig. 9.

Propagation

The propagation of the ultra- and super-high electromagnetic waves in our atmosphere and their reflection from solid bodies are significant. In contrast to the frequencies used in broadcasting where the waves are made to follow the curvature of the earth by reflection or refraction from the layers of ionized air known as the Heaviside layer, these very short radio waves (one meter or less) are propagated in straight lines as is light. In fact, these electrically generated waves can penetrate the Heaviside layers as does light. Because of this property Signal Corps scientists were recently able to project microwaves at the moon and receive a reflected signal some two and one half seconds later. The importance of this characteristic becomes evident when considering the problems of radio control for rockets designed to pass beyond the earth's atmosphere before returning.

Variation of Electromagnetic Radiation with Frequency

To help make these quantities more concrete consider how the properties of electromagnetic radiation and certain types of equipment vary as the frequency is continuously varied from power to hyper-frequencies.

At power frequencies the wavelength is so long and the circuit energy required to produce electromagnetic radiation so large that these frequencies are not usable for radio communication. This condition persists until frequencies of 15 kc or greater are reached. Up to this region, circuit elements of resistance, inductance, and capacitance are well defined. At power frequencies, inductances are large coils usually wound on iron cores to increase the flux and keep the size as small as possible, for many turns of wire are necessary to get usable inductive effects. Condensers are also large in physical size and are filled with dielectric material to obtain the large capacitances required. Resistances can be made without many precautions and still be free of inductive- and distributed-capacity effects. Transmission lines can be single-wire, ground-return systems or two-wire systems unshielded and widely spaced without loss of energy by induction or electromagnetic radiation.

At frequencies beginning about 15 kc, appreciable electro-

*The speed attained by an electron accelerated by a potential difference of V volts is $v=\sqrt{2eV/m}$ where e is the charge on the electron (in electrostatic units), m is the electron mass (8.99×10^{-28} grams) and the velocity v is in centimeters per second. V the potential difference is also in electrostatic units. (This is the non-relativistic expression and is good if v is small compared with the velocity of light.)

magnetic energy can be radiated from antenna systems although they must be large and the power high. The wavelengths are very long, say 10 000 meters, and the radiations follow the curvature of the earth because they are essentially guided between the ground surface and the Heaviside layer. Inductors, capacitors, and resistors are still well defined. However, inductors of reasonable size can now be made without iron, air dielectric condensers can be used and resistors must be specially wound to eliminate inductive effects and distributed capacitance. Single-wire or parallel-wire transmission lines are practical because they can still be short or closely spaced compared with a wavelength.

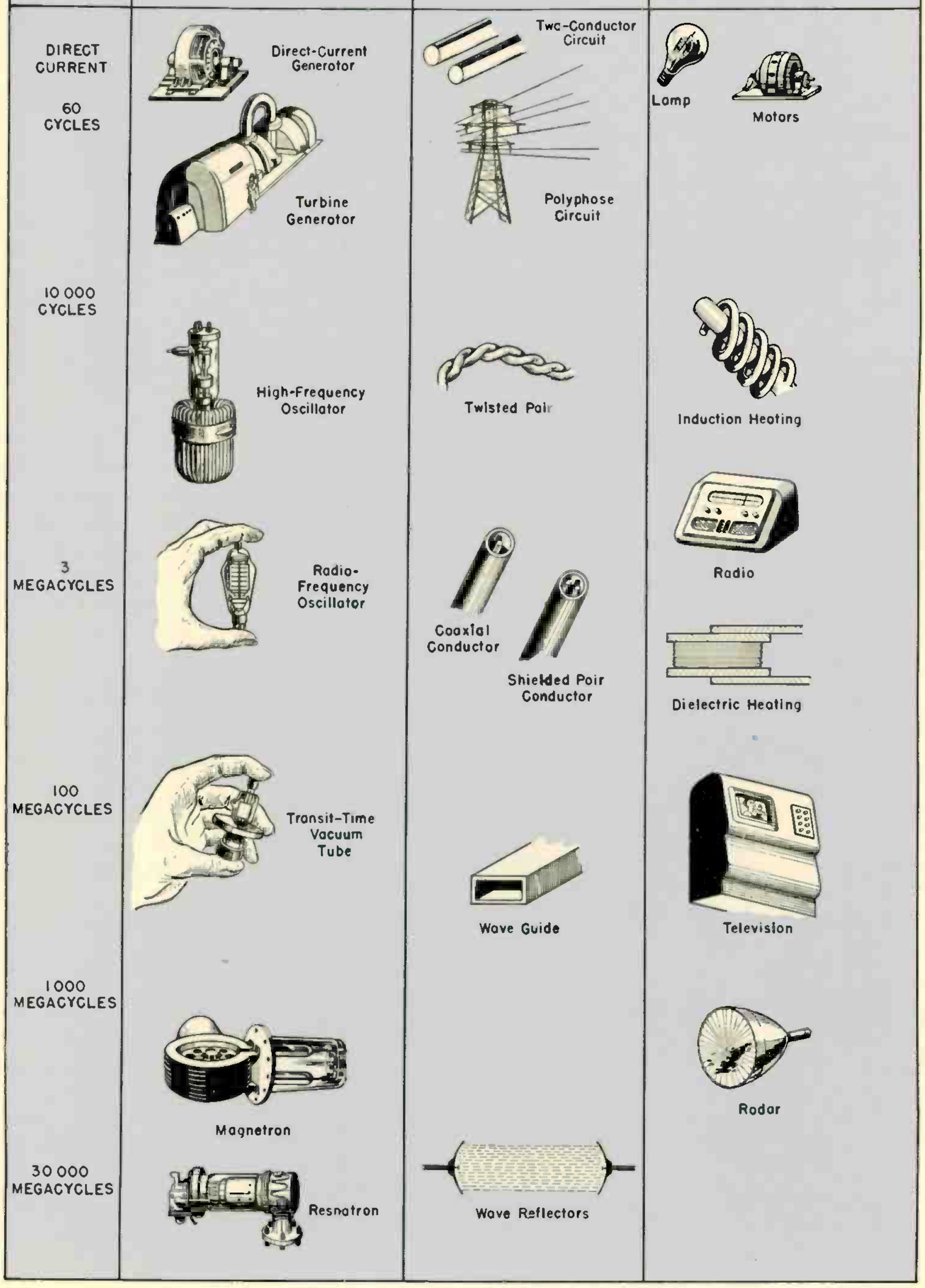
These conditions continue to frequencies of about 3 mc or wavelengths of 100 meters. As the frequencies approach the high end of this region, the range of the ground wave becomes smaller because it is not as well confined by the earth-Heaviside layer system. Fading effects are produced by reflection at the Heaviside layer and interference effects between the ground and reflected-wave systems. Circuit elements are still fairly well defined but are much smaller, and considerable care must be taken with orientation of parts and shielding to prevent interaction of the electric and magnetic fields from these different elements. Carbon-rod or strip-type resistors replace wire-wound types while twisted-pair transmission lines are significantly better than single- or parallel-wire types.

Between 3 and 100 mc, propagation is characterized by multiple-layer characteristics of the Heaviside layer and its daily and seasonal variations that give the familiar skip distance effects and wide variation of efficiency of high-frequency, long-distance radio communication with the time of day and season of the year. At about 100 mc, propagation is almost completely line of sight as is light. Inductance coils have become only a few turns, thimble size and self-supporting. Condensers are midget size and of special design to minimize dielectric losses. Resistors are made as small as possible. Shielding, shortness of leads and orientation of components become of crucial importance. Shielded twisted-pair or shielded twin-conductor transmission lines are necessary.

From 100 to about 1000 mc, propagation characteristics are strictly line of sight, as is also true for the remainder of radio-frequency spectrum. Because the wavelength in this region is from 3 meters to 30 cm, these waves can be more and more easily collimated into well-defined beams by antenna structures of reasonable size. For this reason the high-frequency end of this region becomes useful for radar, particularly long-range ground and ship installations. Resonant-circuit elements can no longer be made from inductance coils and condenser but transmission-line sections of the two-wire or coaxial-line type and special integrated units containing both capacitance and inductance are used. Transmission lines are almost exclusively coaxial lines.

In the 1000- to 30 000-mc portion of the spectrum, which is the microwave region (wavelengths from 30 to 1 cm), capacitance, inductance, and resistance are no longer separate entities, and resonant circuits are either portions of coaxial transmission lines or resonant cavities. All components from oscillators to the antennas must be completely self-shielding. Coaxial transmission lines and waveguides are the only useful transmission lines. Above 6000 mc only waveguides are used.

TABLE 2—SYMBOLIC REPRESENTATION OF THE GENERATORS, TRANSMISSION CIRCUITS, AND UTILIZATION DEVICES OF THE FREQUENCY SPECTRUM



FREQUENCY	GENERATORS	TRANSMITTERS	RECEIVERS
DIRECT CURRENT	Direct-Current Generator	Two-Conductor Circuit	Lamp; Motors
60 CYCLES	Turbine Generator	Polyphase Circuit	
10 000 CYCLES	High-Frequency Oscillator	Twisted Pair	Induction Heating
3 MEGACYCLES	Radio-Frequency Oscillator	Coaxial Conductor; Shielded Pair Conductor	Radio; Dielectric Heating
100 MEGACYCLES	Transit-Time Vacuum Tube	Wave Guide	Television
1000 MEGACYCLES	Magnetron		Radar
30 000 MEGACYCLES	Resnatron	Wave Reflectors	

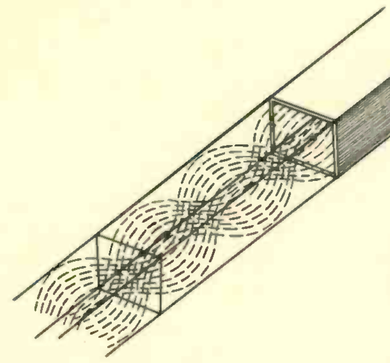


Fig. 8—A representation of standing waves as in a waveguide.

This whole region is characterized by antennas that more and more resemble optical searchlight and telescope systems of the reflecting type. These usually take the form of dipoles and parabolic reflectors variously arranged. Throughout most of this region ordinary electronic tubes cannot be used as detectors. Crystal detectors, either natural or synthetic, are employed.

The frequencies above 30 000 mc are being explored. Present techniques in this region are similar to those just described, but the components, such as oscillators, resonant cavities, etc., are getting very small and power levels necessarily lower than in the fairly well developed microwave region from 100 to 30 000 mc. A waveguide is only a few millimeters in diameter and attenuation per unit length is greatly increased, being proportional to the square root of the frequency. Because of this difficulty, developments in these transmission lines may incorporate series of pairs of parabolic antennas with most of the transmission path through empty space in the form of accurately collimated beams.

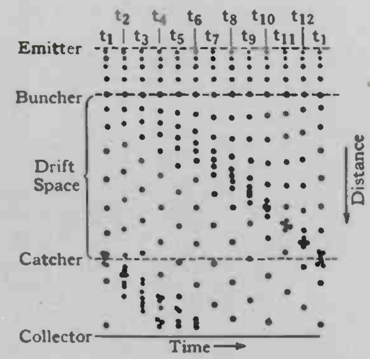


Fig. 9—In the klystron-type, high-frequency generator the electrons are emitted from the cathode at a constant rate but due to the action of fields are bunched and subsequently caught, constituting a current of extremely high frequency.

The microwave region has been brought into practical use almost entirely since the beginning of the war with most of the emphasis on military applications. If one considers bands of 10 kc per channel this new region has added 3 000 000 channels to the radio spectrum. The whole spectrum previously available below 1000 mc would accommodate only 100 000 such channels. The importance of this thirtyfold advance is therefore immediately evident.

In addition to the more obvious applications of these new super-frequency techniques to radar, relaying, television, stratovision, etc., it is worth noting that these methods have many interesting possible applications to scientific research. For example, the study of electrical discharges in gases by excitation with these super-frequencies offers promise because electrode materials play a relatively unimportant role in these discharges. Thus the true properties of gas discharges can be studied without being influenced by effects arising out of the specific electrodes used.

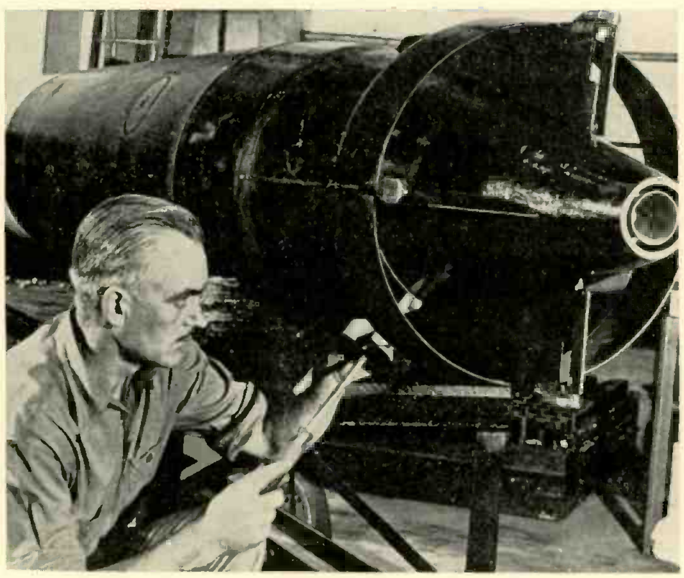
Also the absorption spectra of molecules that occur in these frequency regions can be studied with much higher frequency resolution and much greater convenience than by the older infrared techniques, thus providing a new instrument for examination of the structure of molecules.

Methods have been recently described for using microwave techniques to measure the magnetic moments of nuclei. These magnetic moments are important in the study of the structure of atomic nuclei.

Because the periods of super-frequency oscillations are so very small—tenths of thousandths of microseconds in fact—these techniques will be increasingly used as time references for phenomena that are extremely brief, such as sparks, electrical transients, etc. Similarly these oscillations can be used as time markers to measure the velocities of rapidly moving atomic and nuclear particles.

It is apparent that advances in this field during the war telescoped into a few years extensions of the radio-frequency spectrum not equalled in decades previously and that these advances offer much promise for the future.

Rockets Take to the Water



A new formidable weapon combining the driving force of rocket propulsion with the destructive effects of a torpedo was being made ready for the enemy when the war suddenly terminated. This new weapon, launched from the air but speeding to its target under water, is called a hydro-bomb. In external appearance the hydro-bomb resembles a torpedo but is slightly shorter and is two inches greater in diameter. It carries 600 pounds of high explosives and is propelled through the water by the rocket motor. The bomb is dropped from the plane at about 300 miles per hour. The impact on striking the water closes the switch that ignites the rocket motor's solid fuel. Gyroscopic control keeps the bomb on its intended path and electric controls regulate its depth under water. The 2300-pound bomb is normally dropped from a point about 600 feet above the water although on test it has been dropped as much as 2000 feet without the shock damaging the gyroscopic and electrical controls. The rocket motor, supplied by oxygen and solid fuel contained within the bomb, develops a thrust of 1000 pounds, sufficient to propel the bomb under water at 40 knots.

STORIES OF RESEARCH

A New Magnetic Gradiometer

The saturable core reactor has graduated with honors. Long associated principally with theater lighting controls, these reactors now have the whole world as their stage. For they are the key parts of devices measuring steady magnetic fields, such as magnetometers for measuring the earth's field and compasses for indicating direction and bearing. An improved type of apparatus for measuring magnetic field gradients (rate of change of field in space) has been developed by Mr. W. J. Carr of the Westinghouse Research Laboratories. Known as a gradiometer, it is based on the saturable-reactor principle.

The reactors in the gradiometer consist of two identical cylindrical coils connected in series and excited by an oscillator. The core in each coil is a narrow strip of ultra-thin, high-permeability alloy. About each existing coil is wound a secondary winding. These secondary windings are used to measure the voltage across the coil and are connected in voltage opposition so that normally the output voltage is zero. If, however, the coils are placed at separate positions in a magnetic field, the field along the axis of each coil will influence its induction, and the a-c output voltage will be a measure of the difference in the field between the coil positions.

If the coils are placed parallel to each other, this difference is dependent upon and is a measure of the gradient in the field. A gradiometer of this type can be made to detect differences of appreciably better than one one-thousandth of a gauss in the earth's field. (The horizontal component of the earth's magnetic field in Pittsburgh is about two tenths of a gauss.)

The critical problem in making the gradiometer is the construction of two coils and cores identical enough to avoid spurious responses resulting from any unbalance in their electrical characteristics. This problem of balance in the circuit components is greatly simplified by using a tuned circuit in the output of the apparatus. By this means, all but one particular even harmonic voltage is rejected, while the weaker spurious responses are by-passed.

Phase control of the currents in the secondary windings of the reactors produces a regenerative effect similar to that secured in feeding a portion of the output back into the input of a vacuum tube. As in a vacuum-tube circuit, the sensitivity of the gradiometer is increased by this regeneration. Should a further increase of output be desired, the gradiometer output voltage can be fed into an amplifier.

The gradiometer was developed for a wartime use. It should have peacetime application possibilities in the field of geophysics after its development has reached a manufacturing and commercial stage.

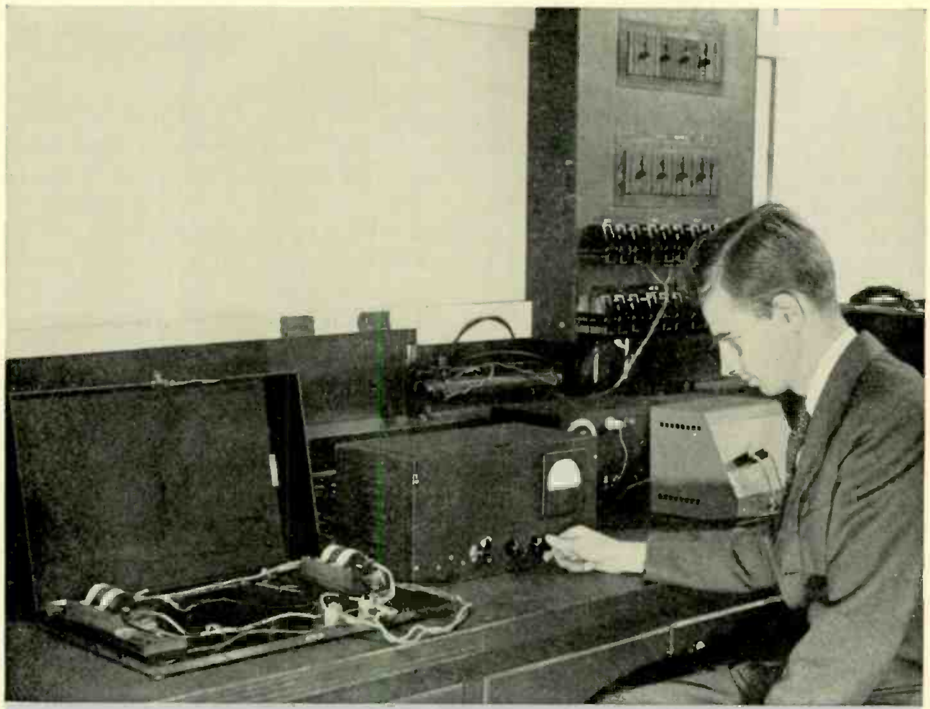
Bearing Down on Stability

The problem of oil-whip has always been a headache to those who design and work with rotating electrical and mechanical equipment, especially of the high-speed variety. Oil-whip begins with a slight deflection of the journal from its normal running position—it may be only a few millionths of an inch. This vibration is sustained and aggravated by pressures within the oil film until eventually both shaft and bearings may be damaged. It has been controlled in many cases with success, but as the speeds of motors, turbines, and the like, mount, so do the dangers connected with oil-whip.

Now, out of fundamental research on vibration and stability in ultra-high-speed rotating machinery, has come a somewhat surprising answer to the problem. For A. C. Hagg of the Westinghouse Research Laboratories has demonstrated that the well-known Michell tilting-pad bearing, long recognized and used as a thrust bearing, is a completely stable, non-whirling journal bearing. In fact, Hagg believes that this bearing, and related types, are probably the only oil-film journal bearings that are incapable of exciting oil-whip, regardless of the system to which they are attached.

Approaching the problem both mathematically and experimentally, Hagg discovered that the Michell bearing achieves stability because the pressures created in the oil-film as the journal whirls in the bearing are unable to do any work on the journal; hence, no vibration results. In all other types of journal bearings, on the other hand, these pressures may go to work on the journal, causing it to whirl or wobble at a frequency that Hagg found to be invariably less than half the rotational frequency of the rotor. The peculiar immunity of the Michell bearing is due to the fact that the forces in the oil-film always act in a fixed direction, governed by a point about which the pads tilt; consequently net work done on the journal is always zero. In other types of bearings, however, the forces swing around with the journal in a circular path, always doing work on it and increasing the amplitude of the vibration until it may do definite damage to the shaft and bearings.

Hagg's discovery makes the tilting-pad bearing very promising in application to such high-speed rotating machinery as turbines and rayon-spinning motors.



The two reactors comprising the magnetic gradiometer are mounted on Micarta bases at the left. Mr. W. J. Carr is here measuring the gradient of the earth's field.

A Package Steam Plant for Laboratories

Small editions of even the largest and heaviest electrical apparatus are readily available that demonstrate full well the principles involved. Mechanical engineering, particularly steam-plant practice, has not generally been so favored. This stands to be changed by a new steam power plant created especially with regard to laboratory needs: compactness, small size, variety of operation of two sets of turbines and generators, but with maximum accessibility for observation of the operation of each component and for test of its performance.

F. K. Fischer
Steam Division

W. R. Harris
Industry Engineering Department
Westinghouse Electric Corporation

The theory and practice of steam power plants can be taught to young engineers with greater ease by a new steam-laboratory equipment of novel design. The equipment, while full scale but small size, is constructed with special reference to the needs of college laboratories where compactness must be accompanied by ease of studying and measuring each basic element of the power plant.* The principal objectives were to enable the student to acquire a knowledge of (a) the operation of power plants, (b) the arrangement of the basic elements that make up a steam turbine-electric power plant, (c) the ways in which steam turbines are applied to the problems of industry, and (d) the accepted test procedures under actual operating conditions in both central-station and factory power plants.

The main elements of the laboratory comprise two independent turbine-generator units, arranged for easy accessibility and test of each basic part, as well as for operation as a unit plant. A representative arrangement of elements and piping is shown in Fig. 1. By simple manipulation of steam valves and electrical connections, the entire gamut of steam-turbine power-plant cycles can be simulated.

Each turbine is a single-stage, two-row, velocity compound impulse unit flexibly coupled to a three-phase, 60-cycle, 220-volt generator operating at 3600 rpm and rated at 25 kw, 80-percent power factor, 31.25 kva. The turbines can be operated condensing or non-condensing at a maximum back pressure of 50 pounds per square inch gauge. In addition to a speed governor and speed changer on each unit, the No. 1 turbine has a back-pressure governor and the No. 2 turbine has an inlet-pressure governor. While the No. 1 turbine is arranged to operate as a high-pressure unit only, the No. 2 turbine is specially nozzled to operate either as a high-pressure turbine taking steam directly from the high-pressure header, or as a low-pressure turbine receiving its steam from the No. 1 turbine exhaust. Each unit is arranged with two hand valves, and a wide selection of the number of nozzles under governor control is possible. Therefore, the effect of multi-valve turbine operation, such as is used on all large turbines, compared to the effect of single-valve throttling control on the efficiency and performance of the power plant can be studied.

When the units are operated in series, the equivalent of a multi-stage turbine is obtained. From the connection between the two turbines, steam can be extracted automatically or non-automatically at an intermediate pressure, or it can be inducted. If so desired, the steam can first be passed through a reheater before entering the inlet of the low-pressure turbine.

The governors are arranged so that the overall regulation of each of the units can be adjusted. With the two machines operating in parallel, load division as effected by turbine regulation can be studied for equal regulation as well as for widely different regulation of the two. Hand speed changers on the governors permit operation over a range of speed. The student can study the functioning of the governor with changing load and speed-changer setting, and can transfer load from one unit to the other, as well as control the speed for synchronizing when starting a unit and placing it in normal operation.

The schematic diagram of equipment and connecting piping, Fig. 2, illustrates the great flexibility of operation possible with the laboratory. One surface condenser is used for the two turbines. Simulating power-plant practice, an atmospheric relief valve is included as an operating precaution. The single-stage air ejector is mounted on an after condenser using raw water as the cooling medium. The after-condenser condensate is normally flashed to the surface condenser through a drain trap and during tests it can be separately measured. To permit determination of the suction head on the condensate pump a gauge glass is mounted on the condenser hot well. The condensate pump, a single-stage unit, operates at 3550 rpm. It develops a head of 168 feet at 5 gallons per minute with 16 inches submergence. This relatively high head is required to keep the feed water from flashing in the feed-water heater.

The feed-water heater is a single-stage unit with means for cooling the water in the heater drains before returning it to the surface condenser. To permit accurate determination of the quantity of feed water, means are provided to reduce its temperature so that vaporization losses are small.

The effect of air leakage on condenser performance and the dependence of the condenser vacuum on air-removal capacity of the air ejector can be demonstrated and made the basis of considerable special testing. The condenser and the feed-water heater, in addition to their use in regenerative feed-water heating operation and test, offer a wide variety of possibilities in liquid heat transfer and condensation studies.

In the operation of the units under various arrangements, table I, the proper use and functioning of control elements as well as basic principles in their application can be demonstrated. Nine basic types of steam-turbine applications to power plants are illustrated, together with five modifications making a total of 14 different operating arrangements possible.

Arrangements *A* and *C* of table I can be used to show that a non-condensing unit on back-pressure control must have its generator tied electrically to a system or unit governed to

*Much credit for the suitability of the power plant to college laboratories is due Professor R. B. Rice of North Carolina State University, who collaborated in its conception and execution.

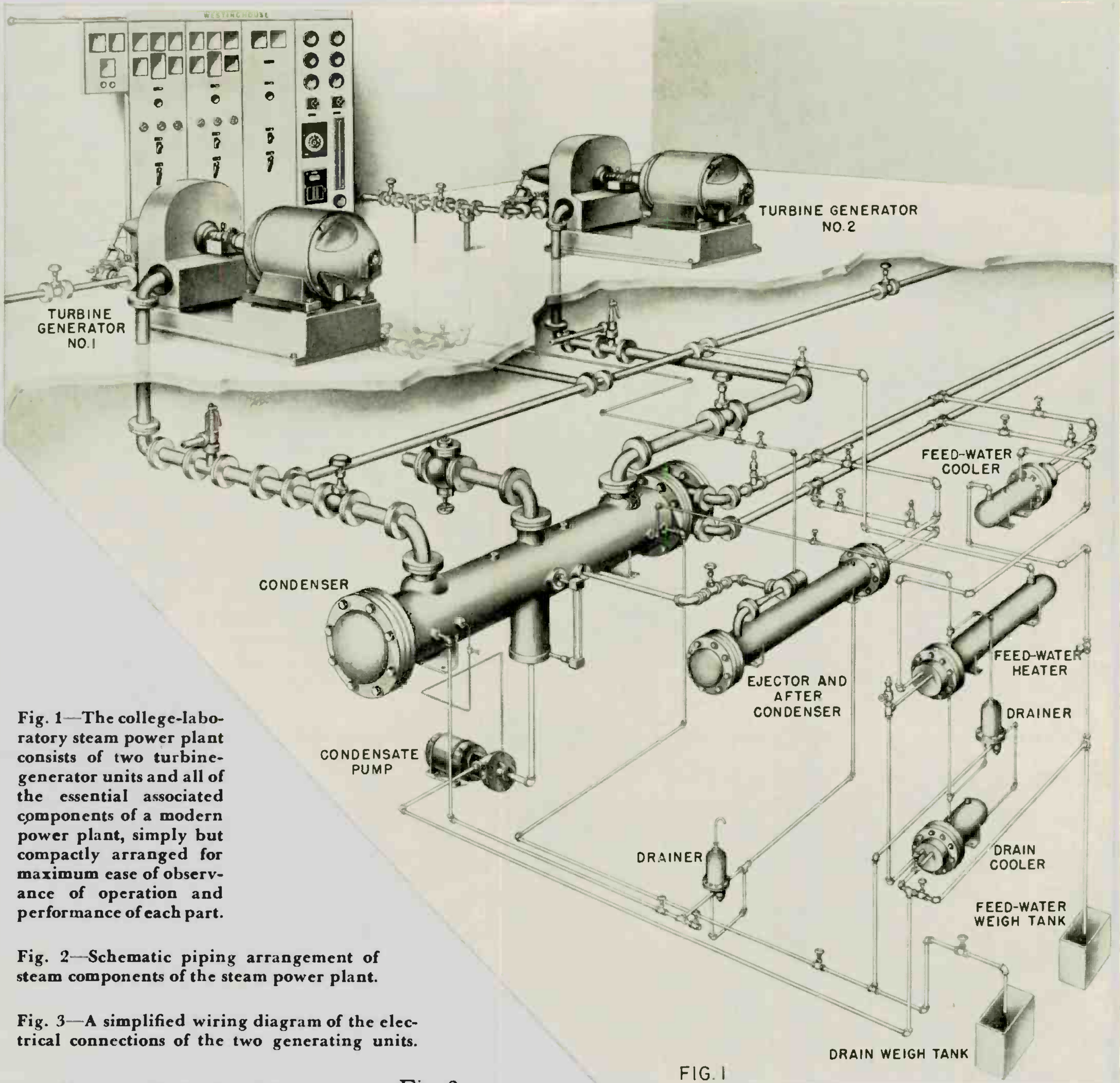


FIG. 1

Fig. 1—The college-laboratory steam power plant consists of two turbine-generator units and all of the essential associated components of a modern power plant, simply but compactly arranged for maximum ease of observance of operation and performance of each part.

Fig. 2—Schematic piping arrangement of steam components of the steam power plant.

Fig. 3—A simplified wiring diagram of the electrical connections of the two generating units.

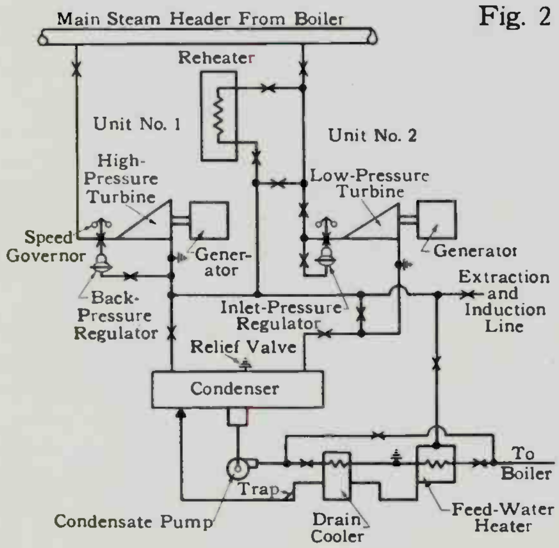


Fig. 2

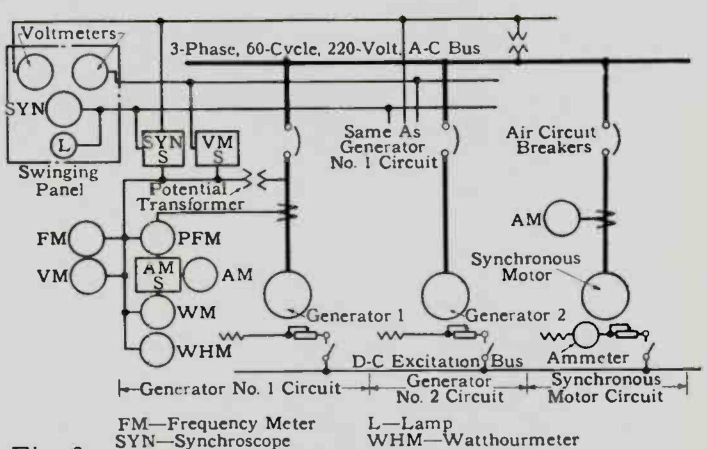
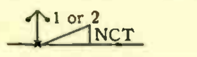
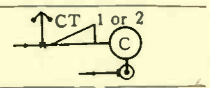
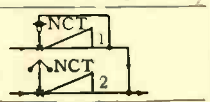
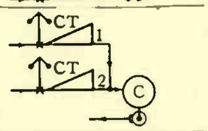
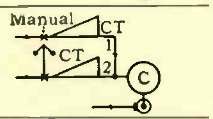
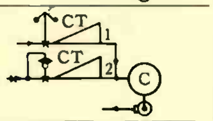
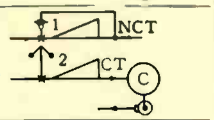
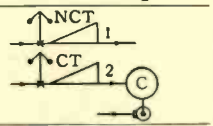
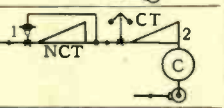
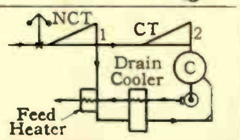
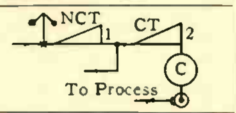
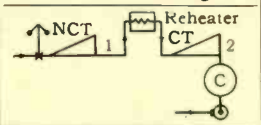
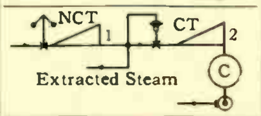
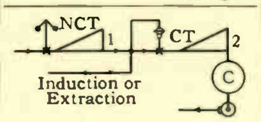


Fig. 3

maintain unit speed and system frequency. Arrangements *E*, *F*, and *I* introduce the problems of multiple-control elements, in which, for example, the action of the pressure regulator in maintaining the desired pressure makes it necessary for the speed governor to act to maintain the desired speed and load. These 14 different arrangements of 9 basic turbine combinations run the gamut of central-station and industrial practice of steam-turbine and electric-generator operation.

TABLE I—PRINCIPAL VARIANTS POSSIBLE WITH THE LABORATORY POWER PLANT

Arrangement Number		Turbine Application	Control Arrangement	Generator Arrangement
A		Non-condensing unit operating alone	Speed-governor control	Generator not electrically tied to another generating unit
B		Condensing unit operating alone	Speed-governor control	Generator not electrically tied to another generating unit
C		Two non-condensing turbines	No. 1 unit on back pressure control and No. 2 unit on speed governor	Generators electrically tied together
D		Two condensing turbines	Both units on speed governor	Generators separate or electrically tied together
D-1		Base-load operation, two condensing turbines	One unit base loaded by manual control, other unit on speed governor	Generators electrically tied together
D-2		Inlet-pressure control, waste-heat boiler application, two condensing turbines	No. 2 unit on inlet pressure control, No. 1 unit on speed governor	Generators electrically tied together
E		Two units. One condensing and one non-condensing	No. 1 unit on back-pressure control. No. 2 unit on speed governor control	Generators electrically tied together
E-1		Two units. One condensing and one non-condensing	Both units on speed governor control	Generators separate or electrically tied together
F		Superposed or topping application. Two turbines in series. No. 2 unit representing the topped turbine.	No. 1 unit on back pressure control with No. 2 unit on speed governor	Generators electrically tied together
G		Regenerative feed-water heating. Two turbines in series. Operation simulates multi-stage turbine.	No. 1 unit on speed governor. No. 2 unit operating with valves open	Generators electrically tied together
G-1		Non-automatic extraction. Two turbines in series. With or without feed-water heating. Extraction pressure function of load on low-pressure unit.	No. 1 unit on speed governor. No. 2 unit operating with control valves open	Generators electrically tied together
H		Reheat cycle. Two turbines in series. With or without feed-water heating.	No. 1 unit on speed governor. Control valve wide open on No. 2 unit	Generators electrically tied together
I		Automatic extraction. Two turbines in series.	No. 1 unit on speed governor control, No. 2 unit on inlet pressure control to maintain desired extraction pressure	Generators electrically tied together
I-1		Mixed pressure induction or automatic extraction. Two turbines in series.	Same as No. I above, except steam inducted when process steam pressure exceeds automatic extraction pressure	Generators electrically tied together

Electrical Equipment

The electrical equipment consists of duplicate generators, either a 60-hp, 80-percent power factor, synchronous motor, or a resistor bank for loading the generators, and a complete set of switchgear. The equipment simulates the apparatus and protective devices found in any modern central-station or industrial power plant but is simplified to provide ease of operation and arranged for clear demonstration of the various operations.

A synchronous motor or resistor bank can be used for loading. The motor method is advantageous because the power factor as well as the magnitude of the load can be varied. Power-factor variation is obtained by rheostatic control of motor field strength and can be adjusted from leading to lagging within the equipment rating. The motor can be connected to a water brake or other suitable means for absorbing its power output.

While not as flexible from the electrical standpoint, a resistor bank forms an adequate means of loading and has the advantage of greater simplicity of apparatus and operation.

The dead-front switchboard, shown in Fig. 1, provides complete instrumentation and control for the electrical system. It consists of a swinging panel for synchronizing instruments, an individual panel for each generator, and a panel for the synchronous motor or resistor bank. The details of control and instrumentation for synchronous motor loading are shown on the single-line diagram of Fig. 3.

Mounted with the electrical switchgear is a gauge and instrument panel for indicating the various steam conditions. An initial steam-pressure gauge, a nozzle-chamber pressure gauge, an exhaust steam pressure gauge, and a pressure governor regulator are provided for each turbine. Space is available for mounting additional devices such as manometers, indicating or recording pyrometers, and such flowmeters as desired.

Apart from its use with the steam apparatus, the electrical equipment is suitable for demonstration and study of many electrical principles. These include standard tests such as reactive-kva distribution and voltage control for parallel operation, synchronizing, and short circuit. In addition the equipment is particularly suited to special tests such as synchronous starting of various combinations of the generators and motor, and study of the problems of starting a motor at rated voltage and frequency where the motor size is large in relation to system capacity. Problems of this type frequently arise in industry and often require thorough and precise evaluation of the factors involved in reaching a workable solution.

The complete steam-plant laboratory has been carefully coordinated to provide the utmost in flexibility and adaptability for laboratory use. Although full-scale equipment is used, it meets the most important criteria for college-engineering laboratory apparatus—economy of space and power without sacrifice of basic characteristics.

George Westinghouse—
His Contribution to Tomorrow

FEW men have been credited with as many inventions as George Westinghouse. Three hundred sixty patents are listed in his name. He was not only prolific of new ideas but also extremely versatile in his interests. Electric-power generation, distribution, and utilization, ship propulsion, railroad operation, natural-gas development, gas engines are but some of the seemingly unrelated fields that reaped the harvest of his inventiveness and business skills.

Although his life was noteworthy for both the number and variety of his engineering contributions, two basic skills stand out as common to them all. First, and rarest, was the ability to see the existing boundaries of the various phases of industry that drew his attention. In each he could see the obstacles or limitations to growth. And, then, having brought the horizons into focus, he proceeded with vigor to find and develop means for their enlargement. These two qualities in essence outline the scope of all science and engineering. Inventive skill is important, of course, but vision must come first.

The inventions of George Westinghouse laid the foundations for new industries, expanded the scope of others. But his greatest contribution, and one on which no patent is possible or desired, is his pattern for all men of science and engineering: *the ability to visualize and define the horizons of man's technical skills and machines and to conceive and develop means for extending those boundaries.*

These vital, dual qualities are admirably displayed in nearly all of Westinghouse's multifarious inventive activities. But they are clearly demonstrated by the three most spectacular, most diverse of his works: electric-power transmission, ship drive, and the airbrake. Consider the situation that prevailed in each upon his entrance to the scene.

The 1880's had brought the miracle of the electric light. The now famous Pearl Street station in New York and Edison's three-wire direct-current system won merited acclaim as the new means of dispelling darkness and easing man's burdens. Direct-current systems sprang up in the large cities and in many towns. The popularity of the new power was immediate. Direct current was being applied to a multitude of uses—lighting, operation of motors, heating, electroplating, etc. Electricity was already assured a great place in our national economy.

At the turn of the century, people thought that the golden age of shipping had arrived. The reciprocating engine had won complete mastery of the oceans from the more romantic but slower sailing vessels. Blue-ribbon fleets of ocean greyhounds driven by impressive, powerful steam engines carried an increasing flow of traffic between the new and old worlds in two weeks or less. Steam-driven cargo vessels hustled goods from land to land. Fast, reliable shipping and passenger transportation—founded on the steam-engine ship—were welding isolated nations into one economic world.

Rail transportation had become an integral part of our national life by the dawn of Civil War reconstruction. A network of railroad lines had spread over the populous centers of the East and was fast reaching westward to link the coasts. Passengers moved from city to city by fast trains that, while not always on time, were considered highly reliable. Freight moved in large volume at low cost. Our railroads were acclaimed for their high order of service.

The young electric-power system, ocean shipping, and the steam railroads were looked upon as reasonably well-advanced, well-founded industries. Some improvements would undoubtedly be made but they would relate to details of size or speed. The fundamentals were secure, the horizons broad. Growth appeared limitless, as indeed so it seemed also with electric power and with marine transportation.

But, Westinghouse was one man of imagination who thought otherwise. Transmission of the low-voltage electric power more than a mile or two from the generating station resulted in excessive loss. Load center had to be close to generating center. Electric-power systems based on direct current were destined to be local affairs. Regional or national integration of electric power was impossible. George Westinghouse perceived this stifling limitation, and when he received word of the experiments of Gaulard and Gibbs with the alternating-current transformer, he quickly sought detailed information, obtained the rights for the United States,

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Great Men of Electrical Engineering—Presented on the next two pages in graphical form are the names of outstanding men of electrical science and their fundamental contributions. The list is regrettably curtailed by space. Others, perhaps equally as important as those chosen, could be added and different or additional achievements could be cited. It is believed, however, that this graphical presentation (similar to the musical chart prepared by Mr. Otto K. Eitel of the Bismarck Hotel, Chicago) gives a fair sketch of the progress in electrical engineering and the great personages who made it possible.

GREAT MEN OF ELE

1580	1600	1620	1640	1660	1680	1700	1720	1740	1760

GILBERT *Established fundamental properties of magnetic bodies.*

Demonstrated + and — character of electricity; lightning rods. **FRANKLIN**

Important discoveries in electrostatics. **CAVE**

Verified inverse-square law of electrical charges. **COU**

First battery producing steady flow of current.

Demonstrated force between curren

Mathematical theory of electric

Ohm's law for determining current an

Laws of induction of electric currents; first electr

First telegr

Discovered laws of induction; firs

Absolute measurements of current, vo

First sel

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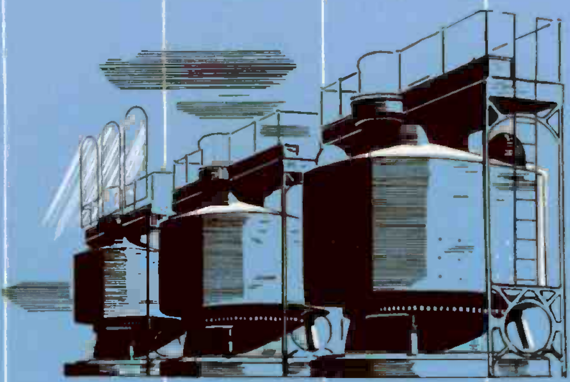
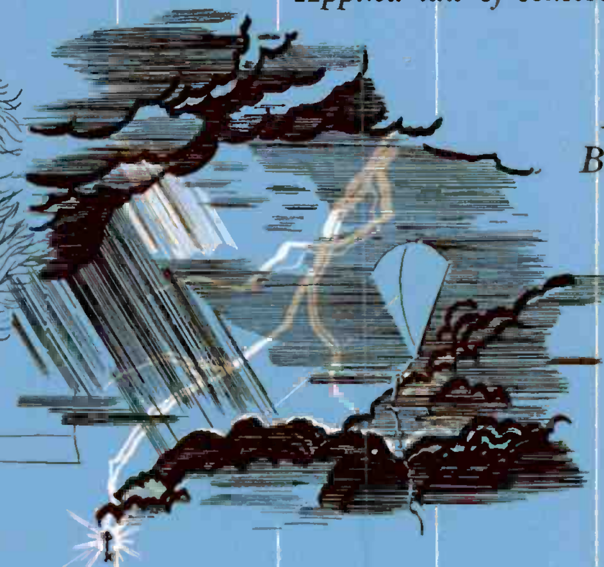


FIRST MAJOR HYDRO-ELECTRIC DEVELOPMENT, NIAGARA FALLS—1896

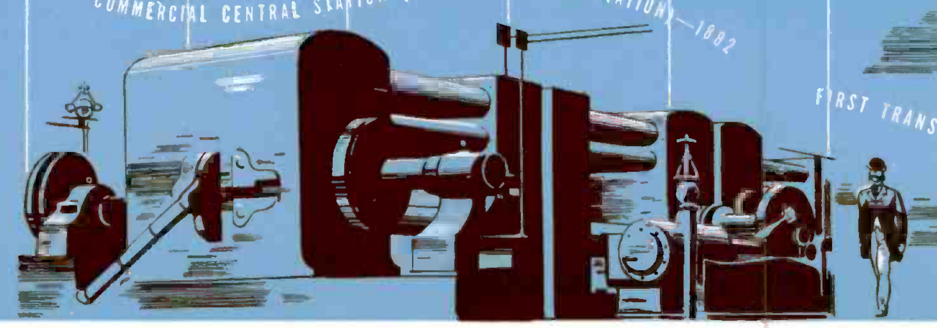
FIRST INSTALLATION OF ALTERNATING CURRENT AT GREAT BARRINGTON, MASS.—1886



THE FIRST RECORDED TELEPHONE CONVERSATION—1876

FRANKLIN AND HIS KITE EXPERIMENT—1752

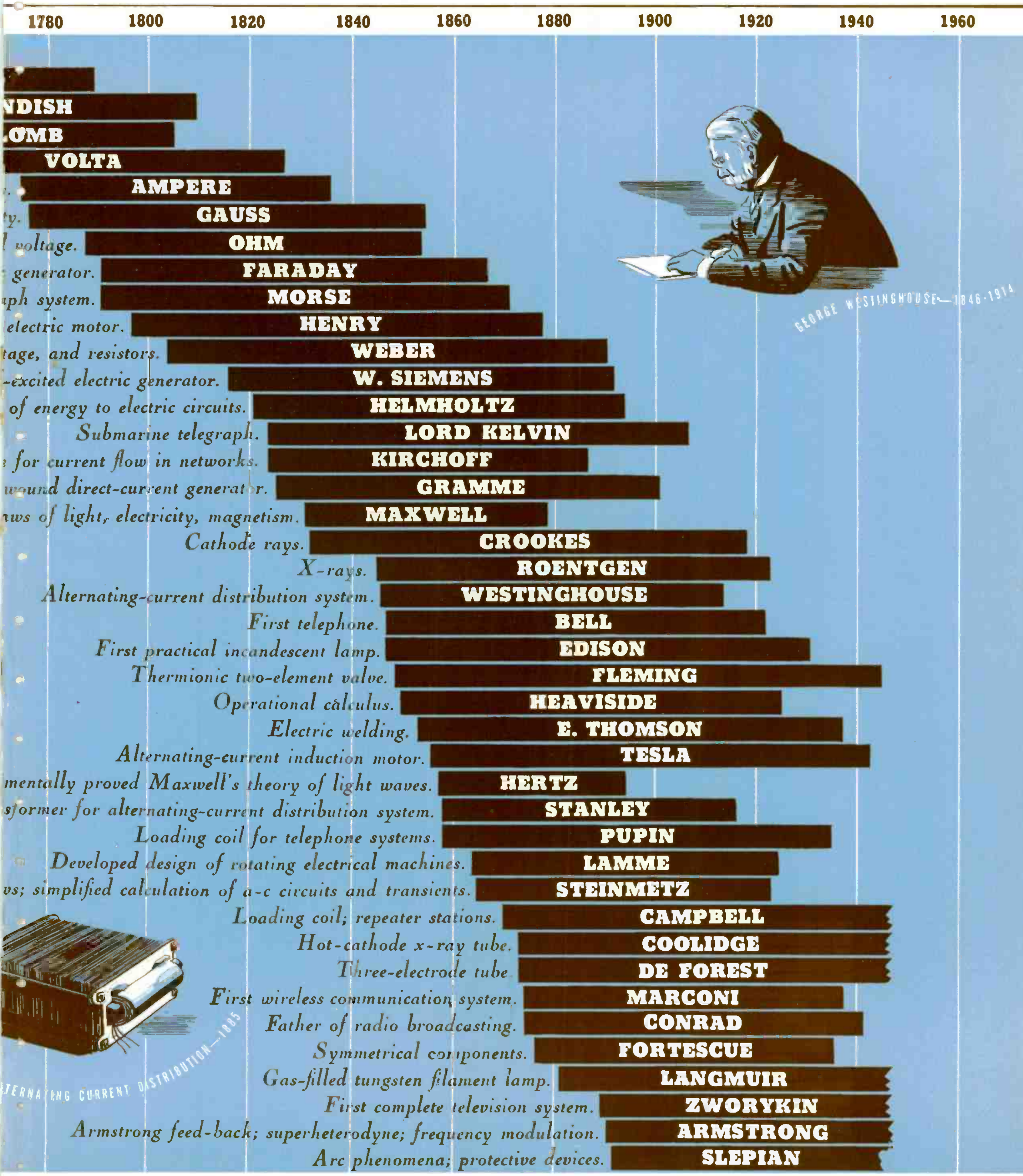
FIRST COMMERCIAL CENTRAL STATION (PEARL ST. EDISON STATION)—1882



FIRST TRANSFORMER FOR

Published by the Westinghou

CTRICAL ENGINEERING



and set his young engineer Stanley to work. The result is well known. Alternating current has increased the horizons of electric power many-fold.

As the nineteenth century gave way to the twentieth it was clear to Westinghouse that steamships—for all our pride in them—had reached their limit. The heavy, slow-speed piston engines, handicapped by the necessity for exhausting to atmosphere, were literally crowding passengers and cargo out of the ships. More powerful engines, demanded for larger, faster vessels, and the enormous bulk of fuel required would leave little room for pay load. Growth in size or speed of vessels had literally met an impasse created by the limitations of the propeller drive.

—first came the realization that train speeds were limited by inadequate brakes. Then came the air brake to free trains from that restriction—

Westinghouse took note of this situation and analyzed the need as for a smaller, lighter, more economical engine. The answer seemed to him to lie in the rotating, high-speed steam turbine, which had been the subject of his boyhood experiments a half century earlier and with which he was experimenting as a drive for electric generators. He had observed the attempts of Parsons of England to use a steam turbine for ship propulsion but it was clear to Westinghouse that a steam-turbine drive for ship propellers was faced with a serious limitation. Turbines must turn fast; propellers, slow. Some speed-changing link was necessary. Westinghouse brought Melville and McAlpine to Pittsburgh to solve this problem. The result was the reduction gear, first and successfully applied in the collier *Neptune*. The steam turbine and reduction gear is now used the world over for large cargo and passenger vessels, both merchant marine and naval.

To young George Westinghouse in the 1860's the railroads were not facing limitless expansion. They seemed cramped, hedged-in by a controlling limitation—the inadequacy of means for stopping trains. Braking of moving trains meant the setting of brakes by hand upon the "down-brakes" whistle by the engineer. Passenger-train speeds were limited by the manual brakes and the crews for operating them. The length, weight, and speed of freight trains had reached an absolute limit. The continuous rise in speed and size of trains had come virtually to a halt at the barrier of inertia. How Westinghouse removed this barrier by invention of the air brake, dramatically proved on the trial run in Pittsburgh by the emergency created when a horse-drawn delivery truck stalled on a crossing, is one of the most thrilling episodes in our industrial history.

The ability to see the boundaries that sharply confine development is the more remarkable when we contemplate how difficult it is even to be aware of ambient limitations. The present stage of technical development always appears good, even marvelous. The radio of today, this year's model automobile seem the acme of design. Few wish for better or think that significant improvement is possible.

The ability to perceive and define technical horizons is fully as important as the second trait that characterized George Westinghouse—the ability to analyze the limitation and to develop a means for its removal. The problem once stated, he searched for a clue to the solution. Finding it—often in unsuspected places (the idea for the air brake came from an article about use of compressed air in digging a tunnel in Italy) he aggressively applied his own engineering skill to its development and freely sought the talent of other engineers as needed.

The three decades since Westinghouse was active have also been rich with examples of similar performance by other men of technology. When he left the industrial scene the telephone was already well developed and wire and radio telegraph seemed to have reached the ultimate range of man's voice and the ability to communicate with rapidity. But the coming of radio broadcasting swept away all physical and geographical restrictions on man's speech or music. Photography and fast transportation had in Westinghouse's day lifted the range of man's vision, enabling him to picture happenings in distant places a few days or weeks after their occurrence. Marvelous! But with television distant events can now be seen as they happen, and, furthermore, they will be seen in natural color. Optical and sonic devices had, before the war, greatly augmented man's natural detection senses. But radar shoves back these puny earth limits to hundreds of miles and at the same time removes the barrier of darkness, fog, or storms. Speed of travel has climbed successive plateaus, each seeming to be virtually an upper limit—and really quite fast enough. Then man found himself against that great barrier—the speed of sound—once held insurmountable. It too has now been pierced and no wise engineer will predict the next upper limit to speed.

The course of the past is clear. What of tomorrow? What limitations unseen, unfelt, that weigh upon us now will be brushed aside by the men of science and engineering, today

— steam-engine propelled ships had reached a barrier of size and speed, recognized by few. The turbine and reduction gear gave rise to a new order of progress in sea-going merchant shipping

and tomorrow? To name them, as said before, is the most difficult part of the task.

An attempt to visualize any *entirely new* human wants or needs is like trying to picture the fourth dimension. However, some new frontiers have been defined and are being aggressively explored. These include prevention and cure of cancer and the common cold, mastery of the secret of photosynthesis, development of means for a new order of speed of human transportation, and exploitation of larger sources of energy of which nuclear fission is the first practical one, and solution of the problems of world-wide distribution of goods. The apparent conflict between technological advances and employment must be resolved. The high rate of loss of the earth's soil, minerals, and flora needs to be cut down.

The more urgent human needs seem to be not so much in fields of technology as in human relations themselves. But perhaps that, too, is an appropriate field for the man of science and engineering. Recent events stemming from the atom-bomb development indicate that in this a bare beginning has been made.

In any case we take comfort in the conspicuous fact that thousands of men skillfully pursue the same goals that beckoned to George Westinghouse: *to perceive our present confines and set about with skill to expand them.*

C. A. Scarlott

Forms and Principles of Servomechanisms

DR. S. W. HERWALD, *Special Products Engineer, Westinghouse Electric Corporation*

SERVOMECHANISM is a term appearing with increasing frequency in the engineering literature. Although the word is not new it confuses many, partly because it is not self-explanatory but more particularly because it applies not to any particular device but to a function. Servomechanisms can be considered a class of automatic regulators whose purpose is to keep a regulated quantity matched to a reference quantity. Usually some distance intervenes between the initiating device and the thing regulated. Moreover, in this matching process some amplification is involved.

The quantities most commonly regulated are the speed, position, or change in rate of speed of some machine. Simple mechanical devices to control liquid in a reservoir by the position of a valve in response to liquid level are servomechanisms. So also are temperature control systems using thermostats to control speed of motors or valves on a heating system or the motor of a refrigerator compressor. Hydraulic governors that control turbine speed to maintain a constant electrical frequency with load, devices to control motor speed on tandem strip mills and paper-making machines so that the moving strips of steel or paper do not become too loose or too tight between mill sections, tracer mechanisms that enable a cutting tool to reproduce the contours of a scale model, a stabilizing device to hold steady the gun of a moving tank, or the mechanism that moves a heavy gun turret around as the gunner sights on the target—these are but a few servomechanisms. Many operate electrically or electronically; others are mechanical, hydraulic, or even gas operated. Sometimes they are used in combination.

Man's muscles ages ago became inadequate for his work. They are even inadequate for controlling his machines. To maintain speed, position, or other behavior of power devices and mechanical systems in accordance with prearranged plan, engineers have conceived many mechanisms. Fighting the mechanized war demanded scores of new ones, which have helped to crystallize these widely different devices into a family of systems commonly identified as servomechanisms

In keeping a regulated quantity matched to a reference quantity, four important characteristics must usually be incorporated within the servomechanism:

1—Fast response
2—High accuracy
3—Unattended control
4—Remote operation

These characteristics become more valuable as the difficulty of the control problem increases, although many simple problems, such as the control of household heating by a thermostat and furnace, are everyday servomechanism applications.

A servomechanism consists of three basic elements: (1) an error-detecting device, (2) an amplifier, and (3) an error-correcting device. As indicated in Fig. 1, each serves a unique function in enabling the regulated quantity to stay matched to the reference quantity. The error-detecting device determines when the regulated quantity differs from the reference quantity. It then sends out an error signal to the amplifier, which in turn supplies power to the error-correcting device. With this power, the error-correcting device changes the regulated quantity so that it matches the reference quantity. The closed loop composed of the error detector, the amplifier, the error corrector, and the regulated quantity is characteristic of all servomechanisms.

Any quantity can be regulated—voltage, speed, temperature, position, direction, torque, to mention a few of the most common. Any quantity also can be used as a reference quantity. The reference quantity need not be the same as the regulated quantity if the proper error-detecting device is employed. For example, it is possible to make the speed of a turbine-driven blower vary with outside temperature, the speed of the blower being the regulated quantity and the outside temperature being the reference quantity. Most practical problems, however, concern the matching of two similar quantities such as regulated position against a standard position or regulated speed against a standard speed.

The error detector of Fig. 1 serves as a means of measuring both the reference quantity (*A*, Fig. 1) and the regulated quantity (*B*, Fig. 1) and of detecting when they are not similar, *e* or *X* being the measure of any difference. The measuring units within the error detector must be the same. For example, in the case of the blower governed by outside temperature, if the temperature is measured as a function of voltage by a thermocouple, then the speed of the blower is also measured as a function of voltage, perhaps by a tachometer. When the voltage representing the reference quantity, outside temperature, is compared to the voltage representing the regulated quantity, speed, the difference obtained is also a voltage. This small difference voltage is the error signal. It varies in magnitude with the amount the turbine speed is different from the required speed for a particular outside temperature, and it has a polarity depending upon whether the turbine speed is higher or lower than the required speed. A number of typical error-detecting devices are shown in table I, Figs. 1 to 14.

The amplifier of Fig. 1 is merely a means of using the signal of low

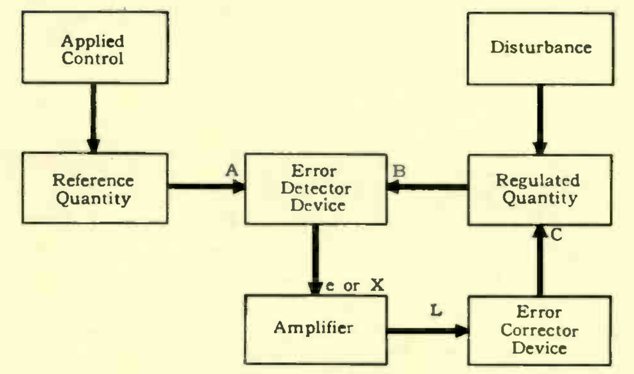


Fig. 1—The essential components of a servomechanism.

Fig. 1

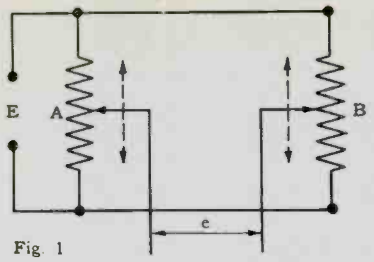


Fig. 2

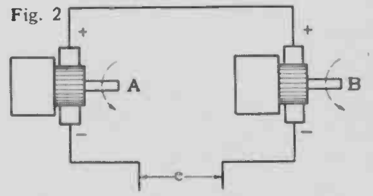


Fig. 3

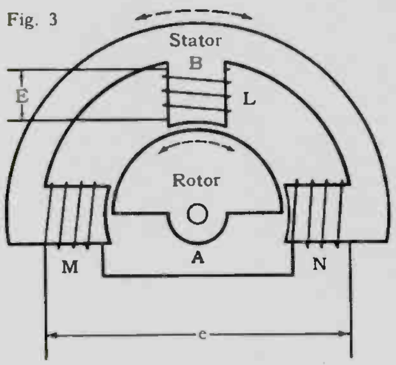


Fig. 4

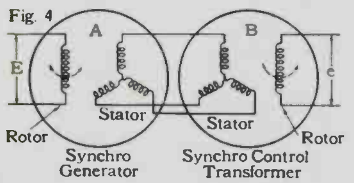


Fig. 5

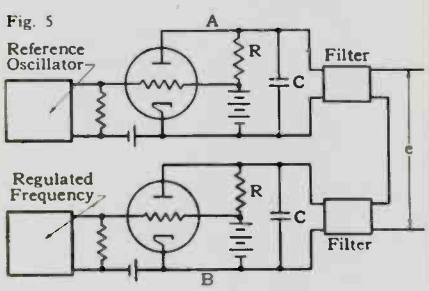


Fig 6

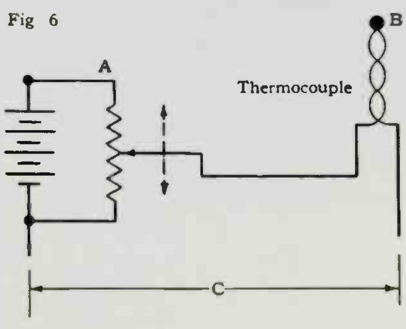


Fig. 7

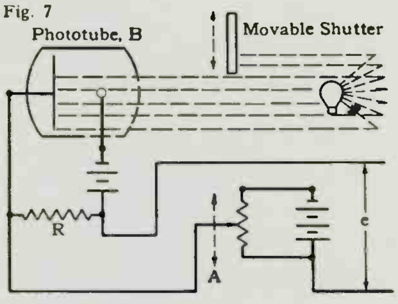


TABLE I—

No.	Type	Main Application	Operation
1	D-c or a-c resistance bridge	Position control	Error voltage, *e*, appears when the position of the moving arms of the potentiometers *A* and *B* are not matched. The power source, *E*, is applied across both potentiometers. *A* measures reference position as voltage and *B* regulated position as voltage, their difference being *e*.
2	D-c tachometer bridge	Speed control	Error voltage, *e*, appears when speeds of tachometers *A* and *B* vary. *A* measures reference speed as a voltage and *B* regulated speed as a voltage. The difference between these voltages is *e*.
3	A-c magnetic bridge	Position control, particularly for gyro pickups where very small forces prevail	Error voltage, *e*, appears when relative positions of rotor *A* and stator *B* do not match. Rotor *A* measures reference position magnetically and stator *B* regulated position magnetically. Voltage *E*, across exciting coil, *L*, provides energy. When rotor covers unequal areas of each exposed stator pole (unbalanced magnetic bridge) pickup coils *M* and *N* have unequal voltages induced. Voltage difference is *e*.
4	A-c synchro-system	Position control where continuous rotation is desired	Error voltage, *e*, appears whenever the relative positions of the rotors of synchro-generator, *A*, and synchro-control transformer, *B*, are not matched. The reference position is measured by *A* as a magnetic flux pattern which is transmitted to the synchro-control transformer through the interconnected stator windings. If the rotor of *B* is not exactly 90 degrees from the transmitted flux pattern, *e* is produced.
5	Frequency bridge	Frequency control	Error voltage, *e*, appears when reference and regulated frequencies differ. Tube channel *A* produces a filtered saw-tooth wave that gives a d-c voltage inversely proportional to the reference frequency. Tube channel *B* produces a similar voltage as a measure of the regulated frequency. The difference of these d-c voltages is *e*.
6	Millivolt bridge	Temperature control	Error voltage, *e*, appears whenever the regulated temperature differs from the reference temperature. The regulated temperature is measured as a voltage by the thermo-electric effect of two dissimilar metals, *B*. The reference temperature is represented as a voltage from the battery-potentiometer source *A*. The difference in these voltages is *e*.
7	Phototube bridge	Position control by intercepting a light beam	Error voltage, *e*, appears when movable shutter is in other than desired position. Light reaching phototube, *B*, measures shutter position. This light is measured as a voltage by the phototube current variation. A reference position of the shutter is represented by the battery-potentiometer voltage. The difference of these voltages is *e*.
8	Mechanical differential	Position control and speed control	Displacement *X* appears whenever the relative reference and regulated positions change. Reference position is measured as an angle by one side of the differential, *A*, and regulated position as an angle by the other side of the differential, *B*. The difference in the two positions rotates the middle member of the differential giving displacement *X*.
9	Beam balance	Voltage control, speed control, and tension control	Displacement *X* appears whenever the variable force is different from the reference force. The variable force, *B*, and the reference spring force, *A*, are measured as moments. The difference in these moments produces displacement *X*.
10	Modified beam balance	Speed control (flyball governors)	Displacement *X* appears when regulated speed, ω, differs from reference speed. This is represented by spring force, *A*, about fulcrum, *O*, the regulated speed by centrifugal force of mass, *B*, about *O*. Difference in moments of forces about *O* produces displacement *X*.
11	Bimetal	Temperature control	Displacement *X* appears whenever the surrounding temperature and the reference temperature are different. The reference temperature is represented by the position of the adjustable reference point, *A*. The surrounding temperature is measured by the position of the bimetal strip, *B*. The difference in these positions produces displacement *X*.
12	Float	Liquid level control	Displacement *X* appears when regulated and reference liquid levels differ. Point *A* is reference. The liquid level is measured as a position by the float *B*. The difference produces displacement *X*.
13	Bellows	Pressure control and temperature control	Displacement *X* appears when surrounding and reference pressures differ. Reference pressure is represented as position by adjustable point, *A*. Surrounding pressure is measured by the bellows as a position. Difference in these positions produces displacement *X*.
14	Piston	Pressure control	Displacement *X* appears when regulated pressure outputs of pump and reference differ. Reference pressure is a force on the piston by spring, *A*. Regulated pressure is a force on the piston by the fluid. Their difference produces displacement *X*.

Fig. 8

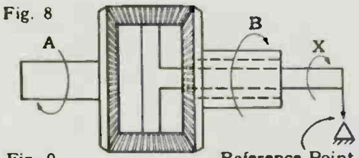


Fig. 9

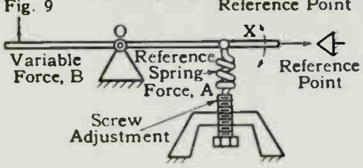


Fig. 10

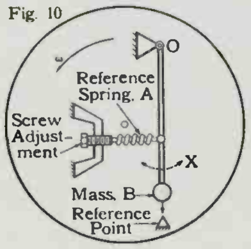
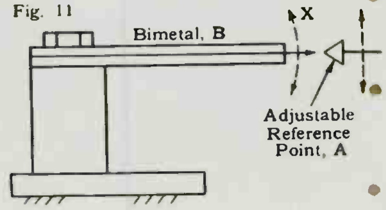


Fig. 11



Possible Modifications	Operating Features	Accuracy Limited by	Features determining energy required to vary reference quantity measurement *A*	Amplifier of Table II frequently used with this device	Error Corrector of Table III frequently used with this device
Potentiometer can be wound on a helix to get more than 360° of rotation.	*A* and *B* can be remote. Continuous rotation not possible.	Potentiometer winding.	Contact arm and bushing friction.	2, 3, 4, 5	1, 2, 3
A can be replaced by a battery as the reference.	*A* and *B* can be remote. Top speed limited by commutator.	Tachometer accuracy. Commutator resistance.	Brush and bearing friction.	2, 3, 4	1, 2, 3
Four poles instead of three can be used with two having exciting windings and two pickup coils connected bucking.	Limited rotation. Air gap usually small.	Machining tolerance, magnetic fringing, and voltage phase shift.	Load taken from *e*. Bearing friction.	2, 4	1, 2, 3
A dual system can be used whereby the unity synchro-system sets the approximate position and the high speed or vernier system sets the accurate position.	Unlimited rotation. The synchro-generator and control transformer can be remote.	Machining tolerance, accuracy of winding distribution.	Distributed or non-distributed winding of control transformer rotor. Load taken from *e*. Bearing and slip ring friction.	2, 4	1, 2, 3
May be used as a speed regulator if *B* is made an a-c tachometer.	*A* and *B* can be remote. Tubes can be either gas or vacuum. A wide range of frequencies can be covered. Vacuum tubes should be used for high frequencies.	Temperature and aging effects on tube and circuit elements.	Tube input impedance.	4	1, 3
An electronic voltage source or another thermocouple can be substituted for *A*.	*A* and *B* can be remote. A wide range of temperature can be covered.	Ability to detect very low millivolt signals.	Contact arm and bushing friction. If electronic voltage source *A* is used, tube input impedance.	2, 4	1, 6
An electronic voltage source or another light source and phototube can be substituted for *A*.	*A* and *B* can be remote. Glass surfaces through which light travels must be kept clean.	Continued accuracy of light source and phototube.	Contact arm and bushing friction. If electronic voltage source *A* is used, tube input impedance.	2, 4	1
Spur-gear differential.	Since *A* and *B* must be located together, synchro-ties or their equivalent can be used to transmit remote positions to *A* and *B*. Continuous rotation possible with speed limited by gears.	Gearing backlash.	Power taken from *X*. Bearing friction. Pitch of gears.	1, 6, 7, 8	1, 2, 3, 4, 5
Any variable force other than a spring can be used.	For remote operation *B* can be a transmitted force. *X* movement limited. By changing springs a wide force range can be covered.	Load taken from *X*. Bearing friction.	Magnitude of forces. Screw pitch and friction.	1, 6, 7	1, 3, 5
Any variable force other than a spring can be used.	A wide speed range can be covered. *X* movement limited.	Load taken from *X*. Friction.	Magnitude of forces. Screw pitch and friction.	1, 7, 8	1, 5
Bimetal can be made snap acting at some standard temperature.	Wide temperature range possible by selection of proper bimetal.	Load taken from *X*. Ability to measure accurately small *X* deflection. Time lag and hysteresis of bimetal.	Mounting of reference point.	1, 6	1, 6
A float controlling a pulley system can be used rather than a lever.	With the proper mechanical arrangement a wide variation in liquid height can be controlled.	Load taken from *X*. Variable density of the liquid. Friction.	Mounting of reference point.	2, 7	3, 4
Spring can be added in addition to bellows spring.	Limited *X* travel.	Load taken from *X*. Hysteresis of bellows spring.	Mounting of reference point.	1, 4, 5, 6	1, 6
A standard pressure source can be substituted for the spring.	*A* and *B* can be remote. Limited *X* travel.	Friction. Load taken from *X*.	Piston forces involved. Screw pitch and friction.	7, 8	5

Fig. 12

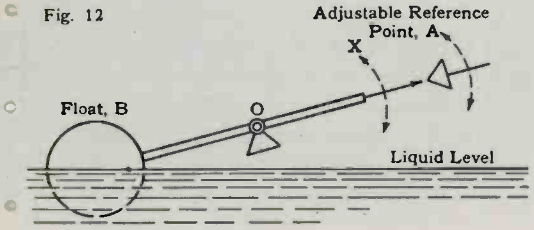
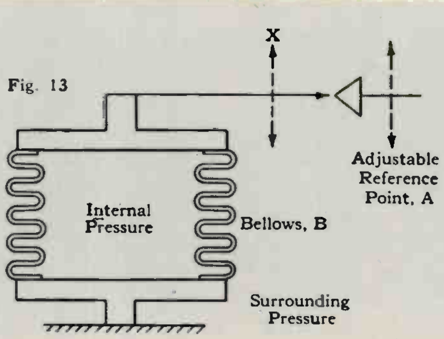


Fig. 13



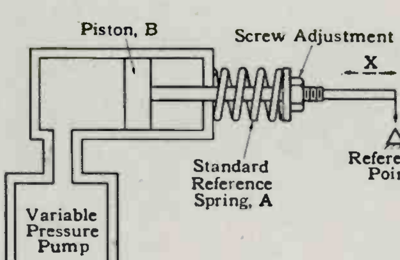
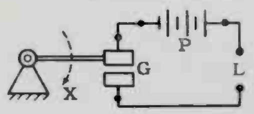
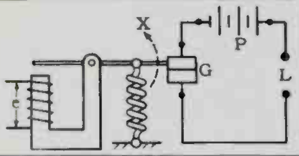
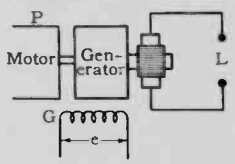
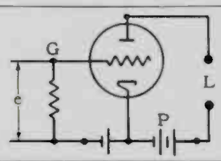
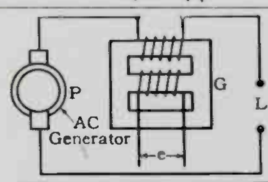
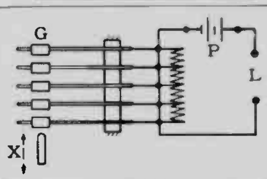
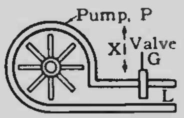
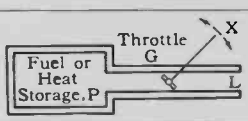
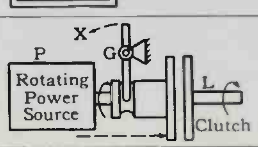


Fig. 14

TABLE II—POWER AMPLIFIERS

No.	Schematic Representation	Type	"Gate" Element	Approximate Input Units	Approximate Output Units	Approximate Power Amplification Factor	Devices Represented by Load, L	Power Control
1		Contact	Contact	Ounces	Watts	1 x 10^7 x t	Relay motor Generator field Impedance Solenoid	On-Off
2		Relay	Contact	Watts	Watts or Kilowatts	1 x 10^3	Relay motor Generator field Impedance Solenoid	On-Off
3		Generator	Field	Watts	Watts or Kilowatts	50	Motor Impedance	Continuous
4		Electronic Tube	Grid	Microwatts	Watts	1 x 10^5	Relay motor Generator field Impedance	Continuous
5		Saturable Reactor	D-C Coil	Milliwatts	Watts	3 x 10^2	Generator field Impedance	Continuous
6		Silverstat	Contacts	Grams	Watts	1 x 10^7 x t	Generator field Impedance	Stepped
7		Valve	Valve Gate	Inch-pound	Horsepower	1 x 10^7 x t	Turret Press Heat absorption	Continuous
8		Throttle	Throttle Valve	Inch-pound	Horsepower	1 x 10^7 x t	Propeller Vehicle Generator Mill	Continuous
9		Clutch	Clutch Disk	Inch-pound	Horsepower	5 x 10^4 x t	Vehicle Mill	On-Off

power level (*e* or *X*, Fig. 1) provided by the error-detecting device to control the error-corrector device. Typical amplifiers are shown in table II. Familiar devices such as generators, valves, relays, and electronic tubes are included.

The error corrector of a servomechanism system actually does the work of regulating. The error-detecting device and the amplifier serve only as a means of controlling the error corrector so as to make the regulated quantity match the reference quantity. Several familiar types of error correctors such as electric and hydraulic motors, gas engines, and turbines are listed in table III.

The disturbance shown in Fig. 1 represents load variations affecting the regulated quantity such as generator voltage drop with load for a voltage regulator, or temperature drop in a room with decrease in outside temperature for a temperature regulator.

Applied control as shown in Fig. 1 is controlled variation of the reference quantity in order to achieve desired changes in the regulated quantity. A good example of applied control to the reference quantity is the familiar one of variation of the reference temperature of a room thermostat. Both the applied control and the disturbance to the regulated quantity are independent. They are influences that upset the existing balance between the regulated quantity and the reference quantity. Servomechanisms readjust this balance continuously and automatically.

Error-Detecting Devices

The error-detecting device has many practical forms. Some of the representative types are given in table I. Each error detector, regardless of whether it is electrical, hydraulic, or mechanical, performs three distinct operations:

1—Measurement of the reference quantity. This element is shown by A in the schematic representation of table I.

2—Measurement of the regulated quantity. This element is shown by B in the schematic representation of table I.

3—Indication of amount of error. This element is shown by e if the output is electrical and by X if the output is mechanical in the schematic representation of table I.

Analysis of the d-c tachometer bridge, No. 2, table I, serves as a typical example. Tachometer A measures the speed of a reference, as a voltage. The speed of the device being regulated is measured by tachometer B as a voltage. The voltage outputs of tachometers A and B are opposed. A voltage difference, e, appears only when the speed of B differs from speed A. Thus a definite error indication is established.

The features of an error detector that most interest the designer are: energy required to measure reference quantity, accuracy, size and reliability.

The greatest amount of design ingenuity can be exercised in the selection of an error-detecting device. Special arrangements to decrease operating forces or to increase accuracy are used. Typical of these is the use of a dual synchro-system to increase accuracy.* In this arrangement one synchro-system, such as No. 3, table I, is geared at unity to the reference and regulated angular positions. A duplicate synchro-system is geared to the reference and regulated angular positions at some higher gear ratio, which is usually an odd number, such as 15 or 31 to one. When the angular discrepancy is large, the unity system takes control and through the amplifier and error corrector brings the angular positions into approximate agreement. At this point the vernier or high gear-ratio system assumes control of the amplifier and error-correcting device and very accurately brings the regulated position into correspondence with the reference position. The high-ratio or vernier system cannot be used alone for it would have as many correspondence points as its gear ratio above unity. The peculiar traits of mechanical, electrical, or hydraulic error detectors can also be used to advantage. As an example, magnetic saturation might be used to get a particular variation of error voltage with error. Similarly, a non-linear mechanical linkage might be used.

Amplifiers

Some typical amplifiers are shown in table II. The broad similarity of all the amplifiers of table II is apparent when one considers that each contains a "gate" element, G, which controls power flow from the power source, P, to the load, L. Each of these gates is a low-power or force element when compared to the power they control. For example, the contact of No. 1, table II requiring ounce-inches to operate may control many watts to the load. For high amplifications single amplifiers can be cascaded. A series composed of an electronic tube, No. 4, table II, a relay, No. 2, table II, and a motor-operated throttle, No. 8, table II, would provide tremendous amplification. Microwatts into the tube could control thousands of horsepower. In servomechanism applications, the load, L, taken from the final amplifier always represents the error-corrector device. The difference in the power available as an error signal and power required to correct the regulated quantity determines the amount of amplification necessary.

Many devices such as the contact, throttle, or valve have their power input determined by the time required for operation. The clutch, for example, requires inch-pounds in a certain time to control horsepower. Therefore in the column for approximate power-amplification factor of table II, a time factor, t, is included. Thus the faster one operates the clutch, the larger the power source required and the less its power amplification.

Error-Correcting Devices

Error-correcting devices are probably the most familiar of the three components of a servomechanism. Commonplace items such as motors, engines, and pistons are all included in the examples of table III.

Every error-correcting device as used in a servomechanism has its power input, L, controlled by amplifier, and it in turn uses that power to correct the regulated quantity. This correction of the regulated quantity is indicated by C.

Many present-day servomechanism applications are the direct outgrowth of replacing man as an error detector. The automatic voltage regulator is an excellent example. With manual voltage regulation, the operator uses a meter to measure the regulated quantity, voltage. He detects the difference in needle position from a fixed reference position and adjusts the field rheostat to realign the needle with the reference. This procedure is duplicated by the automatic voltage regulator. It balances the force of a coil, which is a measure of line voltage against the force of a reference spring. When these forces are unbalanced an error in line voltage is detected. The movement resulting from the unbalanced forces produces a change in field excitation that restores the line voltage to its proper value.

Similar comparisons can be made in the case of automatic speed governing, liquid level control, temperature regulation and a multitude of others. In all of these applications the servomechanism does a more accurate and faster job than man. The human transient response is poor when compared to a well-designed servomechanism.

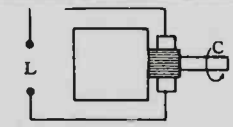
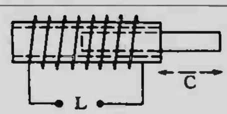
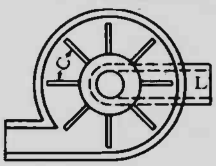
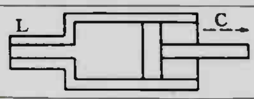
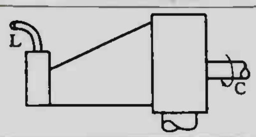
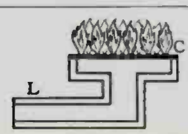
Designing a Servomechanism

The design of servomechanisms is usually broken up into the same three basic categories as given in the schematic diagram, Fig. 1. The designer must select (1) an error detector, (2) an amplifier, and (3) an error corrector that function compatibly with each other and perform the required job. Aside from the usual cost and reliability factors, accuracy and operating force or power determine the selection of the error-detecting device. The amplifier is chosen on the basis of required amplification and time delay introduced.

*A device in which two, three-phase stators are tied electrically. One of the rotors is excited from a single-phase source. Any difference in angular displacement between the two rotors results in a single-phase voltage induced in the second rotor varying sinusoidally in value with the difference in displacement.

A servomechanism is not any specific type of equipment. It is any one of a class of automatic regulators intended to keep a quantity—speed, position, etc.—matched to a reference quantity.

TABLE III—ERROR CORRECTORS

No.	Schematic Representation	Type	Input Energy	Output Energy	Approximate Output Power Range
1		Electric Motor	Electrical	Mechanical Rotation	1×10^{-2} to 4×10^{4} hp
2		Solenoid	Electrical	Mechanical Translation	1×10^{-3} to 15 hp
3		Hydraulic Motor	Hydraulic	Mechanical Rotation	1×10^{-2} to 11×10^{4} hp
4		Piston	Hydraulic	Mechanical Translation	1×10^{-3} to 1×10^{3} hp
5		Steam or Gas Prime Mover	Heat or Chemical (fuel)	Mechanical Rotation	5 to 1.65×10^{5} hp
6		Burner	Chemical (fuel)	Heat	1×10^{2} to 1.5×10^{8} Btu per hr

The error-corrector device is determined by the regulated quantity and ease of coupling to the selected amplifier. Many combinations of error detectors, amplifiers, and correctors can be assembled to fill any servomechanism job. Often there is little to choose between them.

The use of tables I, II, and III illustrates how a servomechanism can be devised. Suppose it was desired to regulate angular position. Where relatively low accuracy is desired, an a-c or d-c resistance bridge, a relay and an electric motor (or a mechanical differential, a contact, and an electric motor) would perform the job. Higher accuracy can be obtained by using an a-c synchro-system with an electronic tube, a generator, and an electric motor; or by using an a-c synchro-system with a valve and hydraulic motor. These components can be chosen from the tables. Each of these is a complete servomechanism and each has its proper place in meeting desired performance requirements. The power of the error-correcting device is determined by the rate at which it is desired to vary the regulated quantity. This rate of varying the regulated quantity also determines the transient errors and the tendency of the system to "hunt."

"Hunting" or self-induced oscillation of the regulated quantity without change in the reference quantity is a problem that has to be faced in all quick-response, high-accuracy servomechanisms. Any closed-loop system such as shown in Fig. 1, where the output feeds back into the input, has a tendency to oscillate.

However, the inherent damping in the simpler servomechanism is usually great enough to overcome this tendency and the system is stable. Where accuracy and response requirements are not too severe, a servomechanism of this self-damped type will perform satisfactorily. To meet the more stringent accuracy requirements, special anti-hunt circuits to give an increased amount of damping are used.

Lately, much attention has been focused on the question of servomechanism stability. The particularly high performance requirements of wartime servomechanism applications have brought this about. The need for the best possible transient response in addition to satisfactory stability requires careful scrutiny of the effects of each type of "anti-hunt" circuit.

In general, there are three approaches to the problem. The first involves getting solutions to the overall differential equation of the system. Since the equations are usually of a high order, the procedure to find the roots is quite difficult. At best, one particular solution can be obtained, and if the effect of varying one parameter is desired the entire root-finding procedure must be gone through again.

The second method is to get the amplitude and phase characteristics of the servomechanism either by direct experimentation or by a variation of the Nyquist method used in feedback amplifier design. It is relatively easy to interpret the phase-amplitude diagram in terms of stability and response. Changing parameters usually requires a new diagram. The third system is to substitute an equivalent electrical circuit for the servomechanism and, by using the transients analyzer, obtain the system response on an oscilloscope as different circuit elements are varied.

Detailed performance and stability calculations are not necessary to understand servomechanism operation. All that is required is a good understanding of Fig. 1. The interrelations shown of the reference quantity, error-detecting device, amplifier, error-corrector device, and regulated quantity provide the basis of all servomechanisms. From combinations of items in tables I, II, and III a large number of servomechanisms can be devised.

Color Television—A Reality

Primitive man added color daubs to his cavewall drawings. Ever since, man has constantly struggled to add color, and consequently realism, to pictorial works. Colored drawings, paintings, mosaics, printing, photography, and now television, are all steps in this development of reality. With the fascination of color added to the educational and entertainment value of television, a new and vital service has been made available to the world—and a potentially vast industry is at our threshold. A practical color television system is here described.

D. L. BALTHIS, *Industrial Electronics Division, Westinghouse Electric Corporation*

HIGH-DEFINITION color television has been proved practical in tests in the New York City area. This new electronic achievement has now reached the stage of development where manufacture of color-television equipment for users such as the Columbia Broadcasting System has already started.

Many war-stimulated ideas and techniques have been applied to hasten the development of color television. The adoption of new ultra-high frequency bands, the extensive investigation of these bands during wartime radar use, and the practicability of rapid nationwide expansion through Stratovision, have cut years from the expected development period.

The advantages of color television are obvious. Even at a first glance the difference between color and black-and-white television is startling. Color introduces a life-like quality. Shadows that appear as drab tones between black and white take on new meaning in color and give a sense of depth that must be seen to be appreciated. Details become more recognizable in color and combine to give a sense of fullness to the picture as a whole. Where color aids in identification, such as in a football game where the teams' jerseys identify the players, color is almost a necessity. Color, too, will immediately aid the value of television as an educational medium.

Fundamentals

Color television is not a new idea. Although kept in the background by the older and more highly developed black-and-white television, color television has been continually advancing for several years. John L. Baird demonstrated color television in England in the summer of 1928 while the Bell Telephone Laboratories presented a three-color system in New York in July, 1929. These and other early systems suffered because of the inherent limitations of mechanical scanning. Not until 1940 was a three-color system employing electronic scanning, both at the transmitter and receiver, demonstrated by the Columbia Broadcasting System.

The basic principles of color and black-and-white television are similar. However, color necessitates additional mechanical equipment—of a simple nature—at the transmitter and receiver. Signals for color synchronization are required in addition to the synchronizing signals normally used with black and white. The video bandwidth of the system must be wider, to accommodate scanning in three colors rather than black and white alone.

In television, whether black and white or color, the image being televised is reduced to a line structure. The picture is electronically scanned from top to bottom in horizontal lines, as shown in Fig. 1. This motion is similar to the manner in which one reads a page in a book.

The cathode-ray tube in which the scanning process occurs can conveniently be called a camera tube. In black and white, the first step of the scanning process at the transmitter is to focus a picture image on the photosensitive surface of this tube. An electron beam is moved vertically downward in steps from left to right over the image. So doing develops a signal voltage, or current, proportional to the brightness of the picture at the point where the beam touches it at any instant. The picture is thus translated into a varying electric signal that is proportional to the light intensity of the image focused on the camera tube. These signals with appropriate synchronizing signals are delivered to the transmitter for broadcasting. This process is rapidly repeated. The number of times per second the picture is scanned vertically is known as the "field frequency," which in black-and-white television is 60 per second. This is sufficiently rapid that the eye detects no flicker; the picture appears continuous. When the scanning beam has completed any one of the 525 horizontal lines it must be quickly returned to the left edge for the start of the next line. This is a horizontal retrace. Likewise when the bottom line of a field has been scanned, the beam must be swept back to the top for the next field, constituting a vertical retrace. During these retrace periods no picture signals are transmitted. In fact, transmission of picture signals is purposely blocked, for reasons explained later, by blanking signals created for the purpose.

Assume that at the receiver is located a second cathode-ray tube equipped with a fluorescent screen and operated so that its electron beam sweeps across the screen and downward in synchronism with the beam of the camera tube. Assume also that the intensity of this beam is controlled so that it follows the instantaneous variations in signal strength of the camera-tube signal. Because the visible pattern appearing on the receiver fluorescent screen varies according to the intensity of the impinging electron beam, the resulting pattern appears to the eye as a reproduction of the picture seen by the camera tube.

The number and narrowness of horizontal lines in which the picture is scanned (Fig. 1) are measures of quality of the recreated image. To reproduce details sharply,

Television is in a state of flux. Shall the industry proceed with the already well-developed black and white or should it wait for color television, which has been successfully tested but is still experimental? The superiority of color and its ultimate desirability no one questions. However, color television is predicated on use of a much higher frequency than now employed for black and white; hence, adoption of color will make equipment based on present standards obsolete. The time required for bringing color television to the point suitable for general use has been variously estimated at from six months to five years. This point, however, is beyond the scope of this article, which describes the system of broadcasting pictures in color.

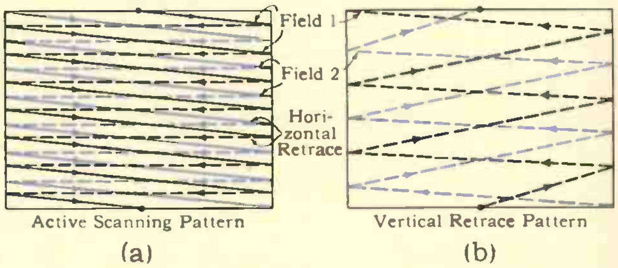
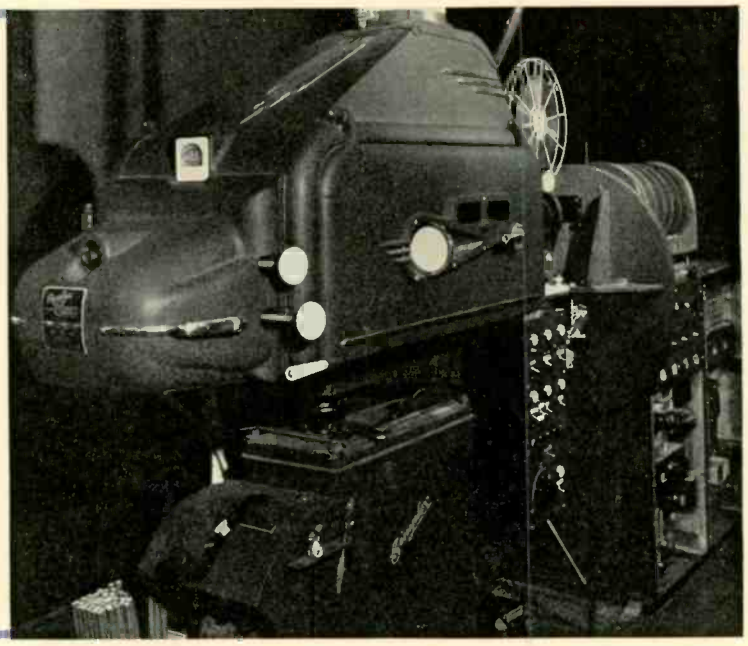


Fig. 1—Method of scanning based on 2:1 interlace ratio. The picture is scanned (a) omitting every other line (indicated by black lines forming first field) followed by scanning that fills in the intervening lines (color lines, forming second field). A complete picture frame (two fields) consists of 525 lines less a few vertical retrace lines (b).



A portion of the color-television studio equipment. It consists, from left to right, of the arc light, the projector, table assembly, including the slide and film projectors, the control panel and lens-selector disc housing and the table rack for the electronic power and control units, and the image-dissector camera located at top center. →

the width of each line must be kept quite narrow and the amount of overlap of the lines kept small and closely controlled. Consequently the narrower the line, the larger the number of horizontal lines that must be transmitted to cover the full height of the picture. The commercial standard for black-and-white television is now 525 lines per picture frame. The number of lines per frame in the color system demonstrated by Baird in 1928 was between 20 and 30.

Each picture frame is normally made up of two picture fields. Each of these picture fields is developed by scanning the picture once vertically while skipping every other horizontal line. This is known as "interlacing," with an interlace ratio of 2:1. Interlacing has been adopted because the picture-frame frequency of 30 per second established in this country permits flicker to be noticeable to the eye unless the viewing period of 1/30 of a second is sub-divided by interlacing one or more times to increase the effective viewing frequency. Thus a picture-frame frequency of 30 per second and an interlace ratio of 2:1 appears to the eye as a picture frequency of 60 per second, which is above the rate detectable as flicker. Higher interlace ratios, say 3:1, which means scanning one line and skipping two, or even 4:1 are possible and have been tried. However, the improvement to the observer is not worth the additional difficulty posed to the circuit designer.

Westinghouse is now engaged in the design, development, and production of the electronic equipment required to convert a 35-mm color slide or 16-mm color moving-picture film and its associated sound, into radio-frequency signals suitable for reception by a color receiver. For convenience, this equipment can be classified in terms of the studio equipment and the transmitter. The studio equipment consists of the components that develop the composite video signal from the slides or film and supply it to the transmitter. The transmitter accepts the composite signal from the studio equipment and, after amplification, uses this signal for amplitude modulation of the ultra-high-frequency carrier wave of the transmitter for broadcasting.

Color televising live scenes instead of pictures is an obvious must and is a development being aggressively pursued. However, this introduces studio problems of illumination and scanning-tube sensitivities that can be attacked separately and that have no fundamental bearing on the color-television scheme. Color televising actual scenes instead of pictures will entail no basic change in the system discussed herein.

Present studio equipment is modeled after the three-color studio equipment designed and constructed by the Columbia Broadcasting System in New York City shown above. This is a direct-viewing receiver designed for the reception of ultra-high-frequency signals from the air. It utilizes a ten-inch cathode-ray viewing tube in conjunction with a magnifying lens to give an effective tube size of twelve inches. If an effective rectangular picture area of 8 by 6 inches is used the picture is composed of 525/6 or 87½ lines per inch.

Basically, this television-studio equipment is the outgrowth of the system first demonstrated successfully by CBS in 1940. However, it was virtually redesigned and rebuilt by CBS in the latter part of 1945, with resulting great improvement in the quality of the reproduced picture.

The system is based on the use of three additive primary colors—red, blue, and green—televised in rapid succession, in the manner indicated in Fig. 2. The light source is a carbon arc, which produces light of all colors. The picture to be televised is dissected into the three colors by rotating a disc containing the three filters between the arc and the picture.

The color filters are segments of acetate or gelatin that transmit light in bands corresponding to the color of the filter —i.e., a red filter transmits red light, etc. Consequently, as the red, blue, and green filters appear between the film and the light source, the image focused on the camera tube is consecutively red, blue, and green according to the intensity of these colors in the film.

The instantaneous signal developed by the camera tube as each red, blue, or green image is scanned then varies in strength according to the intensity of the reds, blues, or greens in the film being scanned. The signals from the camera tube for each color field are accepted by the transmitter and broadcast. Between picture transmissions are interspersed the synchronizing signals required to keep the receiver in step with the transmitter.

At the receiver, scanning is synchronized with that of the transmitter. Hence, it reproduces a picture in black and white on the fluorescent screen of the cathode-ray tube for each red, blue, and green field at the transmitter. These successive black and white fields vary in instantaneous intensity according to the strength of the controlling signal, which, as in the camera tube, varies according to the reds, blues, or greens in the color film being televised.

The color disc at the receiver is rotating synchronously with the color disc at the transmitter. The observer at the receiver views the black and white image on the cathode-ray tube through the receiver color-filter disc. In turn, when the camera tube is scanning the image in red, the observer views the reproduced image at the receiver through the red filter and similarly for blue and green. The result is that the light seen by the observer is colored either red, blue, or green, with the intensity of these colors varying according to the corresponding colors in the televised picture.

The observer views each color field successively, and for 1/144 of a second. The result of this rapid repetition is that the persistence of vision integrates the cyclic red, blue, and green fields into a single color picture where the colors blend to reproduce faithfully the colors in the televised picture.

The speed of the color disc and the shape of the color-filter segments are so chosen that successive color filters remain between the film and the light source while the image on the camera tube is scanned vertically. Transition from one color to another is made during the vertical-retrace period.

The fundamental difference between black-and-white and color television is that in color an image must be transmitted for each primary color employed, as compared to a single image for an equivalent black-and-white system. When this information is transmitted on a single radio-frequency carrier, a system employing three primary colors requires theoretically three times the bandwidth of an equivalent black-and-white system (actually 2.4).

Color television, as now proposed, has been based on the addition of color by mechanical methods. However, experiments directed toward the addition of color by all-electronic means are in progress in this country and abroad. Baird demonstrated a color system in England in August of 1944 using a multi-beamed cathode-ray tube at the receiver for color reproduction. This system, however, still required a rotating color disc at the transmitter. The simplicity and reliability of the mechanical color disc method will probably assure its continued use until all-electronic systems are developed far superior to those yet demonstrated. Electronic methods would not render the existing method obsolete. The same transmission methods and equipment would be applicable.

Studio Equipment

A simplified block diagram of the studio equipment, as developed by CBS and being built by Westinghouse, is shown in Fig. 3. All the electronic units in the studio equipment are operated from a power source of 120 volts, 144 cycles. This choice of a non-standard line frequency, the same as the color-field frequency, eliminates design problems otherwise present. (The same practice is usually employed in black-and-white television where the field frequency and power-line frequency are both 60 cycles.) Driving the television-power generator by a 60-cycle synchronous motor assures that the 144-cycle power is synchronous with the local 60-cycle power.

The synchronizing signal generator is the master timing unit for the system. It provides the horizontal and vertical blanking and synchronizing signals and color pulses required for keying the transmitting and the receiving system. The unit contains a master oscillator controlled by a variable-reactance tube that keeps the system in synchronism with the 144-cycle power frequency of the equipment.

The synchronizing-signal isolation amplifier, as its name implies, is used to isolate the synchronizing-signal generator where interaction of units would affect the generator's stability and also to furnish multiple low-impedance output signals required for coaxial lines and other components of the system.

The horizontal and vertical scanning amplifiers take synchronizing signals from the synchronizing-signal isolation amplifier and furnish the sawtooth sweep wave required by the scanning tube in the camera unit. The color-control panel contains a mechanically driven commutator by which the output signal levels of the camera tube are individually controlled for each red, blue, or green field.

The camera unit contains the camera tube together with its associated deflection and focusing coils, the voltage divider sub-assembly for the control of the voltages on the electrodes of the dissector tube, and the first video amplifier. The particular tube used is the type known as the Farnsworth image dissector. The video signal from the dissector tube is amplified by the first amplifier and is then coupled to the video amplifier and gamma control unit.

The video amplifier and gamma control unit are used to amplify additionally the video signal from the camera unit and,

← A direct-viewing color television receiver as used in demonstrations by the Columbia Broadcasting System of N.Y.

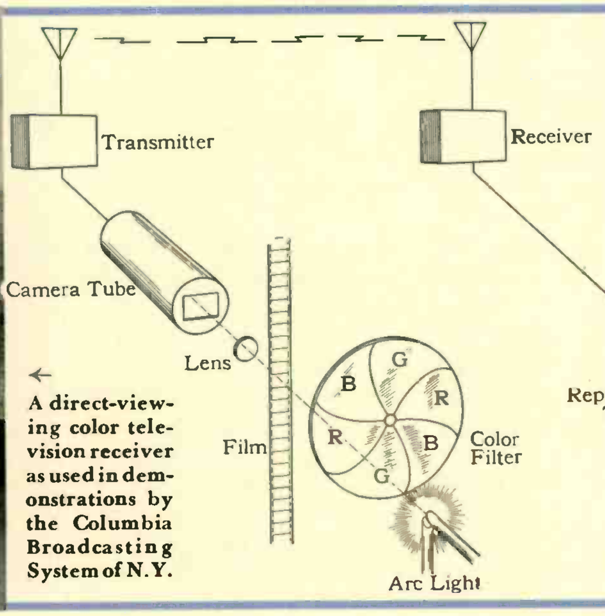


Fig. 2—Schematic representation of the manner of scanning color motion-picture film and transmission and reception of the video signals.

Fig. 3—A block diagram of the studio equipment used for producing the various television signals.

Fig. 4—The composite signal waveform for transmitting video, audio, and synchronizing information.

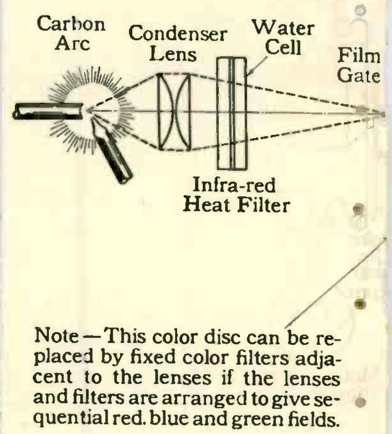
Color television consists of creating and transmitting a signal that can be received and utilized for picture and sound reproduction. This signal is a composite made up of sound, picture, and synchronizing-signal components.

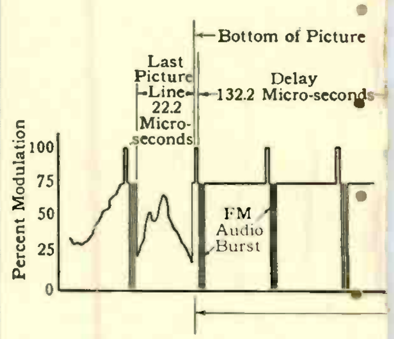
In Fig. 4 the last picture line of one picture field is followed by a succession of signals transmitted during the vertical blanking period and the first two picture lines of the next picture field. The frequency modulated pulses containing the sound or "audio" intelligence occur after each horizontal synchronizing pulse. The vertical synchronizing pulses occur within the vertical blanking period after a brief delay. These pulses are followed after another brief delay by the color synchronizing signals that serve to maintain the color wheel of the receiver in synchronism with the color wheel at the transmitter. The horizontal and vertical blanking signals are used to prevent the display of visual signals at the receiver during the retrace periods of the camera tube scanning beam. All signal levels equal to or greater than 75 percent amplitude as indicated on the modulation scale occur in the black region and are, consequently, not seen at the receiver. The vertical blanking period and its associated signals occur after each field only whereas the horizontal blanking and synchronizing signals occur after each picture line.

As illustrated in Fig. 3, successive frames of the continuously moving, colored, motion-picture film are focused on the photosensitive surface of the camera tube through the action of the rotating lens-selector disk and lenses. These images are scanned by the tube using sweep signals synchronized by the signals from the synchronizing signal generator. The picture signal from the camera tube is amplified in the pre-amplifier and then passes to the video amplifier and gamma control unit. Here, after further amplification, the blanking signals are added to the picture signal and the gamma of the picture signal controlled. The signal then passes to the video-sound-synchronizing signal mixer and line amplifier. Meanwhile, the sound as picked up from the film sound track or microphone is amplified and used to frequency modulate a pulsed oscillator in the sub-carrier generator. The frequency-modulated pulses are also delivered to the video-sound-synchronizing signal mixer and line amplifier. The video-sound-synchronizing signal mixer and line amplifier combine the picture, sound and synchronizing signals into a composite signal and deliver this signal with its three components to the transmitter.

TABLE I—STANDARDS FOR 525-LINE COLOR TELEVISION

Horizontal scanning frequency, cycles	37 800
Vertical scanning frequency, cycles	144
Interlace ratio, cycles	2:1
Frame frequency, cycles	72
Color-frame frequency, cycles	48
Color-picture frequency, cycles	24





also, to add blanking pulses to the video signal and to control the gamma of the output signal. The term gamma is similar to that used in photography and refers to the control of contrast between the bright and dark picture components in the video signal.

The video-sound-synchronizing signal mixer and line amplifier serve as the last link in the video chain, adding the synchronizing signals and sound intelligence to the video signal. The output of this unit is the composite video signal used by the transmitter, the color-and-sound monitor, and, if desired, and black-and-white monitor.

The color-and-sound monitor is equipped with r-f stages and can accept a transmitted signal from the air in addition to monitoring the signal directly from the video-sound-synchronizing signal mixer and line amplifier.

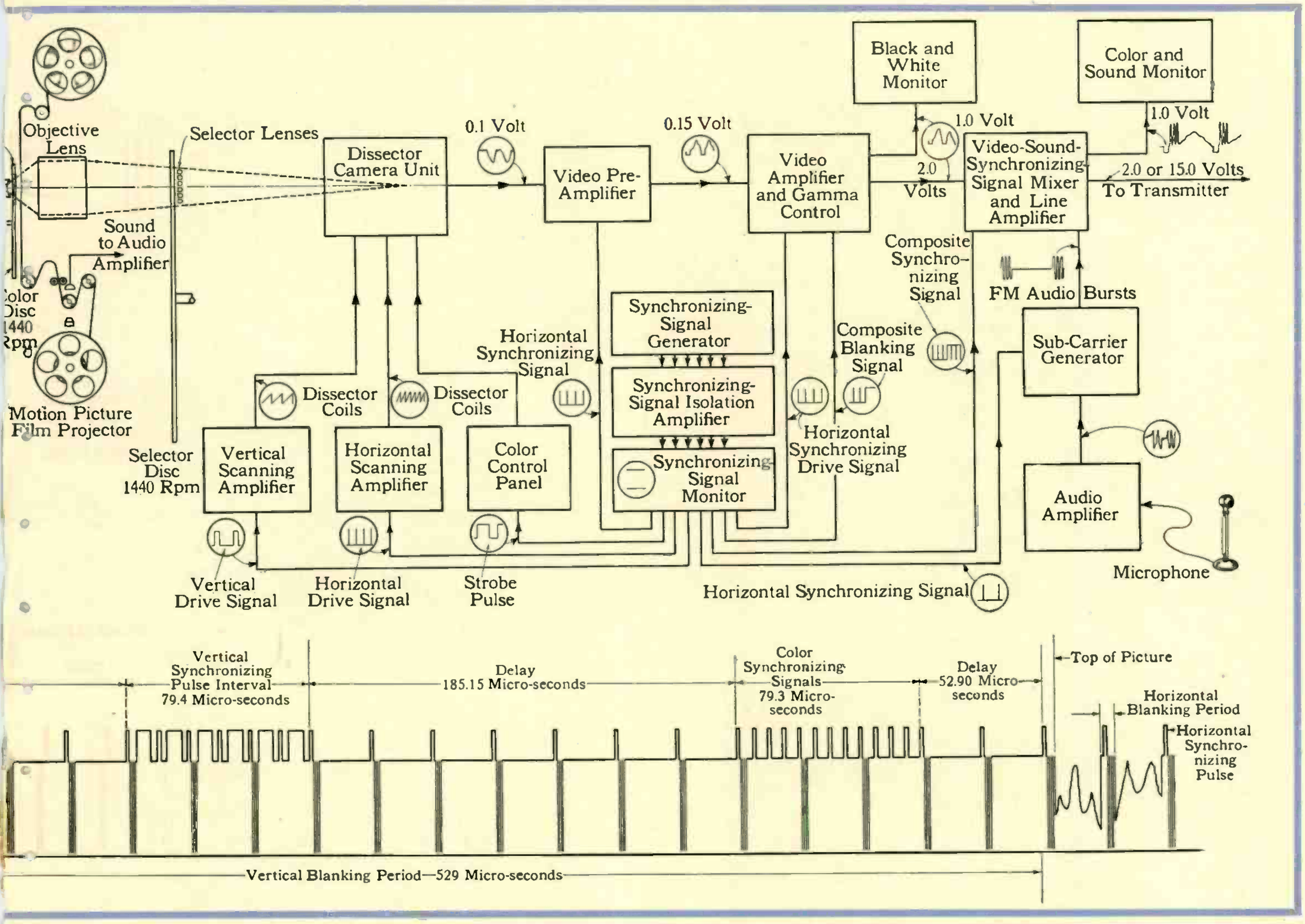
The manner in which sound intelligence is added to the composite output signal of the studio equipment is of special interest. Normally, for black-and-white television, two different adjacent r-f carrier frequencies are employed, one for sound and the other for the video signal. Here, in place of two carriers, sound is transmitted on the same carrier as the video signal. This is an innovation applicable primarily to color television due to the use of higher line-scanning frequencies.

The audio-amplifier amplifies the audio output signal derived from the sound track of the film. This audio signal is then taken by the sub-carrier generator where it is used for frequency modulation of a pulsed oscillator. These frequency-modulated pulses occur at the horizontal scanning frequency. These are approximately 2.5 microseconds in duration.

This method of sound transmission offers the advantages of reducing the channel width required for a given station by the elimination of the sound carrier and sidebands normally required to transmit sound. Other possible advantages include a decreased cost for transmitting and receiving equipment and improved reception of picture and sound resulting from more optimum receiver tuning due to the use of a single carrier frequency for audio and video signals.

The optical part of the equipment consists essentially of the components shown to the left of the dissector-camera unit in Fig. 3. The light source for either film or slides is the carbon arc. A water cell, serving as an infrared radiation filter, is placed between this arc and the color disc and film. This avoids excessive heating of the disc or film and eliminates the infrared radiation that would otherwise pass freely through the red, blue, and green filters and result in picture contamination. After passing through the color disc, the light is then directed through either the color film or color slide and the image focused on the cathode of the image dissector-camera tube on which the picture is viewed.

The lens-selector disk and the six selector lenses are used only with film. The lens selector is slotted and exposes each of the six selector lenses individually, starting with the uppermost lens in the stack and moving progressively downward. This arrangement, in combination with the color wheel, allows six sequential red, blue, and green color images of each frame of the film to be focused on the cathode of the dissector tube.



The film is drawn through the film gate at a constant velocity of 24 frames per second. The vertical scanning motion contributed by the continuous movement of the film is properly combined with the vertical electronic scanning occurring in the camera tube through careful positioning and alignment of the six lenses. The problems associated with the formation of six color images from each frame of the film prevent application of standard motion-picture practice in which the individual film frames are intermittently held stationary before the projector lens.

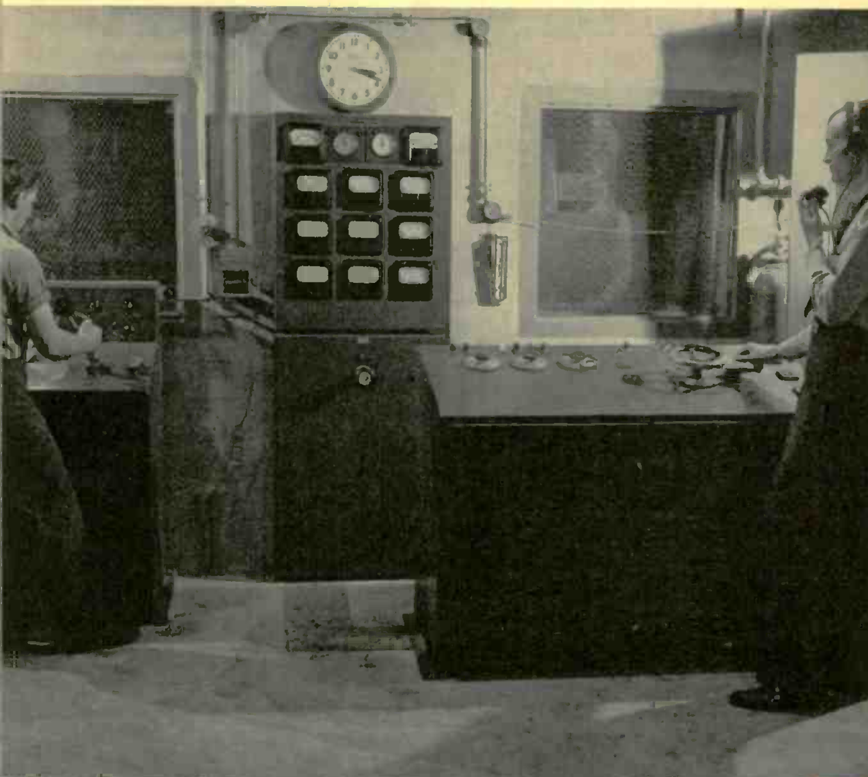
The scanning standards for the studio equipment are given in table I. In this tabulation, a "color frame" refers to the scanning of a picture once each in the three primary colors during which alternate horizontal lines are skipped. A "color picture" is composed of two color frames with a 2:1 interlace ratio and refers to the scanning of the picture once in each of the three primary colors including all horizontal lines.

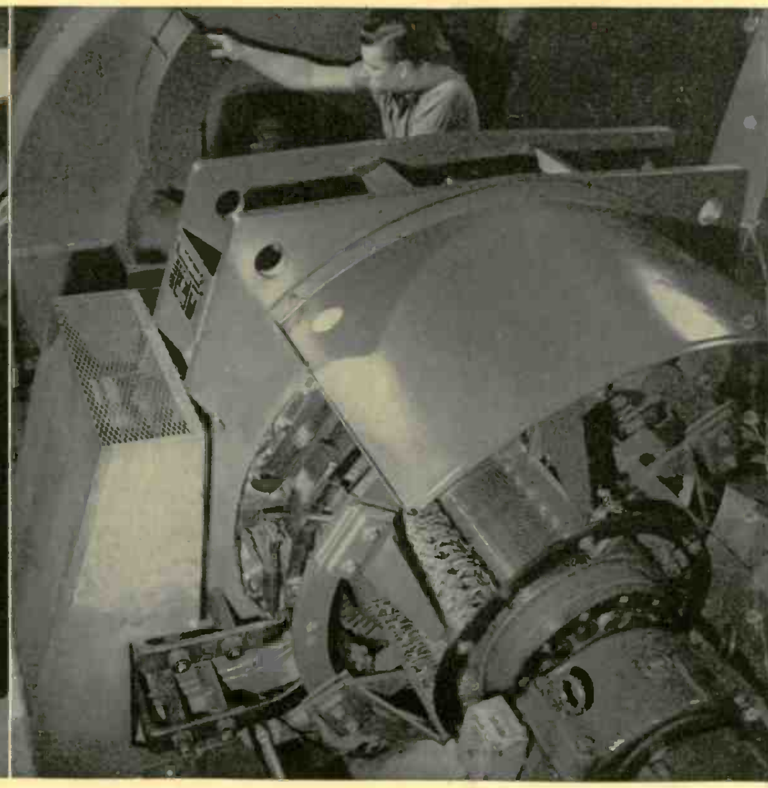
Transmitter

The design of the studio equipment is based upon a video response extending to approximately 10 mc. The established channel width for 525-line black-and-white television is 6 mc and includes allowances for both sound and video carriers and suitable guard bands. The channel requirements for color television, consequently, considerably exceed those of conventional black-and-white television. The convenient solution to this problem is to avoid conflict with black-and-white television completely by the use of transmitting channels in new bands in the ultra-high frequencies (480–920 mc). The ultra-high frequencies in this range were used extensively throughout the war for radar, and considerable operating knowledge and experience are thus available for television application.

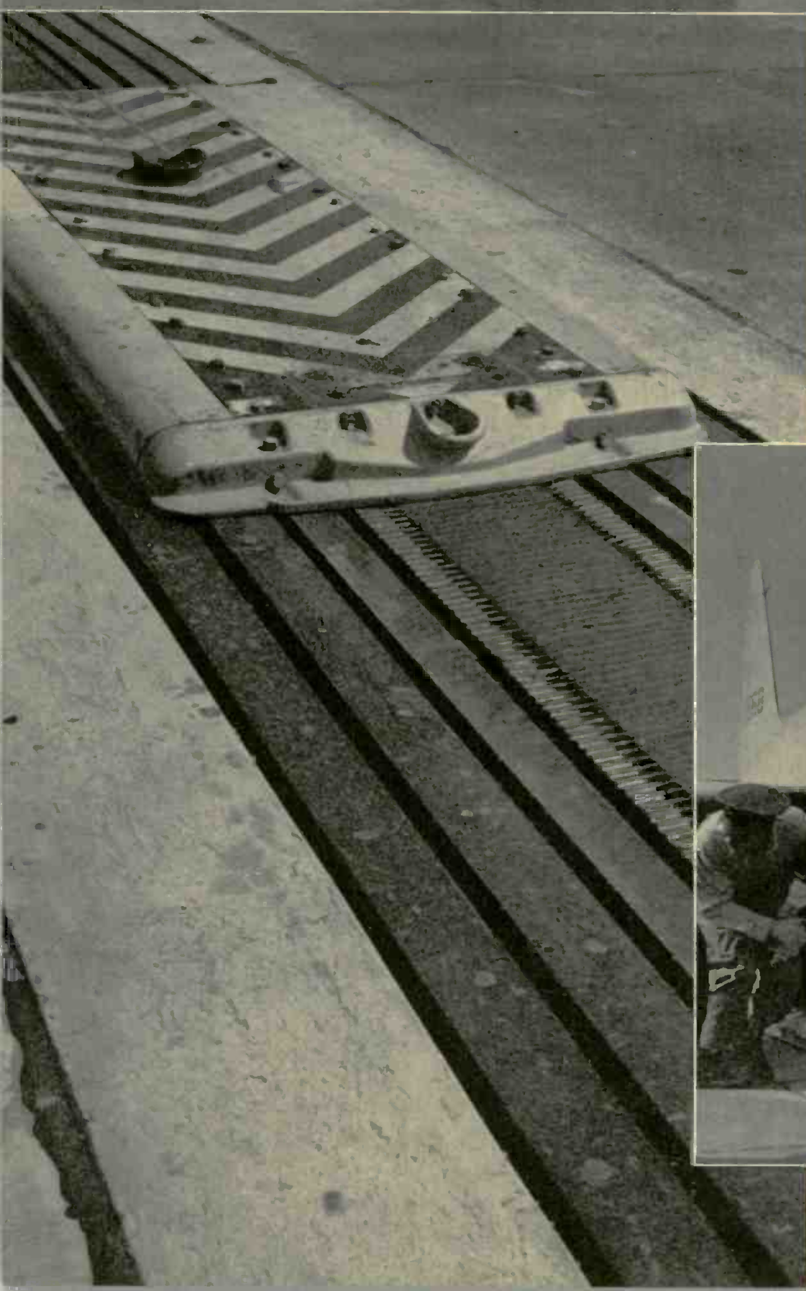
The Columbia Broadcasting System has already conducted a series of tests and demonstrations in New York City using the ultra-high frequencies. The transmitter employed operated at 485 mc with a bandwidth of 10 mc. Transmission at this frequency was found to be superior to that of the conventional black-and-white frequencies for two major reasons. First, the pictures received were free of the multi-path effects (ghosts or reflections) normally encountered in black-and-white television on the lower frequencies. Second, considerable advantage was derived from antenna gain and directional characteristics at the ultra-high frequencies that boosted the nominal power output of the transmitter being developed and designed by Westinghouse for use with the studio equipment, which will operate in the ultra-high frequencies between 525 and 545 mc and is to have a video bandwidth of 10 mc and a peak power output of 1 kw.

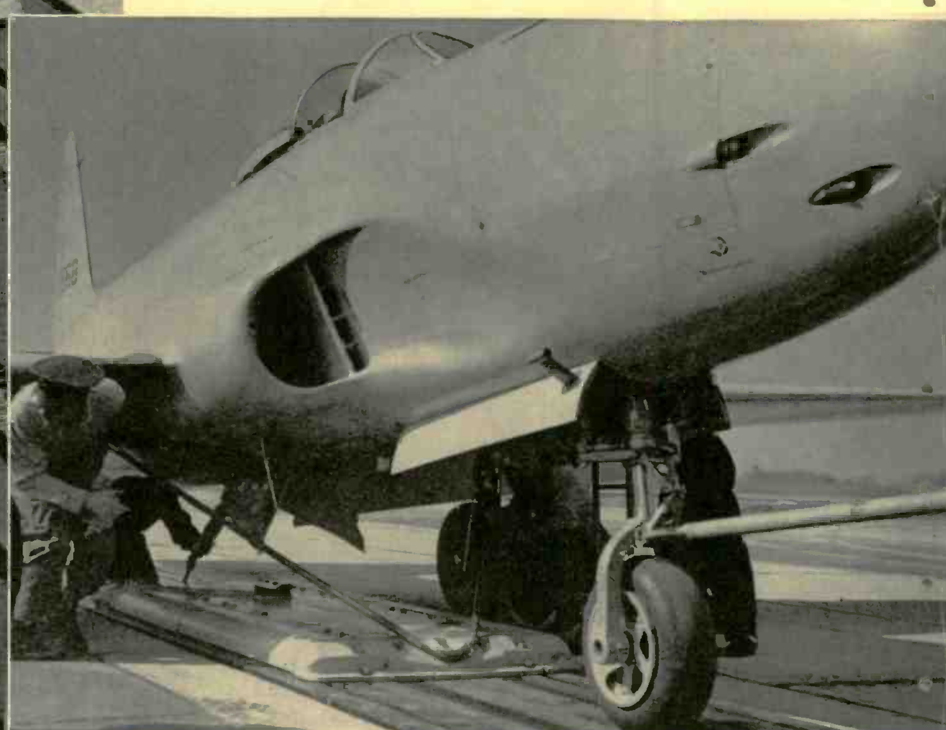
The experiments with color television in the New York area this year, the current developments in equipment design, and present production of studio components suggest the technical maturity of the art of color television. Developments and improvements, it is true, will continue—this is to be expected and desired. Color television presages a new era in communication, in entertainment, in education, and in terms of an exciting, new and great enterprise.





With a wound rotor for a track, the launching car develops 10 000 hp and can attain a speed of over 225 miles per hour. It can bring a 10 000-pound jet plane (below) up to take-off speed of 117 mph in a 340-foot run in 4.2 seconds. It imposes much less stress on the pilot, passengers, and the plane than do hydraulic catapults. Control room and the d-c motor-driven flywheel set in the underground power plant are shown in the views above.





A Wound-Rotor Motor 1400 Feet Long

Motors ordinarily are round. But they don't have to be. Indeed, two induction motors, called Electropults, are now in service, one of which is a quarter of a mile long, the other somewhat shorter. Built during the war, they were intended to serve as devices for launching heavily loaded planes from short runways on Pacific atolls. At present they are being used by the Navy for experimentation with assisted launchings of aircraft, including jet-propelled and pilotless or robot planes.

The Electropult is in every sense an electric motor. It uses the true squirrel-cage-motor principle, except that instead of the stator being in circular form with the rotor revolving within it, the stator is unrolled and laid out flat. The moving element becomes a car, running on the stator as a track. The plane is harnessed to this car and is brought up to take-off speed by the combined forward pulls of its own engines and the Electropult.

For practical reasons the track is made the "cage" or secondary and the shuttle car, the primary; although from a theoretical point of view whether the stationary part is the primary or secondary is immaterial. In any case, energy is transmitted across an airgap between a moving magnetic field and a short-circuited winding.

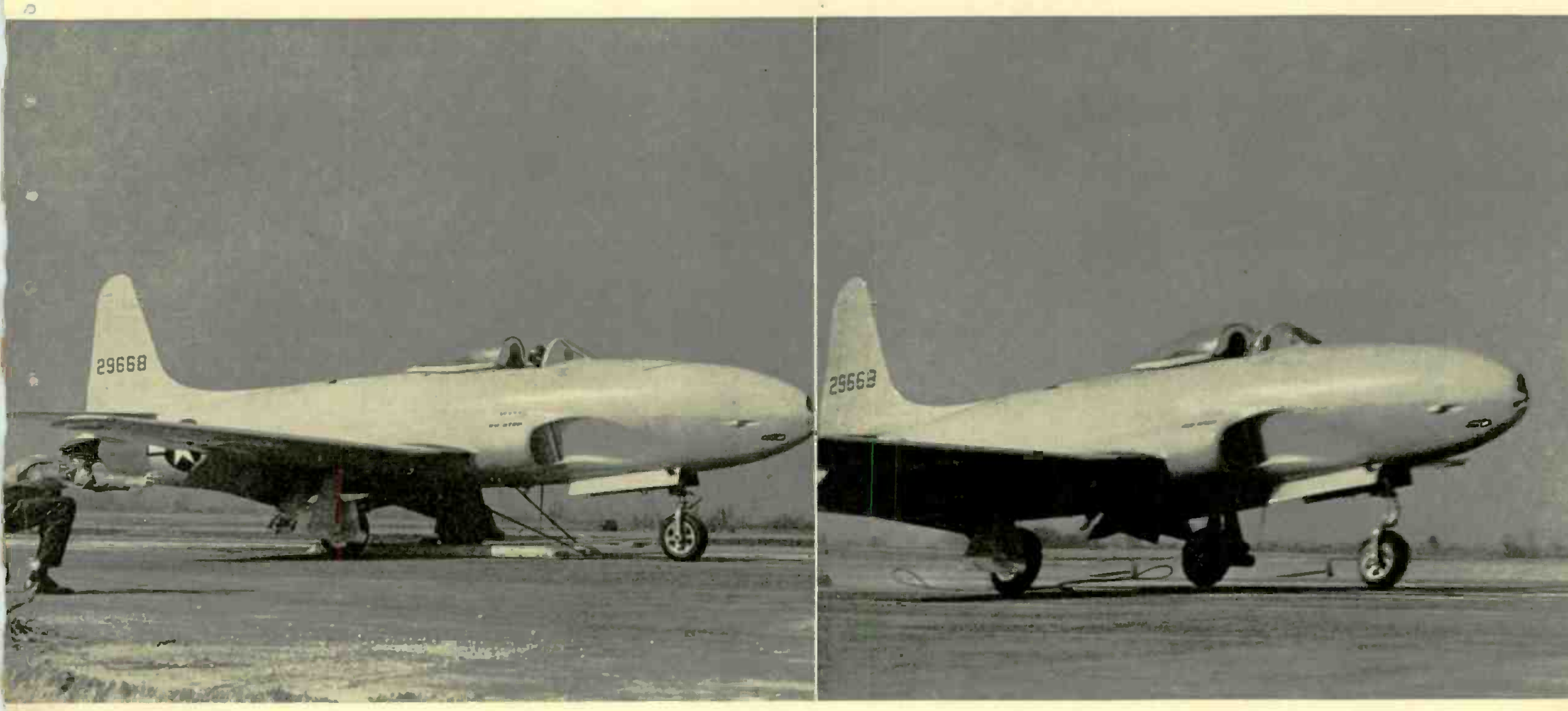
In the larger of the Electropults, the secondary, or track, is 1382 feet long and is made up of 76 sections each 18.2 feet long, set flush with the ground. The active core width is 12 inches. The resistance of the first 1000 feet of the secondary is progressively decreased in four steps. This is done by use of materials of different resistivities for slot bars and their end connections. This gives a wound-rotor effect and enables the tractive force to be held substantially constant as the speed increases. The remaining 382 feet of track is used for braking of the shuttle car. The car is stopped at the end of its run by a combination of dynamic braking and the application of direct current.

The shuttle car that tows the airplane projects above the runway surface only 5½ inches. It is 3½ feet wide and 12 long. Its wheels extend through slots that straddle the secondary and run on buried rails. A set of rails above the wheels prevents the car from being lifted upward.

The amount of power transmitted across the airgap during a launching run is about 10 000 kw. To collect the high current required at the maximum speed of 225 mph, (about 7000 amperes during acceleration and 10 000 amperes during dynamic braking) twelve shoes per phase made of sintered copper graphite on a copper base are held against the submerged collector rails by spring pressure.

The power plant and control station are located in a nearby underground vault. An aircraft-type gasoline engine drives a 750-kw d-c generator. This power is taken by a d-c motor that drives an a-c generator and a heavy flywheel. About 95 percent of the energy for a launching is taken from the flywheel, the remainder being provided by the engine drive.

Although developed for launching military planes, the Electropult has other interesting possibilities. It does not have the limitations in speed or capacity of the mechanical types of launching devices and provides a much more comfortable acceleration rate. Variants of the Electropult may be suitable for large aircraft carriers and for commercial airports as a means of keeping the take-off distance within reasonable limits. Also the Electropult—strangest of electric motors—may even be developed in a form as a retarder for airplane landings, serving the very desirable purpose of shortening the landing run, of large heavy transports.



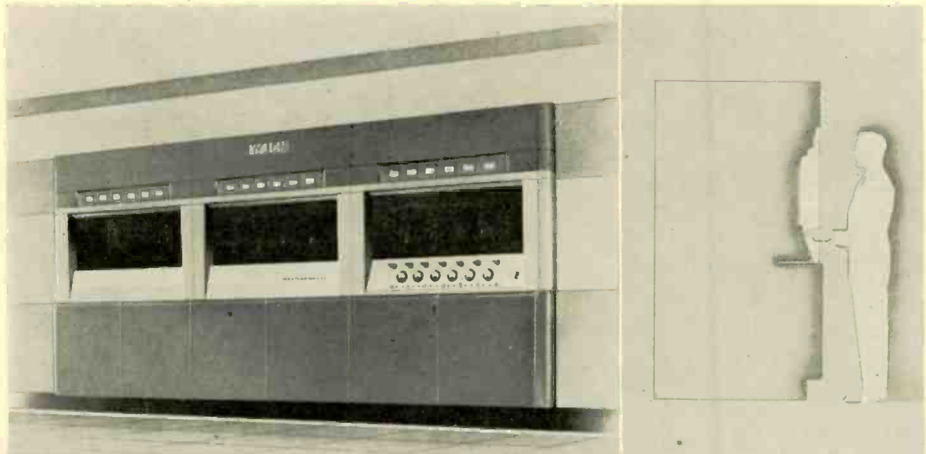
What's New!

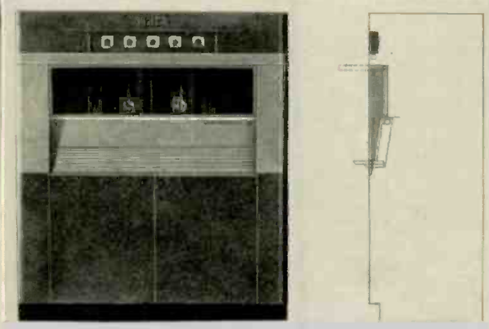
Industrial Secondary Network Design Simplified

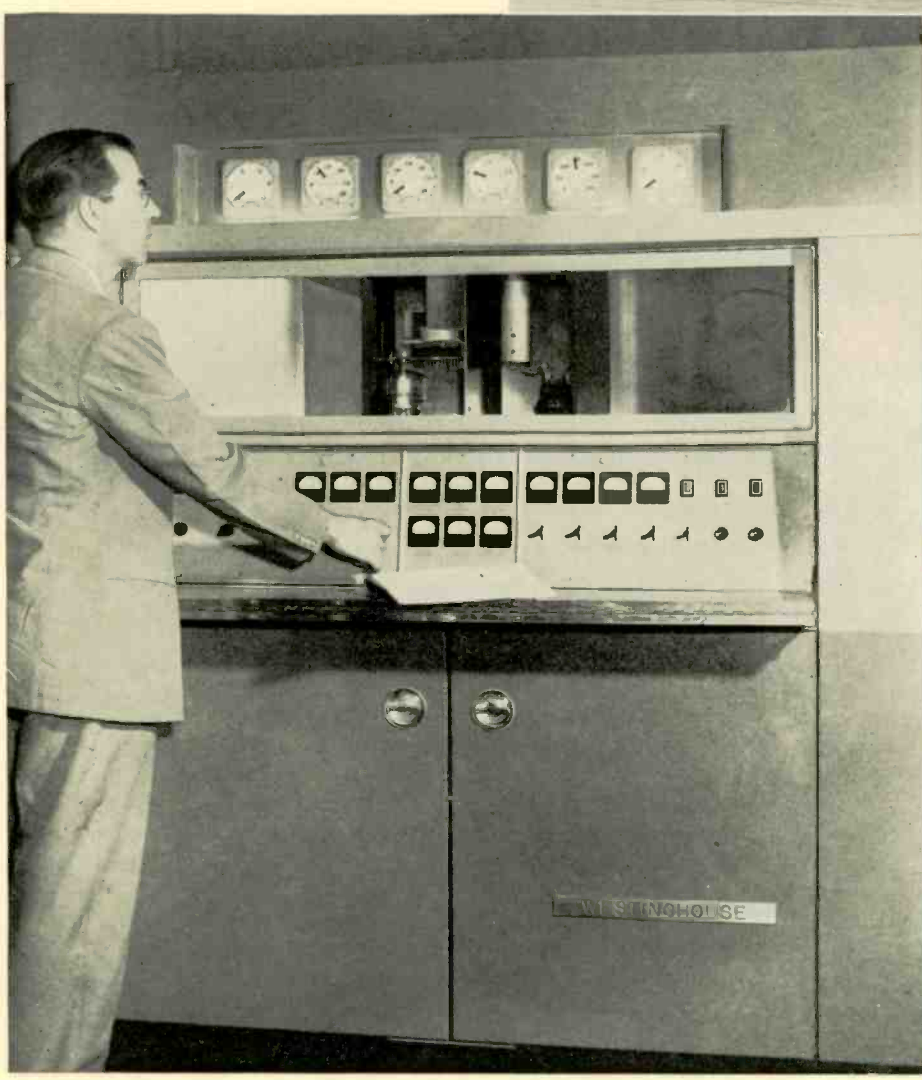
THE excellent service record piled up by secondary network systems in city business areas and large commercial buildings is causing more and more interest in their use for industrial plants. Network continuity-of-service records are excellent. By use of networks, voltage regulation is improved, conductor heat losses are lower, and load division among transformers is even, although heavy loads may be concentrated at one spot.

The secondary network differs from the radial system in three major points. First, a network protector is connected in the secondary leads of each network transformer in place of the usual secondary breaker. Second, the secondaries of all transformers are connected by a ring bus or secondary loop from which the loads are fed over short radial circuits. Third, the high-voltage supply consists of two or more primary feeders having sufficient capacity so that the entire system load can be carried without overloading when one of the primary distribution feeders is out of service.

A booklet entitled "Industrial Plant Network Systems," written by John S. Parsons, distribution engineer of Westinghouse, will prove an invaluable aid to those considering these systems. Summarizing the advantages of industrial networks, the booklet also goes into details of the best systems to be used for most applications.







The new Westinghouse FM broadcast transmitters are based on the findings of a survey among 91 stations. Above are artists' views of a 10-kw and 1-kw FM transmitter incorporating the user suggestions. Left is a completed transmitter.

Five general types of secondary networks are illustrated and the advantages of each are described. The booklet contains a simplified method of calculating short-circuit fault currents on any load bus in the system. Tables and curves are given that reduce these complex problems to but little more than reading a simple chart.

"Industrial Plant Network Systems" can be obtained free by addressing Westinghouse Electric Corporation, P. O. Box, 868, Pittsburgh (30), Pennsylvania, and requesting booklet number B-3690.

Power Line on Parade

VERY few power lines get the opportunity to travel. But at least one is scheduled to make a 30 000-mile tour of the country in the next twelve months. It is a line built by Westinghouse engineers and equipped with all the latest apparatus for the operation and protection of power-distribution lines from source to customer. Mounted on a specially designed truck, the line will be demonstrated under actual working conditions to most of the larger public utilities, municipal, and REA power companies throughout the country.

The demonstration is based on the operation of a complete representative power line actually energized at 2400 volts. Power is fed in from any convenient a-c line capable of supplying 60 amperes at 110 volts, and distributed over a line simulating some five or ten miles of construction. Arranged along 35 feet of miniature line are disconnect switches, boric acid fuse, automatic-reclosing pole-type breaker, lighting-protective devices, and a primary shunt-connected capacitor. There are even automatically operated simulated tree branches to cause line troubles when desired.

Lightning—both cause and cure—takes a prominent place in the show. Actual flashovers and electrical storm troubles are produced by a 100 000-volt lightning generator on any part of the line while it is energized at operating voltage. Lightning arresters and fuses can be operated at will under actual field conditions to protect transformer windings. Fault currents heavy enough to operate fuses and breakers under severe conditions are delivered by a specially designed motor-generator set with a heavy flywheel. Coordination of fuses and reclosers can be shown graphically under any type of fault or overload condition.

More detailed views of many of the distribution devices are given on the second side of the truck, where cutaway sections are mounted to show the interior construction. Exhibits also include a wide assortment of street-light heads and reflectors, various types of meters, fuses, cutouts, and many other types of distribution equipment.

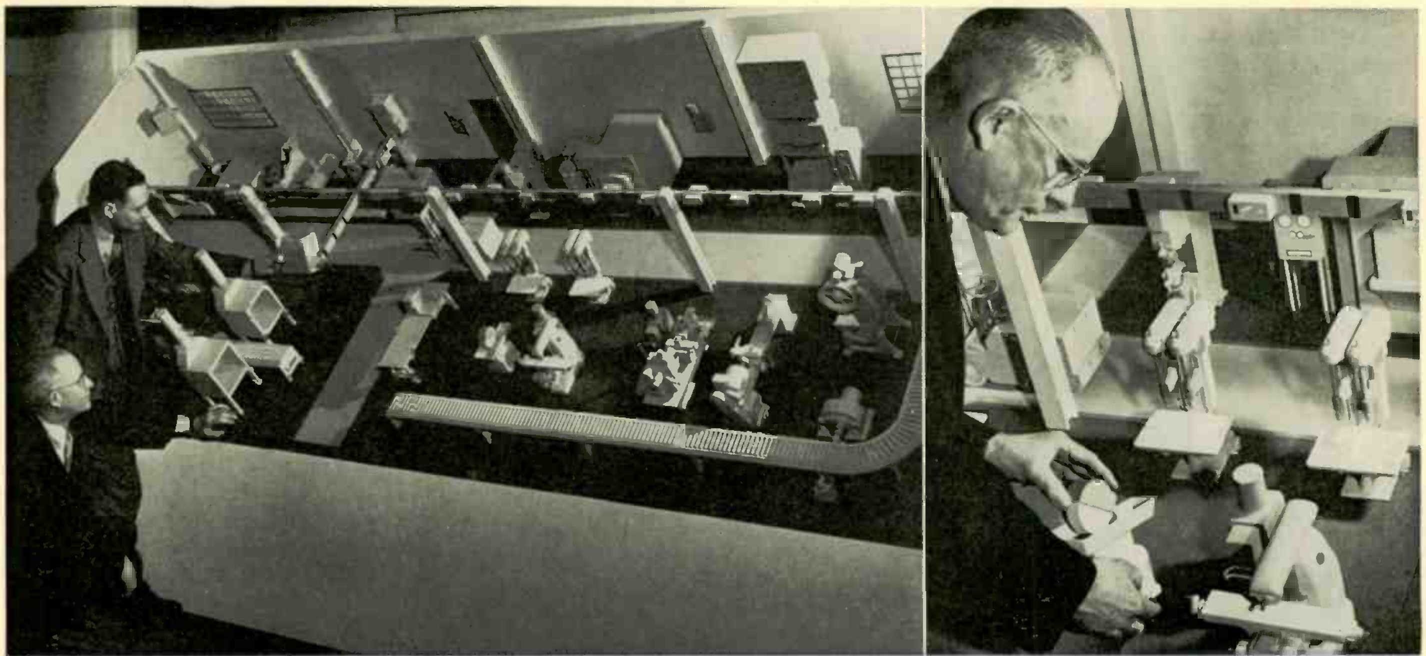
The principles and basic equipments of electric-power distribution and is protection are visibly displayed by a distribution system on wheels. A surge generator makes possible the demonstration of each type of protective apparatus.

REA Construction Manual

All the essential data for the engineering or actual field construction of rural REA distribution lines are included in a booklet issued by Westinghouse. The booklet, although pocket size, is most complete in its scope. It is compiled from official REA drawings and specifications. From detailing the method of digging an anchor hole to drawings complete with dimensions for a 33-kv substation, the booklet omits little of the information necessary to select, order, or apply correct REA-approved equipment in pole-line construction.

The manual is intended for the man entrusted with the building and operation of an REA line. To expedite ordering, an important column has been added to every REA bill-of-material table. It shows the ordering number of every item whether or not it is a Westinghouse product. Other valuable information includes: useful data on pole mountings; application data for reclosing circuit breakers; application instructions for REA distribution transformers; and drawings for a typical REA substation and three-phase power installations not covered by REA official drawings. Nomenclature throughout the book corresponds exactly to that used in the REA official Construction Contract.

The manuals may be obtained at the nominal price of one dollar by addressing Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh, (30), Pennsylvania.



Plug-in scale models of electrical equipments for factories and demountable bus-duct systems show how plants can be modernized.

With a sturdier base section high-voltage arresters become self-supporting.

Lightning Arresters That Stand Alone

As transmission-line voltages increase, so does the height of lightning arresters, more and more units being piled on top of each other to withstand the higher potentials. The height of arresters rated above 100 kv has been such as to require a support at the top to resist pressures developed by high winds. These braces must be insulated as the top of the arrester is at line potential. Thus the braces and necessary structure complicate the switchyard and add to its expense.

Braces part way up would be at lower potential and somewhat simpler but their effect is to upset the voltage distribution over the arrester resulting in either unsatisfactory arrester operation or the use of a higher voltage arrester.

The problem is being solved by making the bottom section of the arrester larger in diameter than the others. Rated electrically at 37 kv this section is used as the bottom unit of the arrester stack. Standard 25- and 38-kv units are mounted on the more massive unit in the usual fashion to make up 109- and 121-kv arresters. The arrester is interchangeable with present installations because the bolt circle of the new base section is the same as previously used.

The result is that a costly structure needed solely for bracing the arrester is no longer required.

Production Power Forum—An Industry Aid

With materials and labor costs steeply rising, industry has a host of major problems. The electrical industry, with new developments in electronic controlled resistance welding, infrared drying, improved lighting, better wiring, high-frequency heating, etc., has the answers to many of those problems. An impressive traveling forum has been assembled by Westinghouse to help bring these problems and answers together. Productive Power, as it is called, is a mobile forum consisting of elaborate demonstration models of seven applications of electric power, accompanied by speakers who, by aid of these demonstration models, movies, charts, and case examples, show how effective use can be made of these electrical aids by industry. Although the forum employs attractive staging, action equipment, and ingenious lighting, it has been designed to be transported by trucks and is expected soon to begin a nationwide tour.

Care for Electronics

Electronics is getting well beyond the glamour stage. Large quantities of many kinds of electronic apparatus are in service, and with service goes need for maintenance. Care of this equipment is being reduced to general rules, which are set forth in a handbook "Maintenance of Industrial Electronic Equipment." The basic maintenance operations are discussed as applied to vacuum and ignitron tubes, capacitors, resistors, fuses, bushings and insulators, relays, switches, transformers, filter chokes, terminal blocks, meters and other components. Safety precautions to be observed during preventive maintenance operations are also included. A copy of the booklet, B-3658, may be secured from the Westinghouse Electric Corp., P.O. Box 868, 30, Pa.

PERSONALITY PROFILES

Dr. J. E. Hill is equally at home with a nucleus, a microwave, or a star. The first two have taken up most of his working time since he joined Westinghouse in 1940, while the third is part of his hobby of astronomy which he rode diligently until war work interfered. A winner of one of the five annual Westinghouse Research Fellowships, Dr. Hill came to the Research Laboratories from the University of Rochester where he was granted his doctorate and where he worked on the cyclotron with Dr. Lee A. DuBridge, recently appointed president of California Institute of Technology. This followed seven years as an instructor in physics at Kalamazoo College in his home town, where he went after obtaining his B.S. degree from Western Michigan College and his M.S. degree from the University of Michigan.

The purpose of the Westinghouse Fellowships is to promote pure research, and Dr. Hill was well into some interesting phases of nuclear fission when war intervened to put the emphasis on immediate military projects. The result was that Dr. Hill was asked to refrain from smashing atoms and concentrate on the development of microwave apparatus. Here he distinguished himself in the field of radar developments for the Army and Navy, one of his special projects being work on an airborne set for night-fighters. At this writing Dr. Hill has returned to his first love of nuclear physics and has taken up residence at Oak Ridge, Tenn., as one of a group of Westinghouse scientists and engineers asked by the Army to assist in development of an atomic power plant. Some day when the pressure eases he hopes to devote a little spare time to look-

ing through the business end of a telescope as he did while at the University of Rochester. Gives him a new perspective on things, he says.

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While *W. R. Harris* was in high school in Welch, West Virginia, a civics teacher assigned the class an essay on "What I Want To Do." Young Harris chose as his subject electrical engineering. A few years later he was enrolled in that school at West Virginia University, indicating a singleness of purpose that subsequent events have verified. Even the lure of big-name dance bands—he played a hot sax at college proms and local nighteries—didn't sway Harris from his course. Then, when he joined the Westinghouse graduate-student course in 1937 with a B.S. in E.E. to his credit, he decided on application engineering as his field. A year later he was doing just that in the Industry Engineering Department.

Harris' specialty is the application of electrical drives and control apparatus to paper-mill machinery, with particular emphasis on the Rototrol as a regulator of speed, tension, and position. But he also devotes considerable time to the design of electrical equipment for college laboratories, like the steam laboratory set-up he describes jointly with F. K. Fischer in this issue. One evening a week you'll find him at the Westinghouse Educational Center teaching a course in the application of electrical equipment to industry, as part of the University of Pittsburgh-Westinghouse graduate study plan. Harris, incidentally, obtained his master of Science degree in 1941 under this plan. In addition, just to make it a full day, he conducts a class in industrial-motor application on the Westinghouse student training course.

F. K. Fischer is no stranger to these pages. He was co-author of one of the most popular articles ever printed in this magazine, "The Gas Turbine," in May, 1944. Fischer, a graduate of Rensselaer Polytechnic Institute in 1930, has spent most of his time at Westinghouse in the Steam Turbine Division, of which he is now on application engineer.

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Since 1938, when *S. Herwald* was awarded a B.S. in mechanical engineering at Case University, he has pursued a teaching fellowship at Case for a year, achieved an M.S. in engineering and a Ph.D. in mathematics and engineering, both at the University of Pittsburgh. Early in that period (1940) he came to Westinghouse and has served under the tutelage of such engineers of renown as E. Arnold and J. F. Peters. Most of the war years were spent applying servomechanisms to aircraft fire-power control and turret stabilization. One servo problem of particular interest in which he has had a hand was the development of a method of airplane-wing vibration for testing the action of large wing structures at high speed.

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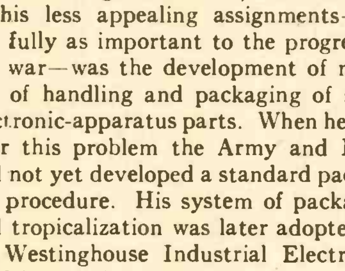
At 28, *D. L. Balthis* is an electronics engineer with a string of accomplishments to his credit. Of course most electronics engineers are young, because electronics is an infant branch of engineering. Balthis' record is representative of the pattern set by so many young physicists during the war years when electronics was accelerated to the status of a major industry. The timing was just right for Balthis. He was ready for industry just before the war broke in 1941. He came to Westinghouse in June before the attack at Pearl Harbor, setting to work in the Industrial Electronics Division. His war assignments carried top priority. He aided in the development of the now famous SCR 584 and SCR 784 radar sets, and later assisted with the design of the proximity fuse, one of the best kept secrets of the war. Not all of his work



was with the glamour stuff, however. One of his less appealing assignments—but one fully as important to the progress of the war—was the development of methods of handling and packaging of spare electronic-apparatus parts. When he took over this problem the Army and Navy had not yet developed a standard packaging procedure. His system of packaging and tropicalization was later adopted for all Westinghouse Industrial Electronics Division equipment.

Balthis' formal technical training was obtained in Virginia. He majored in physics at Randolph-Macon obtaining his B.S. in 1940. Following graduation he spent a year at Virginia Polytechnic Institute, which conferred on him a Master of Science degree.

Unrolled Motor

The most powerful locomotive ever built is likewise the smallest. It is also the fastest thing on wheels. The rotor of this unusual motor develops 15 000 hp, can attain a speed of 225 mph, yet is only a half foot high. It is the Electropult, the Navy's newest airplane launching machine. (See p. 160.)