Mr. T. R. Scott

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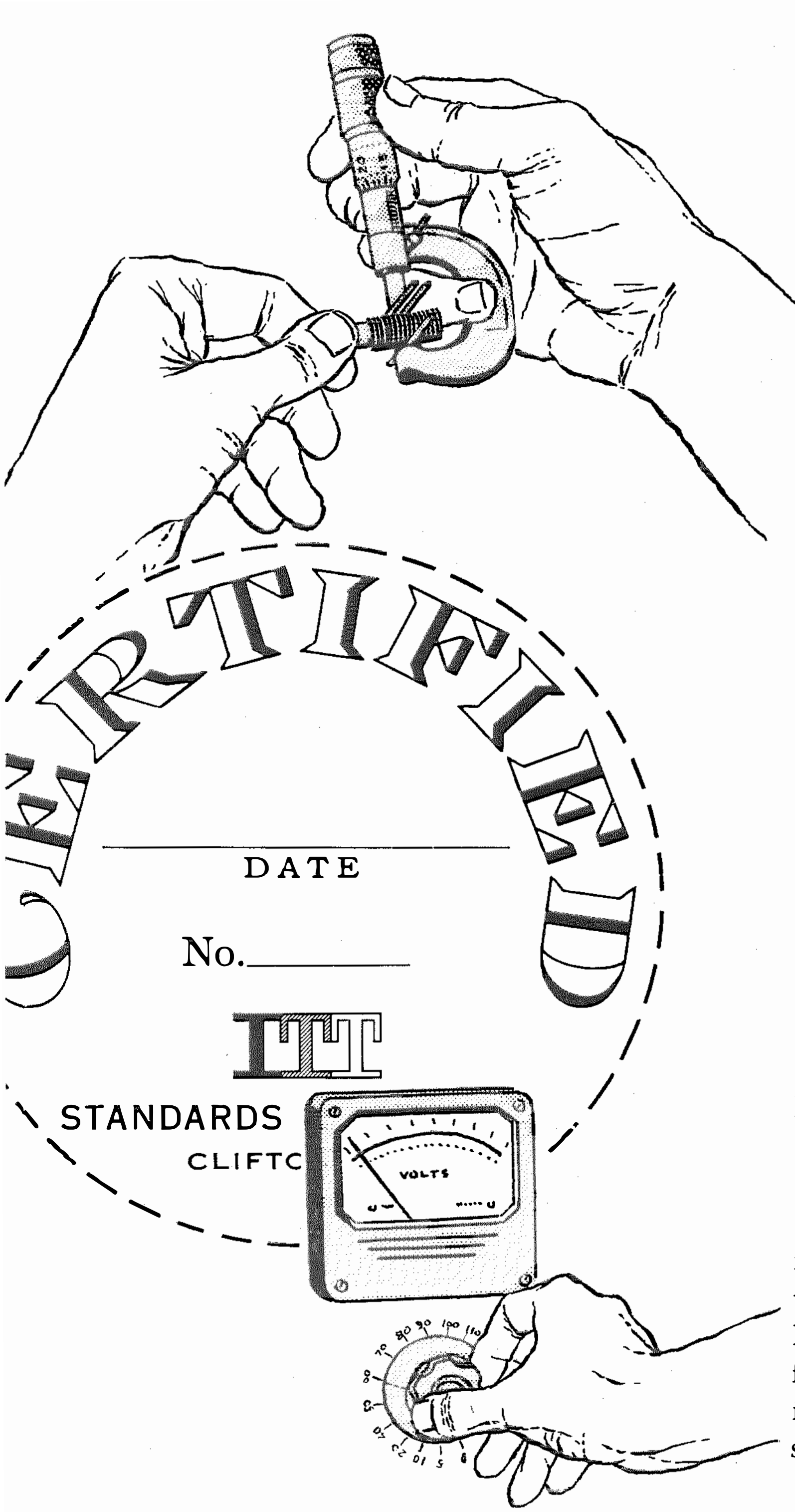
ELECTRICAL COMMUNICATION

The Technical Journal of
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
AND ASSOCIATE COMPANIES

CONTENTS

VOLUME 36 **1960** **NUMBER 2**

ITT STANDARDS LABORATORY



Measurements of mechanical and electrical properties are made with a wide range of precision depending on the specifications for the product under manufacture. Often, the established pattern of specialization in industry results for instance in the production of mating parts, such as screws and nuts, in different locations. Nevertheless, these mating parts must be coordinated as to size and material to fit together and support the designed load regardless of where, when, and under what conditions they are manufactured.

In high-output economical production on automatic machines, it is not safe to assume that the cutting tools retain their original sharpness and dimensions, or that the machines remain in adjustment indefinitely. It is necessary that the work and the tools themselves be checked from time-to-time against production gages to avoid out-of-tolerance performance.

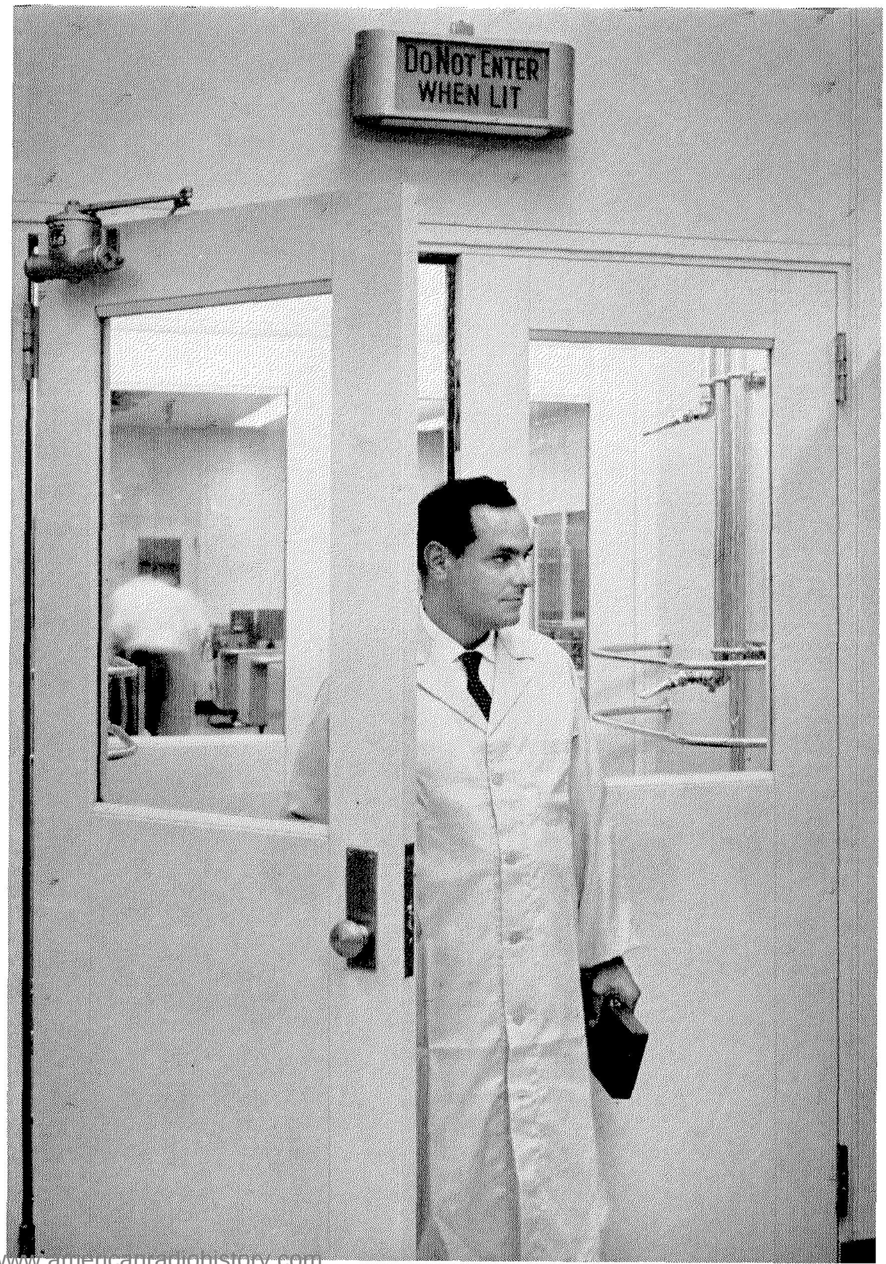
In time, the production gages may wear and are in turn checked by master gages that are used only for this purpose. It is to the testing and certifying of these master gages and the corresponding electrical devices that the ITT Standards Laboratory is dedicated. The following description of its facilities is divided into two parts, the first on mechanical and the second on electrical precision testing.

1. Mechanical Laboratory

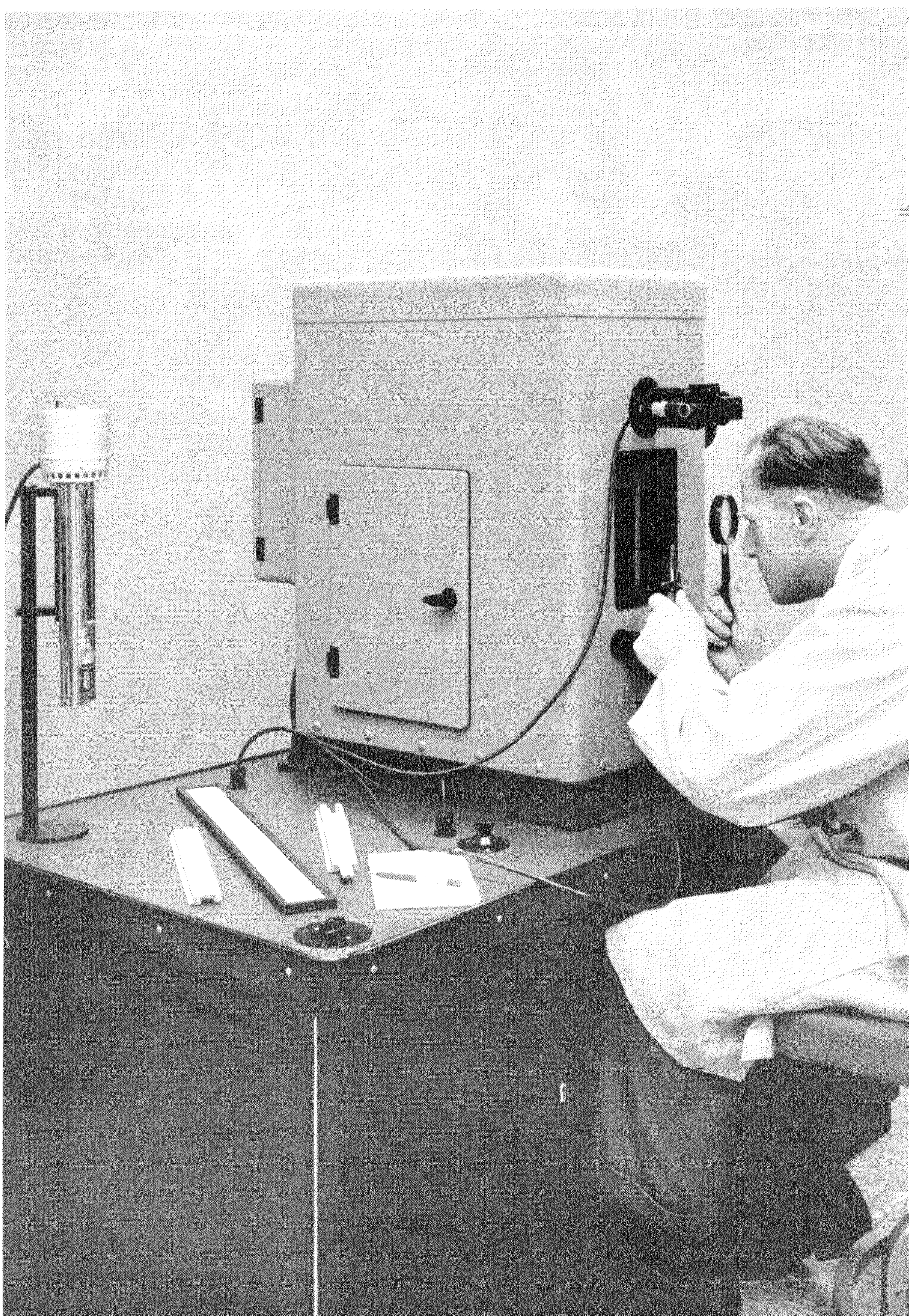
In the field of mechanical measurement, the fundamental unit is that of length. Perhaps with the exception of hardness, all tests are in terms of dimensions. Consequently, it is the first prerequisite that facilities be available to provide an absolute standard for length that can be compared and transferred to other standards directly suited to the various tests, many of which are basically comparisons of master and unknown gages.

In many fields of measurement, particularly those involving length and time, science is increasingly coming to rely on atomic physics. One important discovery is that each atomic element when sufficiently excited, say electrically, radiates discrete frequencies; for a given element, the frequencies never vary and they have been measured to great accuracy. These frequencies have become our standard measure of time—the wavelengths corresponding to them are our primary measure of length.

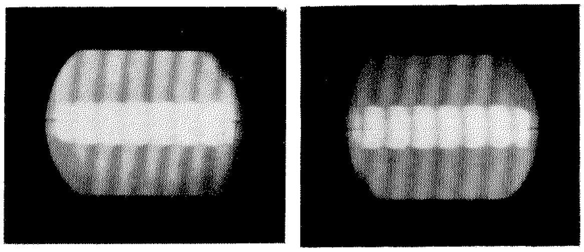
The International Bureau of Weights and Measures has decreed that the standard of length is established by the wavelength of one emission line in the red region of the visible light given off from an electric discharge between cadmium electrodes. This wavelength, being both unvarying under constant conditions and readily produced by simple means, is an ideal standard of length. It is particularly well suited to the measurement of very-small dimensions.



Entrance is made to the mechanical laboratory through an interlocked compartment in which all dust and lint is blown from the clothing of an individual; absolute cleanliness is necessary to assure accuracy of measurements.



1.1 Gage Blocks



Interference fringes at two wavelengths of light.

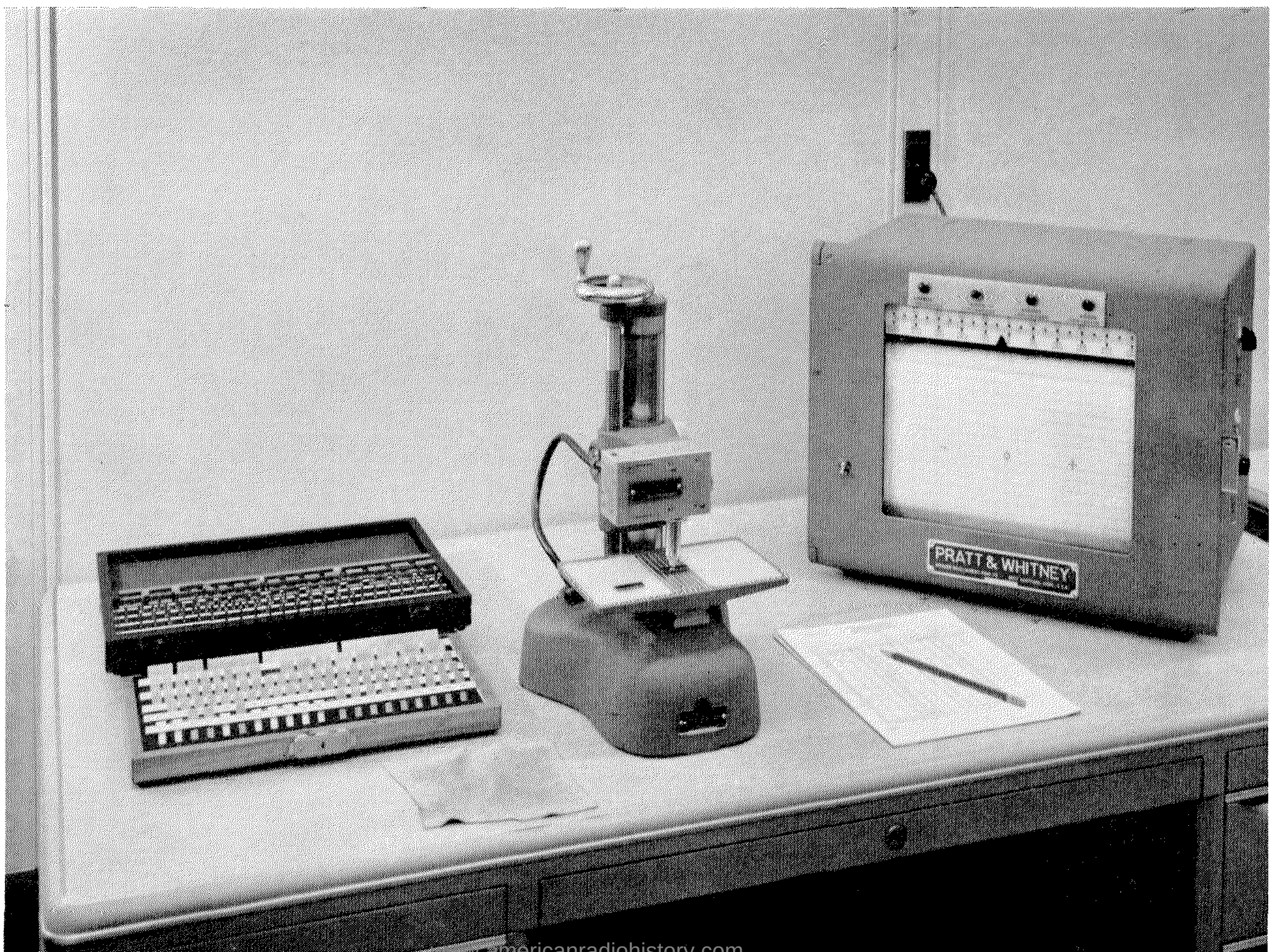
In the Carl Zeiss, Koester's Absolute Interferometer, shown on the facing page, is established the calibration of reference gage blocks to an accuracy of better than ± 0.000 002 inch (0.000 051 millimeter). These blocks are used in industry and science as reference standards of length. The "working" blocks are periodically checked against these masters.

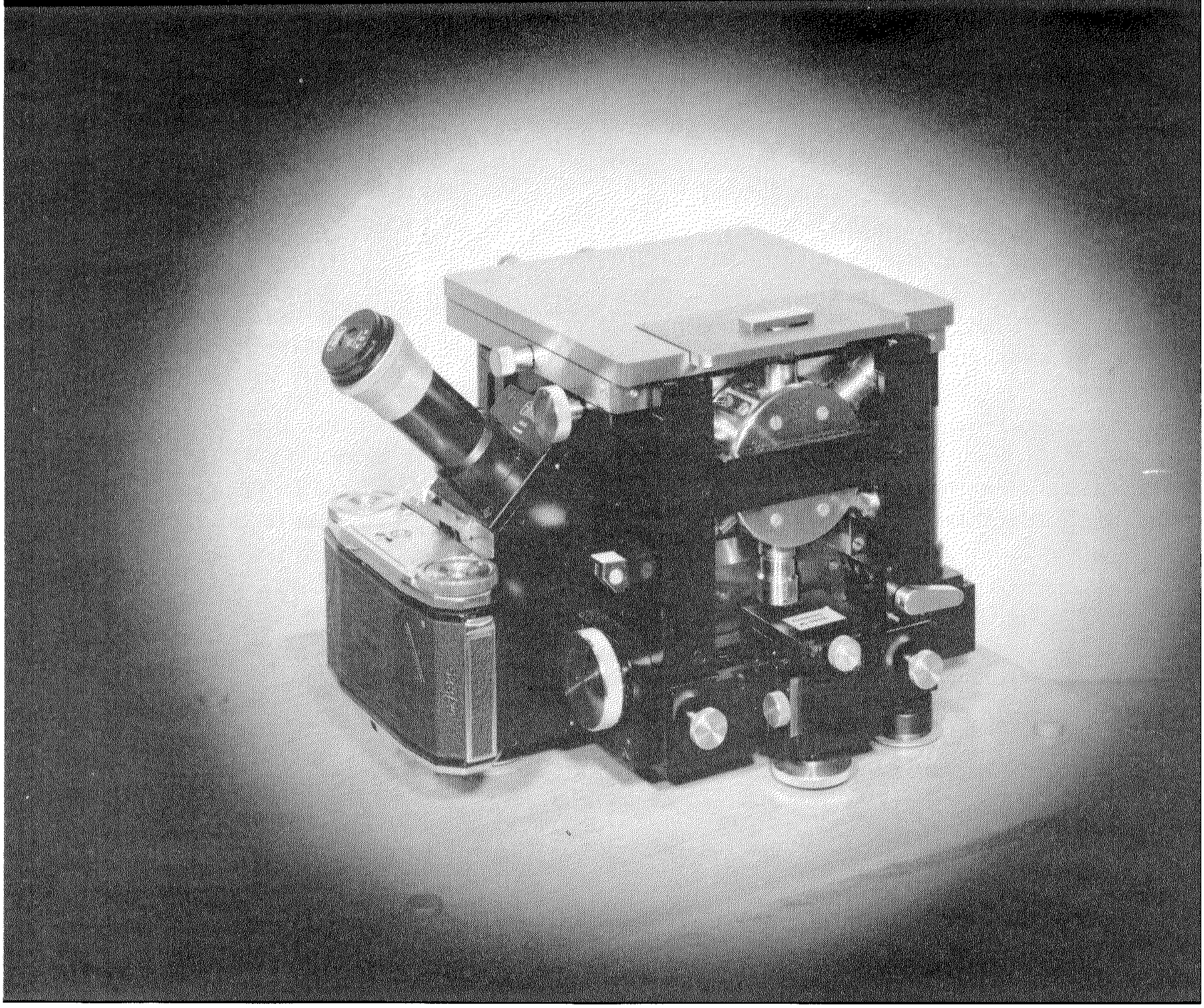
In the interferometer, the exact length of a block and its parallelism are measured in terms of the wavelengths corresponding to 6 frequencies in the visible part of the emission spectrum of the rare gas, helium.

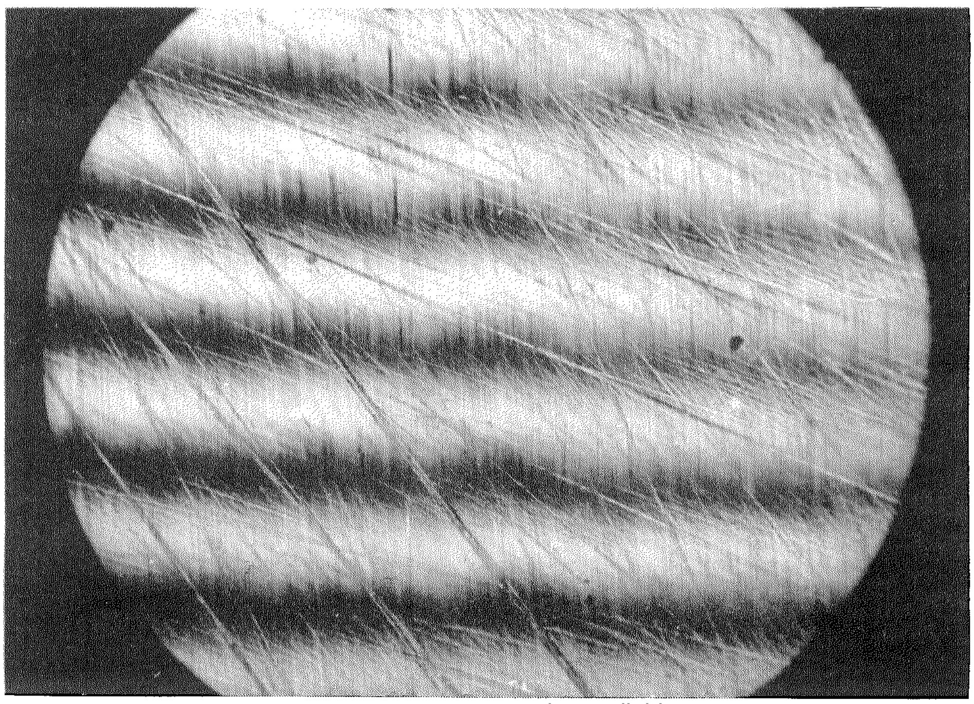
In the photograph, the physicist rechecks the temperatures within the instrument to within 0.01 degree centigrade after making a measurement. He will determine the dimensions of the block using the special slide rules on the desk. Because the wavelength of light in air changes very slightly depending on humidity, barometric pressure, and temperature, a correction factor will be obtained using the electrical psychrometer and a barometer mounted on the back corners of the table.

The interferometer is the instrument that sets the accuracy of all measurements made in the mechanical laboratory.

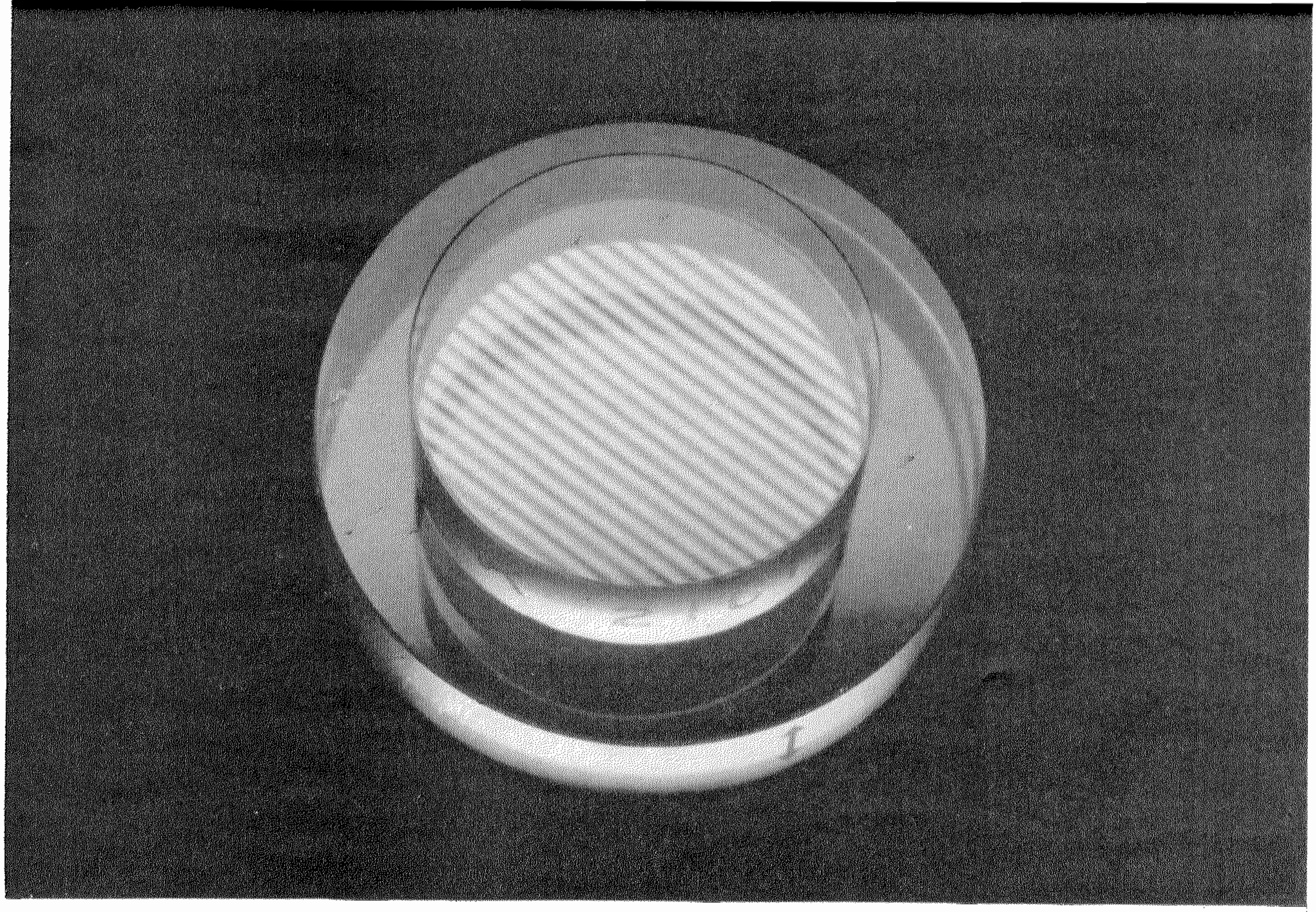
Gage blocks can be intercompared to within ± 0.000 001 inch (0.000 025 millimeter) on the Pratt and Whitney Electrolimit Gage.



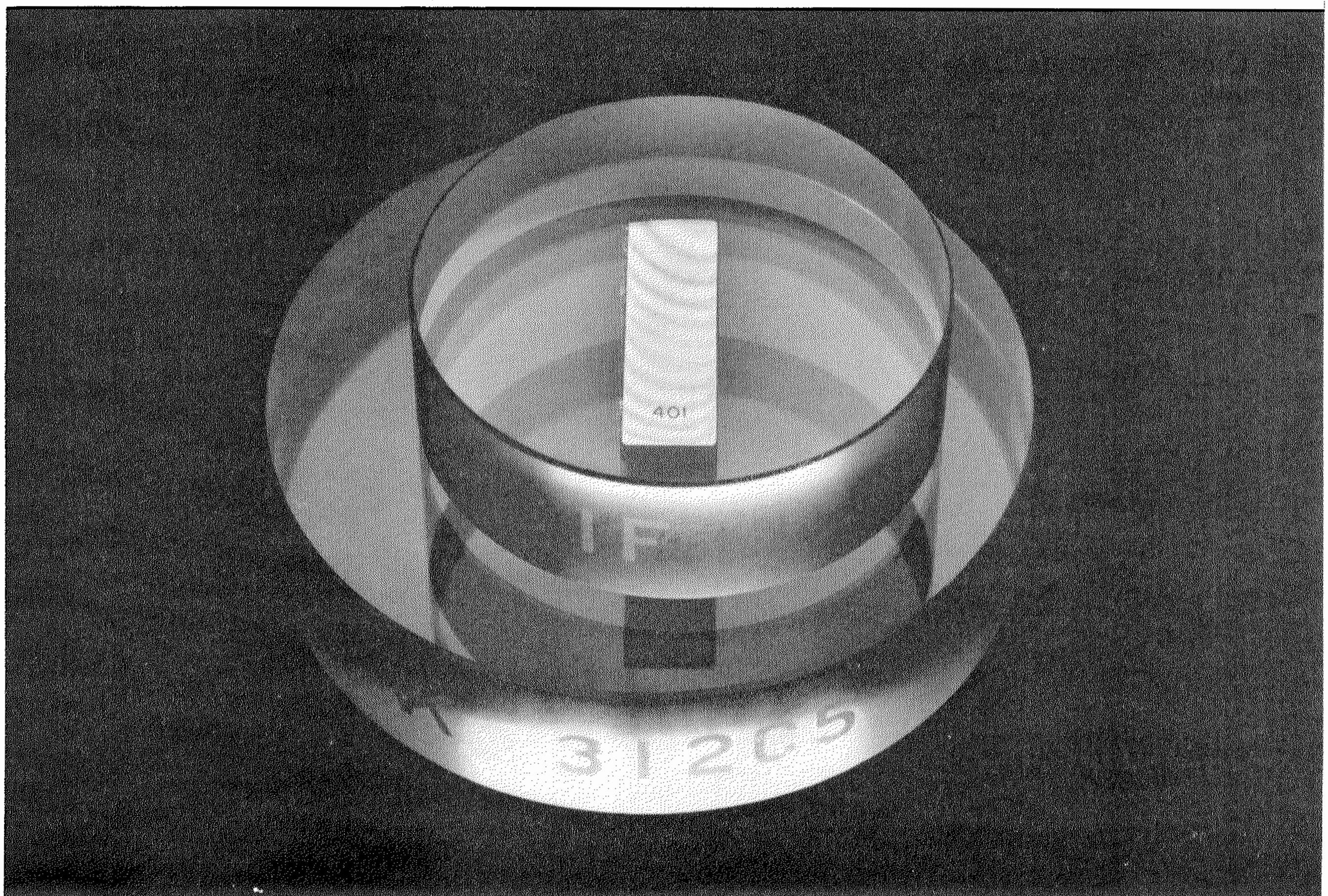




The interference mic
measures the surface f
gage blocks and other p
surfaces. A 600-diame
largement of the view
the instrument is show
left. The average width
dark bands in the enlar
indicate that the scratc
3 to 4 microns deep;
eye, the surface is smo
highly polished.



Optical flats like those shown above can be used to determine the flatness of small objects. The straight parallel bands indicate that the flats are as nearly perfect as possible; the curved unevenly spaced bands on the surface of the gage block shown below indicate that it is very badly worn.

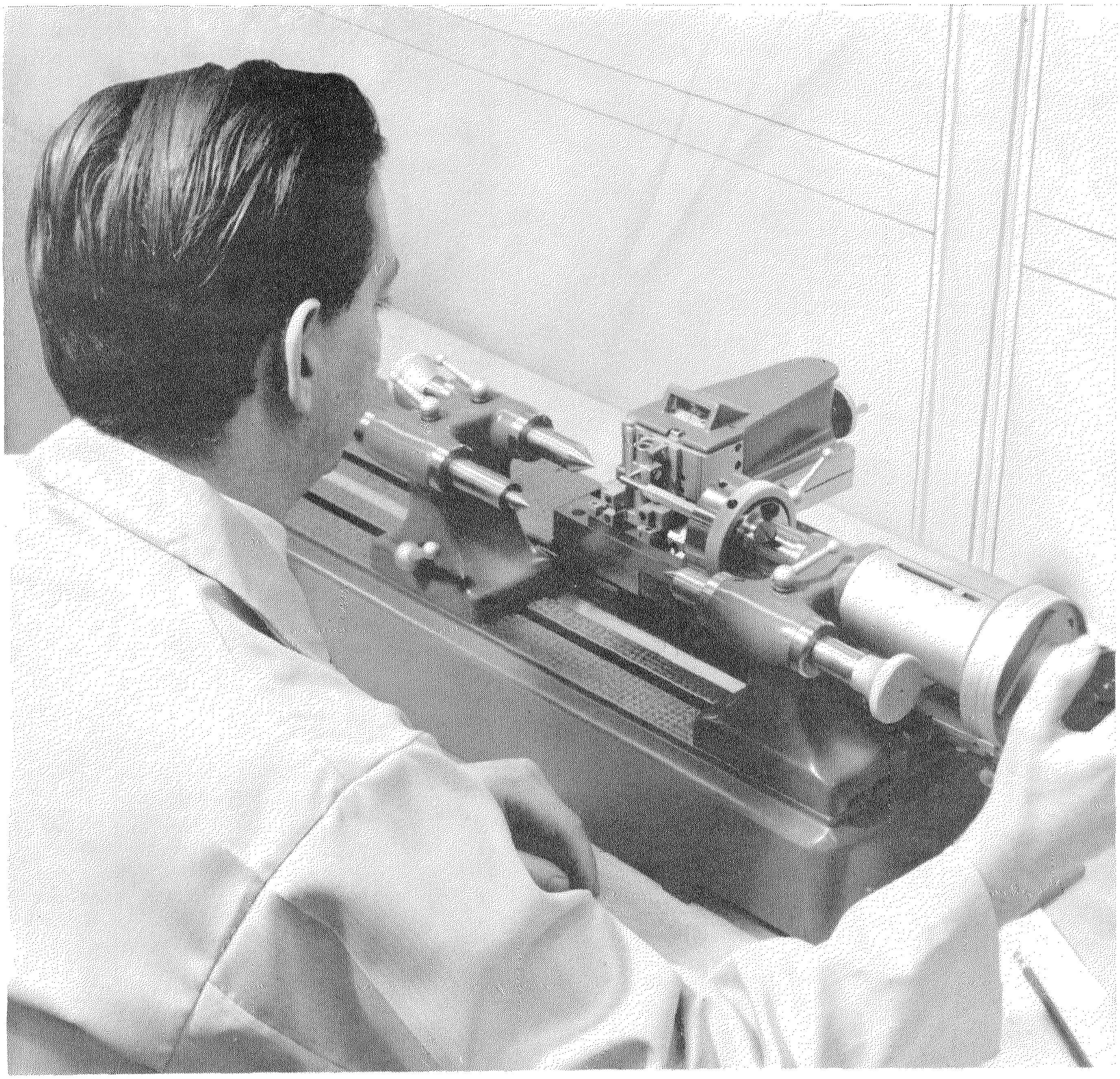


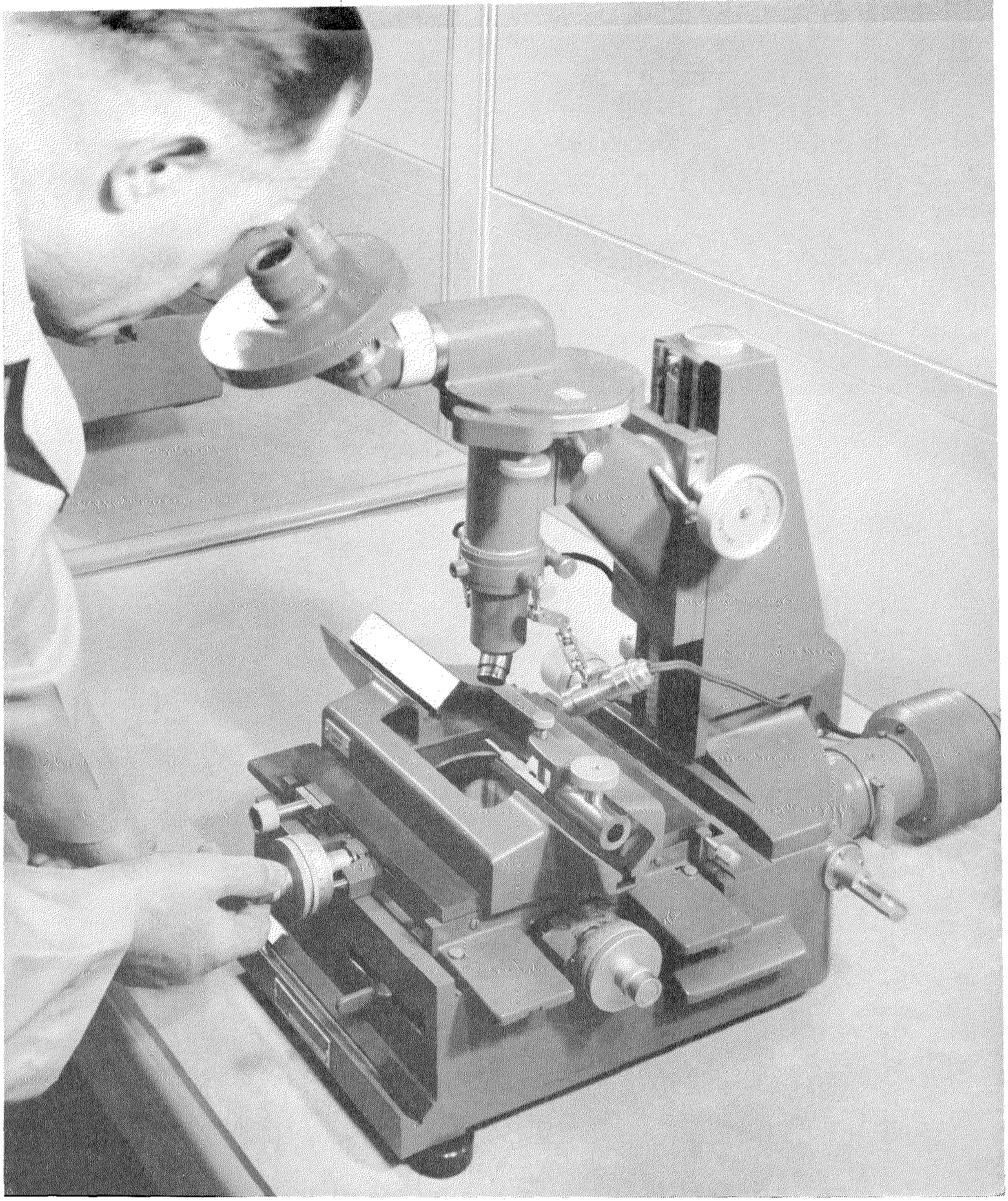
1.2 Threaded Set Plugs and Ring Gages

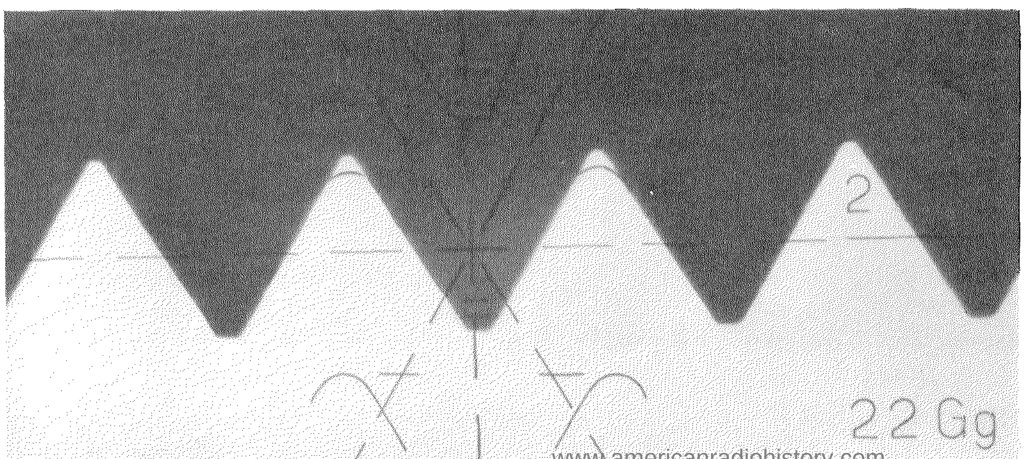
Usually, three features of threaded set plugs are checked for wear. In general, it is unnecessary to test for surface finish and hardness.

The first check, of pitch diameter, is made on the Pratt and Whitney standard measuring machine (opposite page). The plug with thread-measuring wires inserted between the threads and the measuring anvils is held under a prescribed pressure. The measurement over the wires is indicated by the calibrated scale to within 0.000 01 inch (0.000 25 millimeter). The correction allowing for the thread-measuring wires is then subtracted to give the pitch diameter. Several measurements are taken along the plug.

The second test (below) is on the Sheffield lead-measuring machine in which a probe travels along the threaded part of the plug to disclose pitch inaccuracies of less than 0.0001 inch (0.0025 millimeter).







Thread shape is then compared with a master template on a Leitz toolmaker's microscope (left and above).

Threaded ring gages are checked against set plugs, this having been established as being the most practicable method.

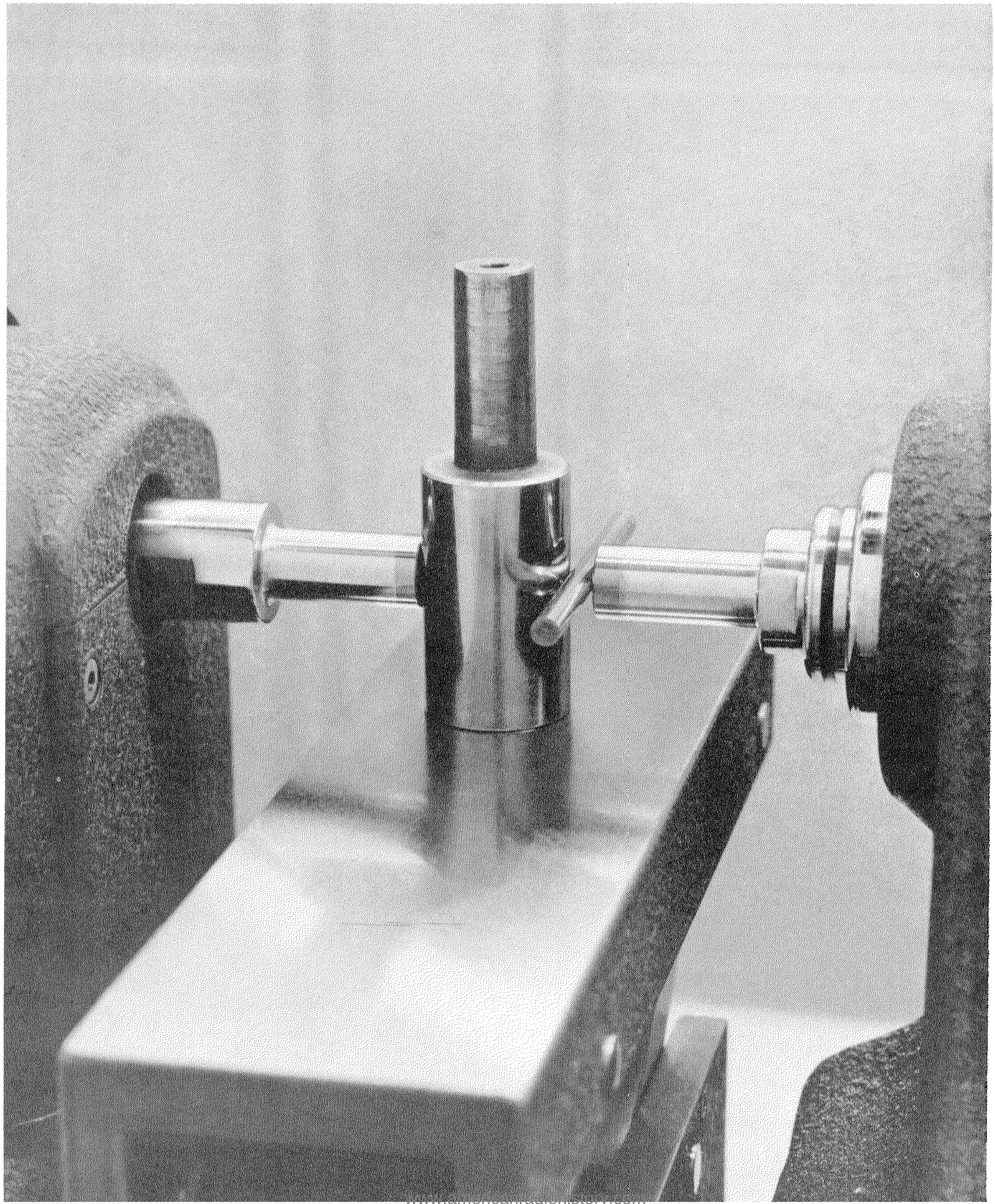
1.3 Plain Set Plugs and Ring Gages

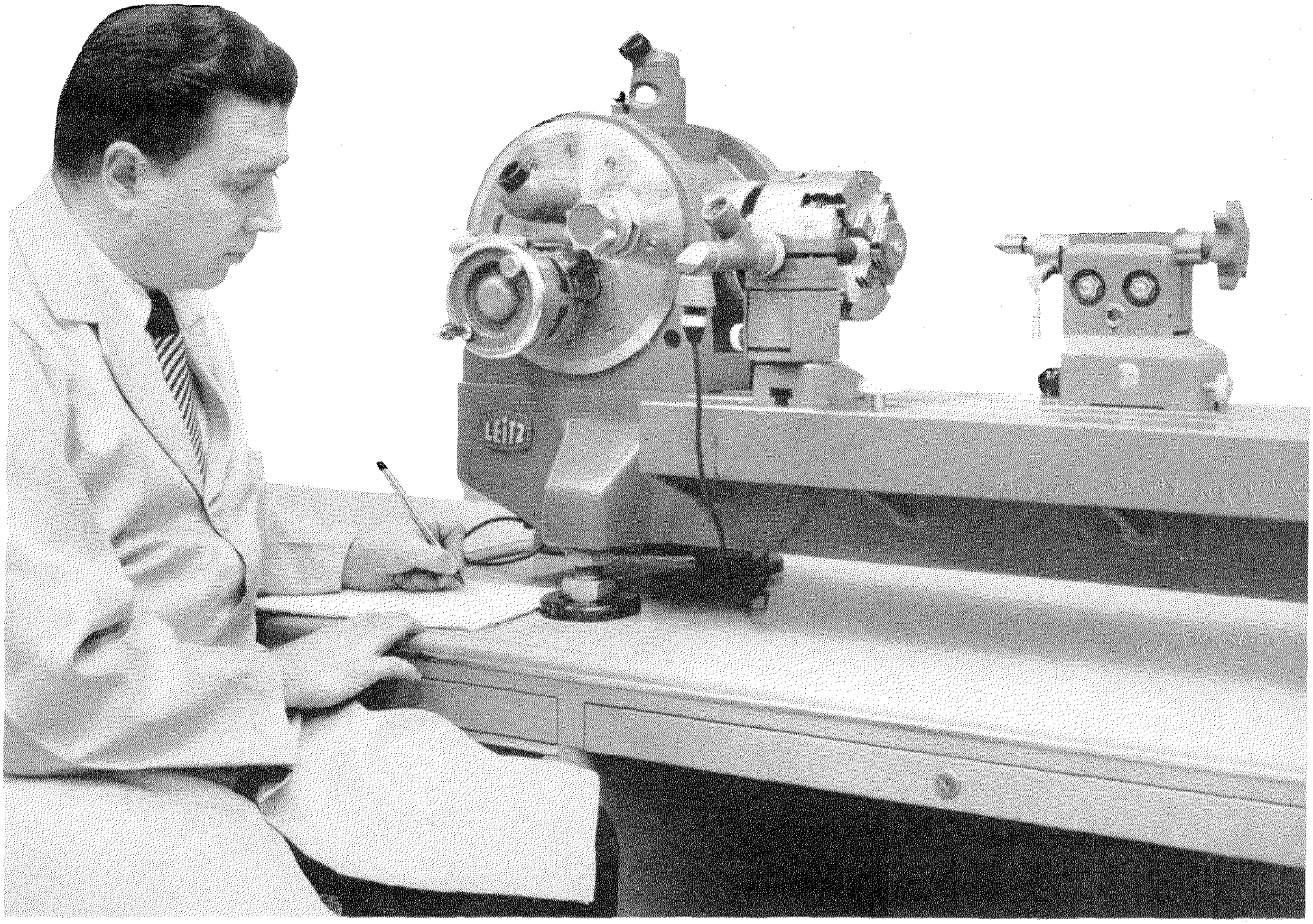
The diameter and roundness of the plug are measured on the Pratt and Whitney standard measuring machine. The ring gage is checked for diameter, roundness, and taper in the Leitz Perflectometer, which through two microscopes measures the device under test against an accurately calibrated scale. It will measure roundness, internal and external curved surfaces, length, or other linear dimensions between the range of 0.004 to 8 inches (0.01 to 20 centimeters). Taper and out-of-roundness at any depth inside a hole, up to 1.2-inches (3-centimeters) deep, can be directly measured.

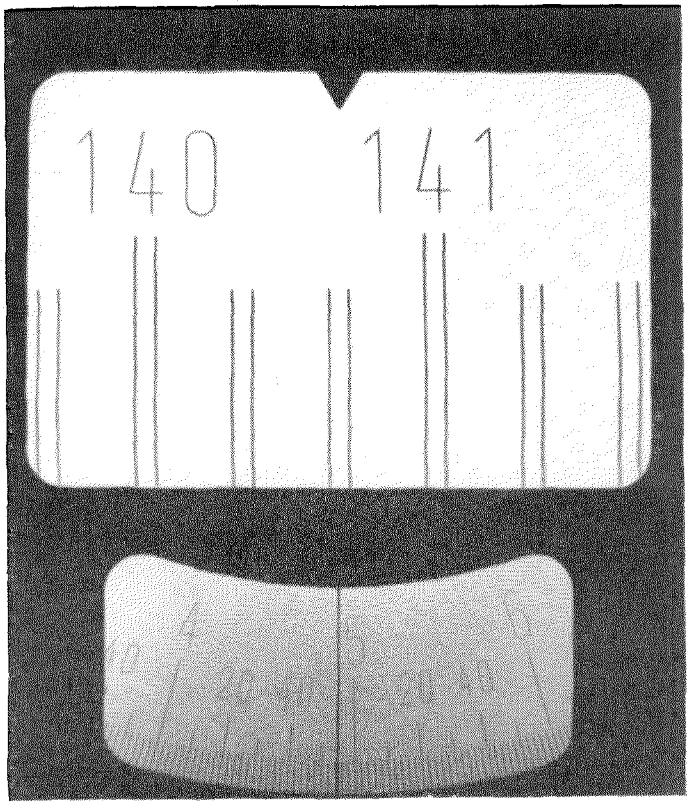
On the wall are the laboratory air-conditioning temperature and humidity controls and recorder.

1.4 Thread-Measuring Wires

The diameters of thread-measuring wires are checked for size and roundness on the Pratt and Whitney standard measuring machine using an extra cylinder between the anvil and the wire, and at a right angle to the wire, to assure point contact between the wire and the arbor.

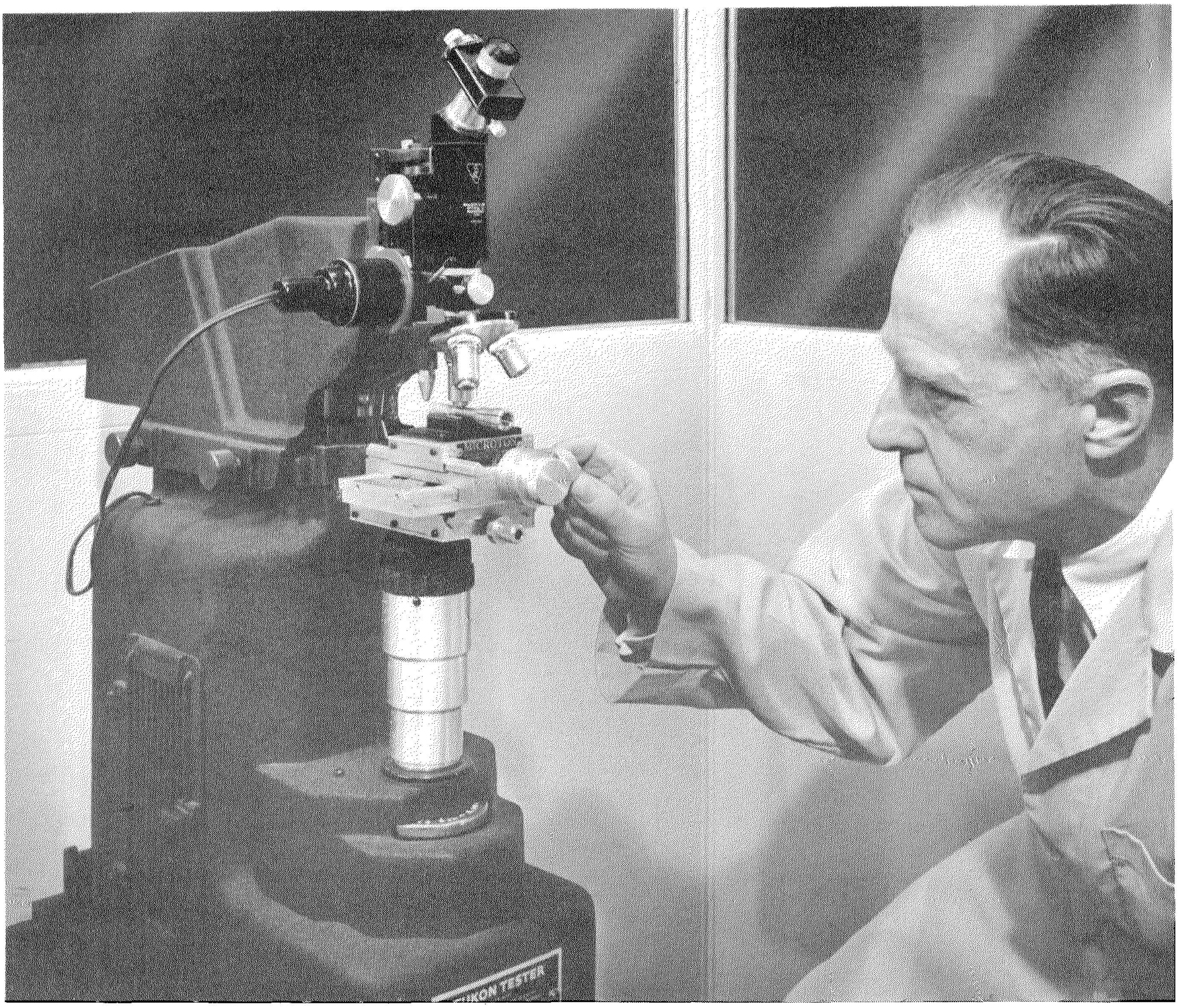


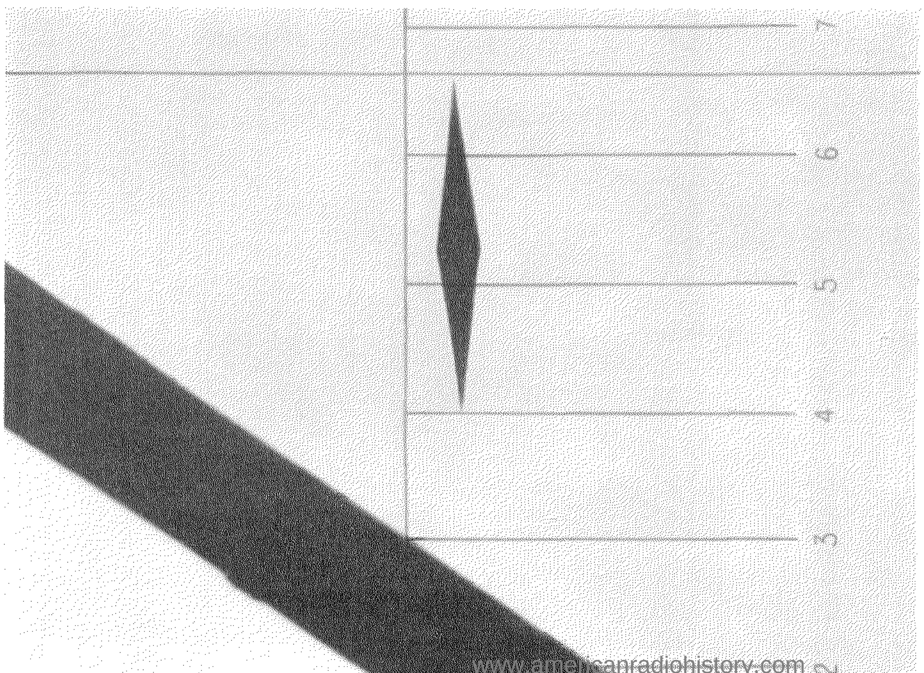




1.5 Master Gears

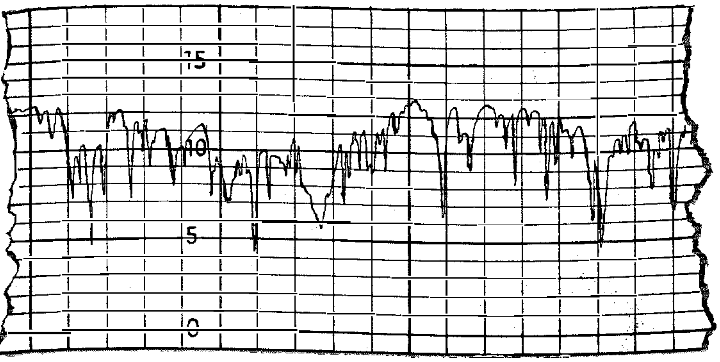
The Leitz optical dividing head spindle will mount a chuck if desired to hold the item being tested. A reference probe is used to index rotation. The instrument permits angle to be determined to within 2 seconds of arc. The head may be tilted to any angle between the horizontal and vertical positions, the particular angle being indicated to within 30 seconds of arc.





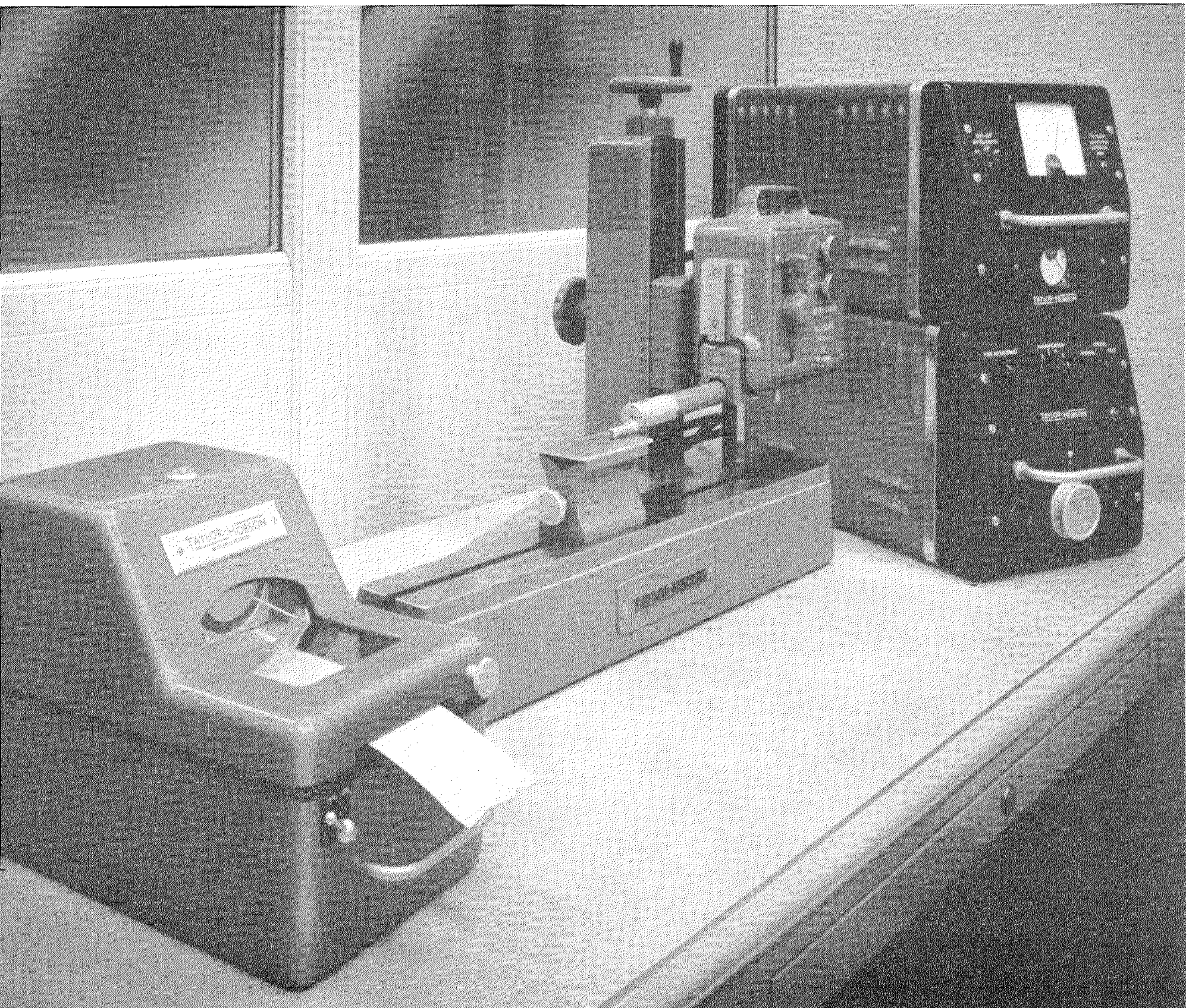
1.6 Hardness Testing

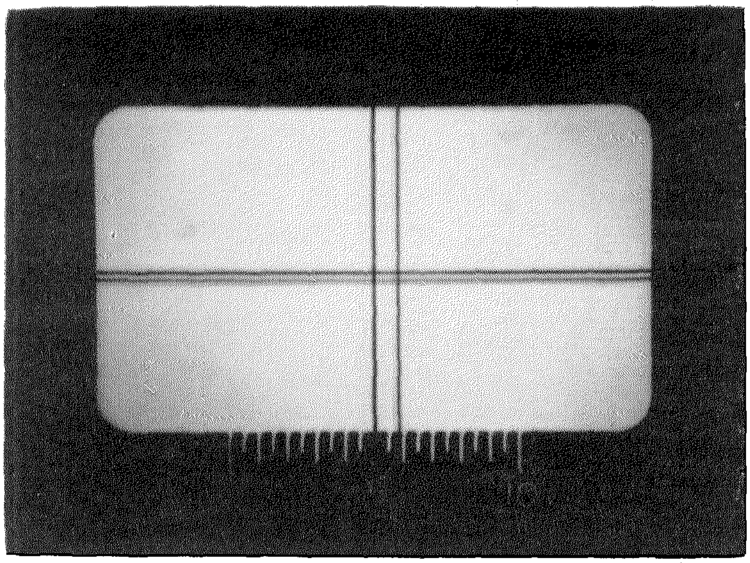
Both the Tukon machine an the Rockwell hardness teste are available for the calibratio of hardness testing samples The Tukon machine, measur ing Knoop and Vickers (dia mond-pyramid) hardness, i shown here. Knoop impressio is shown with a human hai for comparison.



1.7 Surface Roughness

A Talysurf instrument is used to measure surface roughness in micro-inches and produces a permanent record of each test. A recording of a relatively rough surface is also shown.





1.7 Flatness and Small Angles

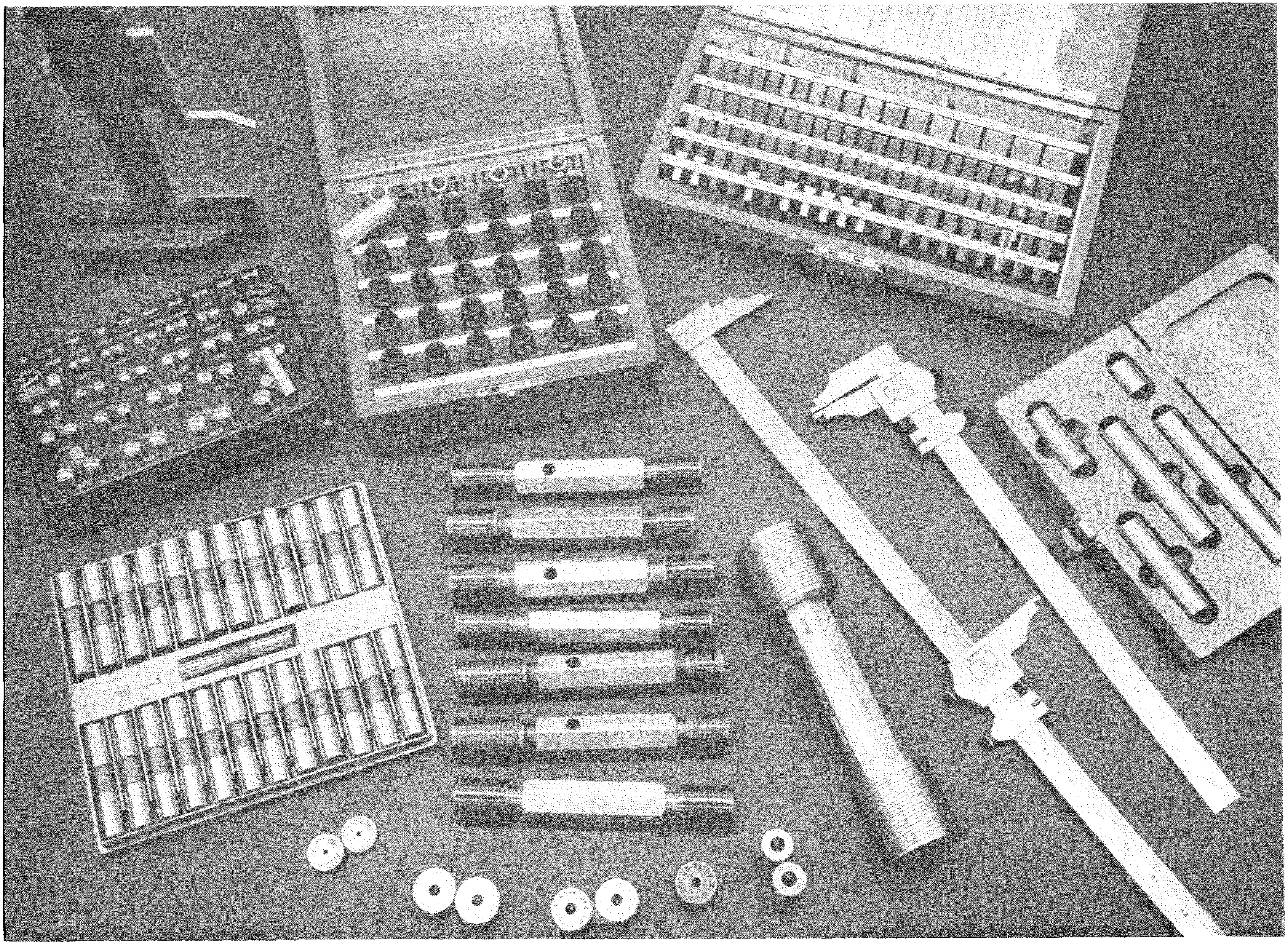
The autocollimator is an ingenious de in which a projected image of a pair of cı hairs within the instrument is reflected i mirrors to return to the instrument for servation. Tilting of a mirror displaces returned image (as shown at the left) the amount of displacement can be accur: measured. In the photograph below, the pl cist is checking the flatness of the surface a the far edge of the stone table. He moves mirror nearest him along it and takes a prog sive series of readings.

Over-all view of mechanical laboratory.

1.8 Typical Mechanical Measurement Capabilities

Measurement	Range	Accuracy
Length	Gage Blocks to 5 Inches (125 Millimeters)	±0.000 002 Inch (0.000 051 Millimeter)
	Above 5 Inches (125 Millimeters)	±0.000 01 to ±0.000 02 Inch (0.000 25 to 0.000 51 Millimeter) Depending on Length
Flatness	Gage Blocks	±0.000 002 Inch (0.000 051 Millimeter) or Better
	*Larger Surfaces or Angular Displacements	±0.000 005 Inch (0.000 13 Millimeter) or 0.1 Second
Angle	Full Circle (0 to 360 Degrees)	±2 Seconds or Better
	Small Angles to 10 Minutes	±0.2 Second
Surface Finish	Small Reflective Items or Silvered Replicas	0.000 01 to 0.000 002 Inch (0.000 25 to 0.000 051 Millimeter)
Surface Roughness	Peak-to-Peak 0.002 Inch (0.05 Millimeter) and Below	±0.000 001 to ±0.000 01 Inch (0.000 025 to 0.000 25 Millimeter), Depending on Roughness
Hardness	Full Range of Knoop, Vickers	Tukon ±0.0002 to ±0.0009 Millimeter Impression Length
	Full Range of Rockwell	Rockwell ±0.5 to ±1.5 Scale Numbers
Screw Lead	All Threads to 80 per Inch (30 per Centimeter)	±0.000 02 Inch (0.000 51 Millimeter)
Screw Pitch Diameter	To 13 Inches (3.3 Centimeters)	±0.000 01 to ±0.000 02 Inch (0.000 25 to 0.000 51 Millimeter), Depending on Diameter
Levelness	*Surface Above 6.5 by 3 Inches (165 by 75 Millimeters)	Angle of Inclination to ±1 Second of Arc

* Portable equipment.



Some typical work handled by the mechanical laboratory.

2. *Electrical Measurements*

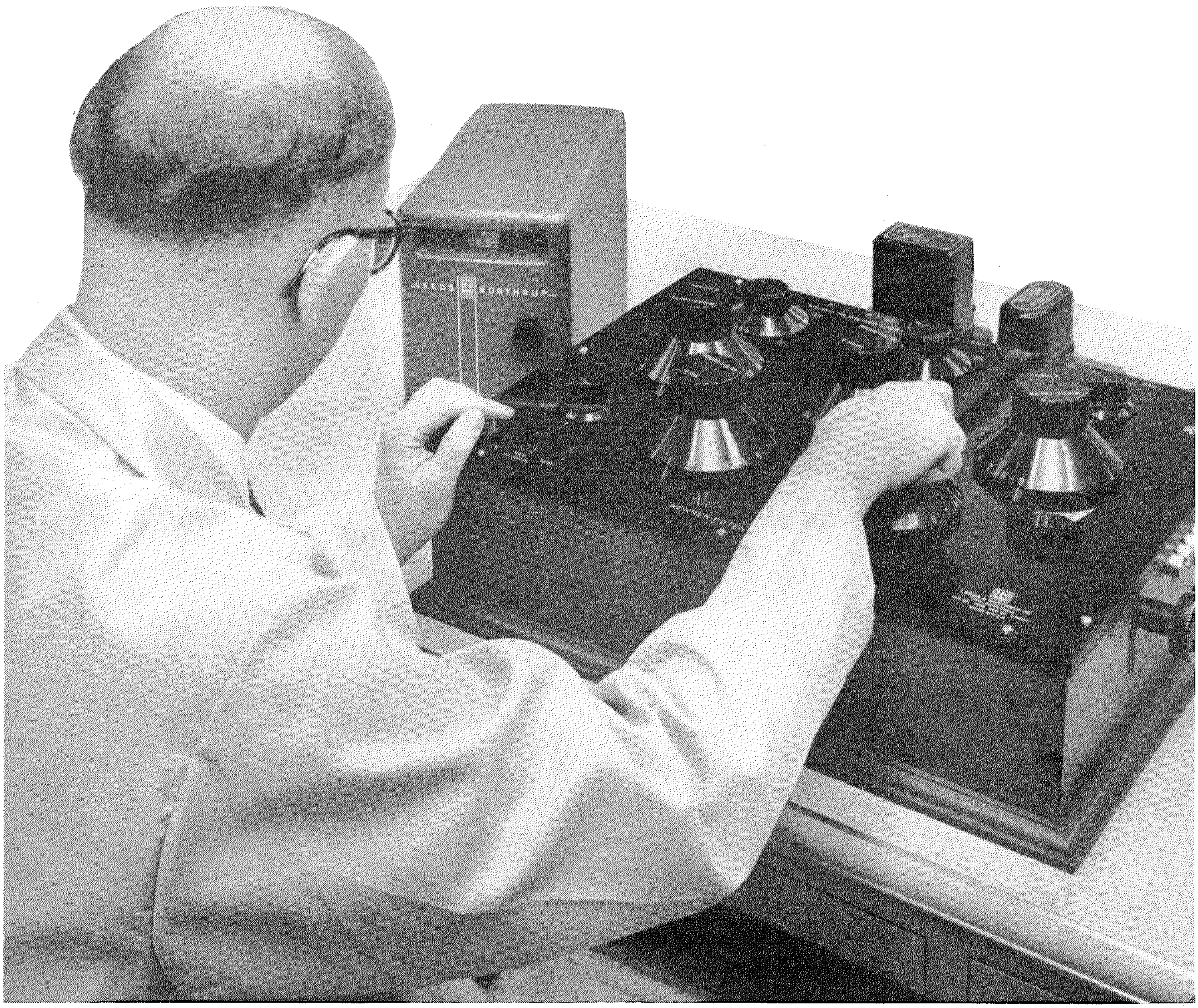
The accuracy that can be obtained and that is required in electrical testing is in general much lower than that characterizing the mechanical field. "Parts per million" usually is replaced by "parts per thousand" for electrical measurements except for frequency.

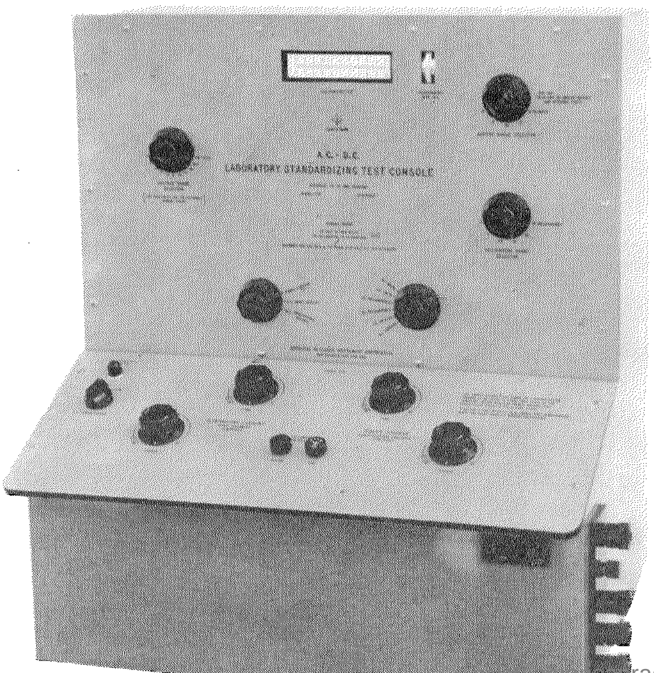
The possibility of contact potential or resistance and the existence of interfering electric and magnetic fields that may induce voltages and currents of significant intensity in equipment under test place unusual responsibility on the engineer for the arranging, connecting, and shielding of the test apparatus. Thus, the technique of measuring is highly important and may, if faulty, produce errors greatly in excess of those inherent in the standards to which the unknown is being compared. Similarly, the equipment must be effectively guarded against deterioration.

2.1 Voltage, Current, and Power

The laboratory standard of voltage employs unsaturated-type standard cells that have been certified by the National Bureau of Standards. They produce voltages that are known to within 0.01 percent.

Leeds and Northrup *K-3* potentiometers (below) are used with standard-cell reference voltages for both voltage and current measurements. The test bench shown has two positions, one for voltage determination and the other for current measurement; they are used simultaneously for calibration of power-measuring devices.



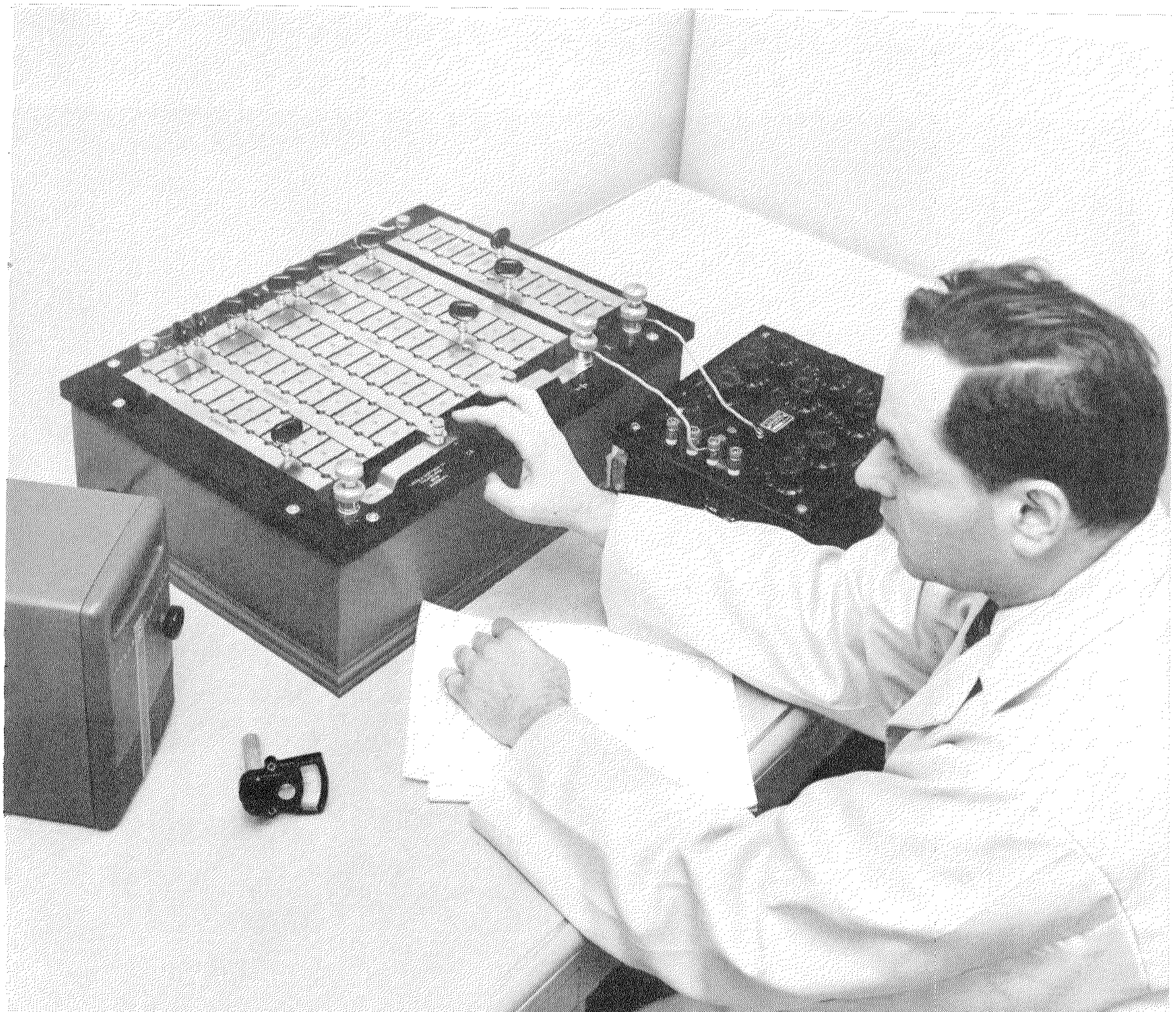


For microvolt measurements, a Wenner potentiometer (above) is used.

Voltage and current measurements at frequencies up to 15 000 cycles per second are made on a Sensitive Research transfer device (at left) employing the Hermac principle.

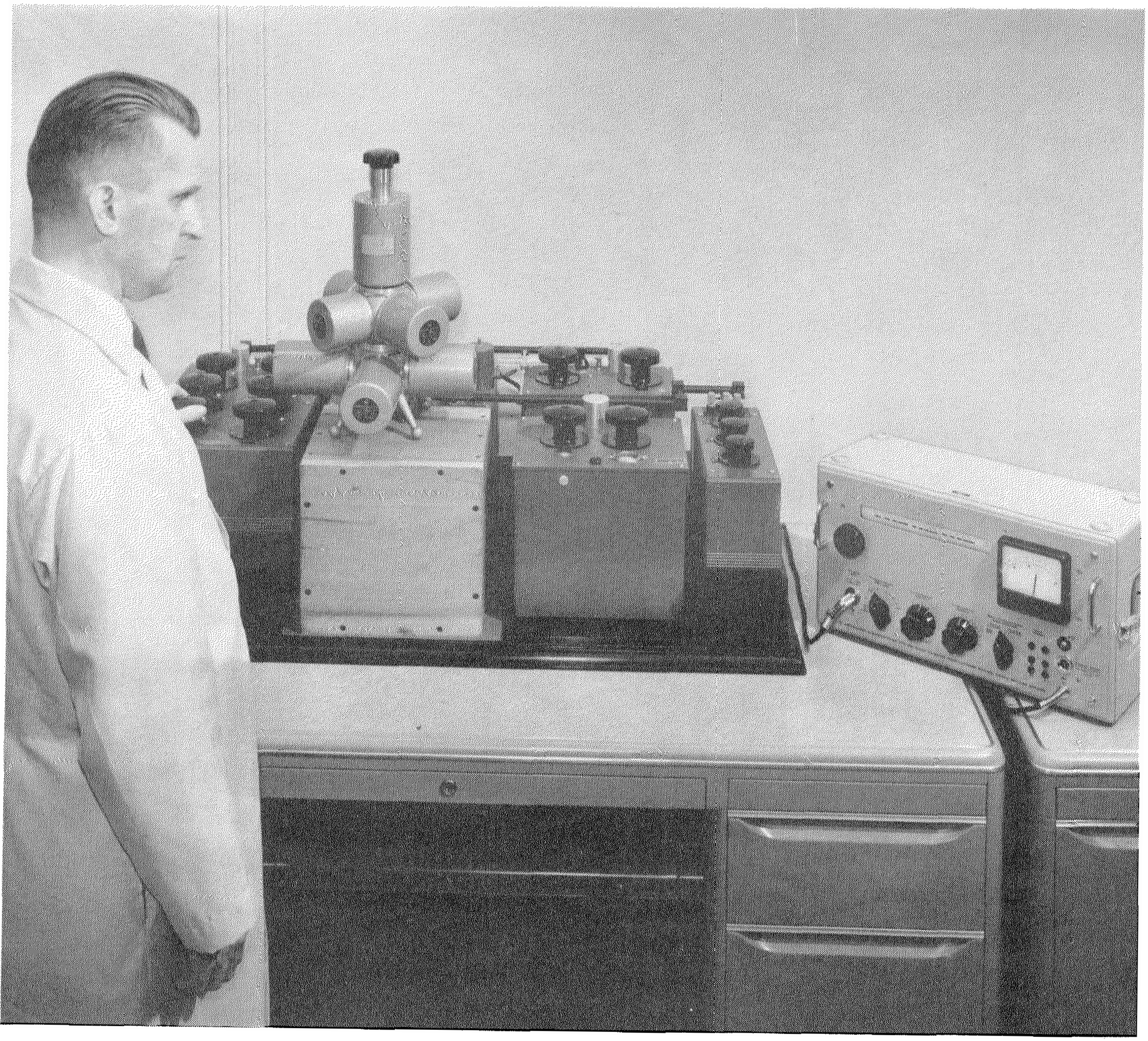
2.2 Resistance

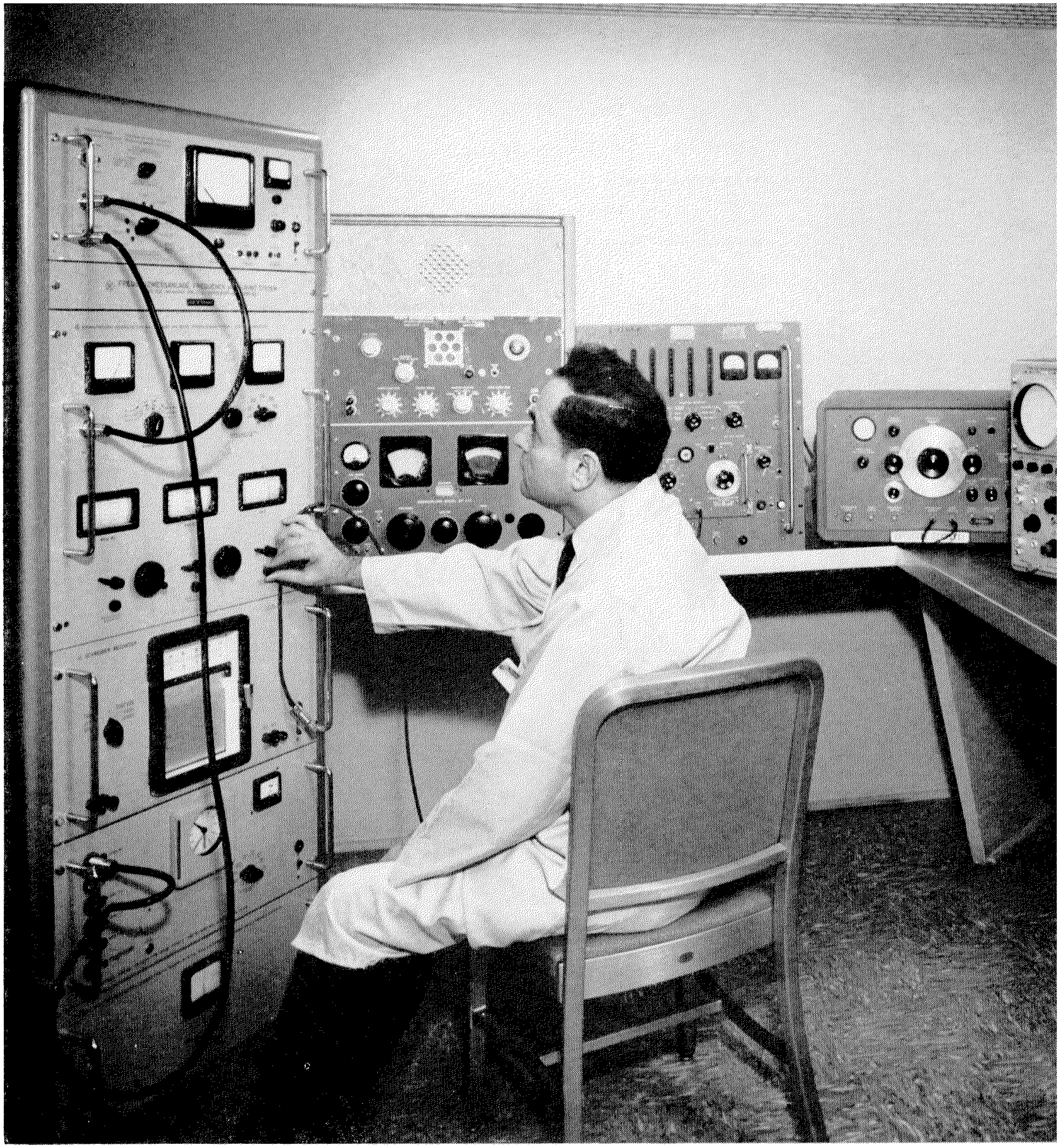
Resistance measurements are made with a Leeds and Northrup type-*4230* Anthony-Pattern Wheatstone bridge as shown below.



2.3 Reactance

Reactance standards consist of General Radio type-*1482* inductors and Jahre standard capacitors, all of which have been certified by the National Bureau of Standards. The use of the standard capacitors with a Leeds and Northrup capacitance and conductance bridge may be seen below.





2.4 Frequency

The basic standards of frequency for the United States are those broadcast by the National Bureau of Standards. For practical flexibility in measurements, a Rohde and Schwarz decade frequency-synthesizing system *XZA* is set to the broadcast standard frequency. Frequencies between 30 cycles per second and 600 megacycles per second can be measured and frequencies between 30 cycles per second and 30 megacycles per second can be generated in the equipment. By harmonics, the generated frequencies can be extended usefully to 600 megacycles per second. A high-speed impulse counter is about to be calibrated above.

Since the calibration work of the electrical laboratory is accomplished mainly by comparison with known quantities, the laboratory must maintain a set of laboratory reference standards of resistance, reactance, and voltage of many-times greater accuracy than the inspection equipment they are used to calibrate.

The transfer elements above are such devices The main requirement is that of stability of value The devices are periodically sent to the Unitec States' National Bureau of Standards, where they are measured, their exact values determined, anc they are then returned to the ITT Standards Laboratory.

Typical work handled in the electrical laboratory is shown on the opposite page

An over-all view of the electrical section of the laboratory is shown on the opposite page.

2.5 Physical Layout of Laboratory

The ITT Standards Laboratory is a room within a room. It is built within but completely isolated from vibration, shock, and the environmental conditions of the ITT Federal Division manufacturing plant at Clifton, New Jersey. The walls and ceiling are of steel with special windows having heat and sound insulating properties. The mechanical laboratory floor is a 60-ton (54-tonne) slab of reinforced concrete 12-inches (31-centimeters) thick floating on a vibration-absorbing material that, in turn, is in a concrete-lined pit in the earth. Flexible material around its edges isolates the floor from the walls and plant floor. Air conditioning with special filtering maintains the mechanical laboratory at 20 degrees centigrade and the electrical laboratory at 23 degrees centigrade, the recognized standards for these types of measurements. Positive air pressure is maintained within the laboratories so all leakage is to the outside, preventing dust from entering.

2.6 Typical Electrical Measurement Capabilities

Measurement	Range	Accuracy
Resistance	1 Ohm to 11 Megohms	±0.01 Percent
Capacitance	1 Picofarad to 1.1 Microfarads at Power Factors Between 0.0001 and 0.1 and Conductances Between 0 and 300 Micromhos at Frequencies to 50 Kilocycles per Second	±0.1 Percent or ±1 Picofarad, Whichever is Greater
Inductance	0.1 Microhenry to 10 Henries at 1 Kilocycle per Second	±0.2 Percent or ±0.1 Microhenry, Whichever is Greater
Frequency	30 Cycles per Second to 600 Megacycles per Second	1 Part in 10 Million
Potential, Direct	10 Microvolts to 750 Volts	±0.02 Percent
Potential, Alternating	10 Millivolts to 750 Volts by Reverse Direct-Current Method (Electrodynamometers and Thermocouples)	±0.02 Percent
	0.3 to 1500 Volts, Direct Current to 25 Kilocycles per Second	±0.05 Percent
Current, Direct	10 Microamperes to 50 Amperes	±0.05 Percent
Current, Alternating	10 Microamperes to 50 Amperes by Reverse Direct-Current Method	±0.05 Percent
	0.002 to 20 Amperes, Direct Current to 25 Kilocycles per Second	±0.05 Percent
Power	To 3000 Watts by Reverse Direct-Current Method	±0.05 Percent

ITT Standards Laboratory—Operation

By SAMUEL SILVERMAN

ITT Standards Laboratory, Clifton, New Jersey

MASS production of equipment, particularly for the armed services, has demanded increasing requirements of measuring techniques and instruments to permit components and assemblies to be interchangeable both electrically and physically even though they may be produced in different plants.

In the main, there is little or no difference between the techniques and instruments currently employed in manufacturing to test and evaluate the produced equipment and those employed by the laboratories in the development of the prototype units. The design dimensions and tolerances later become production specifications and a discrepancy, no matter how slight, can result in a disastrous failure. Employment of a standardizing laboratory as an authoritative reference will preclude any disagreement of measurement between engineering and manufacturing.

The Air Materiel Command, realizing the neccessity for agreement of measurements among contractors and various governmental agencies, issued a directive stating that all measurements shall be related directly or indirectly to the United States' National Bureau of Standards.

The National Bureau of Standards is limited in the amount of calibration work it can do directly for industry and urges the establishment of standardizing laboratories that would serve industry in general and be served in turn by the Bureau.

In 1957, the ITT Standards Laboratory was set up to provide calibration service to the ITT System and to others. It, in turn, relies on the National Bureau of Standards for the calibration of its laboratory reference standards.

1. Classification of Standards

The National Bureau of Standards points out that such adjectives as primary, secondary, basic, fundamental, and absolute have become meaningless through misuse. Therefore the Bureau has developed a new nomenclature as a substitute for the older and now imprecise terminology. Its statements[1] on this subject follow.

"Standards are classified into categories under this system, the first category being the prototype category that includes the arbitrary and independent standards of length, mass, time, and temperature on which our measuring practices are based. The other standards, defined in terms of the prototypes, are classified in derived, calibration, and instrument categories. A fifth category, called standard materials, includes pure chemicals and other materials that are not defined in terms of standards of the prototype category. The items that the Bureau has been supplying under the standard sample program fall into the categories of calibration standards or standard materials.

"Within each category, the standards are ranked as national standards, national reference standards, and national working standards. It is suggested that standardizing laboratories cooperating with the Bureau rank their standards within each category as laboratory reference standards and laboratory working standards."

2. Types of Standards Laboratories

Standards laboratories may be classified in two categories. One type is designed to provide the very-highest order of accuracy. Complexity of equipment and of methods of measurement are necessary. For electrical measurements they will maintain such things as a bank of normal cells with the associated temperature-stabilized oven, standard cell comparators, and standard resistors immersed in a temperature-stabilized oil bath. Facilities are also available for performing research to advance the art of measurements, calibration, and instrumentation. This is the National Bureau of Standards type.

The other type of standards laboratory functions primarily to fulfill the calibration needs of industry. The equipment consists mainly of

[1] "Research Highlights of National Bureau of Standards," Annual Report 1958, Miscellaneous Publication *226*; page 96.

ITT STANDARDS LABORATORY

WORK REQUEST

ITEM Polyranger DATE 11/27/59

MANUFACTURER Sensitive Research CERT. NO. E-1338

MODEL/SER. NO. A/804591 CONTROL NO. 6-17504

REQUEST BY Rosamilia DEPT. 026

LOCATION Q.C. Laboratory PURCH. ORD. ______

SERVICE DESIRED

Replace Thermo-couple; Adjust and Calibrate

STANDARDS/INSTRUMENTS USED SENS. RES. MODEL: THACH/30429

COMMENTS THERMO-COUPLE REPLACED HEATER & JUNCTION SPOOLS ADJUSTED. CHECKED J. Wynn 11/29/59

RECEIVED BY ______ DATE ______ DATE STARTED 11.30.59

SHIPPING NO. ______ DATE COMPLETED 11.30.59

CARRIER ______ TIME 3½ HOURS

RETEST DATE MARCH 1. 1960 EXAMINER O. Weeks

Work request form submitted with each job.

ITT STANDARDS LABORATORY

METER WORK SHEET

ITEM DC VOLTMETER DATE 12.24.59.

MANUFACTURER WESTON CERT NO. E 1403

MODEL/SER NO. 931 / 33555 CONTROL NO.

METER ACCURACY ± .5% BALANCE ✓

MECH ZERO ADJUST ✓ F.S. DIVISIONS

FULL SCALE VOLTS:	931 VOLTS:	LN/K3	VOLT BOX MULTIP.	STAND VOLTS:	TOLERANCE VOLTS			DIFFERENCE VOLTS:
	0 ✓							
7.5	7.5	.15035	7.5/50	7.5175	±.0375			+.0175
	6	.12042	"	6.021	±.0375			+.0210
	4.5	.09005	"	4.5025	±.0375			+.0025
	3	.15043	3/20	3.0086	±.0375			+.0086
	1.5	.07606	"	1.5212	±.0375			+.0212
	0 ✓							
30	30	.15039	30/200	30.078	±.15			+.078
	0 ✓							
75	75	.15045	75/500	75.225	±.375			+.225

COMMENTS

DATE 3.24.60 EXAMINER O. [illegible]

FX 470

Work sheet on which the laboratory staff enters calibration data and makes all necessary calculations. It is attached to the work request form.

working standards calibrated against reference standards that are periodically certified by the National Bureau of Standards.

3. *ITT Standards Laboratory*

ITT Standards Laboratory may be classified as one employing laboratory reference standards certified by the National Bureau of Standards for calibrating its laboratory working standards. The working standards are used to check the measuring equipment submitted to the laboratory for calibration.

Before proceeding with the establishment of the standards laboratory, much valuable information and advice was obtained from the National Bureau of Standards and from manufacturers of precision measuring equipment. The general policy was to acquire instruments produced by long-established reputable companies. Only instruments with a history of stability, repeatability of setting, reliability, and suitable for accurate comparison with the standards of the National Bureau of Standards were selected.

To ensure that the choice of equipment and methods were suited to the needs of a representative factory, surveys were made to determine the adequacy and range of the measurement capabilities of the test maintenance, quality control, and tool inspection services of the ITT Federal Division, in whose plant the standards laboratory would be housed. The test maintenance group, reporting to test engineering, is responsible for the inventory, maintenance, and calibration of all special and conventional test equipment. The quality-control laboratory, beside other functions, performs evaluation tests, including shock, vibration, and environmental tests of purchased items. The metallurgical and chemistry laboratory is under the jurisdiction of the quality-control department. The tool-inspection department of the fabrication division is accountable for the accuracy and condition of the mechanical gages.

Studies of the existing measuring facilities served as a guide in the selection of standardizing equipment, particularly with regard to the avoidance of duplication and assurance that there would be no gaps in the ranges of required services.

A detailed description of the standards laboratory is given in the first article in this issue.

4. *Responsibility for Calibrations*

The heads of the standards laboratory, quality control, test engineering, and engineering of manufacture agreed on which group was to be accountable for the calibration of the electrical instruments and mechanical gages. The decisions were based in large part on the degree of accuracy of the calibration instruments then immediately available to these various groups.

To affix the responsibility for the calibration of the mechanical gages was relatively simple. All master, reference, and other precise gages would be standardized and certified by the standards laboratory. These include gage blocks, setting plugs, plain ring gages, vernier calipers, vernier height gages, large surface plates, thread and gear measuring wires, and other instruments employed by the tool-inspection group to calibrate inspection gages. The gages classified as inspection gages such as hand micrometers, thread-ring gages, and others are calibrated by the tool-inspection department. The recalibration periods for all gages are determined by engineering of manufacture.

Due to the complexity and the wide range of the electronic test equipment, it was difficult to arrive at a clear-cut division of responsibility between the standards laboratory and the test maintenance group. Here, instead of establishing the responsibility for each instrument, the accuracy ranges, functions, or applications were used to set up classifications or families of electrical equipment. For example, the direct-current voltmeter may be any one of several types, such as; electrodynamometer, vacuum tube, thermocouple, electrostatic, digital, iron vane, and potentiometer, with accuracies ranging from within 0.01 percent to over 3 percent.

After weighing very carefully the many facets of the electrical calibration problem, it was agreed that the standards laboratory would certify indicating-type ammeters, voltmeters, and wattmeters having accuracy ratings of 0.75 percent or better, impedance decade boxes, bridges, Q meters, digital instruments, and working standards. Production and conventional test instruments, multitesters, vacuum-tube voltmeters, and special test equipment are calibrated by the test maintenance group. The periods for recalibration are determined by test engineering.

Work sheets are provided for all calculations or calibration data. These sheets are permanently attached to the work-request form and filed.

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.

1. ITEM - DESCRIPTION AC AMMETER	QTY.	7. ITTF NO. G-19865	8. GOVERNMENT NO.
2. MANUFACTURED BY WESTON		9. LOCATION Q.C. LABS	10. SUPERVISOR KOSAMILIA.
3. MODEL AND SERIAL NO. 433/40518		11. UNIT COST	12. PROPERTY OF
4. USED ON OR WITH		13. CALIBRATION SCHEDULE 3 MONTHS.	14. DEPARTMENT CODE
5. SALES ORDER	6. SHOP OR PURCHASE ORDER	15. CALIBRATION SPECIFICATION .75%	

ISSUED TO			CALIBRATION OR INSPECTION				
DATE	TO	RETURNED	DATE	ACCEPTED	REJECTED	NEXT DUE	REMARKS
			10/2/58	E447		1/2/59	
		12/30/59	12/31	E635		4/1/59	
		4/2	4/13	E859		7/27/59	ZERO UNSTABLE, ADJ. JEWEL
		7/2	7/22/59	E1069		10/28/59	
		10/30	11/16/59	E1278		2/16/60	

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Calibration control card. These cards are filed in the laboratory by dates on which rechecking is due.

5. *Operating Procedure*

For each item submitted for calibration, certification, or the determination of critical dimensions, a work-request form is prepared giving the description of the instrument, name of the supervisor, department, and the work to be performed. This information is entered in a log book where a number, prefixed by the letters *M* for mechanical and *E* for electrical is assigned to the item. This number is also used as the certification or report number and is added to the work-request form and work sheets.

The work-request form remains with the instrument until all calibrations or measurements are completed. There is noted on this form all repairs or critical adjustments that may have been required by the instrument and the laboratory working standards employed in its calibration.

A calibration control card is maintained for each gage or instrument certified by the laboratory. These cards are filed chronologically according to the date on which recalibration is due. In addition to the accuracy specification and calibration schedule, the received date, calibration date, certificate number, and recalibration date are entered on the control card. All repairs are noted and, if detailed information is required, reference can be made to the work sheets. If an instrument is found to be unacceptable, the certificate number is entered under the reject column and no recalibration date is shown.

Repairs on meter movements and associated elements such as shunts and multipliers are done by an instrument repairman who is assigned to the standards laboratory. A complete supply of replacement parts for most of the frequently used meters is maintained. These parts include such items as pivots, jewels, thermocouples, complete movements, resistance wire, and cases. Equipment repair, other than movements, is performed by the test maintenance group.

Electrical instruments found unacceptable by the standards laboratory are sent to the test maintenance group for disposition. The decision will be whether the defective instrument should be returned to the manufacturer for repair or be scrapped. The unacceptable mechanical gages are turned over to engineering of manufacture for disposition.

Certificates of measurement are issued when an instrument or gage meets the original manufacturer's specifications or other applicable specifications. A certificate sticker showing the certificate number and the recalibration due date is affixed to each certified instrument. A measurement report is issued for measurement of piece parts, components, or for limited calibration of multifunction meters.

When an instrument or gage is not resubmitted for checking to the laboratory on the due date, the staff quality-control group is notified. The quality-control department polices the calibration program by constant surveillance of the calibration status of instruments and gages throughout the manufacturing division and also in the standards laboratory.

6. Calibration of Reference Standards

The implementation of the standards laboratory was carried out with the philosophy that the laboratory would be self-standardizing to as great an extent as possible. Where this is impracticable, transfer reference standards periodically certified by the National Bureau of Standards are employed.

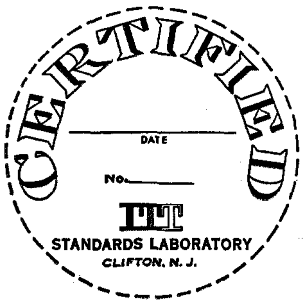
Standard cells are shipped at least once a year to the National Bureau of Standards for certification. Not fewer than two standard cells are sent each time for certification so they can be cross-checked on the Wenner potentiometer to ascertain their condition on arrival from the Bureau. At all times, there are two certified standard cells on standby service functioning as references for comparison with the working cells. As the newly certified standard cells arrive from the Bureau, they become the reference cells and the previous working cells are sent to the Bureau for certification. The older reference cells then serve as working cells.

The laboratory also maintains the following reference standards certified by the National Bureau of Standards:

Resistors from 0.001 to 10,000 ohms in decade steps.

Inductors from 100 microhenries to 10 henries in decade steps.

Capacitors from 10 picofarads to 1000 picofarads in decade steps. An adjustable capacitor whose setting can be determined to within 0.01 picofarad over the range from 6 to 20 picofarads.



The sticker that goes on each certified instrument to identify its laboratory file also gives the date for rechecking.

The period between certifications of these laboratory reference standards by the Bureau is not greater than 18 months. They are employed to standardize corresponding working standards and other laboratory working standards such as impedance bridges and decades. All laboratory working standards are calibrated at least every 12 months.

For mechanical dimensional standards, a 121-block set of *AA* gage blocks have been certified by the National Bureau of Standards and subsequently checked on the Carl Zeiss Koester's Interferometer at the laboratory. These master gage blocks are used to calibrate the inspection gage blocks and mechanical instruments of the laboratory once a year.

Thus, all measurements performed by the standards laboratory can be related directly or indirectly to the National Bureau of Standards.

7. Other Functions

Need for special measurements may arise as a result of problems encountered either in engineering or manufacturing. If the accuracy and the urgency dictate, such measurements may be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These coefficients k are similar to those mentioned for the p's and consist of a fraction of which both the numerator and the denominator are polynomials in y and of equal degree. The expressions for these coefficients depend on the type of grading chosen, the mode of hunting, and the traffic offered to the grading.

A few arbitrarily chosen coefficients follow.

In the exact solution of the probabilities $P(5)$ and $P(6)$ for a three-split homogeneous grading having two outlets per subgroup ($s=3$, $n=2$) the coefficients k include the fraction

$$A = \frac{6561\,y^3 + 19\,197\,y^2 + 20\,628\,y + 7900}{297\,y^3 + 871\,y^2 + 938\,y + 360}$$

where y is the average traffic offered to each split.

In the exact solution for a four-split homogeneous grading having one outlet per subgroup ($s = 4$, $n = 1$), the probability $P(4)$ of finding any call pattern with four simultaneous calls, includes the coefficient

$$B = \frac{43\,776\,y^4 + 128\,784\,y^3 + 146\,668\,y^2 + 77\,421\,y + 16\,080}{46\,848\,y^4 + 138\,000\,y^3 + 157\,344\,y^2 + 83\,136\,y + 17\,280}$$

while the coefficients of $P(5)$ and $P(6)$ contain the fraction

$$C = \frac{34\,560\,y^4 + 101\,520\,y^3 + 115\,440\,y^2 + 60\,840\,y + 12\,615}{46\,848\,y^4 + 138\,000\,y^3 + 157\,344\,y^2 + 83\,136\,y + 17\,280}.$$

It will be agreed that, even for the above two simple examples of gradings, the coefficients have a somewhat complicated appearance.

Similar coefficients are always found in conjunction with probability problems of limited accessibility. Their values vary between two limits determined[3] by $y = 0$ and $y = \infty$.

The coefficients, however, that relate to the homogeneous gradings that are dealt with in this paper show a remarkable property. It appears that the limiting values for the coefficients lie very close together. Table 1 gives the limiting values for the above three fractions.

The difference between the corresponding values of the above two columns appears not to exceed approximately 1 percent. This convergence increases with the values of s and n and permits considerable simplification of (1).

As already stated, the probabilities $p(c)$ relating to specific traffic patterns having c simultaneous calls consists of a factor y^c and a coefficient similar to those of the P's. Consequently (1) includes two types of terms, the one type having y^c as a factor and the other y^{c+1}. For $y = 0$, the terms including y^{c+1} disappear; and, for $y = \infty$, the terms containing y^c disappear. Thus the following two incompatible systems of recurrent equations[2] are obtained.

$$c\,p[c] = \sum y\,f(c)\,p[c-1], \quad \lim y \to 0. \qquad (3A)$$

$$sy\,p[c] = \sum F(c)\,p[c+1], \quad \lim y \to \infty. \qquad (3B)$$

The solution of each of these two systems of equations provide two limiting values for the probabilities p relating to specific call patterns.

Either system may be used for obtaining a very close approximation of the wanted probabilities.

In the following, use will be made of only the system of equations valid for $y \to \infty$ because it provides more-convenient results and also includes a small safety margin.

For symmetrically loaded homogeneous gradings consisting of twos exclusively, the complete system of equations for (3B) is

$$\begin{aligned} sy\,p[{}_1c_2,\ {}_2c_3 \cdots {}_1c_3,\ {}_2c_4 \cdots] &= ({}_1c_2 + 1)\,p[{}_1c_2 + 1,\ {}_2c_3 \cdots {}_1c_3,\ {}_2c_4 \cdots] \\ &+ ({}_2c_3 + 1)\,p[{}_1c_2,\ {}_2c_3 + 1 \cdots {}_1c_3,\ {}_2c_4 \cdots] \\ &+ \cdots \qquad (4) \end{aligned}$$

The suffixes relate to the splits. Therefore, ${}_1c_2$ indicates the number of busy outlets of the 1–2

TABLE 1

LIMITING VALUES OF COEFFICIENTS

Coefficient	$y=0$	$y=\infty$
A	21.9444	22.0909
B	0.9304	0.9344
C	0.7300	0.7377

[3] H. A. Longley, "Efficiency of Gradings," *Post Office Electrical Engineers Journal,* volume 41; April and July, 1948.

Assessment and Control of Cathode Interface Impedance*

By JOHN SEYMOUR

Standard Telephones and Cables Limited; London, England

PRESENTLY, almost all receiving-type electronic valves employ an oxide-coated cathode that consists basically of a nickel sleeve carrying a coating of alkaline-earth oxides. Between the sleeve and coating there exists an interface layer whose effect on the cathode performance is normally negligible during the first thousand hours of operation. The structure of the cathode is illustrated in Figure 1, with its equivalent electrical circuit.

In general, the coating behaves as an *n*-type semiconductor whose impurity centres are free

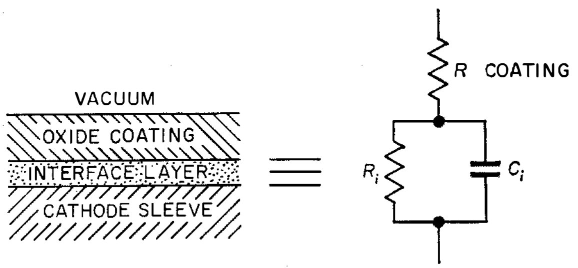


Figure 1—Structure and equivalent circuit of the oxide-coated cathode.

metal ions caused by oxygen deficiencies in the lattice. It normally consists of an equimolar mixture of barium and strontium oxides with a little calcium oxide, which is activated by free barium ions. These are released in the coating through the action of reducing agents such as magnesium, silicon, and aluminium, which diffuse from the sleeve when the cathode temperature is raised to about 1300 degrees Kelvin during processing. A typical reaction with the coating is

$$Si + 4BaO = Ba_2SiO_4 + 2Ba. \quad (1)$$

This shows that barium orthosilicate is formed in addition to free barium, and this compound has been identified in the interface layer of cathodes based on sleeves containing silicon. Also free barium will be released both in the layer and in the coating. During the life of the cathode at a temperature normally between 1000 and 1100 degrees Kelvin, this reaction will proceed slowly until all the reducing agent is used up. At the same time barium will be lost by evaporation from the coating and replenished by diffusion from the interface layer. Eisenstein[1] has shown that barium orthosilicate is also an *n*-type semiconductor, so that as the excess barium content of the interface layer is reduced, its resistance will rise until it reaches a limiting value determined by its intrinsic resistivity. Values up to 1000 ohm–centimetres^{-2} of coating have been observed for British valves.

It is found that the rate of growth of the resistance is larger for higher cathode temperatures due to the higher rate of chemical action but is decreased when cathode current flows. This is probably due to the potential gradient between the cathode sleeve and the emitting surface, which opposes the flow of positively charged barium ions out of the interface layer. For this reason, computer valves that spend a large part of their lives in the quiescent state are particularly prone to the build-up of interface resistance.

As shown in Figure 1, the resistance is associated with capacitance in parallel so that to a first approximation the valve acquires a cathode time constant that may vary from about 5×10^{-7} to 5×10^{-6} second.

The value of interface resistance R_i is given by

$$R_i = \rho d/s, \quad (2)$$

where

ρ = resistivity of the interface layer at the operating temperature

d = thickness of the layer

s = coated area of the cathode.

Thus, miniature valves with small cathode areas will be particularly prone to deterioration through interface development.

* Originally published under the title, "Computer Valves and Cathode Interface Impedance," in the *Journal of Electronics and Control*, First Series, volume 3, pages 107–125; July, 1957.

[1] A. Eisenstein, "Leaky-Condenser Oxide Cathode Interface," *Journal of Applied Physics*, volume 22, pages 138–148; February, 1951.

The effect of interface layers was first observed with cathodes from which pulse currents of high density were drawn. Under these conditions high potential gradients were produced across the layer, preventing the maximum current being drawn from the cathode and distorting the pulse shape. In extreme cases the Joule heating effect would cause sparking and damage to the cathode. The distortion that results from drawing current from a cathode with a high interface resistance is illustrated in Figure 2, where *B* is the current pulse from triode *2* of a high-slope double triode with a measured interface resistance of 630 ohms. This may be compared with Figure 2A, which is the pulse current from triode *1*, which although in the same valve, had no measurable interface resistance. The triodes were diode-connected in each case and the same pulse voltage applied. The rapid leading-edge decay and lower final current are evident for the triode with interface resistance. These effects are simulated in triode *1* by inserting a 600-ohm resistor in parallel with a 0·001-microfarad capacitor in the cathode lead, as illustrated in Figure 2C. This distortion will also occur if the valve is operated as a triode and a rectangular pulse signal is applied to the control grid, so that the output from a pulse amplifier will be seriously affected if any one of its valves has grown a high value of interface resistance.

Another effect of interface resistance is to place additional cathode bias on the valve. This will result in a fall of anode current, which may be serious when only a little bias is already employed, and also a lowering of the mutual conductance by negative feedback. The feedback will be frequency-dependent so that the effective mutual conductance is given by

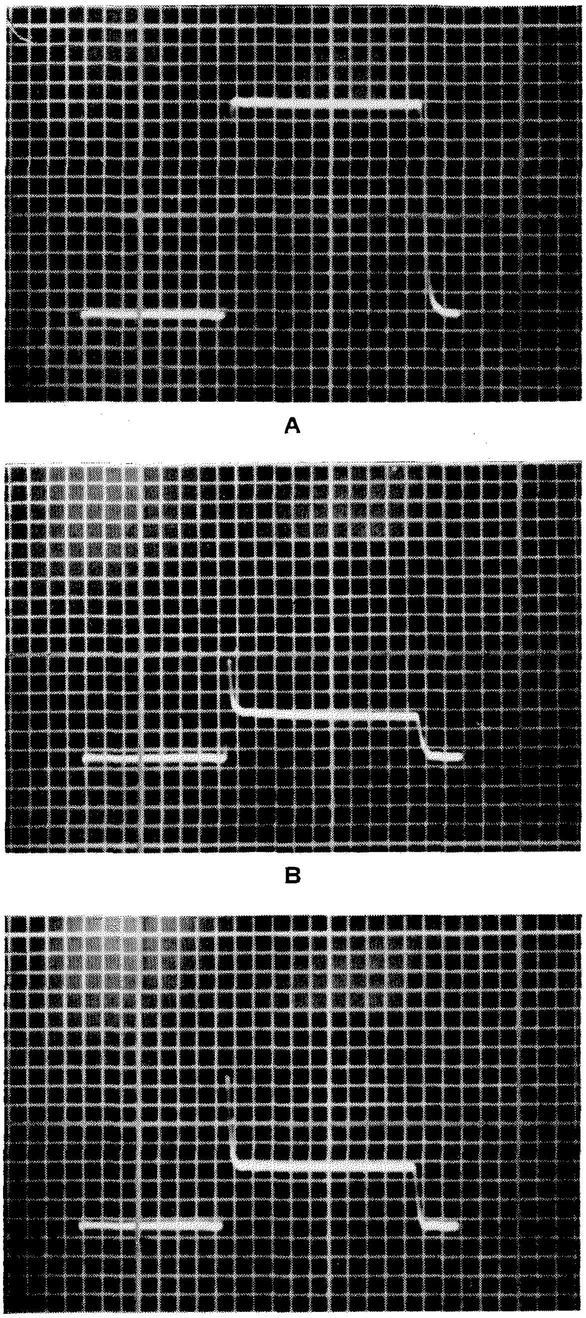
$$g_m' = g_m/(1 + g_m R_i'), \qquad (3)$$

where

R_i' = real component of the interface impedance
g_m = mutual conductance when R_i is zero.

At frequencies above about 10 megacycles per second, $R_i' = 0$, so that $g_m' = g_m$, and below about 10 kilocycles per second, $R_i' = R_i$. As the frequency varies between these limits, so R_i varies from zero to R_i but it has been shown[2]

[2] J. R. Tillman, J. Butterworth, and R. E. Warren, "Dependence of Mutual Conductance on Frequency of Aged Oxide-Cathode Valves and Its Influence on their Transient Response," *Proceedings of the Institution of Electrical Engineers*, volume 100, part 4, pages 8–15; October, 1953.



C

Figure 2—Cathode current waveforms for the two sections of the double triode for rectangular pulses of 10-microsecond duration repeated 50 times per second. *A* is for triode *1* having no interface impedance and producing a current of 68 milliamperes. *B* is for triode *2* and has a leading-edge current of 33 milliamperes and a trailing-edge current of 15 milliamperes. *C* is for triode *1* with 600 ohms in parallel with 0·001 microfarad in the cathode lead. The leading- and trailing-edge currents are 50 and 20 milliamperes respectively.

that a more-complicated resistance–capacitance network than the simple parallel combination of Figure 1 is required to explain the dependence of R_i' on frequency. However, this simple circuit is a useful approximation.

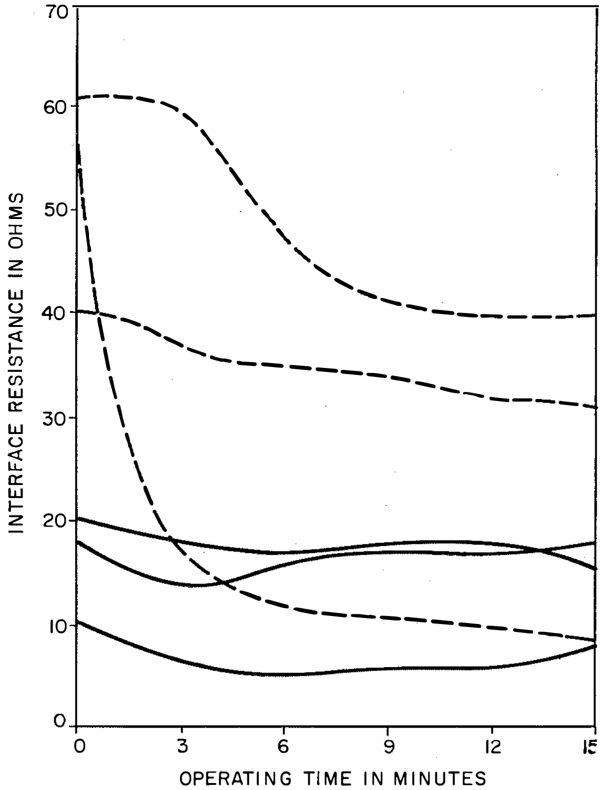


Figure 3—Values of interface resistance as a function of time. Direct-current measurements were made.

1. *Some Properties of Interface Resistance*

1.1 Effect of Cathode Current

Figure 3 illustrates the effect on the interface resistance of six high-slope pentodes of passing a cathode current I_k of 7 milliamperes with a heater voltage V_h of 6·3 volts. The resistances were measured by the direct-current method described in a later section, where $I_k = 7$ milliamperes is needed to give the required mutual conductance for balance. The solid curves apply to three valves that had been run for 1000 hours with $I_k = 12$ milliamperes and $V_h = 6{\cdot}3$ volts, while the dotted curves apply to three other valves that had been run for 1000 hours with $I_k = 0$ and $V_h = 8{\cdot}0$ volts. It may be seen that the valves in which R_i had increased with current flowing showed little change during measurement, while those that had been run under zero-current conditions could show a marked fall in R_i during measurement. This behaviour is thought to be due to activation of the interface layer by barium ions diffusing back from the cathode coating.

1.2 Effect of Cathode Temperature

Since the interface layer is a semiconductor, its resistance should be strongly temperature dependent. The relation between R_i and V_h, which determines the cathode temperature, is illustrated in Figure 4 for the pentode and double-triode types mentioned above. Both groups had been run for about 6000 hours with $I_k = 0$, the triodes at $V_h = 6{\cdot}3$ volts and the pentodes at $V_h = 8{\cdot}0$ volts. The value of R_i is about doubled when V_h is lowered from 6·3 to 5·5 volts, while for a 10-per-cent variation of V_h about the rated value of 6·3 volts, there is approximately a 40-per-cent variation of R_i.

Metson[3] has published a curve relating the dependence of cathode temperature on heater voltage for a cathode of the pentode type and in Figure 5 the observed R_i values for four valves are plotted logarithmically against these temperature values. A straight-line relation is obtained, which tends to confirm the view that

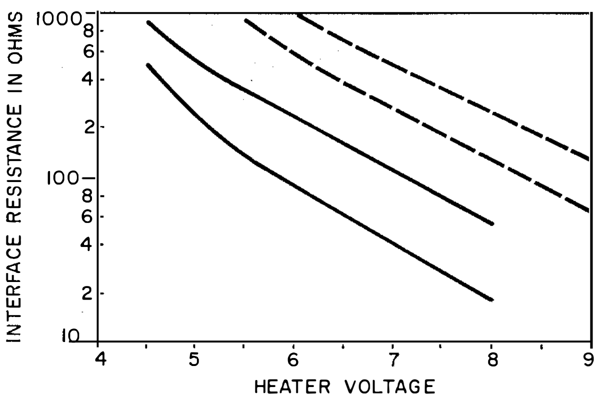


Figure 4—Interface resistance as a function of heater voltage. The two dashed curves are for two sections of a double triode and the two solid-line curves are for pentodes.

[3] G. H. Metson, "Life of Oxide Cathodes in Modern Receiving Valves," British Post Office Research Report number *12 944;* 1951.

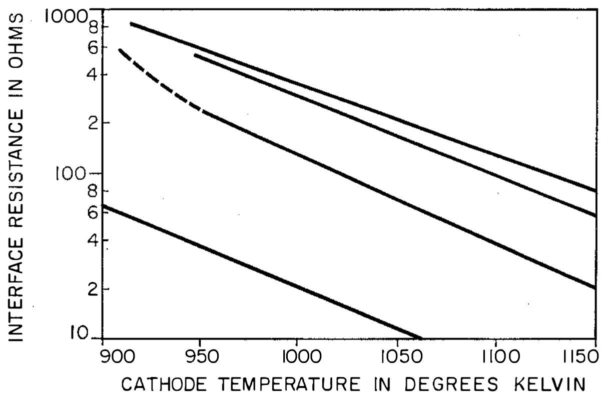


Figure 5—Interface resistance as a function of cathode temperature.

the interface layer is semiconducting. These measurements were made using a pulse method described later.

1.3 Effect of Running Conditions

Figure 6 shows the effect on the growth of R_i of running pentodes at normal cathode temperature with zero and normal cathode current, and also at increased cathode temperature and zero cathode current. The curves were plotted from points representing the mean of four values. At normal cathode temperature there is a small difference between the effect of zero and normal cathode current on R_i growth, but when the temperature is increased to about 1150 degrees Kelvin at $V_h = 8{\cdot}0$ volts, the rate of growth of R_i is greatly increased and the curve shows signs of saturation at 230 ohms and 4700 hours. As outlined above, the increase in resistance is thought to be due to the loss of barium ions from the interface layer; this process will occur more rapidly as cathode temperature is increased, but will be retarded as cathode current is increased. However, heat will be dissipated in the electrode collecting the current and some gas molecules will be liberated; as a result, gas ions will enter the cathode and combine with barium ions in the coating and interface layer so that the activating effect of the current will be counteracted. Hence, there may be only a small difference in the rate of growth of R_i between zero and normal-current life conditions at normal cathode temperature.

When all the barium ions have been removed from the interface layer due to diffusion into the coating and recombination with gas ions, the interface resistance should remain constant at its highest value unless cathode current causes it to fall. This state appears to have been reached on the valves run at $V_h = 8{\cdot}0$ volts and it is apparent that it will be many thousands of hours before it is reached at $V_h = 6{\cdot}3$ volts. For this reason, accelerated life tests at high cathode temperature are useful to indicate differences in the rate of R_i growth between different cathode materials, since the time required to reach a limiting value is short compared with tests at normal temperature.

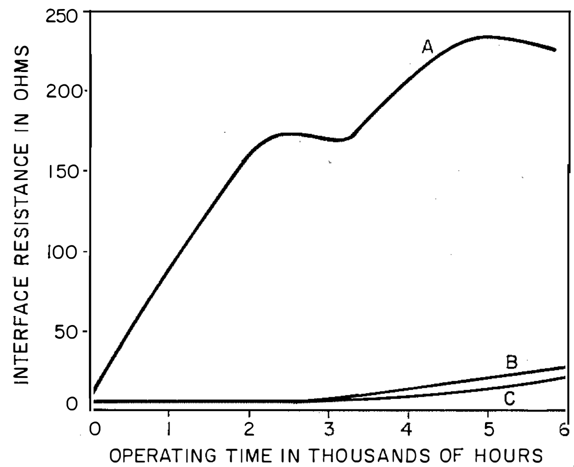


Figure 6—Dependence of interface growth on operating conditions of pentode. For A, $V_h = 8{\cdot}0$, cathode current $= 0$; for B, $V_h = 6{\cdot}3$, cathode current $= 0$; for C, $V_h = 6{\cdot}3$, cathode current $= 11$ milliamperes.

2. *Methods of Measuring Interface Resistance*

2.1 Direct-Current Methods

The two main effects described above provide two different methods of measuring interface resistance; namely, the dependence of mutual conductance on frequency and the distortion of a rectangular voltage pulse. Methods based on the reduction of mutual conductance have been described by Metson,[3,4] Eaglesfield,[5] and others

[4] G. H. Metson, S. Wagener, M. F. Holmes, and M. R. Child, "Life of Oxide-Coated Cathodes in Modern Receiving Valves," *Proceedings of the Institution of Electrical Engineers*, volume 99, part 3, pages 69–81; March, 1952.

[5] C. C. Eaglesfield and P. E. Douglas, "Method of Measuring Interface Resistance and Capacitance of Oxide Cathodes," *British Journal of Applied Physics*, volume 2, pages 318–320; November, 1951.

and entail using the valve as an amplifier with a gain of less than unity, or as a cathode follower. These may be called direct-current methods since direct cathode current flows during measurement.

If the anode impedance of the valve is large compared with its load resistance R_L, then at a high frequency where R_i' is negligible, the gain is

$$S_1 = g_m R_L. \quad (4)$$

At a lower frequency where $R_i' = R_i$, the gain is

$$S_2 = g_m R_L/(1 + \alpha g_m R_i), \quad (5)$$

where $\alpha =$ (cathode current)/(anode current). If R_L is increased by resistance R_x so that $S_1 = S_2$,

$$\frac{g_m\,(R_L + R_x)}{1 + \alpha g_m R_i} = g_m R_L.$$

Hence

$$R_i = R_x/\alpha S_1. \quad (6)$$

The circuit used to measure the values of R_i is shown in Figure 7 for a triode ($\alpha = 1$). A known fraction $R_4/(R_3 + R_4)$ of the input signal is mixed with the output signal at P. When the two signals are equal in amplitude and exactly 180 degrees out of phase, a null signal is obtained at P, so that

$$S_1 = R_4/(R_3 + R_4) \quad (7)$$

and hence

$$R_i = R_x(R_3 + R_4)/R_4. \quad (8)$$

In practice, 10 megacycles per second is used as the high frequency and 1 kilocycle per second as the low frequency with separate amplifiers and detectors for each signal. The 10-megacycle-per-second amplifier is a conventional tuned-anode–tuned-grid type with a gain of about 700, feeding a valve voltmeter, while the 1 kilocycle-per-second amplifier is resistance–capacitance coupled with a gain of about 100 000, connected to a cathode-ray-type tuning indicator. Measurement of R_i is effected by adjusting the cathode bias rheostat R_k for null indication with the 10-megacycle-per-second input and with this setting of R_k, the decade box R_x is adjusted for a null with the 1-kilocycle-per-second input.

It is found on valves with very-low values of R_i that it is not possible to obtain a null at 1 kilocycle per second. This will occur when $S_1 \neq S_2$, for then

$$R_i = \frac{R_x}{S_2} + \frac{S_1 - S_2}{S_1 S_2} R_L$$

or

$$R_i = (R_x/S_2) + R_0 \quad (9)$$

so that a zero-error resistance R_0 is introduced. A difference between S_1 and S_2 will occur when the anode and grid signals are not exactly 180 degrees out of phase at each frequency. At 10 megacycles per second, this is due to the transit time of electrons from the control grid to the

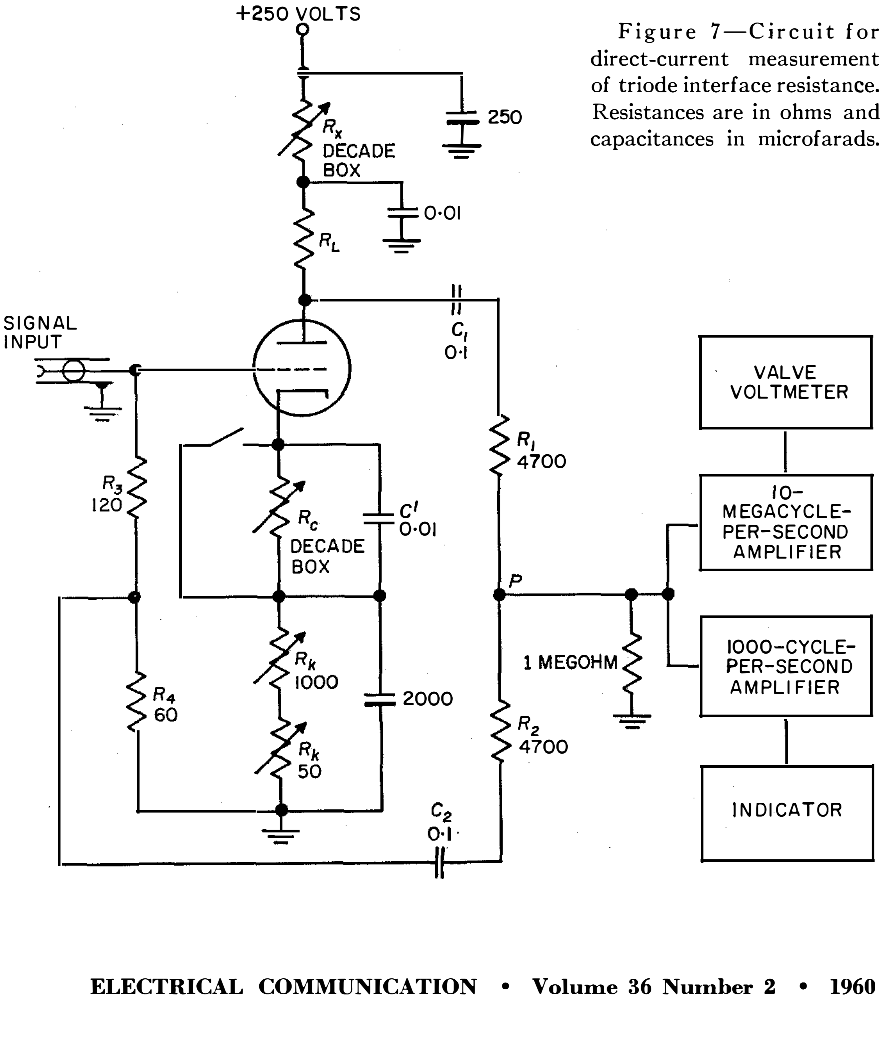


Figure 7—Circuit for direct-current measurement of triode interface resistance. Resistances are in ohms and capacitances in microfarads.

anode, distortion introduced by the valve, and valve and circuit stray capacitance. At 1 kilocycle per second, phase shift from 180 degrees is caused only by distortion of the input signal, which can be different from the 10-megacycle-per-second distortion since neither signal may be a true sine wave. The simplest way to determine R_0 is to calibrate the apparatus for each valve type to be measured by inserting an artificial interface impedance in the cathode lead. This is the decade box R_c by-passed by a 0·01-microfarad capacitor as shown in Figure 7. For a valve with low interface resistance, R_x' is determined for a range of values of R_c.
Then,

$$R_c + R_i = (R_x'/S_2) + R_0.$$

Subtracting from (9), where R_x is the reading for $R_c = 0$,

$$R_c = (R_x' - R_x)/S_2. \quad (10)$$

The graph of R_c against $R_x' - R_x$ is a graph of R_i against R_x and thus is the calibration curve. For the pentode and each half of the double triode, the curves correspond to:—

$$\text{Pentode } R_i = (3{\cdot}96/\alpha)\, R_x + 1 \quad (11)$$

$$\text{Triode } R_i = 2{\cdot}73\, R_x, \quad (12)$$

so that R_0 is 1 ohm for the pentode and zero ohms for the triode.

Apart from the constant zero error, the greatest source of inaccuracy arises from setting R_k to obtain a null signal at 10 megacycles per second since an appreciable rotation of R_k may produce no visible change on the detector. This results in an error in setting S_1 that corresponds to an error in the indicated values of R_i of $\pm$ 1 ohm for both valve types.

2.2 Pulse Methods

Methods based on the distortion of a rectangular pulse have been described by Waymouth,[6] Wagner,[7] and others where direct cathode current may or may not be drawn. Pulse methods can be applied to diodes as well as multi-electrode valves. For a diode (or a multi-electrode valve connected as a diode with the control grid as the anode) with a rectangular voltage pulse V developed across it, the instantaneous quantities are:

v = potential drop across interface impedance
i_c = current through C_i
i_r = current through R_i
i_k = total cathode current.

Then,

$$i_k = i_c + i_r$$

$$\frac{V - v}{r_D} = C_i \frac{dv}{dt} + \frac{v}{R_i},$$

where r_D is the diode impedance between cathode coating and anode. Hence it can be shown that

$$v = V \frac{R_i}{R_i + r_D} \left\{ 1 - \exp\left(- \frac{t}{RC} \right) \right\} \quad (13)$$

and

$$i_k = \frac{V}{r_D} \left[1 - \frac{R_i}{R_i + r_D} \left\{ 1 - \exp\left(- \frac{t}{RC} \right) \right\} \right], \quad (14)$$

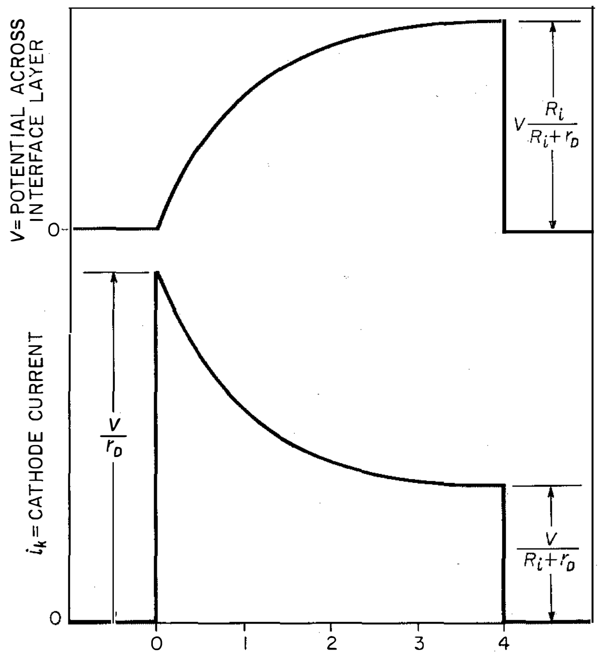


Figure 8—Theoretical curves of potential drop across an interface layer and cathode current of a diode with an interface layer as a function of t/RC.

[6] J. F. Waymouth, Jr., "Deterioration of Oxide-Coated Cathodes Under Low Duty-Factor Operation," *Journal of Applied Physics*, volume 22, pages 80–86; January, 1951.
[7] H. M. Wagner, "Cathode Interface Impedance and its Measurement," *Proceedings of the National Electronics Conference*, volume 8, pages 553–561; 1952.

where

$$\frac{1}{RC} = \frac{1}{C_i}\left(\frac{1}{R_i} + \frac{1}{r_D}\right). \quad (15)$$

Curves of v and i_k against t/RC are shown in Figure 8. It may be noted that the resistance r_D, which includes cathode coating resistance, has the effect of reducing the time constant R_iC_i by appearing in parallel with R_i. Also, r_D will be constant throughout the pulse duration only if the difference between the leading and trailing edge currents is small since r_D is a function of diode current.

From (14) and Figure 8 it can be seen that the leading-edge pulse current is limited by the diode impedance r_D while the trailing-edge current is limited by $R_i + r_D$. These principles can be used to measure R_i by the simple circuit shown in Figure 9A. An adjustable calibrated resistance R_x is introduced in series with the test valve and i_k is observed on the oscilloscope when a rectangular voltage pulse is developed across the test circuit. If interface impedance is present, the i_k waveform will appear as in Figure 9B when R_x is zero. By increasing R_x, the new leading edge may be made the same height as the original trailing edge, so that $R_x = R_i$. A pulse duration sufficiently long to show the level part of the i_k waveform is required, so that the minimum time is about $4RC$. Values of R_iC_i have been observed in the range 5×10^{-7} to 5×10^{-6} second, so a pulse duration of from 2 to 20 microseconds is needed.

The sensitivity of this method is improved if the exponential part of the i_k waveform is studied alone and this can be done by cancelling the non-exponential part with an inverse rectangular waveform as illustrated in Figure 10. The resultant decay can then be amplified and observed alone; also, any decay due to droop of the applied voltage pulse is eliminated, so that a perfectly shaped pulse is not required.

The measurements described in the previous section were made in this way using the circuit shown in Figure 10. Here the rectangular voltage is developed across the valve diode in parallel with two adjustable resistances and, since the centre tap of the pulse-transformer primary winding is earthed, the difference between the two primary currents flows in the secondary winding and can be observed on an oscilloscope connected across it. In practice, R_1 is continuously adjustable from 0 to 1000 ohms and R_x is adjustable in decades 0 to 10, 0 to 100, and 0 to 1000 ohms. Both R_1 and R_x must be non-inductive or they will distort the fast-rising pulse leading edge. In a later development of this system, the currents in each arm are compared by a difference amplifier. With R_x = zero, R_1 is adjusted until the trailing edge of the secondary output is level with the main trace so that $R_1 = r_D$. R_x is then adjusted until the leading edge is level, when $R_x = R_i$.

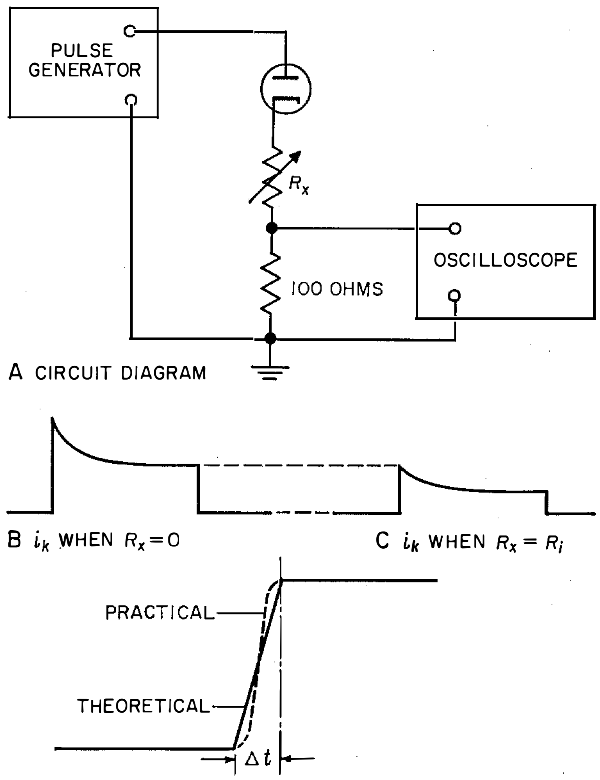


Figure 9—Circuit and cathode current waveforms for a simple pulse method of measuring interface resistance.

It has been assumed so far that the applied voltage pulse reaches its maximum value V in an infinitesimally short time. This is never true in practice and it may be assumed that the voltage increases linearly from zero so that at any time t after the beginning of the pulse, where $t = 0$, its height is given by $V' = at$. This means there will be a small voltage v_0 developed across the interface impedance in the time Δt that the pulse has taken to reach its maximum value (see Figure 9D); it may be shown that

$$v_0 = V\frac{R_i}{R_i + r_D}\left[1 - \frac{RC}{\Delta t}\left\{1 - \exp\left(-\frac{t}{RC}\right)\right\}\right], \quad (16)$$

where $VR_i/(R_i + r_D)$ is the potential drop across the interface at the end of the pulse and may be written as V_f. Hence

$$V_0/V_f = 1 - (RC/\Delta t)\{1 - \exp(-t/RC)\}. \quad (17)$$

If $\Delta t > 0 \cdot 1\ RC$, a fraction V_0/V_f of the final potential drop across the interface will occur at the beginning of the pulse, so that the indicated value R_x will be less than the true value R_i.

For a typical r_D value of 150 ohms, and allowing $R_x \nless 0 \cdot 9\ R_i$, the maximum allowable pulse rise time Δt when $RC = 10^{-7}$ second is $0 \cdot 05$ microsecond. As RC increases, the error in R_i will decrease for a fixed rise time. If Δt is small compared with RC, C_i can be deduced from the whole i_k waveform by

$$C_i = (i_1/i_2)(T/R_i), \quad (18)$$

where

i_1 = leading edge current
i_2 = trailing edge current
T = time for decay curve to discharge by 63 per cent.

The factor i_1/i_2 takes into account the shunting effect of r_D and any load resistors.

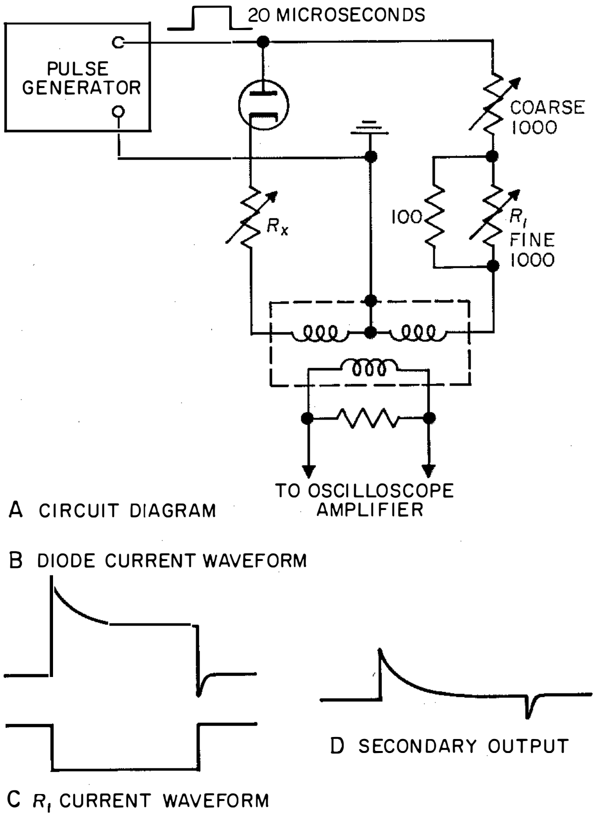


Figure 10—Circuit and waveforms for measuring interface resistance using a pulse transformer.

2.3 Comparison of Direct–Current and Pulse Methods

The pulse method is capable of an accuracy similar to the direct-current method until the interface time constant becomes small enough to cause an error due to the pulse rise time. It has an advantage over the direct-current method in that no R_i change occurs during measurement due to the low duty factor of the cathode current. For a 20-microsecond pulse at 50 cycles per second, 50 milliamperes of pulse current is equivalent to 50 microamperes of direct current, compared with 7 milliamperes of cathode current flowing during measurement by the direct-current method. A further advantage is that all types of valve can be measured, while the direct-current method is only applicable to multigrid valves with a mutual conductance greater than about 2 milliamperes per volt. Also, the pulse method provides simple visual indication of interface presence and indicates deviations from the exponential decay curve. The main disadvantage is that a high-quality pulse generator and oscilloscope are required while the apparatus for the direct-current method is comparatively simple.

When valves operating under conditions known to cause growth of interface resistance are measured by pulsed and direct-current methods, it is found in general that the pulsed values are about 10-per-cent greater than the direct-current values, which may be explained by the activating effect of the direct current. It has been found that measurements made on some valves before operation or after a short period of operation under current-drawing conditions gave pulsed R_i values of several hundred ohms, but direct-current R_i values of only a few ohms. The time constant of these pulsed currents was much longer than would be expected from a cathode interface layer and the difference in observed R_i values can be explained by the existence on the control grid of an impedance of a similar nature to the cathode impedance but of longer time constant. This could be caused by a very-thin high-resistance film on the grid lateral wires and supports, or on the anode of a diode. Whenever pulsed grid current flows, its waveform shows a decay and when the pulse has finished, a negative charge will remain on the grid and can cut off the anode current until it has leaked off. Such effects limit the performance of pulse amplifiers and switching circuits and the phenomenon is still a subject of investigation.

TABLE 1

CATHODE SLEEVE COMPOSITIONS IN PERCENTAGE BY WEIGHT*

Element	Cathaloy *A-30*	Cathaloy *A-31*	Cathaloy *A-32*	*0* Nickel	*ST* Nickel
Aluminium	0·03–0·08	0·04	0·05–0·10	0·02	0·005
Carbon	0·03–0·10	0·03–0·10	0·03–0·10	0·04	0·08
Cobalt	0·40–0·60	0·40–0·60	0·40–0·60	0·90	0·10
Chromium	—	—	—	0·03	0·03
Copper	0·05	0·10	0·05	0·1	0·05
Iron	0·10	0·10	0·10	0·20	0·10
Magnesium	0·01–0·06	0·01–0·06	0·01–0·06	0·05–0·10	0·03–0·07
Maganese	0·05	0·05	0·05	0·05	0·05
Sulphur	0·005	0·005	0·005	0·005	0·005
Silicon	0·02	0·02–0·06	0·02	0·05	0·03
Titanium	0·01	0·02	0·01	0·02	0·005
Tungsten	—	3·75–4·25	2·0–2·50	—	3·50–4·25
Nickel	Balance	Balance	Balance	Balance	Balance

* Except where a range of percentages is given, all figures represent the maximum permissible content.

3. *Growth of Interface Resistance in Valves*

Double triodes are vital components in some computers and life tests have been run to simulate the electrical conditions of this form of operation. With regard to the cathode, these conditions are normal temperature and negligible direct current irrespective of the components associated with the valve, so that the valves were run with heater voltages only applied and all electrodes unconnected. A control experiment with electrode voltages applied to cut off the cathode current of one triode and with the electrodes of the other triode unconnected showed there was no significant difference in the rate of interface growth between the two conditions.

After more than 6000 hours of operation, two distinct classes appeared; triodes in which R_i did not exceed 9 ohms at any time and triodes in which this value was exceeded and R_i continued to rise for periods from 340 to 6300 hours. Values at the end of operation ranged from 32 to 342 ohms with the largest occurring in valves where R_i began to rise earliest and a good correlation existing between low values of cathode current and transconductance and high values of R_i. This erratic behaviour prevents any accurate prediction of R_i values during operation and so leads to uncertainty in estimating valve performance at any time.

4. *Effect of Cathode Sleeve*

All the valves mentioned so far used the *0*-nickel cathode sleeve that is standard throughout the British valve industry. During an investigation to evolve an oxide-coated cathode that does not suffer from interface growth and can still be employed in mass-produced valves, experiments were carried out using nickel sleeves with various constituents added. In particular, the American Cathaloy *A-30*, *A-31*, and *A-32* sleeves were compared with *ST* nickel, an alloy being developed in conjunction with the British Post Office, and *0* nickel. The compositions of these materials are given in Table 1, and it may

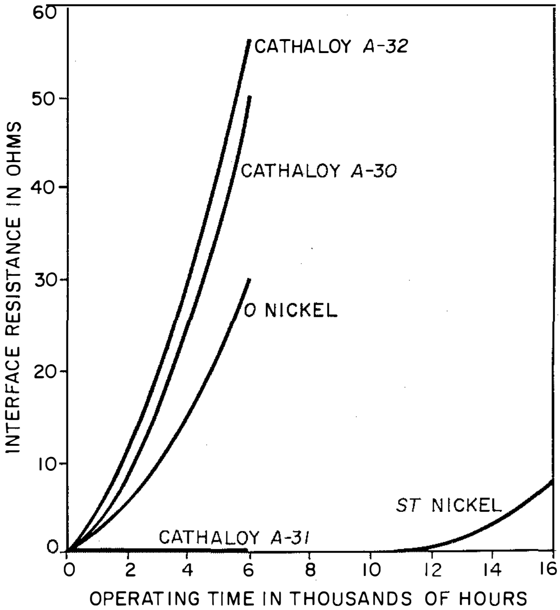


Figure 11—Accelerated life tests on pentode with various cathode sleeve materials. $V_h = 7{\cdot}0$, cathode current $= 0$.

be seen that Cathaloy *A-30* has aluminium and magnesium as its main active constituents; *A-31* has magnesium and tungsten; *A-32* has aluminium, magnesium, and tungsten; *ST* nickel has magnesium and tungsten; and *0* nickel has magnesium and silicon. The effect of these materials on R_i is illustrated in Figure 11, based on accelerated life tests run by the British Post Office. It is clear that the materials containing appreciable amounts of aluminium or silicon favour R_i growth, while *ST* nickel containing magnesium and tungsten only, shows no signs of R_i growth until after 15 000 hours of operation. Examination of these sleeves showed that the concentration of aluminium had increased during operation probably due to migration from the other parts of the valve. Research is being carried out on the elimination of the sources of this impurity and it is considered that, even at present, valves employing *ST* nickel should not develop interface resistance before 20 000 hours of operation at normal current.

The new alloy is being introduced in the manufacture of special-quality valves at the Brimar factory at Footscray and its effect on the maintenance of mutual conductance is shown in Figure 12 for double triodes. As expected, the improvement during zero-current operation is even more pronounced than during normal operation.

5. *Discussion of Results*

If the silicon content of the cathode sleeve is kept low, this in itself discourages the formation of a barium orthosilicate layer, but Rittner[8] has suggested the following explanation of the beneficial effects of tungsten in reducing interface growth. While the cathode coating is being broken down during exhaust, the following reaction proceeds quickly:—

$$3BaCO_3 + W = Ba_3WO_6 + 3CO \qquad (19)$$

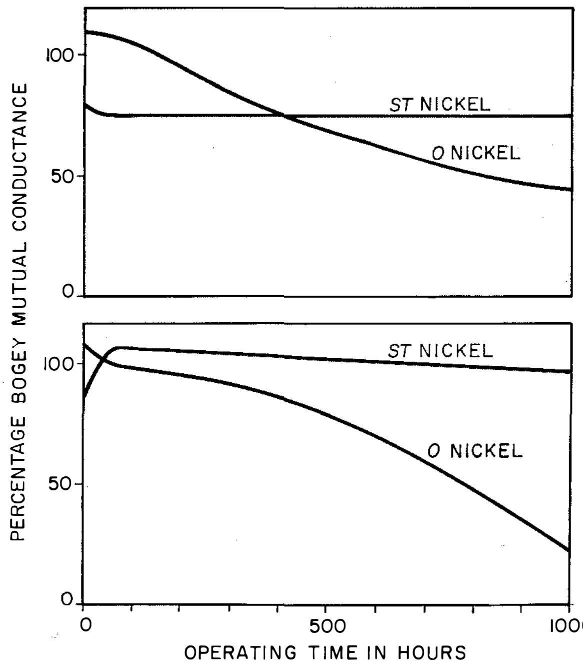


Figure 12—Comparison between effect of *0* nickel and *ST* nickel on mutual conductance in double triodes. Top graph for normal operation and bottom graph for operation with zero cathode current.

[8] E. S. Rittner, "Theoretical Study of Chemistry of Oxide Cathode," *Philips Research Reports*, volume 8, pages 184–238; June, 1953.

and any good reducing agent, A, such as magnesium or silicon, will react to form free barium thus,

$$Ba_3WO_6 + 6A = 6AO + W + 3Ba. \quad (20)$$

In this way free barium is formed by reaction with the layer itself so that a very-long time is required to deactivate it and cause interface resistance to rise. Furthermore, if silicon is present, it will react with the barium tungstate layer to form free barium rather than with the coating to form barium orthosilicate.

Previous reports have suggested that aluminium inhibits interface growth, but this has been proved untrue under production conditions. It seems that aluminium is as harmful as silicon in promoting interface growth and for this reason aluminum content in *ST* nickel is kept as low as possible. Magnesium is included since its presence does not annul the beneficial effects of tungsten and it is necessary as a reducing agent to ensure adequate electron emission from the cathode coating. The magnesium content is not more than that of *0* nickel, since any further increase results in the formation of low-resistance films on the valve insulators causing undesirable leakage and noise effects.

6. Conclusion

Although British valves suffer less from the growth of cathode interface resistance than other valves employing cathode sleeves with a higher silicon and aluminium content, the unpredictable nature of interface growth makes desirable its elimination. It is considered that good progress on a production scale has been made with the introduction of *ST* nickel and further progress is being made in overcoming manufacturing difficulties caused by removing reducing agents from the cathode sleeve. It is therefore expected that the complete range of Brimar special-quality valves will employ interface-free cathodes in the near future, with a consequent improvement in stability of characteristics and pulse performance.

7. Acknowledgment

Acknowledgment is made to the British Admiralty for permission to make use of the information contained in this paper.

Evaluation of Intermediate-Frequency and Baseband Diversity Combining Receivers*

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TECHNIQUES of diversity reception have advanced rapidly with the advent of beyond-the-horizon communication. Because of the rapidly fluctuating signals encountered in tropospheric scatter propagation, strong-signal selection (switching diversity) has been largely supplanted by more-sophisticated signal-combining techniques. Present tropospheric scatter systems commonly employ either postdetection ratio-squared combining or, more recently, a technique of predetection linear addition. A theoretical and experimental study comparing these two methods is the subject of this paper. Apart from obvious advantages of simplicity, the predetection technique exhibits lower distortion under multipath conditions, due to the linear combining process.

• • •

Diversity reception is particularly effective against the continual rapid fading encountered in tropospheric scatter communication. Two or more signals are separately received at different frequencies or over different paths sufficiently diverse so that the signal levels do not fade coherently. The signals are then combined so that communication is maintained unless all signals fail simultaneously.

Diversity combining can be accomplished in various ways. Combining can be performed either before or after detection and the signals can be selected (switched) or added either linearly or in variable proportions.

The simplest combining method is to select the strongest signal by simple switching. Selective diversity falls somewhat short of optimum combining, however, and introduces switching transients and lags that become serious under the rapidly fluctuating conditions of tropospheric scatter propagation.

Baseband combining (postdetection ratio-squared) has been extensively used for tropospheric scatter communication. Received signals are adjusted in level and added after detection. It has been shown[1] that optimum diversity combining occurs when the received signals are proportioned according to the square of their signal-to-noise ratios and added. The well-known baseband[2] combiner circuit approximates this relation over the most significant range of signal ratios. Signal proportions in the common output are controlled by measurement of amplified out-of-band noise in each receiver.

During deep fades, the noise output from a frequency-modulation receiver rises sharply to a level comparable to full signal output. In combining frequency-modulation signals after detection, although large signal inequalities are statistically infrequent, a close approximation to ratio-squared combining must be provided over a wide range of signal ratios to provide sufficient rejection of the greatly increased noise accompanying weak signals. Linear addition is therefore impractical for frequency-modulation postdetection combiners.

If signals are combined in a linear portion of the receiving equipment, prior to limiting and detecting, the original received amplitude ratio is preserved and simple linear addition of the signals without adjustment of ratio provides a combined signal-to-noise ratio within 0.6 decibel of optimum. By providing suitable control of signal phase, a technique of predetection combining[3] has been developed for tropospheric

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This study was sponsored in part by the United States Army Signal Engineering Laboratories; Fort Monmouth, New Jersey.

[1] L. R. Kahn, "Ratio Squarer," *Proceedings of the IRE,* volume 42, page 1704; November, 1954.

[2] C. L. Mack, "Diversity Reception in UHF Long-Range Communications," *Proceedings of the IRE,* volume 43, pages 1281–1289; October, 1955.

[3] F. J. Altman and W. Sichak, "A Simplified Diversity Communication System for Beyond-the-Horizon Links," *IRE Transactions on Communication Systems,* volume CS-4, pages 50–55; March, 1956.

scatter communication, using simple linear addition of the received signals at a point before the received signal levels are altered by limiting. Linear addition approximates optimum combining for most received signals, deviating slightly from the ideal for very-large signal ratios.

The ideal performance of various combiners has been calculated[4] (Figure 1). The curves show statistical variation in signal-to-noise ratio under the Rayleigh fading conditions encountered in tropospheric scatter propagation. The effect of frequency-modulation threshold is indicated. Results are given for the cases of signal selection by switching, linear addition of signals, and ratio-squared addition, with combining performed either before or after detection. Curve *2* (predetection linear addition) and curve *5* (postdetection ratio squarer) are the only combining forms commonly used. Selective diversity (curve *1*), while simpler and only slightly inferior in signal-to-noise ratio, is avoided due to switching transients. Predetection ratio-squaring (curve *3*), while entirely practical, does not appear justified for the small additional advantage derived. Postdetection linear addition (curve *4*) is clearly undesirable.

1. Discussion

1.1 Combiner Circuits

Published information on the combining circuits, particularly the intermediate-frequency combiner, is somewhat incomplete. Block diagrams are shown for the intermediate-frequency-combining receiver (Figure 2B) and the baseband-combining receiver (Figure 2A) used in this study. The receivers were designed at the same time and were nearly identical, making use of common units and subassemblies wherever possible.

For baseband combining (Figure 2A), two complete receivers are used and all combining functions are performed using the video-frequency (baseband) output. For each receiver, noise components above the normal signal frequency are selected, amplified, and detected to produce a control voltage that is applied to the corresponding combiner tube to control the combining ratio. Any difference in these control voltages varies the combining ratio, favoring the signal having the lower noise.

Since a failure at any point in either signal channel or failure in a noise amplifier will make the affected receiver appear to have low noise, and thereby suppress the remaining operative channel, protection is provided by adding a pilot tone at the transmitter. The pilot tone is received along with the signal, passed through the noise amplifiers for protection against failure, and finally used to operate an alarm relay that disconnects a channel when the pilot tone is absent, thus permitting the remaining channel to function normally. Protection against disabling

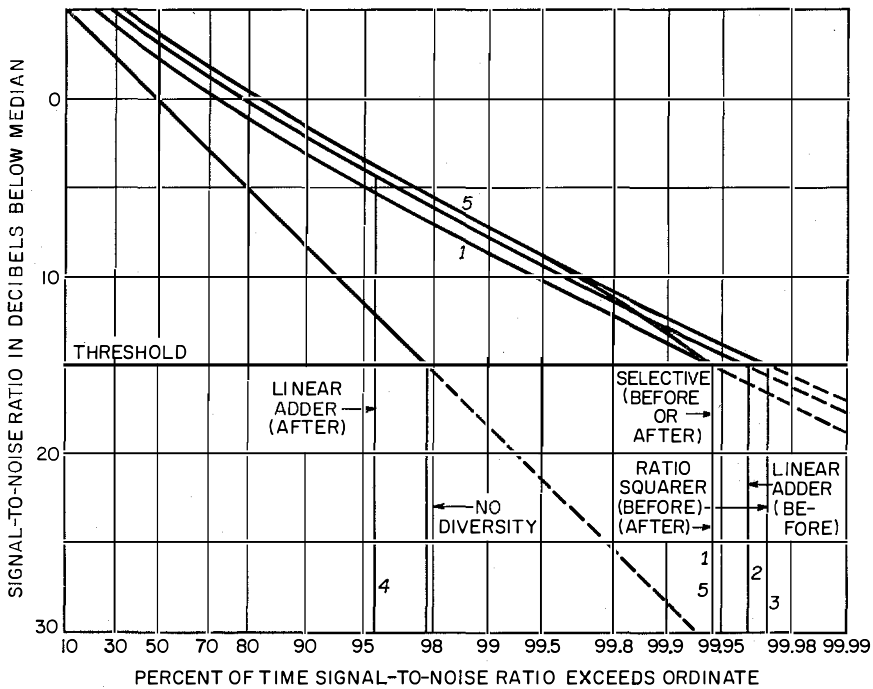

Figure 1—Performance of diversity combiners before and after detection, including frequency-modulation threshold.

[4] D. J. Brennen, Lincoln Laboratory, private communication.

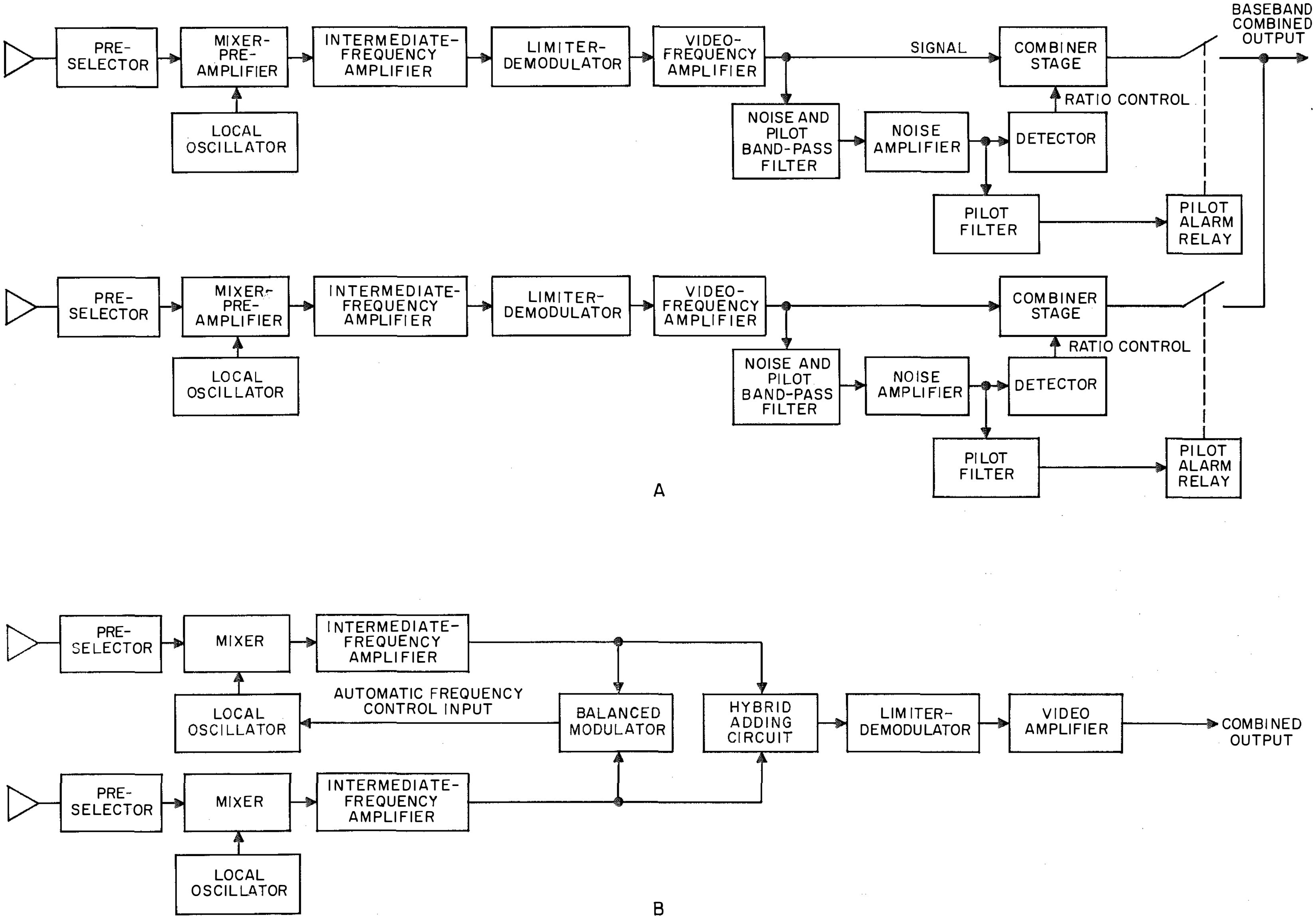

Figure 2—Block diagram of diversity receivers, A = baseband combining, B = predetection combining.

the receivers by the accidental loss of the pilot tone is obtained by providing dual pilot tones and an alarm circuit at the transmitter.

For intermediate-frequency combining (Figure 2B), separate receiver front ends are used, as shown, up to the intermediate-frequency amplifier output. Relative signal phase is measured at this point by a balanced modulator (phase detector) and the phase is controlled by supplying a corrective direct voltage to one local oscillator, causing it to advance or lag in phase with respect to the other local oscillator as required to establish additive signal phase at the combining point. The resulting cophasal signals are added in a hybrid and the combined signal is applied to the limiters and discriminator.

Amplifiers and reactance tubes have been avoided in the combiner so that tube failures are confined to the signal channels, making the combining circuit basically fail-safe (failure at any point in either receiver does not interfere with normal operation of the remaining receiver).

1.2 Physical Characteristics

Intermediate-frequency combining offers certain obvious advantages of simplicity, reliability, few adjustments, ease of maintenance, compactness, and lightness. A comparison of these factors is given in Table 1.

TABLE 1

Comparison of Two Combining Methods

	Baseband Combining	Intermediate-Frequency Combining
Number of Tubes Required for Dual Diversity	21	0
Additional Equipment Required	Pilot tone detector and relay to protect against failure of a noise amplifier or intermediate-frequency amplifier	0
Adjustments per Receiver	3	1
Ease of Maintenance	Normal maintenance for three chassis containing 23 tubes. Intermediate-frequency gain adjustment not required. Critical adjustment of signal levels is required under conditions of aircraft multipath propagation	Periodic intermediate-frequency gain adjustment required. Combiner unit is treated as a component (1 printed card, approximately 16 components, no tubes)
Size	Approximately 1400 cubic inches (33 cubic decimeters)	Approximately 48 cubic inches (0.79 cubic decimeter)

1.3 Field Experience

The availability of closely similar tropospheric-scatter receivers of common design greatly facilitated comparison of the combiners. Diversity receivers of this design using baseband combining are in use in several military systems. The same design, using intermediate-frequency combining for space-diversity reception, is in use between Puerto Rico and the Dominican Republic, and a link from Sardinia, Italy, to Minorca, Spain, uses frequency diversity with the intermediate-frequency combining equipment. A similar intermediate-frequency combiner, but with 20-megacycle-per-second bandwidth, is used in the Florida–Cuba television and telephone link, giving four-fold diversity by a combination of dual space and dual frequency diversities. No corresponding baseband combiner of comparable bandwidth has been developed.

Field experience with these links has not shown serious difficulties with either type of combiner. Various experimenters, however, have indicated that distortion is generated in the baseband combiner under certain multipath propagation conditions. The effect appeared to be caused by unequal signal levels at the combiner grids, an abnormal condition caused by selective fading in the otherwise equal frequency-modulation outputs. The linear addition used in predetection combining avoids this form of distortion. Analysis predicted other differences in the behavior of pre- and post-detection combiners in the presence of multipath propagation; a comparison is included below.

2. *Theoretical*

The following theoretical study compares the relative degree of distortion produced using the two combiners when multipath signals caused by airplane interference are present. In the specific case under study, two frequency-modulation receivers are operated in diversity while an airplane reflection is present in the propagation path. Each received signal is composed of two waves: a normal scatter (direct) wave and a wave reflected from the airplane. The reflected wave is delayed with respect to the direct wave. Since the airplane reflecting surface is infinitesimal compared with the scattering volume and at the modulation frequency the antenna spacing is insignificant with respect to the propagation path length, the path lengths of the two direct waves are assumed to be identical, as are the path lengths of the two delayed waves.

If we neglect whole cycles of radio-frequency phase difference between each direct wave and its associated delayed wave (delay difference appearing as a phase angle at modulation frequency), and if we restrict the amplitude of each reflected wave to be less than its corresponding direct wave, the two signals can be represented as

$$E_1 = d \sin(\omega t + m \sin pt) + r \sin[(\omega t + \alpha) + m \sin(pt + \gamma)] \quad (1)$$

and

$$E_2 = d_1 \sin[(\omega t + \theta) + m \sin pt] + r_1 \sin[(\omega t + \theta + \beta) + m \sin(pt + \gamma)], \quad (2)$$

where

d, d_1 = amplitudes of direct waves
r, r_1 = amplitudes of reflected (delayed) waves
$\omega/2\pi$ = carrier frequency
$p/2\pi$ = modulation frequency
m = modulation index
θ = phase angle between the two direct waves
α, β = phase angle between the direct waves and their associated delayed waves
γ = modulation phase angle.

These two signals produce an instantaneous frequency from the combiner of the desired signal frequency $\omega + pm \cos pt$ and a frequency distortion term ω_d, or,[5]

$$\omega_i = \omega + pm \cos pt + \omega_d, \quad (3)$$

where pm = transmitter angular frequency deviation.

$$\omega_d = pB\left\{\frac{K^2 + K\cos[\psi + B\cos(pt+\gamma/2)]}{1+K^2+2K\cos[\psi+B\cos(pt+\gamma/2)]} \times \sin\left(pt + \frac{\gamma}{2}\right)\right\}, \quad (4)$$

where

$$K = r_e/d_e < 1,$$

where r_e is the total reflected component and d_e is the total direct component in any one demodulator.

$B = 2\,m\,|\sin \gamma/2|$
ψ = phase angle from d_e to r_e (α, β) or the angle of $(r + r_1)/(d + d_1)$.

The distortion term ω_d can be expanded into a Fourier series to show its harmonic content. This gives

$$\omega_d = pB\Big\{\sum_{n=1}^{\infty}(-1)^{n+1}K^n \cos n\psi J_0(nB) \times \sin(pt + \gamma/2) + \sum_{n=1}^{\infty}\sum_{r=1}^{\infty}(-1)^{n+r+1}K^n \times \cos n\psi J_{2r}(nB) \times [\sin(2r+1)(pt+\gamma/2) - \sin(2r-1)(pt+\gamma/2)] + \sum_{n=1}^{\infty}\sum_{r=1}^{\infty} \times (-1)^{n+r+1}K^n \sin n\psi J_{2r+1}(nB) \times [\sin(2r+2)(pt+\gamma/2) - \sin 2r(pt+\gamma/2)]\Big\}. \quad (5)$$

Equation (5) can be simplified for the cases $x = 0, \pi/2, 3\pi/2$, or π. For $x = \pi$, (6) reduces, on grouping terms, to

$$\omega_d = -pB\left[\sum_{n=1}^{\infty}K^n \frac{2J_1(nB)}{nB}\sin\left(pt+\frac{\gamma}{2}\right) - \sum_{n=1}^{\infty}K^n \frac{6J_3(nB)}{nB}\sin 3\left(pt+\frac{\gamma}{2}\right) + \sum_{n=1}^{\infty}K^n \frac{10J_5(nB)}{nB}\sin 5\left(pt+\frac{\gamma}{2}\right) - \ldots\right]. \quad (6)$$

We can now calculate the level of harmonic distortion present by comparing the amplitude of the third harmonic with the amplitude of the fundamental by the relation

$$\left(\begin{array}{l}\text{level of third harmonic in decibels}\\ \text{down from fundamental}\end{array}\right) = 20 \log\left[\frac{\sum_{n=1}^{\infty}K^n \frac{6J_3(nB)}{nB}}{m}\right] \quad (7)$$

for the case $x = \pi$. For the other cases, a similar form is used.

[5] I. H. Gerks, "An Analysis of Distortion Resulting from Two-Path Propagation," *Proceedings of the IRE*, volume 37, pages 1272–1277; November, 1949.

2.1 Intermediate-Frequency Combiner

In the intermediate-frequency combiner, the two signals are made cophasal and are added linearly. The ratio $|(r + r_1)/(d + d_1)|$ may therefore be expressed as

$$K = \left(\frac{r^2 + r_1^2 + 2r\, r_1 \cos \phi}{d^2 + d_1^2 + 2d\, d_1 \cos \theta} \right)^{1/2}, \qquad (8)$$

where

$$\theta = \tan^{-1} \left(\frac{r \sin \alpha}{d + r \cos \alpha} \right) - \tan^{-1} \left(\frac{r_1 \sin \beta}{d_1 + r_1 \cos \beta} \right) \quad 0 \leqslant \alpha, \beta \leqslant \pi,$$

$$\phi = \beta - \alpha + \tan^{-1} \left(\frac{r \sin \alpha}{d + r \cos \alpha} \right) - \tan^{-1} \left(\frac{r_1 \sin \beta}{d_1 + r_1 \cos \beta} \right) \quad 0 \leqslant \alpha, \beta \leqslant \pi.$$

2.2 Baseband Combiner

In the baseband combiner, ratio-squared addition is used (the signals are added in proportion to their relative signal-to-noise ratios). The ratio in this case is given by

$$D_B = \frac{D\,(r^2+d^2+2r\,d \cos \alpha) + D_2(r_1^2+d_1^2+2r_1\,d_1 \cos \beta)}{(r^2+d^2+2r\,d \cos \alpha) + (r_1^2+d_1^2+2r_1\,d_1 \cos \beta)}, \qquad (9)$$

D_B = third-harmonic distortion (voltage amplitude) of base combined output

D_1 = third-harmonic distortion (voltage amplitude) of receiver *1*

D_2 = third-harmonic distortion (voltage amplitude) of receiver *2*.

2.3 Comparison of Harmonic Distortion From the Two Combiners

A complete statistical analysis of this problem necessitates evaluation of an intractable integral. However, specific solutions are readily obtained by choosing values for the symbols in (5). Prior work[5] shows that the distortion increases as the direct and delayed waves approach amplitude equality and phase opposition. If therefore one allows the direct waves to be equal and the delayed waves are set at 0.9 and 0.8 of the amplitudes of their respective direct waves, by varying the phase angle between the direct and delayed waves the harmonic distortion present can be calculated for any chosen values of modulation frequency, frequency deviation, and time delay. A modulation frequency of 15 kilocycles per second, a frequency deviation of 240 kilocycles per second, and a 0.8-microsecond delay were chosen and the distortion was computed. The results are shown in Figure 3. The receiver using the intermediate-frequency combiner demonstrated a significantly lower distortion level over almost the entire range of phase angle variation. Since β is a random angle, however, only average distortion level has significance.

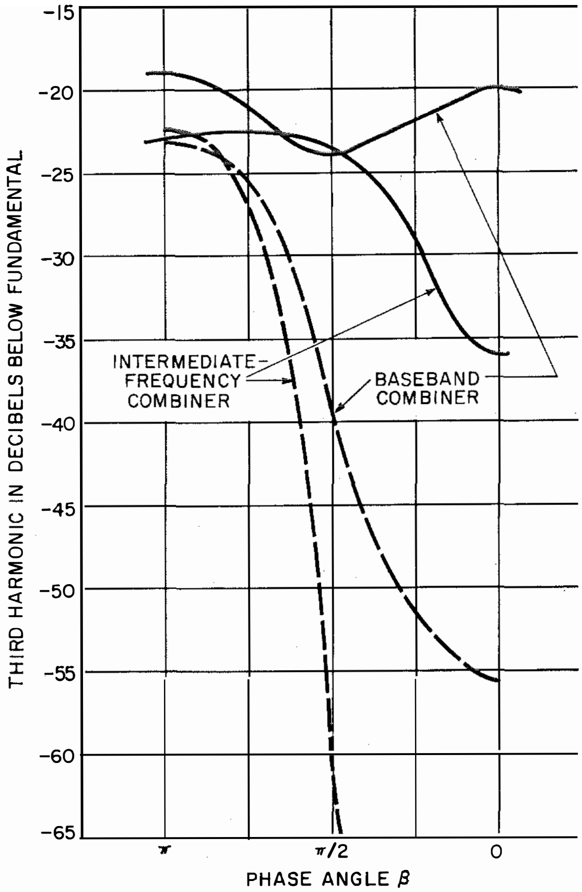

Figure 3—Third-harmonic distortion versus phase angle for 240-kilocycle-per-second deviation; 15-kilocycle-per-second modulating frequency; 0.8-microsecond time delay $d = d_1 = 1$; $r = 0.9$; $r_1 = 0.8$; $\alpha = \pi$; and $0 \leqslant \beta \leqslant \pi$. The dashed curves indicate theoretical values and the solid lines experimental results.

The theory considers only distortion products of an ideal receiver with ideal combining. Except for ratios of r and d near unity, and angles near π, the theoretical distortion is not as large as other effects of imperfect ratio-squared combining and residual distortion.

The advantage held by the intermediate-frequency combiner in harmonic distortion level is achieved because it tends to add the larger components in the multipath signals cophasally, increasing their amplitude, while decreasing the amplitude of the smaller components by adding them in less-advantageous phase.

3. *Experimental Study*

3.1 Test Circuit

Two dual-diversity receivers were available, one using intermediate-frequency combining and the second using a ratio-squaring baseband combiner. Other components—intermediate-frequency amplifiers, limiter–demodulators, et cetera—were of common design. The center frequency of the receivers was 970 megacycles per second and the intermediate-frequency bandwidths were 2 megacycles per second. By cross-connecting at a point following the intermediate-frequency preamplifiers with a coaxial switch, a comparison between the combiners was obtained under identical test conditions.

To provide reproducible conditions simulating aircraft multipath signals, a multipath simulator was used as the signal source. Figure 4 is a block diagram of the test circuit.

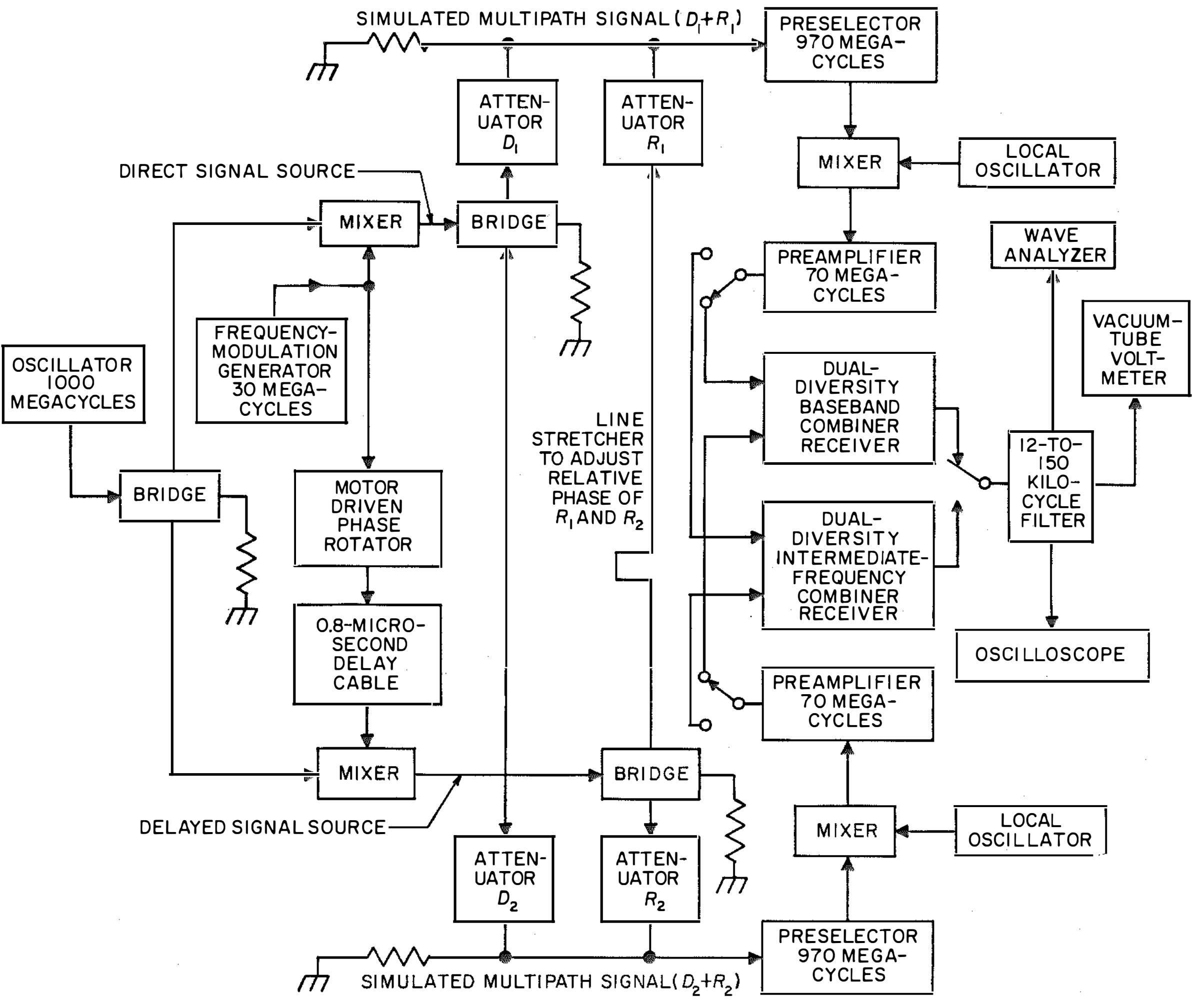

Figure 4—Block diagram of multipath simulator and test setup. D_1, D_2 = Direct (undelayed) signal components at 970 megacycles per second; R_1, R_2 = reflected (delayed and Doppler phase rotated) signal components at 970 megacycles per second.

3.2 Test Procedure

Direct components were adjusted for equal amplitude about 20 decibels above threshold. The two halves of each diversity receiver were designated receiver *1* and receiver *2*. Delayed components were adjusted so that the worst distortion in receiver *1* occurred approximately 180 degrees from worst distortion in receiver *2* (as measured with the common phase-shifter controlling delayed-signal phase).

The motor-driven phase shifter was operated at various speeds and output waveform observed on an oscilloscope while transferring periodically between baseband and intermediate-frequency combining. The object of this visual test was to observe distortion characteristics under conditions simulating Doppler shift, noting whether magnitude or character of distortion was affected by the frequency shift. Distortion was noticeably affected by deviation, but appeared to be independent of Doppler frequency shift, making it possible to evaluate distortion products quantitatively in a point-by-point check with the wave analyzer.

3.3 Test Results

3.2.1 Distortion

Quantitative measurements of distortion were made. Distortion was measured as a function of third harmonic present in decibels below the fundamental. Figure 3 shows data taken with test conditions identical with those chosen in the case explored in the theoretical analysis. The variation in distortion level for the receiver using an intermediate-frequency combiner was 13.5 (maximum-to-minimum) and for the baseband combiner, 5 decibels. The receiver using a baseband combiner demonstrated a 4.2-decibel-greater average distortion. Further measurements were made with different modulating frequencies, frequency deviations, and direct-to-delayed-wave amplitude ratio. Results are given here in Table 2. These results substantiated the previous measurements and showed that changes in modulation frequency, et cetera, do not disturb the relative amplitudes of the distortion from the two combiners. The distortion present in each receiver of a diversity pair was measured prior to combining. The distortion in the combined output was also measured. These data are given in Table 3.

TABLE 2

Distortion Comparisons of Two Combining Methods

ϕ	$d = d_1$	r	r_1	Peak Deviation in Kilocycles per Second	Modulation Frequency in Kilocycles per Second	Third Harmonic in Decibels Below Fundamental	
						Baseband Combiner	Intermediate-Frequency Combiner
$\alpha = \pi$, $\beta = \pi$	1	0.8	0.7	60	15	34	40
$\alpha = \pi$, $\beta = \pi$	1	0.8	0.7	60	40	37	48
$\alpha = \pi$, $\beta = \pi$	1	0.9	0.8	240	40	14	18
$\alpha = \pi$, $\beta = 0$	1	0.9	0.8	60	40	25	59

TABLE 3

Distortion in Combined Output
15-Kilocycle-per-Second Modulation; 240-Kilocycle-per-Second Deviation; 0.8-Microsecond Delay;
$d = d_1 = 1$; $r = 0.9$; $r_1 = 0.8$; $\alpha = \beta = \pi$

Point of Measurement	Third-Harmonic Distortion in Decibels Below Fundamental	
	Baseband Combiner	Intermediate-Frequency Combiner
Receiver *1*	19	18
Receiver *2*	32	32
Combined Output	19	24

It is seen that, whereas the baseband combiner is controlled by the most-distorted signal, the receiver using the intermediate-frequency produces an intermediate level of distortion.

3.2.2 Quieting

Frequency-modulation quieting curves were taken (continuous-wave signals, no multipath effects). Results are shown in the curves of Figure 5. Outputs were not equal for the two combiners, so that the ordinates indicated are only relative.

3.2.3 Unequal Signal Delay

Another condition, with a single direct signal supplied to the left receiver and a delayed signal to the right receiver, was also investigated. The two signals were adjusted for approximate equality at 20 decibels above threshold and second-harmonic distortion was measured with 15-kilocycle-per-second modulation (240-kilocycle-per-second deviation) and with 60-kilocycle-per-second modulation (240-kilocycle-per-second deviation). The results are given in Table 4.

4. *Conclusions*

The intermediate-frequency combiner demonstrates significant advantages over the baseband combiner in distortion level, frequency-modulation quieting, simplicity, and reliability. A 4.2-decibel advantage in average distortion level was found experimentally for the intermediate-frequency combiner. The theoretical and experimental studies of distortion level were in agreement when there was high distortion due to multipath fading. When low multipath distortion was present, the distortion observed experimentally was due to other-than-ideal operation of the two receivers.

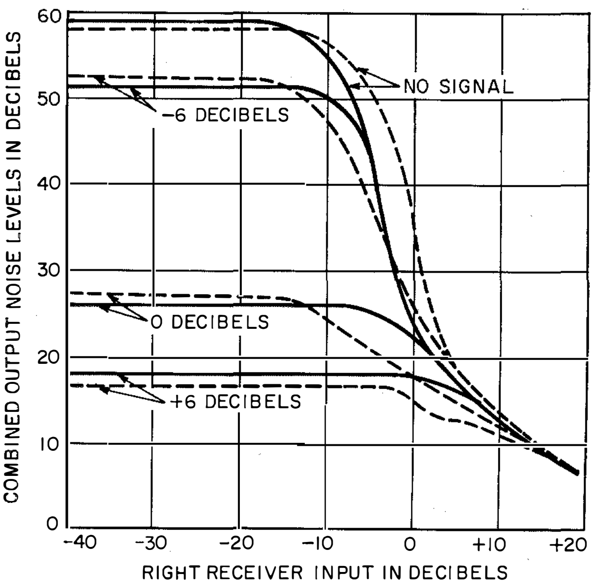

Figure 5—Comparative quieting characteristics for dual-diversity receiver. The labels on the curves are the input to the left receiver, the abscissa the right receiver input. Solid curves = baseband combining; dashed curves = intermediate-frequency combining. Reference input level (0 decibels) chosen for approximately 30-decibel quieting in each receiver. Relative output scales are arbitrary due to differing output amplifiers.

TABLE 4

DISTORTION CAUSED BY UNEQUAL SIGNAL DELAY

Modulation Input to System in Kilocycles per Second	Second-Harmonic Distortion in Decibels Below Fundamental	
	Baseband Combiner	Intermediate-Frequency Combiner
15 240	44	49
60 240	40	46

The baseband combiner was found to have a 0.6-decibel advantage in signal-to-noise ratio except near threshold where the intermediate-frequency combiner held a slight advantage. The intermediate-frequency combiner is much-less complex than the baseband combiner, containing only passive elements compared to the 21 tubes necessary when the baseband combiner is used. The gain in reliability is obvious.

The rise in distortion observed for baseband combining at $\alpha = \pi$, $\beta = 0$, appears to arise from nonlinearity in the combining stage with greatly differing input waveforms.

5. *Acknowledgments*

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Design Concepts of a High-Brightness Airborne Radar Indicator*

By EDWARD W. KOENIG

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WHILE normal cathode-ray-tube radar indicators have been accepted for shipboard use where ambient lighting could be controlled, they have not been acceptable for the high ambient light levels encountered in aircraft cockpits. A display with at least 1000 foot–lamberts of illumination is considered necessary for reliable presentation of radar information under bright daylight conditions in an open cockpit. Modern aircraft and radar system designers have searched for a display capable of this brightness. One of these systems, the *AN/APG-53* radar, developed at the Naval Avionics Facility, Indianapolis, was designed with such a display as an integral part. The Farnsworth *7176* Iatron® tube was chosen as the display element, and Farnsworth Electronics was chosen to develop the indicator circuits (the cognizant group is now organized as part of ITT Laboratories). This indicator has now been completed and shows great promise of being accepted as a component for airborne radar systems. It is at present being flight tested for the Douglas *A4D-2N* Skyhawk.

Because of the inclusion of this high-brightness indicator in the initial weapons-system concept as one of the major instruments on the control panel, it was necessary to specify a minimum size and weight for the unit that would best utilize the limited cockpit space available. For this reason, the indicator has the dimensions of approximately $5\frac{5}{8}$ inches (14 centimeters) square and 16 inches (41 centimeters) long, and weighs less than 14 pounds (6.3 kilograms). The unit contains a 5-inch- (12.7-centimeter-) diameter storage tube and all the necessary circuits for a multipurpose radar indicator. The indicator is shown in Figures 1 and 2. Transistors, printed wiring boards, and miniature components make this assembly possible. It will be the purpose of this paper to define some of the results of this minification and to describe the unique problems associated with the inclusion of a high-brightness storage tube as a display element.

1. Display Tube

The selection of a display tube was made on the basis of the brightness requirements more than any other single factor. Signal-storage capability was originally considered only as a means of producing the required brightness but has proved to be a desirable factor on its own. A disadvantage inherent in storage tubes which was recognized from the beginning, was their comparatively lower resolution. In this application, the resolution was not considered unduly restrictive. A view of the Iatron indicator tube used in this indicator is shown in Figure 3.

Characteristics of the tube are as follows.

Brightness: 3000 foot–lamberts at 10 kilovolts and full storage.

Resolution: Approximately 30 lines per inch (0.75 line per millimeter).

Contrast: 5 shades of gray.

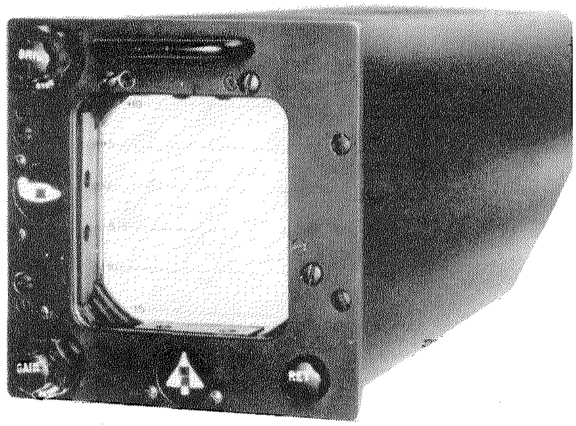

Figure 1—Airborne radar indicator for azimuth, elevation, and range.

* Reprinted from Institute of Radio Engineers', "Proceedings of the East Coast Conference on Aeronautical and Navigational Electronics," Baltimore, Maryland; October 27–28, 1958.

The development reported in this paper was performed under subcontract to Douglas Aircraft Company on Contract *NOas-57-183*. The indicator is a portion of the *AN/APG-53A* Radar Set, developed at Naval Avionics Facility, Indianapolis.

Length: 12.5 inches (32 centimeters).
Diameter: $5\frac{1}{16}$ inches (12.8 centimeters) at the bulb and $1\frac{9}{16}$ inches (6.5 centimeters) at the neck.
Useful screen diameter: 4 inches (10 centimeters) maximum.
Focusing Method: Electric field.
Deflection Method: Electric field.

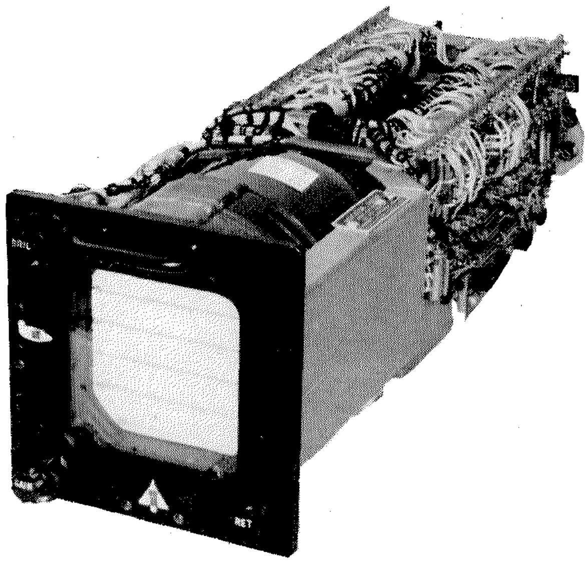

Figure 2—Indicator with cover removed.

The method of operation of the Iatron can be seen by reference to Figure 4. The Iatron contains a normal cathode-ray tube for writing, a flooding gun with its cathode and anodes, and a pair of fine-mesh screens.

The method of operation of the storage tube is partly that of a normal cathode-ray-type gun

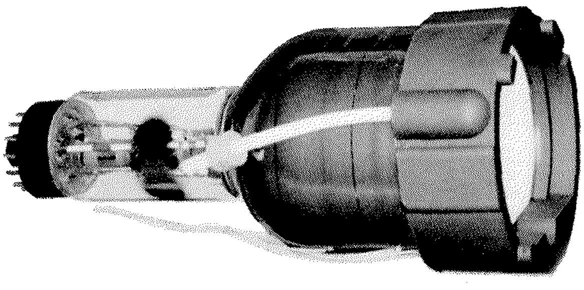

Figure 3—Iatron *7176* display tube with special mounting ring at the viewing end.

with deflecting electrodes to produce a writing beam that impinges on the backing electrode. This backing electrode is constructed of a fine-mesh nickel screen coated with an insulating material that has a high secondary-emission ratio. Each electron that hits the backing electrode causes secondary emission, leaving a slight positive charge in the location of the hit. Secondary electrons generated here are gathered by the comparatively coarse-meshed collector screen and carried away. While the writing beam is continually scanning its pattern, the flooding-gun cathode is continually emitting an unmodulated beam of electrons that are allowed to spray out in an unfocused fashion. Electrostatic lens action of wall coatings (flooding-gun anodes) control this spray so that it is collimated and approaches the screen section as a parallel beam. When this spray approaches a portion of the backing electrode, it will either be repelled by the slight negative charge on the insulator material or it will pass through the electrode in those regions

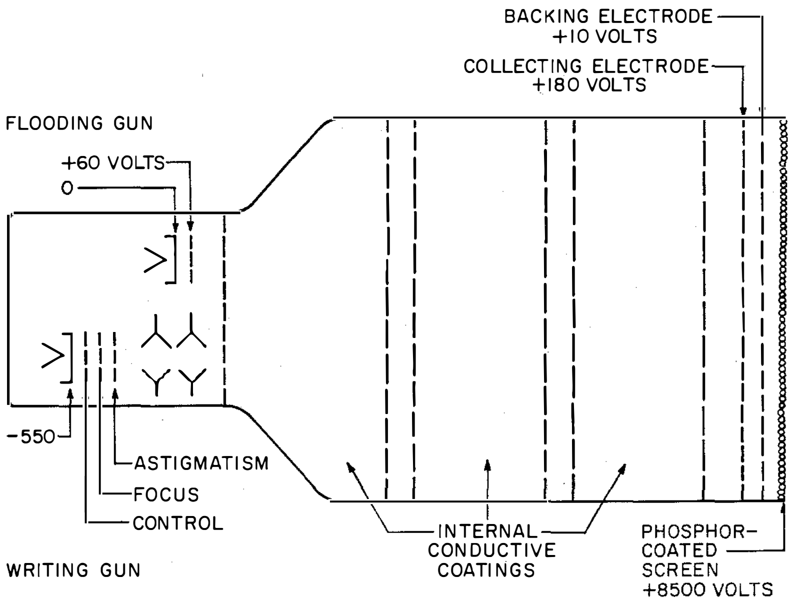

Figure 4—The Iatron tube contains a normal gun for writing and a flooding gun providing electrons that are collimated by the lens action of three conductive coating bands on the tube wall. The electrons must then pass through two fine-mesh screens to reach the phosphor-coated viewing screen.

where information has been written. Once these flooding-gun electrons have passed through the backing electrode, they are rapidly accelerated to the viewing phosphor by its potential of approximately 8500 volts.

From this description, several characteristics may be noted:

(A) Writing-gun performance is not only dependent on the grid characteristics of the writing gun, but on the characteristics of the backing electrode and its secondary-emission characteristics. The low values of beam current needed for full writing allow the beam to be controlled by a relatively small dynamic grid-voltage range, of the order of 5 volts. Since the beam current must be kept low, the writing-gun grid will be operated near cutoff at all times.

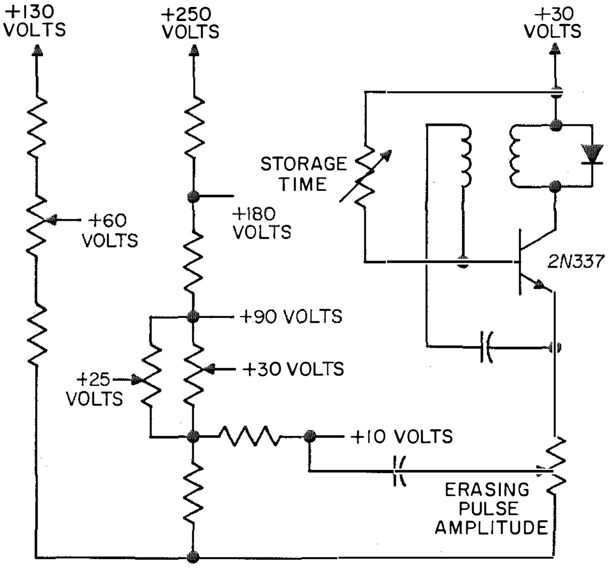

Figure 5—Extra voltages and erase-pulse generator for the storage functions are provided by these circuits.

(B) The phenomenon of writing a charge pattern on the insulating material allows an information storage time of the order of minutes and allows buildup of signal patterns by integration of presented information as desired. These effects can be utilized to increase viewing time and to improve signal-to-noise ratio, thereby increasing radar range. In the design of a radar indicator, it is necessary to make a determination of the amount of signal buildup required by the operation. Long storage time may be undesirable if it causes confusion by the display of retained targets or it may be highly desirable in other applications because it will display the track of a moving target.

(C) Instantaneous light output of a written line on Iatron tubes is comparable to that of a cathode-ray tube with the same accelerating potential, but with the inclusion of the storage screens it is possible to retain the same brightness as the original writing spot. Storage for even a short time will then increase the average brightness to phenomenal values, in the order of 1000 to 3000 foot–lamberts. This brightness is particularly desirable in airborne applications, allowing viewing of the radar screen in bright daylight with the sun shining directly on the screen. This particular feature was the major objective when specifying this type indicator for the *A4D-2N*.

(D) Storage time of this display tube can be controlled by applying voltage pulses to the backing electrode. Any variation in the backing-electrode voltage will have an effect on the charge pattern on the insulating coating. By applying a sharp repetitive pulse to this screen, the insulator tends to equalize its charge depending on the amplitude and rate of the erasing pulses applied. Erasing rate control becomes a very-effective storage control and is presented as such to the pilot. For the present application, a storage time of between 0.5 and about 3 seconds is provided. Storage time may be varied from milliseconds to minutes.

(E) Adverse effects of magnetic fields on the slow flooding beam require the use of a good magnetic shield. In normal use, the shield is made to fit closely around the tube; however, in this application, the space required did not allow a separate shield, so the dust cover is made of mu-metal, and a separate shield is fitted around the neck of the tube.

(F) Sturdiness has been attained by careful design of the mechanical structure. Strengthened joints and adequate supports have stiffened the inner parts to allow use of the tube in an aircraft with little or no isolation. In this application, the tube is supported by the large plastic ring potted to the front viewing portion of the tube and by a spring-mounted socket assembly. The tube qualifies under *MIL-T-5422* specifications.

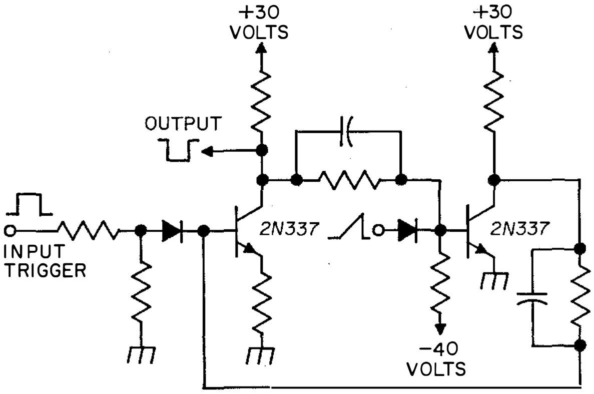

Figure 6—Sweep multivibrator.

2. *Circuits*

Circuits that are not needed for normal cathode-ray tubes but are unique to a storage-tube display include those for voltage supplies for the flooding-gun grid and anodes, voltage for the collector and backing electrode, and an erasing pulse generator. These requirements were combined in this instance by a relatively simple resistive voltage-divider network and a transistor blocking-oscillator pulse generator. The schematic for these particular circuits is given in Figure 5.

2.1 Deflection Circuit

A notable difference in a storage tube is that although 8000 or more volts are used on the phosphor, this is not the accelerating potential against which the writing gun and deflecting plates are working. Storage screens between the writing gun and the phosphor act as a shield; hence, the accelerating potential is that of the writing-gun cathode to the backing-electrode screen. This voltage may be quite low, in this case in the order of 550 volts. For circuit simplicity, it is easiest to float the writing-gun section at a negative potential, allowing the storage screens and flooding-gun circuits to operate near ground potential. This relatively low accelerating potential makes possible a deflection sensitivity of the order of 30 volts per inch (12 volts per centimeter) and makes the sweep-circuit design compatible with transistor techniques. The sweep circuit designed for this equipment is capable of 140-volt peak-to-peak deflection. The simplified schematics of Figures 6 and 7 show that the circuit is comprised of a triggered multivibrator with amplitude reset, a bootstrap waveform generator, and an emitter-follower output preceding a low-gain amplifier.

Silicon transistors are used throughout as shown in the schematics. Circuit design had to take into consideration the wide variations among transistors of a single type, variations of direct-current beta and collector cutoff current with an increase in temperature and the additional base-current requirements of low-temperature operation. Some of the techniques were to choose only high-quality transistors that had the limits of manufacture clearly defined. Each stage then had to be designed for the lowest gain that might be expected over the complete temperature range, and the base-current circuits designed so that an additional 2 milliamperes could be supplied for reliable low-temperature operation.

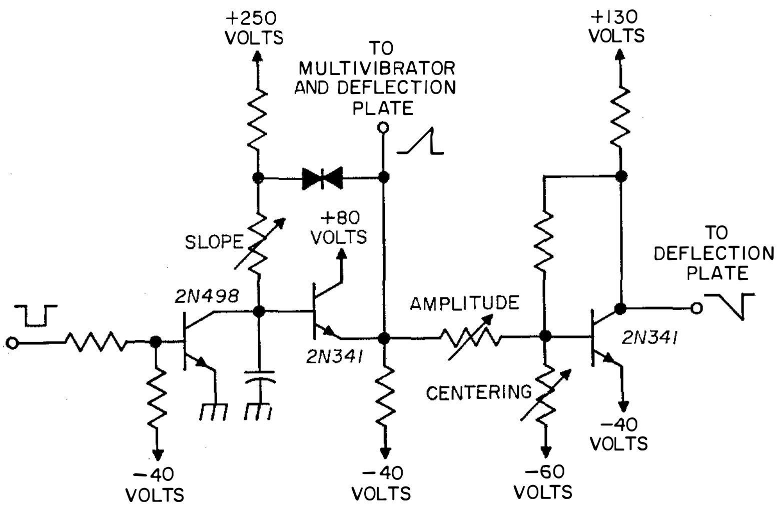

Figure 7—Sweep generator.

Triggering of the multivibrator is possible over a wide range of input signal amplitudes and pulse widths. The method of returning the flip-flop to its quiescent state after a sweep period is somewhat unique in that the controlling factor is the amplitude of the sweep signal and not the sweep length. This method of triggering reduces the likelihood of jitter by removing much of the dependence on the trigger action from active elements (transistors) and allowing it to depend more on the passive elements of the charge path.

A transistor sweep generator using a 30-volt double-anode zener diode as the bootstrap coupling element allows generation of a 70-volt sawtooth with a linearity of better than 1 percent. Because of resistor and capacitor tolerance variations, it is necessary to specify the zener voltage to within 5 percent. Sweep rate or slope can then be controlled by an adjustable resistor in the charge path.

Following the bootstrap sweep generator is an emitter-follower, providing a low impedance for the bootstrap circuit and for the flip-flop trigger return. This emitter connection is also used for one of the deflection plates. The other deflection plate receives an inverted signal from a low-gain amplifier driven by the emitter-follower. A large amount of dynamic feedback is used to reduce drift and variations caused by temperature. Control of the amount of signal current determined the voltage output and acts as an amplitude control. Control of the quiescent base current is used as a centering adjustment. The self-bias feedback resistor is nearly the same value as the load resistor, providing a strong degeneration of any variation in output signal.

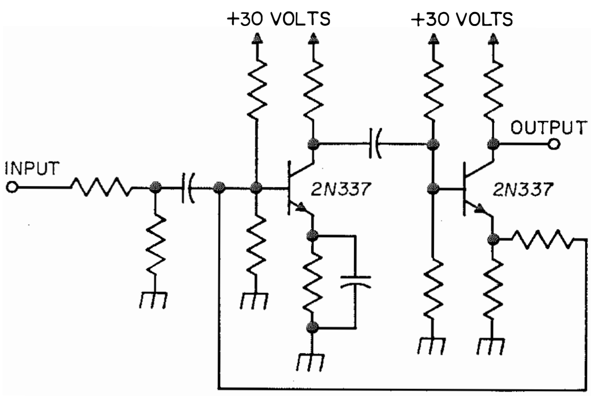

Figure 8—One of the feedback-pair video-frequency amplifiers.

2.2 Video-Frequency Amplifier

Video amplification of the radar signals as received at the indicator is accomplished by two pairs of transistors, one pair of which is shown in Figure 8. Each pair has a feedback path from output emitter to input base. This feedback, in conjunction with partially bypassed emitter resistors, allows the amplifier to be flat to over 6 megacycles per second at room temperature and flat to at least 4 megacycles per second at elevated temperatures. Each feedback pair has a low input impedance and fairly low output impedance (of the order of 30 and 1000 ohms, respectively). A maximum signal of 12 volts appears at the output and is capacitively coupled to the writing-gun grid. Blanking of the Iatron tube is accomplished by coupling a square wave from the sweep multivibrator to a blanking emitter-follower operating at cathode potential as shown in Figure 9. This blanking signal (negative-going during the sweep period) brings the Iatron tube grid–cathode voltage from beyond cutoff to some bias setting chosen on the bias voltage divider. Radar information is applied in positive polarity to the grid. Complete schematics of the sweep and video circuits are included in Figures 10 and 11 for an over-all understanding of the techniques used.

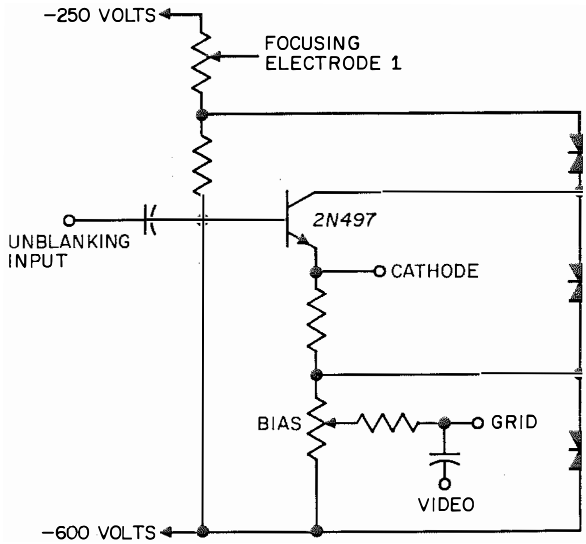

Figure 9—Blanking circuit.

3. *Packaging*

Although the circuits discussed are not a complete description of all that is in the indicator, it is felt that the remaining portions are unimportant for a general discussion. Selection of components was restricted to MIL-approved parts in all cases where it was possible to include them. Derating of components and mounting procedures were used that would give a maximum of reliability consistent with the design requirements. Two etched printed-wiring boards are used, containing a total of 15 transistors, 9 relays, 15 trimmer resistors, and all of the associated components.

To contain the necessary circuits and components in the package size of $5\frac{5}{8}$ inches (14 centimeters) square by 16 inches (41 centimeters) long, yet retain accessibility and good construction, it was necessary to spend considerable effort on the package. As shown in Figure 2, there is a frame closely fitting the Iatron tube, acting as a mount for the tube and to which two

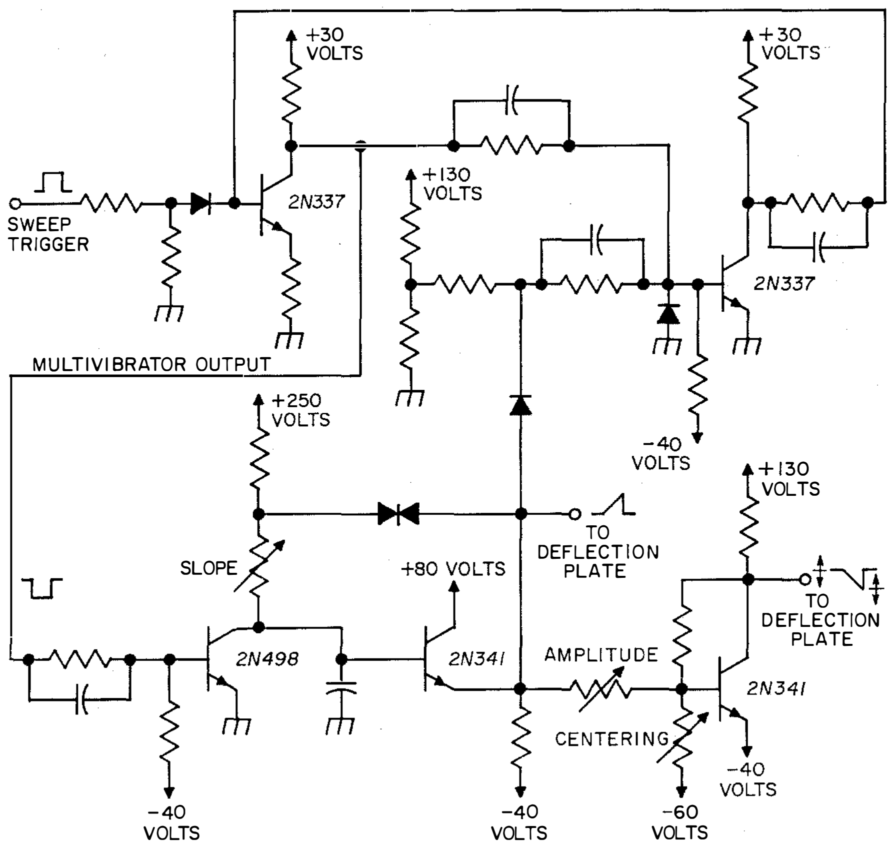

Figure 10—Complete sweep circuit.

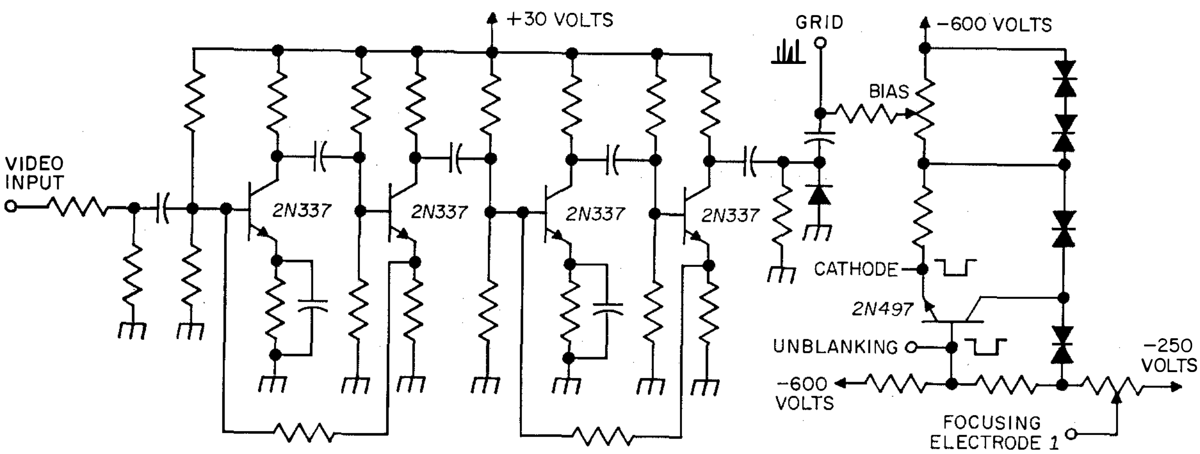

Figure 11—Complete video-frequency circuit.

printed wiring boards, the high-voltage supply, and the front panel are attached. The tube base is held in a spring-mounted socket and the front end is supported by a relatively soft potting material. The unit is then placed in a moderately tight dust cover and is ready for insertion in the aircraft instrument panel.

One of these indicators has been in flight test since April and has logged over 100 hours of flight time to date. Pilot reaction to the high brightness display is extremely favorable, indicating that the 1000 foot–lamberts of brightness available from this display will satisfy thei requirements. Transistor circuits keep hea dissipation to a minimum and compact packaging has allowed construction of a complete rada indicator as a cockpit panel instrument. It i believed that this development will constitut an advance in the state of the art of airborn displays.

Iatron Storage Display Tube with Coaxial Writing and Flooding Guns*

By MICHAEL F. TOOHIG

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PRINCIPLES of design and operation of storage cathode-ray display tubes are well known[1–3]. The Iatron® storage cathode-ray tube that is the subject of this paper differs from most other tubes of this type in that the writing and flooding guns are both symmetrically placed about the axis of the tube; conventionally the flooding gun is on the tube axis, the writing gun off the axis. This tube was developed to solve a difficult packaging problem for radar indicator.

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A radar display unit was needed for a fighter-airplane cockpit, Physically, a storage cathode-ray display tube, tube shields, video amplifier, two deflection amplifiers, and an erase generator were required to fit into a 3-by-11-inch (7.6-by-27.9-centimeter) cylinder. Electrically, an image brightness of 1000 foot–lamberts at a final voltage of 4000, a viewing time of 30 seconds, and a number of less-stringent characteristics were specified.

An investigation of three possible designs showed that one having the envelope shape of a conventional cathode-ray tube would satisfy the packaging requirements since the four special circuits could be built around the necked-down portion of the envelope using minification techniques.

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[1] M. Knoll and B. Kazan, "Viewing Storage Tubes," *Advances in Electronics and Electron Physics*, volume 8, Academic Press, Incorporated, New York, New York; 1956: pages 448–499.

[2] M. Knoll and B. Kazan, "Storage Tubes and Their Basic Principles," John Wiley and Sons, Incorporated, New York, New York; 1952.

[3] D. W. Davis, "Characteristics and Application of the Iatron Storage Tube," *Communication and Electronics*, volume 29, pages 47–53; March, 1957: also, *Electrical Communication*, volume 35, number 2, pages 93–102; 1958.

1. Description of Tube

The design satisfying these requirements uses a ring-shaped flooding gun and a writing gun that are symmetrically placed about the axis of the tube. The writing gun is so positioned that the writing beam passes through the central opening in the flooding gun after being deflected. A diagram of the tube is shown in Figure 1. The tube

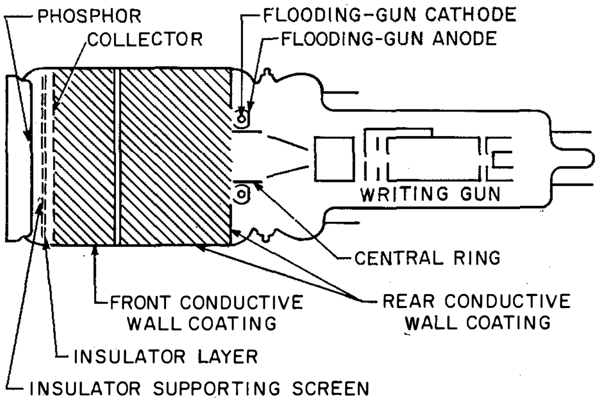

Figure 1—Diagram of Iatron tube with coaxial guns.

has an aluminized *P20* phosphor on the flat face-plate; a storage screen of 500-wire-per-inch (20-wire-per-millimeter) electroformed copper mesh of 45-percent optical transmission having an evaporated dielectric coating on the gun side; a collector screen of 16-by-32-wire-per-inch (0.6-by-1.3-wire-per-millimeter) knitted tungsten mesh of 92-percent optical transmission; two aquadag electrodes painted on the inner surface of the bulb; a metal plate in the plane of the flooding gun that is internally connected to the rear wall coating; a ring flooding gun; and a writing gun. The gun connections are made to a 9-pin stem on the necked-down section of the envelope and to an 8-pin ring-shaped stem on the rear shoulder of the envelope. The remaining connections are made at lead pins on the flooding section of the envelope. The high-voltage connection is made to the front seal rings, which are then potted into an insulating sleeve.

2. *Operation of Flooding System*

Conventional flooding systems use a source of electrons on the axis of the tube at the focal point of an electron-optical lens, giving a collimated flooding beam in front of the lens. The optical analogue of this is shown in Figure 2A.

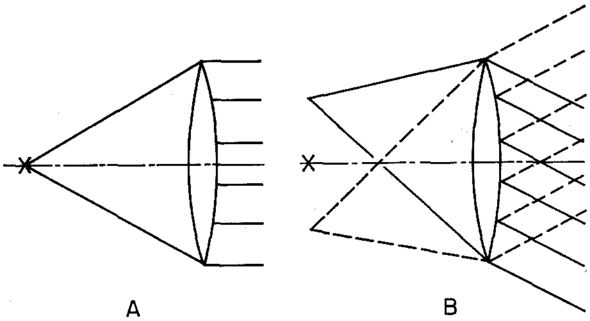

Figure 2—Optical analogues of flooding beam systems.

A detailed study of the problem of using the ring-shaped flooding gun in a design assuring negligible shading across the storage-screen area revealed that the best approach was the electron-optical analogue of the case shown in Figure 2B. Rays from a point source off the lens axis in the plane of the focal point of the lens emerge from the lens in a parallel beam at an angle to the lens axis determined by the distance of the point source from the axis. If a ring of such sources is used, all rays are at the same angle to the lens axis. The electron-optical equivalent of this case is shown in Figure 3. The electrons from each

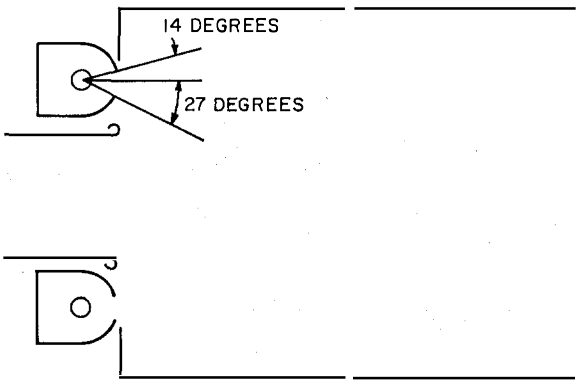

Figure 3—Diagram of ring-gun flooding beam system.

elemental section of the cathode cover the entire storage screen area. This is accomplished by the asymmetrical anode aperture shown, by placing the rear wall electrode of the flooding section at flooding anode potential, and by a special ring-shaped electrode in the central opening of the ring gun to control the injection angle of the inner surface of the ring-shaped beam. The electron lens is a double lens formed by the two rear wall electrodes and the front wall and collector screen. Typical operating voltages are shown in Table 1.

TABLE 1

OPERATING VOLTAGES FOR IATRON TUBE WITH COAXIAL WRITING AND FLOODING GUNS

Electrode	Voltage
Phosphor	4000
Insulator Support Screen	15
Collector Screen	125
Forward Wall	80
Rear Wall	12
Flooding Anode	12
Flooding Cathode	0
Central Cylinder	15
Writing-Gun Second Anode	20
Writing-Gun First Anode	−350
Writing-Gun Cathode	−450

Minimum shading requires that variations in both the normal velocity component of the flooding electrons and the flooding-current density over the storage surface be small. Since, ideally, all electrons should be oriented at the same angle with respect to the axis of the tube, the normal velocity component should not vary appreciably over the surface. In practice, after proper adjustment of the potentials of all electrodes, and particularly that of the central cylinder, it is found that little shading is present. An insulator transfer characteristic is shown in Figure 4A and a flooding gun characteristic in Figure 4B. The cutoff potential varies by only a few tenths of a volt over the storage surface and, when the tube is operated as specified in Table 1, a phosphor current of 670 microamperes is obtained for a flooding current of 2.8 milliamperes.

3. *Achievement of Required Viewing Time*

The viewing time is the period required for the visible presentation of information stored at maximum brightness to fade to cutoff while continuous erasing pulses are being applied. When the minimum erasing duty cycle (erasing-pulse width times frequency) is used, the viewing time is maximum. The minimum erasing duty cycle is the condition where the negative charge deposited on the storage surface just compensates for the positive charge resulting from accumulation of positive ions when the insulator potential is just below the cutoff potential of the insulator transfer characteristic. The erasing pulses are applied to the insulator supporting screen. If the erasing pulse amplitude is increased in steps and at each step the erasing duty cycle is adjusted to maintain the insulator just at the cutoff potential (that is, just compensating for the positive ion current), it has been found that the viewing time increases with increasing erasing pulse amplitude.

The reason for this can be shown qualitatively from consideration of the curve of secondary emission ratio versus bombarding energy below the first crossover potential, as shown in Figure 5. The erasing current I_e required to compensate the positive ion current I_i is

$$I_e = (1 - \delta)\, I_b W f \qquad (1)$$

when $I_e = |I_i|$, where

I_e = erasing current
I_i = ion current
δ = secondary emission ratio, always less than 1
I_b = flooding beam current
W = erasing pulse width
f = erasing pulse frequency
Wf = duty cycle.

From (1), it can be seen that when $I_e = I_i$, Wf decreases with δ. It is assumed in the following that I_i is constant, although, in reality, it is found that the positive-ion writing rate varies somewhat over the insulator transfer characteristic, increasing with the flooding current to the phosphor. As the amplitude of the erasing pulses applied to the insulator support screen is increased, δ decreases as shown in Figure 5 and Wf must be decreased to maintain I_e constant.

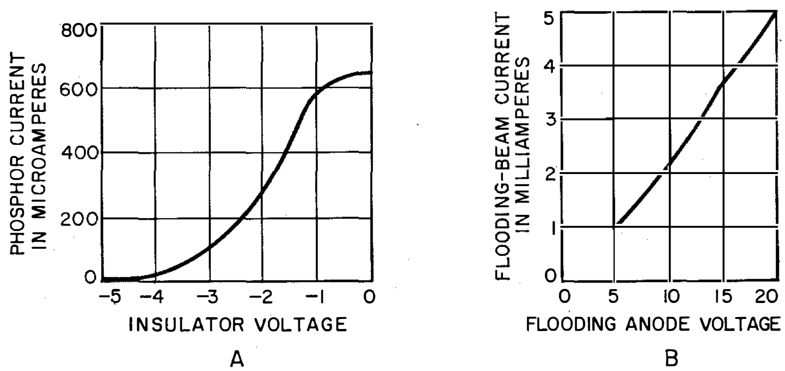

Figure 4—Insulator transfer characteristic at *A* and ring-flooding-gun characteristic at *B*.

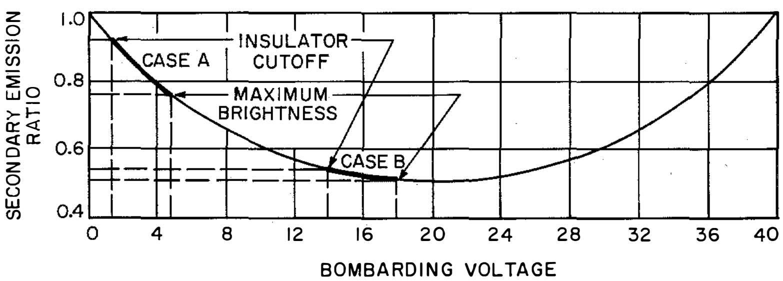

Figure 5—Secondary-emission ratio versus bombarding voltage below the first crossover potential (40 volts).

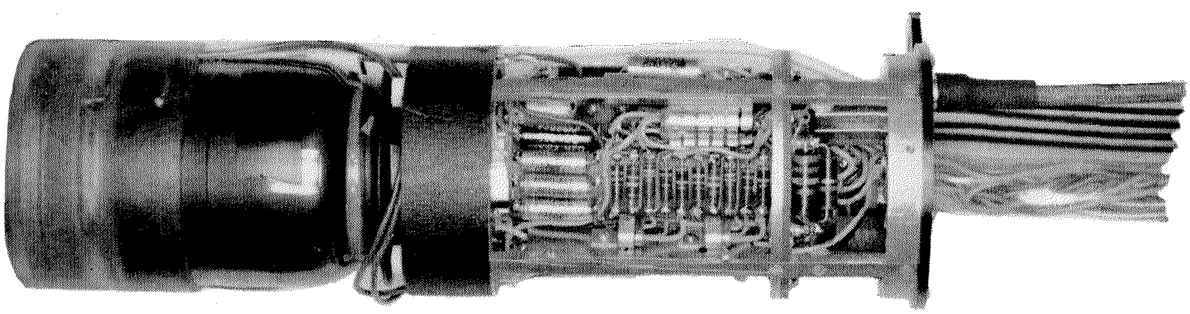

Figure 6—Tube with associated circuits in mount around tube stem.

As a result of this decrease in Wf required to compensate the positive ion current at the insulator cutoff potential, the viewing time increases as will be shown with the aid of Figure 5. The increase in viewing time occurs because the difference in the value of δ between the insulator cutoff level and the maximum brightness level decreases as the erasing-pulse amplitude increases.

This can be demonstrated by considering cases A and B in Figure 5. In case A, the erasing pulse amplitude is 5 volts while in case B it is 18 volts. From (1), it is seen that $(Wf)_A \approx 7\ (Wf)_B$. Therefore, the erasing current deposited in the areas written to maximum brightness is 0.25 $(Wf)_A I_b$ in case A, and only 0.50 $(Wf)_B I_b = 0.07\ (Wf)_A I_b$ in case B. Thus, case-B operation permits the longest viewing time since less erasing current is deposited at the high light levels.

4. *Filamentary Gettering*

Since viewing time is a function of positive ion current, the smaller the ion current the longer the viewing time. Thus, positive ion current must be maintained at as low a value as possible during the life of the tube; the vacuum of the device must be as high as possible. A study of a number of methods revealed that a technique[4] developed by Langmuir offered the simplest solution to the problem. This involved heating a tungsten filament to about 2700 degrees centigrade and evaporating a film of tungsten on the glass wall of the tube.

The filament is 5-mil (0.127-millimeter) tungsten wire developed for use in projection lamps; it is positioned between the ring gun and rear shoulder of the envelope. The tungsten is evaporated with the entire tube immersed in water for cooling. Improvements in vacuum of 3 to 10 times or better have been obtained on a number of tubes; the improvement appears to depend on how well the filament has been outgassed before the tube is sealed off. Several tubes were effectively regettered three times before the filaments burned out.

[4] S. Dushman, "Scientific Foundations of Vacuum Technique," 1st edition, John Wiley and Sons, Incorporated, New York, New York; 1949: page 673.

5. *Packaging*

The tube was originally designed because of a serious packaging problem in a radar indicator. A view of the 2.5-inch- (6.4-centimeter-) diameter tube and the special circuits built around the 1.38-inch-(3.5-centimeter-) diameter writing-gun neck are shown in Figure 6. The final assembly is shown in Figure 7. The indicator mounted in the cockpit of an *F101* fighter airplane is shown in Figure 8.

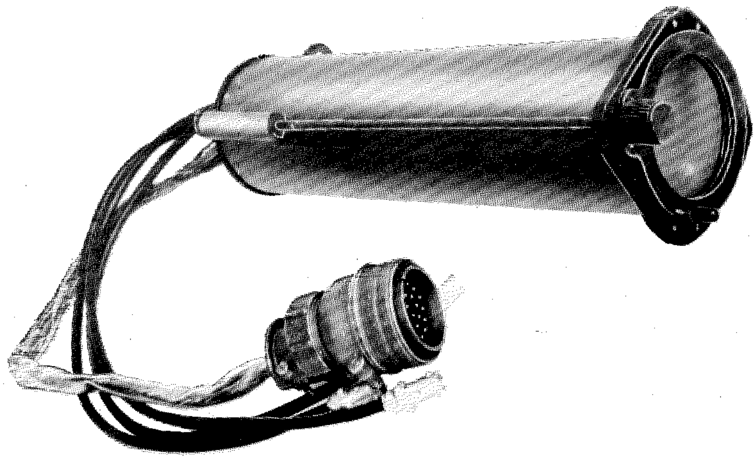

Figure 7—Radar indicator assembly. The cylinder is 11 inches (27.9 centimeters) long.

The design principles of this tube permit fabrication of storage tubes of all sizes with the same general form as that of conventional cathode-ray tubes. This is most important from a packaging viewpoint in the case of magnetically deflected tubes. In addition, positioning the writing gun on the axis eliminates the trapezoidal distortion of presently available display storage tubes.

6. *Acknowledgments*

The successful completion of this development was possible because of the contributions of a number of people in ITT Laboratories, Fort Wayne. Particular thanks are due Dr. G. Papp for the original idea of the flooding system and for the ring gun itself; Dr. P. Rudnick for assistance in designing the electron optics of the flooding system; Mr. M. E. Anderson for sharing the

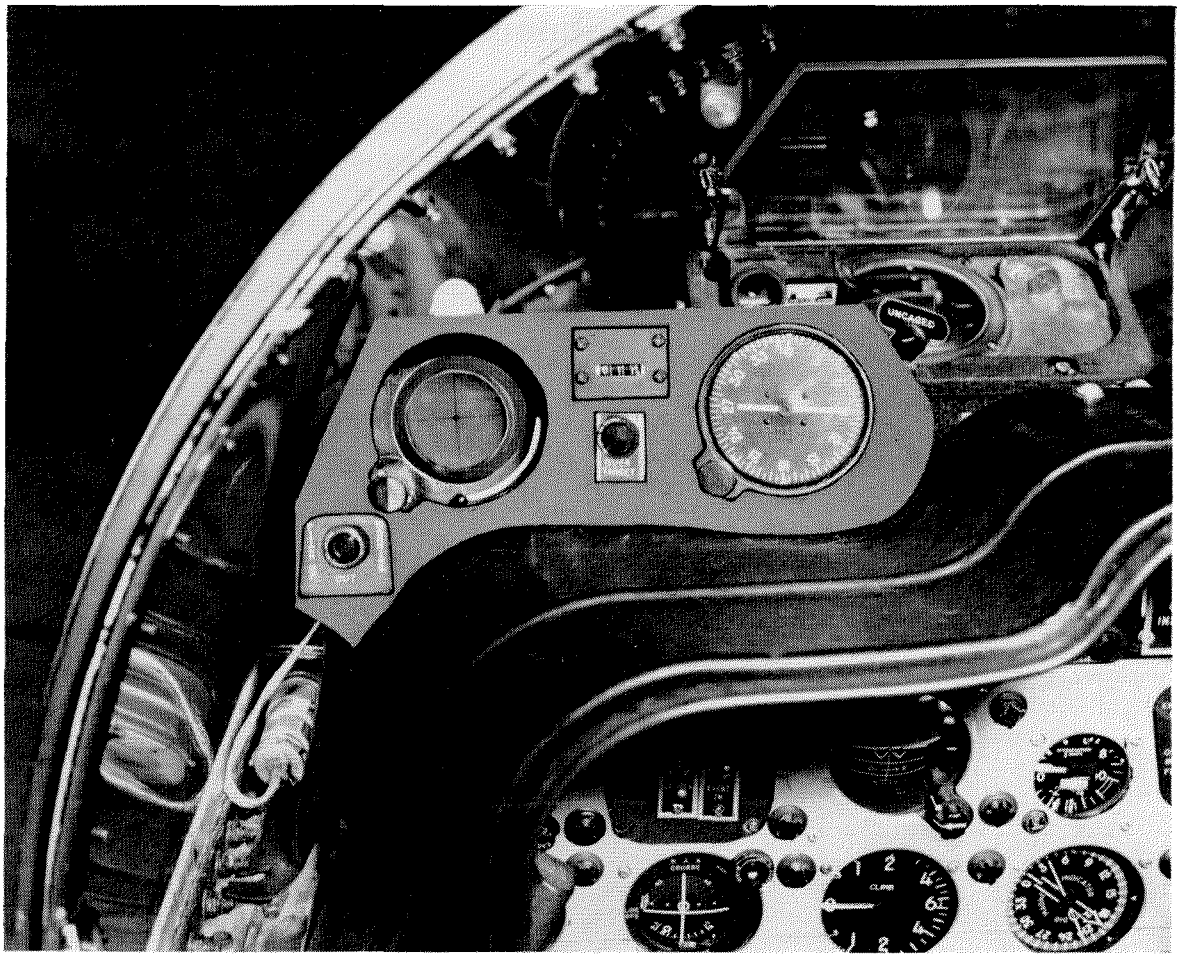

Figure 8—Radar indicator in aircraft cockpit.

project responsibilities during the development and for contributions toward the final design; Mr. A. J. Knight for mechanical design of the gun and tube; Mr. D. W. Davis, supervisor of the project, for guidance and assistance in the many problems that came up in the course of development; and Mr. E. L. McDermit, project engineer on the equipment development, for evaluation of the tube's performance and valuable suggestions for improving the design during development.

World's Telephones—1958 *

A TOTAL of 117 800 000 telephones at the beginning of 1958 reflects an increase of 7 800 000 in one year. The United States, with 63 621 000, accounted for more than half of the total number of telephones in the world.

Twelve countries or areas with 25 000 or more telephones also had at least fifteen telephones per 100 population. They were: Alaska, Australia, Canada, Channel Islands, Denmark, Hawaii, Iceland, New Zealand, Norway, Sweden, Switzerland, and the United States.

A notable addition to this year's report is official information about the Union of Soviet Socialist Republics, which brings to fifteen the list of countries with one million or more telephones.

In general, these statistics reflect the situation as of January 1, 1958. In the table of telephones by countries, estimates are shown for those places that ordinarily report statistics but that did not do so this year in time for publication. For countries that have not supplied data for five years or more, the official figures last reported are shown, and estimates for January 1, 1958 are used in computing continental and world totals.

Telephones included in this report are those that have access to the general network. They include main telephones (individual and party line), extension, private branch exchange, public pay telephones, service, and official telephones.

* Abridgement from the 1958 issue of a booklet published by the American Telephone and Telegraph Company, New York, New York, entitled "The World's Telephones."

TELEPHONES IN CONTINENTAL AREAS, JANUARY 1, 1958

Area	Number	Total		Privately Operated		Automatic	
		Percent of Total World	Per 100 Population	Number	Percent of Total Telephones	Number	Percent of Total Telephones
North America	68 470 600	58.1	36.1	67 737 200	98.9	60 736 500	88.7
Middle America	835 900	0.7	1.3	753 600	90.2	651 100	77.9
South America	2 845 000	2.4	2.2	1 360 600	47.8	2 372 800	83.4
Europe	35 231 900	29.9	6.3	5 695 600	16.2	28 266 800	80.2
Africa	1 663 200	1.4	0.7	31 200	1.9	1 180 700	71.0
Asia	6 062 700	5.2	0.4	3 930 700	64.8	3 702 000	61.1
Oceania	2 690 700	2.3	17.4	193 400	7.2	1 929 600	71.7
World	117 800 000	100.0	4.2	79 702 300	67.7	98 839 500	83.9

TELEPHONE BY COUNTRIES AS OF JANUARY 1, 1958

Country or Area	Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation	
				Private	Government
NORTH AMERICA					
Alaska	33 227	19.10	83.9	8 176	25 051
Canada	4 816 118	28.64	79.9	4 108 131	707 987
Greenland	0	—	—	—	—
St. Pierre and Miquelon	392	7.84	0	0	392
United States	63 620 863	36.82	89.4	63 620 863	0
MIDDLE AMERICA					
Bahamas	7 953	6.12	98.8	0	7 953
Barbados	7 422	3.23	99.9	7 422	0
Bermuda	9 880	21.96	100	9 880	0
British Honduras	924	1.09	0	45	879
Canal Zone (1) (2)	7 543	27.94	100	0	7 543
Costa Rica	12 354	1.17	2	11 973	381
Cuba	151 458	2.37	89	151 458	0
Dominican Republic	14 675	0.54	86.2	14 525	150
El Salvador	11 258	0.47	77.2	0	11 258
Guadeloupe and Dependencies	2 086	0.85	0	0	2 086
Guatemala	11 717	0.32	85	0	11 717
Haiti	4 200	0.11	85.7	0	4 200
Honduras	4 677	0.26	92	0	4 677
Jamaica and Dependencies	27 462	1.71	96.7	27 462	0
Leeward Islands:					
Antigua	520	0.93	0	0	520
Montserrat	100	0.71	0	0	100
St. Christopher-Nevis	325	0.61	0	0	325
Virgin Islands (United Kingdom)	1	0.01	0	0	1
Total	946	0.72	0	0	946
Martinique	4 799	1.90	70.2	0	4 799
Mexico	413 005	1.31	74.7	411 584	1 421
Netherlands Antilles	9 831	5.15	96.8	3 040	6 791
Nicaragua	6 332	0.48	67.1	0	6 332
Panama	23 030	2.35	83.6	22 470	560
Puerto Rico	71 164	3.12	65.6	66 204	4 960
Trinidad and Tobago	27 570	3.60	88.7	27 570	0
Virgin Islands (United States)	2 976	10.63	0	0	2 976
Windward Islands:					
Dominica	364	0.57	0	0	364
Grenada	810	1.01	100	0	810
St. Lucia	527	0.58	70.2	0	527
St. Vincent	426	0.53	0	0	426
Total	2 127	0.68	55.5	0	2 127
SOUTH AMERICA					
Argentina	1 181 121	5.89	83	86 872	1 094 249
Bolivia	23 200	0.71	90	23 200	0
Brazil	869 800	1.40	83	869 800	0
British Guiana	4 947	0.97	15.9	0	4 947
Chile	160 343	2.22	67.4	159 853	490
Colombia	222 932	1.67	95.4	0	222 932
Ecuador	22 000	0.56	95	500	21 500
Falkland Islands and Dependencies	392	17.82	0	0	392
French Guiana	878	3.03	0	0	878
Paraguay	8 185	0.50	89.9	0	8 185
Peru	79 171	0.79	81.4	79 171	0
Surinam	4 352	1.69	95.5	0	4 352
Uruguay	128 896	4.60	77.8	1 350	127 546
Venezuela	139 826	2.19	94.4	139 826	0
EUROPE					
Albania (4)	1 555	0.14	10.6	0	1 555
Andorra	100	1.67	0	0	100
Austria	592 197	8.46	93.2	0	592 197
Belgium	986 953	10.93	83.3	0	986 953
Bulgaria (5)	54 347	0.77	39.4	0	54 347
Channel Islands:					
Guernsey and Dependencies	11 030	25.95	27.6	0	11 030
Jersey	15 640	26.97	0	0	15 640
Total	26 670	26.67	11.4	0	26 670
Czechoslovakia (5)	350 708	2.88	59.4	0	350 708
Denmark	951 034	21.05	50.3	838 645	112 389
Finland	524 600	12.04	74.1	399 957	124 643
France	3 498 900	7.92	72.5	0	3 498 900
Germany, Democratic Republic	1 123 278	6.45	92.5	0	1 123 278
Germany, Federal Republic	4 731 945	8.75	97.7	0	4 731 945
Gibraltar (1)	2 047	8.19	100	0	2 047
Greece	153 773	1.89	93.4	0	153 773
Hungary (3)	390 000	3.97	78	0	390 000

(1) Excluding telephone systems of the military forces.
(2) June 30, 1957.
(3) Data partly estimated.
(4) January 1, 1943 (latest official statistics).
(5) January 1, 1948 (latest official statistics).
(6) March 31, 1958.
(7) January 1, 1947 (latest official statistics).
(8) Under government operation since 1949.

TELEPHONE BY COUNTRIES AS OF JANUARY 1, 1958—*Continued*

Country or Area	Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation	
				Private	Government
EUROPE (Continued)					
Iceland	33 295	19.96	66.3	0	33 295
Ireland	129 553	4.47	71.9	0	129 553
Italy	2 871 011	5.91	96	2 871 011	0
Liechtenstein	3 265	21.77	100	0	3 265
Luxemburg	38 420	12.20	88.8	0	38 420
Malta and Gozo (6)	10 112	3.14	54	0	10 112
Monaco	7 400	35.24	100	0	7 400
Netherlands	1 318 269	11.88	96.9	0	1 318 269
Norway (2)	646 522	18.49	67.6	54 568	591 954
Poland	405 800	1.42	70.5	0	405 800
Portugal	304 937	3.41	65.8	208 604	96 333
Rumania (7)	127 153	0.77	75.8	126 131 (8)	1 022
San Marino	377	2.69	100	0	377
Spain	1 339 653	4.51	78.6	1 321 743	17 910
Sweden	2 409 842	32.60	82	0	2 409 842
Switzerland	1 385 125	26.84	99.7	0	1 385 125
Turkey	203 523	0.80	87.2	0	203 523
Union Soviet Socialist Republics	3 558 000	1.78	46.1	0	3 558 000
United Kingdom (6)	7 354 690	14.25	79.2	0	7 354 690
Yugoslavia	198 055	1.09	72.2	0	198 055
AFRICA					
Algeria	153 275	1.44	78.6	0	153 275
Angola	5 337	0.12	95.7	0	5 337
Ascension Island	59	28.92	76.3	59	0
Basutoland (3)	800	0.12	5	0	800
Bechuanaland	275	0.09	0	0	275
Belgian Congo	22 370	0.17	86.7	0	22 370
Cameroons (French Administration)	4 243	0.13	58.4	0	4 243
Cape Verde Islands	127	0.07	0	0	127
Comoro Islands	0	—	—	—	—
Egypt	180 881	0.75	81.5	0	180 881
Ethiopia and Eritrea	8 422	0.04	81.3	0	8 422
French Equatorial Africa	6 665	0.14	36.8	0	6 665
French West Africa	28 051	0.14	57.1	0	28 051
Gambia	591	0.22	98.3	0	591
Ghana	17 055	0.35	53.8	0	17 055
Ifni	121	0.27	0	121	0
Kenya	32 401	0.51	77.3	0	32 401
Liberia (3)	1 800	0.13	100	500	1 300
Libya	8 264	0.73	56.9	0	8 264
Madagascar and Dependencies	11 412	0.23	45.9	1 327	10 085
Mauritius and Dependencies	7 690	1.29	8.2	0	7 690
Morocco	126 301	1.24	85.2	19 832	106 469
Mozambique	9 136	0.15	74	0	9 136
Nigeria, Federation of, and British Cameroons	26 500	0.08	49.9	0	26 500
Portuguese Guinea	357	0.06	0	0	357
Reunion	5 099	1.67	0	0	5 099
Rhodesia and Nyasaland:					
Northern Rhodesia	18 000	0.80	94	1 700	16 300
Nyasaland	4 300	0.16	90	0	4 300
Southern Rhodesia	62 000	2.38	82	0	62 000
Total (3)	84 300	1.12	85	1 700	82 600
Ruanda-Urundi	1 241	0.03	92.5	0	1 241
St. Helena	119	2.38	0	0	119
São Tomé and Principe	333	0.55	0	0	333
Seychelles and Dependencies	162	0.41	100	162	0
Sierra Leone	3 195	0.13	83.9	0	3 195
Somaliland, British Protectorate	350	0.05	0	0	350
Somaliland, French	808	1.21	100	0	808
Somaliland (Italian Administration)	1 507	0.11	0	0	1 507
South West Africa	11 806	2.23	43.3	0	11 806
Spanish Guinea	833	0.40	71.1	833	0
Spanish North Africa	6 682	4.51	100	6 682	0
Spanish Sahara	40	0.08	0	40	0
Sudan	19 411	0.19	75.6	0	19 411
Swaziland	1 114	0.47	32.3	0	1 114
Tanganyika	13 047	0.15	51.2	0	13 047
Togoland	1 196	0.10	69.9	0	1 196
Tunisia	34 622	0.91	57.4	0	34 622
Uganda	11 505	0.20	78	0	11 505
Union of South Africa (6)	828 434	5.75	67.1	0	828 434
Zanzibar and Pemba	1 045	0.37	4.3	0	1 045

Telephones by Countries as of January 1, 1958—*Continued*

Country or Area		Number of Telephones	Per 100 Population	Percent Automatic	Type of Operation	
					Private	Government
ASIA						
Aden Colony		3 518	2.35	100	0	3 518
Aden Protectorate		0	—	—	—	—
Afghanistan	(3)	6 500	0.05	30	0	6 500
Bahrain		2 247	1.80	100	2 247	0
Bhutân		0	—	—	—	—
Brunei		470	0.78	99.1	0	470
Burma	(3)	8 000	0.04	0	0	8 000
Cambodia		2 818	0.06	0	0	2 818
Ceylon		30 017	0.32	93.5	0	30 017
China, Mainland	(5)	244 028	0.05	72.9	94 945	149 083
China, Taiwan		*51 513*	0.53	*48.9*	0	*51 513*
Cyprus		14 584	2.68	87.3	0	14 584
Hong Kong		74 800	2.79	100	74 800	0
India	(6)	334 680	0.08	58.3	3 100	331 580
Indonesia		84 789	0.10	11.9	0	84 789
Iran		64 637	0.33	54.8	0	64 637
Iraq	(3)	47 100	0.72	78	0	47 100
Israel		79 998	4.05	93	0	79 998
Japan	(6)	3 886 327	4.22	60.6	3 886 327	0
Jordan		15 125	0.98	63.6	0	15,125
Korea, Republic of		55 868	0.25	45.6	0	55,868
Kuwait	(3)	2 000	0.96	80	0	2 000
Laos	(3)	550	0.03	50	0	550
Lebanon		40 238	2.58	91.3	0	40 238
Macao		1 883	0.93	100	0	1 883
Malaya		61 736	0.98	66.9	0	61 736
Maldive Islands		0	—	—	—	—
Muscat and Oman		155	0.03	100	155	0
Nepal		0	—	—	—	—
Netherlands New Guinea		1 084	0.15	0	0	1 084
North Borneo		1 956	0.49	87.2	0	1 956
Pakistan		57 632	0.07	69.6	0	57 632
Philippine Republic		73 791	0.32	76.5	63 343	10 448
Portuguese India		327	0.05	0	0	327
Portuguese Timor		458	0.09	0	0	458
Qatar		748	1.87	100	748	0
Ryukyu Islands	(1)	5 452	0.66	29.3	0	5 452
Sarawak		2 135	0.34	60.3	0	2 135
Saudi Arabia	(3)	17 000	0.24	5	0	17 000
Singapore		46 811	3.18	100	0	46 811
Syria		37 150	0.91	83.4	0	37 150
Thailand		13 920	0.06	100	0	13 920
Trucial Oman		0	—	—	—	—
Viet-Nam, Republic of		12 667	0.09	84.7	0	12 667
Yemen		0	—	—	—	—
OCEANIA						
Australia		1 873 791	19.22	71	0	1 873 791
British Solomon Islands		274	0.26	0	0	274
Caroline Islands		203	0.47	0	0	203
Cocos (Keeling) Islands		59	9.08	100	0	59
Cook Islands		212	1.25	0	0	212
Fiji Islands		4 938	1.38	61.3	0	4 938
Gilbert and Ellice Islands		110	0.27	75	77	33
Guam		10 761	15.60	100	0	10 761
Hawaii		193 229	31.07	100	193 229	0
Mariana Islands (less Guam)		350	5.00	71.4	0	350
Marshall Islands		555	3.96	99.1	0	555
Nauru		0	—	—	—	—
New Caledonia and Dependencies		2 900	4.26	65	0	2 900
New Hebrides Condominium		270	0.49	0	0	270
New Zealand	(6)	605 224	26.60	64.7	0	605 224
Niue Island		73	1.46	0	0	73
Norfolk Island		50	5.00	0	0	50
Papua and New Guinea		4 343	0.24	79.5	120	4 223
Pitcairn Island		0	—	—	—	—
Polynesia, French		986	1.31	0	0	986
Samoa, American		331	1.66	100	0	331
Samoa, Western		747	0.75	0	0	747
Tokelau Islands		0	—	—	—	—
Tonga (Friendly) Islands		564	0.99	0	0	564

Telephone Conversations During 1957

Data were not available for all countries

Country or Area		Thousands of Conversations			Per Capita
		Local	Long Distance	Total	
Alaska		100 200	900	101 100	581.0
Algeria		78 300	26 500*	104 800	10.0
Argentina		3 301 000	39 000	3 340 000	168.2
Australia		1 233 700	106 000	1 339 700	138.9
Belgium		536 700	96 400	633 100	70.4
Brazil		4 807 700	56 700	4 864 400	79.4
Canada		8 068 100	178 600	8 246 700	497.1
Ceylon		66 500	6 000	72 500	7.9
Channel Islands		17 600	600	18 200	182.0
Chile		392 900	24 200	417 100	58.6
Colombia		750 000	9 400	759 400	57.4
Costa Rica		43 200	900	44 100	42.6
Cuba		516 400	6 700	523 100	81.7
Denmark		1 032 600	196 500	1 229 100	273.1
Dominican Republic		6 200	100	6 300	2.3
Egypt		542 600	13 100	555 700	23.1
El Salvador		21 200	2 600	23 800	10.1
Finland		602 400	101 900	704 300	162.5
French West Africa		17 800	2 100	19 900	1.0
Germany, Democratic Republic		786 800	126 300	913 100	52.8
Germany, Federal Republic		2 848 900	724 100	3 573 000	66.5
Greece		369 100	7 300	376 400	46.5
Hawaii		314 500	2 500	317 000	522.2
Iceland		72 400	1 800	74 200	452.4
Ireland		95 800	15 100	110 900	38.4
Israel		136 500	5 400	141 900	73.3
Italy		4 471 000	310 200*	4 781 200	98.9
Jamaica		96 000	1 000	97 000	60.8
Japan	(1)	10 000 000	729 500	10 729 500	118.0
Lebanon		53 500	5 100	58 600	38.4
Madagascar		11 400	1 100	12 500	2.5
Malaya		146 100	15 200	161 300	25.7
Mexico		826 200	13 000	839 200	26.7
Morocco		89 100	13 900*	103 000	10.2
Netherlands		903 100	328 000	1 231 100	111.8
Nigeria, Federation of, and British Cameroons		39 400	1 900	41 300	1.2
Norway	(2)	489 400	57 500	546 900	157.2
Peru		291 800	4 000	295 800	29.8
Philippines		505 300	1 100	506 400	22.3
Portugal		276 600	53 200	329 800	37.0
Puerto Rico		149 500	3 200	152 700	67.4
South West Africa		12 600	1 700	14 300	27.3
Spain		2 550 000	98 600	2 648 600	90.0
Sweden	(3)	3 511 600	114 400	3 626 000	490.5
Switzerland		539 600	476 700*	1 016 300	198.6
Syria		98 400	6 600	105 000	25.8
Trinidad and Tobago		84 800	5 400	90 200	119.6
Turkey		250 300	10 400	260 700	10.3
Union of South Africa	(1)	936 900	68 100	1 005 000	70.9
United Kingdom	(1)	3 709 000	330 000	4 039 000	78.5
United States		75 810 000	2 975 000	78 785 000	460.0
Uruguay		480 800	7 000	487 800	175.8
Viet-Nam, Republic of		16 100	200	16 300	1.2
Yugoslavia		314 800	24 700	339 500	18.9

(1) Year ended March 31, 1958.
(2) Year ended June 30, 1957.
(3) Year ended June 30, 1958.
* Three-minute units.

United States Patents Issued to International Telephone and Telegraph System; November 1, 1958—April 30, 1959

Between November 1, 1958 and April 30, 1959, the United States Patent Office issued 144 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

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R. T. Adams and R. K. Van Vechten, ITT Laboratories, Automatic Tuning System, 2 874 274.

P. R. R. Aigrain, Laboratoire Central de Télécommunications (Paris), Calling Circuit Identification, 2 872 524.

P. R. R. Aigrain, Laboratoire Central de Télécommunications (Paris), Transmission of a Derivative Signal by Pulse Code, 2 862 186.

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P. R. R. Aigrain and S. Van Mierlo, Bell Telephone Manufacturing Company (Antwerp), Multiplex Switching Means, 2 862 059.

B. Alexander, ITT Laboratories, Magnetic Switching Circuit, 2 881 331.

B. Alexander and J. F. Sullivan, ITT Laboratories, Pulse-Pair Detector, 2 861 184.

D. F. Allison, ITT Laboratories, Electric Current Rectifier, 2 869 057.

M. Arditi, ITT Laboratories, Microwave Filters, 2 859 417.

M. Arditi, ITT Laboratories, Microwave Lines and High-Q Filters, 2 867 782.

M. Arditi, ITT Laboratories, Radio-Frequency Circuits, 2 868 966.

M. Arditi, ITT Laboratories, Traveling-Wave Electron Discharge Devices, 2 863 093.

J. Augustin, C. Lorenz (Stuttgart), Automatic Attachment Switch-Over Device, in Particular for Teleprinters, 2 865 983.

J. W. Augustin, C. Lorenz (Stuttgart), Page Printer, 2 864 482.

G. W. Bain, Farnsworth Electronics Company, Image Multiplier, 2 871 368.

R. M. Barnard, D. S. Girling, and N. C. W. Judd, Standard Telephones and Cables (London), Manufacture of Electrical Capacitors, 2 861 321.

A. H. W. Beck and T. M. Jackson, Standard Telephones and Cables (London), Electric Discharge Tubes, 2 872 620.

D. A. Beresford, Standard Telephones and Cables (London), Units for Suppression of Electrical Interference, 2 878 433.

F. C. E. M. Berger and P. A. H. Roussel, Compagnie Générale de Constructions Téléphoniques (Paris), Power-Line Signaling System, 2 860 324.

W. Berthold, C. Lorenz (Stuttgart), Gun System Comprising an Ion Trap, 2 859 364.

M. C. Branch and R. G. Mills, Standard Telephones and Cables (London), Static Electrical Code Translating Apparatus, 2 883 469.

F. H. Bray and R. G. Knight, Standard Telephones and Cables (London), Automatic Telecommunication Exchanges, 2 872 527.

A. E. Brewster, Standard Telecommunication Laboratories (London), Magnetic Recording Device, 2 868 891.

K. S. Brown and T. N. Basnett, Standard Telephones and Cables (London), Prestressed Grids for Electron Tubes, 2 861 211.

F. Buchholtz, Mix & Genest (Stuttgart), Circuit Arrangement for the Transmission of Signals, 2 860 194.

G. Buchmann and R. Karolus, C. Lorenz (Stuttgart), Condenser Loudspeaker, 2 872 532.

H. G. Busignies, Federal Telephone and Radio Company, Direction Finder, 2 871 476.

H. G. Busignies, ITT Laboratories, Long-Distance Communication System, 2 871 344.

H. Busignies, P. R. Adams, G. A. Deschamps, and M. Rogoff, ITT Laboratories, Nondispersive Infrared Analyzer, 2 866 900.

H. Busignies, M. Rogoff, and G. A. Deschamps, ITT Laboratories, Electronic Spectroanalysis Computer, 2 866 899.

J. W. Butterworth, Mackay Radio and Telegraph Company, Automatic Keyer for Lifeboat Radio Equipment, 2 869 116.

J. W. Butterworth, Mackay Radio and Telegraph Company, Piezoelectric Resonator, 2 878 451.

N. J. Cafarelli, Jr., ITT Laboratories, Quasi-stereoscopic Systems, 2 865 988.

A. M. Casabona, ITT Laboratories, Landing and Traffic Control System, 2 878 469.

A. M. Casabona, ITT Laboratories, Time-Spacing Measuring Apparatus, 2 866 157.

J. L. Culbertson, Kellogg Switchboard and Supply Company, Combined Toll and Free-Service Telephone Trunking System, 2 874 224.

D. Davidoff, ITT Laboratories, Frequency-Shift-Keying Circuit, 2 866 161.

C. L. Day, Farnsworth Electronics Company, Electron Discharge Device, 2 864 022.

M. Den Hertog, Bell Telephone Manufacturing Company (Antwerp), Electrical Identification or Selection Equipment, 2 884 489.

M. Dishal, J. S. LeGrand, G. L. Pelligrinelli, H. W. Morrow, and J. A. Koehler, ITT Laboratories, Control System for Correcting Phase and Amplitude, 2 861 177.

M. J. DiToro, ITT Laboratories, Communication System, 2 868 882.

S. H. M. Dodington, ITT Laboratories, Transmitter–Receiver Tuning System, 2 877 344.

A. Ducamp and M. den Hertog, Bell Telephone Manufacturing Company (Antwerp), Electrical Connecting Circuits, 2 862 060.

J. M. C. Dukes and J. Kemp, Standard Telephones and Cables (London), Unitary Antenna–Receiver Utilizing Microstrip Conductors, 2 874 276.

C. R. J. Dumousseau and A. E. J. Chatelon, Laboratoire Central de Télécommunications (Paris), Systems for Recording and Selecting Information, 2 881 415.

C. W. Earp, Standard Telephones and Cables (London), Electric Signal Communication Systems, 2 871 290.

C. W. Earp and D. L. Cooper-Jones, Standard Telephones and Cables (London), Radio Direction-Finding System, 2 860 336.

E. H. Eberhardt, ITT Laboratories, Secondary Emission Measurement, 2 882 486.

W. H. G. Eick, C. Lorenz (Stuttgart), Automatic Tuning of High-Frequency Apparatus, 2 878 358.

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H. Havstad, ITT Laboratories, Resonant Circuit, 2 875 376.

R. M. Heintz, Inductor Alternator, 2 866 111.

R. Helmert, C. Lorenz (Stuttgart), Circui Arrangement for Light Signals with Tw Clear Positions in Track Route Interlockin Diagrams, 2 864 940.

J. A. Henderson, Capehart-Farnsworth Company, Information Location Circuit 2 875 372.

A. J. Henquet and J. J. Perrot, Le Matérie Téléphonique and Compagnie Générale d Constructions Téléphoniques (Paris), Grou Selection System, 2 882 344.

R. C. P. Hinton and F. W. Warden, International Standard Trading Coproratior Party-Line Electrical Communicatio Systems, 2 868 869.

H. L. Horwitz and G. L. Hasser, Federal Telephone and Radio Company, Intercept Discrimination, 2 871 300.

H. L. Horwitz, M. E. Homan, and G. L. Hasser Federal Telephone and Radio Company Line Finder Allotting System, 2 876 287.

J. F. Houdek, Jr. and E. J. Braeutigam, Kellog Switchboard and Supply Company, Permanent-Magnet Display Signal, 2 866 965.

R. W. Hughes, ITT Laboratories, Pulse Communication System, 2 866 970.

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B. B. Jacobsen and I. V. Feldhusen, Standard Telephones and Cables (London), Measurement of Group Delay in Electric Communication Systems, 2 877 409.

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J. M. Johnson, Kellogg Switchboard and Supply Company, Polarized Magnetic-Operating Device, 2 883 589.

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R. V. Judy, Kellogg Switchboard and Supply Company, Trunk-Test Apparatus, 2 880 283.

A. G. Kandoian, ITT Laboratories, Antenna, 2 875 443.

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A. G. Kandoian, ITT Laboratories, Ultra-High-Frequency Antenna Unit, 2 860 339.

A. G. Kandoian and R. A. Felsenheld, ITT Laboratories, Ultra-High-Frequency Television Antenna, 2 860 341.

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G. F. Klepp, Standard Telephones and Cables (London), Electric Discharge Devices, 2 880 350.

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J. A. Kostriza and P. Terranova, ITT Laboratories, Microwave Transmission Lines, 2 877 426.

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J. Kruithof, Bell Telephone Manufacturing Company (Antwerp), Crossbar Switch, 2 867 691.

J. J. B. Lair, ITT Laboratories, Crystal Semiconductor Device, 2 878 399.

J. J. B. Lair, ITT Laboratories, Direction-Finder System, 2 861 264.

C. C. Larson, Farnsworth Research Corporation, Method of Making Double-Sided Mosaic, 2 874 101.

E. C. Lee, Standard Telephones and Cables (London), Flexible Connecting Means for Anchoring a Submarine Cable to a Repeater Housing, 2 877 031.

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E. J. Leonard, Kellogg Switchboard and Supply Company, Busy-Verification Automatic Telephone System, 2 874 225.

E. J. Leonard, Kellogg Switchboard and Supply Company, 100-Line Direct-Access Crossbar Telephone Switching Unit, 2 871 297.

L. Lewin and A. E. Pethick, Standard Telephones and Cables (London), Hybrid-T Waveguide Structure, 2 882 500.

N. Lewen and H. Oden, Mix & Genest (Stuttgart), Circuit Arrangement for Logically Handling Procedures that Arrive at Any Time, 2 860 188.

P. E. Lighty, J. Albanes, and J. H. Gesell, ITT Laboratories, Crystal Rectifier and Manufacture Thereof, 2 863 106.

K. L. Lindsay, Capehart-Farnsworth Company, Apparatus for Forming Cathodes, 2 870 315.

F. T. Machalek, Farnsworth Electronics Company, Piano Hammer, 2 870 665.

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M. L. Miller, Capehart-Farnsworth Company, Pulse Selector Circuit, 2 874 279.

F. H. Mittag, Mix & Genest (Stuttgart), Arrangement for the Destination-Marking of Dispatch Container in Transportation, 2 877 718.

A. E. Nashman and G. Rabow, ITT Laboratories, Sweep Voltage Generator, 2 875 334.

H. Nishio and Y. Yasuda, Nippon Electric Company (Tokyo), Traveling-Wave-Tube Device, 2 882 439.

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A. D. Odell, J. D. Reynolds, and P. W. S. Harrild, Standard Telecommunication Laboratories (London), Electrical Circuits Employing Transistors, 2 860 259.

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S. B. Ost, International Standard Trading Corporation, Random-Pulse Counter, 2 860 286.

G. Papp, Capehart-Farnsworth Company, Microwave Electron Discharge Tubes, 2 870 374.

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S. Phanos, ITT Laboratories, Crystal Filter Circuits, 2 868 898.

R. L. Plouffe, Jr., ITT Laboratories, Pulse Communication System, 2 881 256.

A. J. Radcliffe, Jr., Kellogg Switchboard and Supply Company, Multichannel Telephone Carrier System, 2 871 293.

A. J. Radcliffe, Jr. and A. R. Denz, Kellogg Switchboard and Supply Company, Transistor Limiter Amplifier, 2 874 312.

D. S. Ridler and B. F. Armsby, Standard Telecommunication Laboratories (London), Driving Arrangements, 2 883 475.

D. S. Ridler and D. G. N. Hunter, Standard Telecommunication Laboratories (London), Hybrid Balancing Network for a Magnetic Recorder, 2 863 003.

T. P. Robinson and P. R. Dawkins, Standard Telephones and Cables (London), Electrical Control Circuits, 2 881 856.

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D. C. Rogers and W. J. Pohl, Standard Telephones and Cables (London), Traveling-Wave Tubes, 2 871 392.

A. Rothbart, ITT Laboratories, Digital to Analog Translator, 2 881 419.

J. Rottgardt, C. Lorenz (Stuttgart), Process of Making Transparent Luminescent Screens, 2 876 129.

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R. D. Salmon, F. J. L. Turner, and A. F. Burr, Creed & Company (Croydon), Printing Telegraph Apparatus, 2 882 972.

J. C. Samuels, Farnsworth Electric Company, Cathode-Follower Oscillator, 2 874 290.

H. Seidel, ITT Laboratories, Microwave Switch, 2 866 167.

K. O. Seiler, Suddeutsche Apparatefabrik (Nurnberg), Semiconductor Crystals for Rectifiers and Transistors and Method of Preparation, 2 864 729.

S. C. Skaraeus and B. G. O. Svensson, Standard Radio and Telefon (Stockholm), Arrangement in a Radar Station, 2 862 203.

G. Stavis and J. Engel, ITT Laboratories, Omnidirectional-Beacon Antenna, 2 866 194.

F. A. Stearn, Federal Telephone and Radio Company, Switch Control Apparatus, 2 860 212.

F. Steiner and E. Mortek, Standard Telephon und Telegraphen Aktiengesellschaft Czeija, Nissl & Co. (Vienna), Rolled Capacitor, 2 881 373.

B. Thomson and E. W. Swift, Standard Telephones and Cables (London), Glass-to-Metal Seals, 2 867 947.

D. Tini, Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Milan), Combined Telephone Ringing and Inductive Coil Arrangement, 2 863 951.

C. G. Treadwell, Standard Telephones and Cables (London), Keyed Frequency-Modulation Carrier-Wave Systems, 2 860 185.

F. Vollenschier, Mix & Genest (Stuttgart), Circuit Arrangement for Telecommunication Systems, in Particular Telephone Systems, 2 878 320.

E. P. von Bergen, Standard Telephones and Cables (London), Apparatus for Coating Stranded Conductors for Electric Cables, 2 863 171.

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W. H. D. Yule, Standard Telephones and Cables (London), Electrical Relays, 2 874 246.

Electronic Spectroanalysis Computer

2 866 899

H. G. Busignies, M. Rogoff, and G. A. Deschamps

Apparatus and circuits for automatically determining the quantitative ingredients of a complex specimen by infrared spectroanalysis are described. A complex waveform is derived from the sample and a mixture of waves corresponding to the components of the complex wave is compared with this waveform. From the residual difference derived by comparison, the separate component waves are adjusted until the mixture corresponds with the complex waveform.

Systems for Recording and Selecting Information

2 881 415

C. R. J. Dumousseau and A. E. J. Chatelon

A system in which information received at random may be routed to a storage device, such as a magnetic tape, suitable for the particular category. Each group of information is preceded by signals representing a preparatory signal and a category-indicating signal. The received groups are recorded with the accompanying signals in a temporary storage. On reading of each signal group in succession, the preparatory signal prepares for operation the category storages. The category-indicating signals then complete the connection for storage of the group in the proper category storage.

Digital-to-Analog Translator

2 881 419

A. Rothbart

Digital information is translated into a voltage vector indication representing an angle between 0 and 360 degrees. This is done by connecting an alternating-current source to a servomotor through a series of phase shifters of differing phase characteristics. The pulses representing the digital number determine which of the phase shifters are to be serially connected and thus the rotary position of the servomotor.

Static Electrical Code Translating Apparatus

2 883 469

M. C. Branch and R. G. Mills

A coordinate array of magnetic loops is provided with wires threaded through the loops in two coordinates. The wires are connected to circuit elements such that a small current due to a low voltage between wire terminals serves to produce an increase in the voltage between the terminals. This increased voltage produces sufficient current to magnetize the loop threaded by the wire.

Method of Soldering Germanium Diodes

2 867 899

B. Jacobs

A method of soldering an electrode to a germanium diode consists in floating a germanium pellet on a quantity of molten solder in an inert atmosphere to provide a thin layer of solder on the pellet, then placing an electrode connector on the solder layer and melting the layer to bond the connector thereto.

Apparatus for Coating Stranded Conductors for Electric Cables

2 863 171

E. P. von Bergen

An extrusion head has been designed for assuring the separate coating of wires and the complete filling of interstices between the wires of a multistranded cable. A closing die with a tapered bore is provided. The wires of the cable pass in separated condition from the large end to the small end of the bore, and the plastic extrusion chamber opens into the closing die between the ends of the bore.

Arrangement in a Radar Station

2 862 203

S. C. Skaraeus and B. G. O. Svensson

A radar station has been designed to operate in the presence of jamming signals that, in general, do not cover the entire operative range of the system. The receiver of the system is continuously scanned over a given frequency band to receive the jamming signals and any returned radar pulses. The transmitter of the system is continuously scanned in frequency with the receiver and a radar pulse is automatically transmitted when the jamming signals are not present.

Long-Distance Communication System

2 871 344

H. G. Busignies

This arrangement is for communicating by radio energy between two points separated so that the horizon intervenes between the points. A device, such as a gun, is provided to produce a dispersive reflecting zone in the upper atmosphere. The antennas at the two points are pointed at the zone. At one of the stations there is provided a device to detect a change in the character of this zone and to control the device to replenish the material in the zone in response to a change in character thereof.

Flexible Connecting Means for Anchoring a Submarine Cable to a Repeater Housing

2 877 031

E. C. Lee

To prevent relative rotation of the repeater with respect to the cable, armour wires are bent outwardly and fastened in radial grooves within the housing. The cable is also stiffened at its point of connection to the housing to prevent sharp bends. In these ways damage due to twisting of the repeater housing and bending of the cables is minimized.

Omnidirectional-Beacon Antenna

2 866 194

G. Stavis and J. Engel

An antenna array has been designed to provide good vertical-angle coverage for tacan beacons. A normal vertical array of biconical dipoles is provided with spacing between the dipoles and energy supply to them, such as to make the principal radiation lobe incline upwardly, for example at an angle of 5 degrees. Above the normal array is another antenna element that is separated from the array by a counterpoise. This element provides a greater vertical energy distribution than the array, and so tends to fill in the normal cone-of-silence zone immediately above the array.

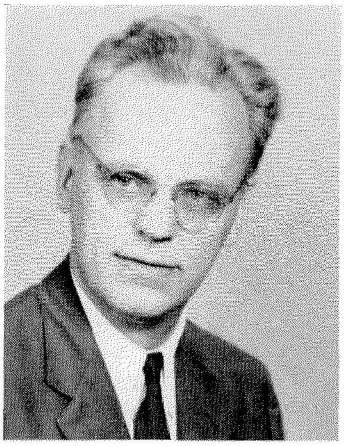
Device Having Vibrating Reeds

2 876 445

J. M. B. A. Wuyts

A device for use in telephone signaling having vibrating reeds tuned to different frequencies to serve as different signals. The separate reeds are fastened to the diaphragm of a conventional carbon transmitter. Push buttons cause a selected reed to vibrate, when the diaphragm vibrates at the reed frequency.

Contributors to This Issue



ROBERT T. ADAMS

ROBERT T. ADAMS was born on January 6, 1915, in Sparkill, New York. He studied at Cornell University.

For eight years he was with Western Electric Company where he was engaged in test-equipment development and production engineering.

Since joining ITT Laboratories in 1946, Mr. Adams has been engaged in circuit studies and system development, primarily in the field of communications. He became an executive engineer of the laboratories in 1954. Since 1955, he has been active in scatter communications and his group was responsible for the diversity receivers developed for the broad-band telephone

EDWARD W. KOENIG

and television link between Florida and Cuba. Now a senior scientist, he is engaged in consulting and technical planning activities. He reports in this issue on the advantages of intermediate-frequency diversity combining.

Mr. Adams is a Senior Member of the Institute of Radio Engineers.

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EDWARD W. KOENIG was born in Johnstown, Pennsylvania, in 1928. He received B.S. and M.S. degrees in electrical engineering from Purdue University in 1952 and 1953, respectively.

In 1953, he joined Capehart-Farnsworth Corporation (later ITT Laboratories), where he has been active in the development of specialized television and display systems. He reports in this issue on a storage-tube aircraft radar display.

Mr. Koenig is a member of the Institute of Radio Engineers.

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BARRY M. MINDES was born in New York City on December 15, 1931. He received the B.S. degree in physics from the College of the City of New York in 1954. From 1954 until 1956 he served in the United States Army. Since 1956, he has been with ITT Laboratories, where he has done development work in communications. He is coauthor of the paper in this issue on diversity combining methods.

Mr. Mindes is a Member of the Institute of Radio Engineers.

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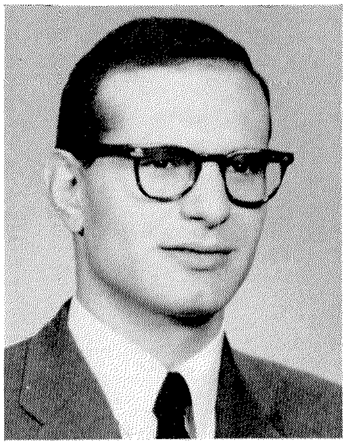
JOHN SEYMOUR was born in 1927 in Colombo, Ceylon. He received the B.Sc. (Special) degree in Physics from London University in 1952.

In the same year he joined the development staff of the Brimar valve



BARRY M. MINDES

engineering department of Standard Telephones and Cables. He has been engaged in work on oxide-coated cathodes and their evaporation products and is author of an article in this issue on cathode interface impedance.

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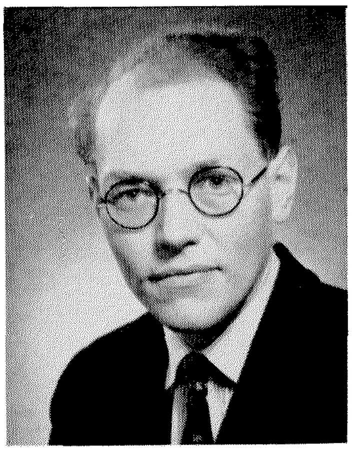
SAMUEL SILVERMAN was born in Brooklyn, New York, on January 25, 1914. He attended the College of the City of New York.



JOHN SEYMOUR

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After managing several commercial enterprises, he joined Federal Telephone and Radio Corporation in 1943. He was engaged in radio transmitter engineering, testing, and inspection until 1957 when he was assigned to the ITT Standards Laboratory, of which he is now director.

Mr. Silverman is the author of a paper in this issue on the work of the ITT Standards Laboratory.

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M. F. TOOHIG received the B.S. and the M.S. degrees in physics from Boston College.

His 9 years experience includes research and development in exterior, interior, and terminal ballistics, the development of storage cathode-ray tubes and barrier-grid storage tubes. He reports in this issue on the new coaxial latron tube.

M. F. TOOHIG

Mr. Toohig is a member of the Inst tute of Radio Engineers and th American Institute of Physics.

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