Charles Snider pours liquid nitrogen into a col of the new cesium-beam frequency standard as Beehler adjusts the atomic beam detector. The U- resonant cavity used to excite the cesium transi suspended above the center of the machine.

STANDARDS AND CALIBRATION IN RADIO AND ELECTRONICS

ELECTRONICS is now the fifth largest industry in this country. It has been predicted that it will step into first place within 10 years. With this rapid growth has come the problem of accurately measuring the basic radio and electronic quantities so as to insure the unfailing performance of an ever-increasing variety of components and equipment.

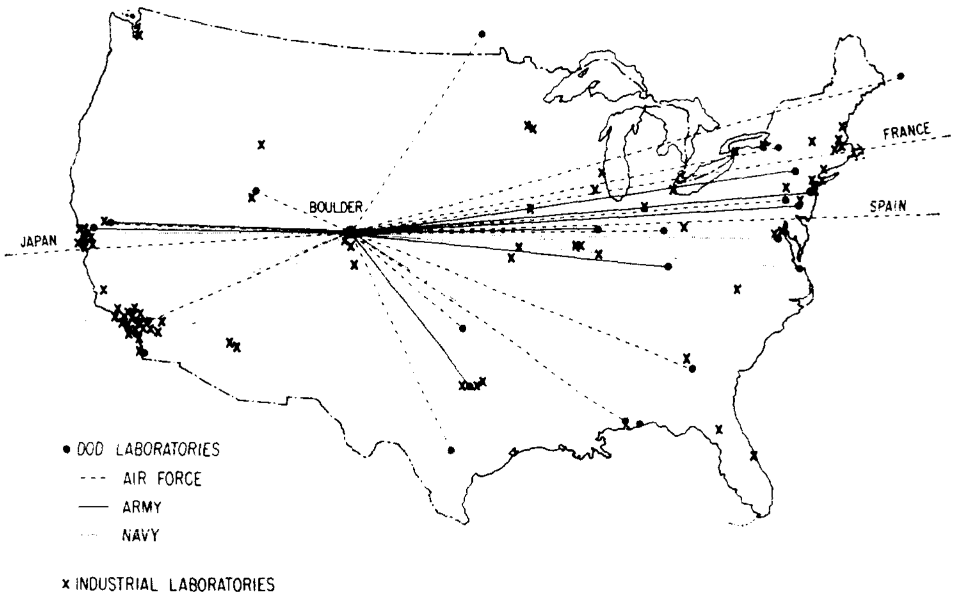
Such frontier areas as space exploration, automation, and miniaturization are subjecting electronic equipment to new and complex uses as well as extreme environments. In these applications the need for accuracy on the production line becomes increasingly important. In the missile field, for example, it is estimated that reliability above 90 percent can be achieved only if each component has not more than a 1-to-1,000 probability of failure. To produce components having the necessary uniformity and accuracy requires a chain of calibration leading from the assembly line back ultimately to the precise electrical standards maintained for American science and industry by the National Bureau of Standards.

As indicated by the recent Aerospace Industries Association Survey,[1] the precision needs of the military services and industry are now outstripping the availability of standards and calibration services in the radio-electronics field. Although manufacturers have attempted to fill the gap by establishing procedures to calibrate their own working standards, these working standards lose much of their value if they are not calibrated in terms of the national standards.

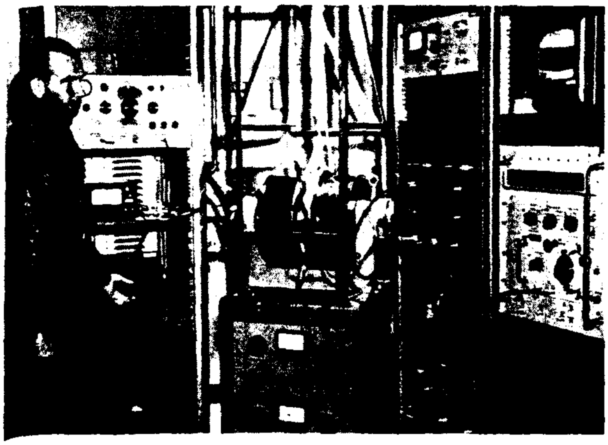
In an effort to meet these urgent needs, the Bureau's Radio Standards Laboratory in Boulder, Colo., is expanding its program of radio standards research and calibration services. Within the limits of its facilities and staff, the Laboratory is seeking to provide the improved standards, measurement techniques, and associated instrumentation that are needed for all radio frequency and microwave quantities. At the present time, standards are being established or improved for frequency, power, attenuation, voltage, impedance, noise, field strength, interference, conductivity, dielectrics, and magnetics. In addition, a new laboratory has recently been activated to study radio properties of materials with advanced techniques.

Microwave Impedance

Impedance measurements play an essential role in the design, production, and evaluation of electronic equipment; however, it is also one of the most difficult



Top military and industrial reference laboratories served by the NBS Electronic Calibration Center during its first year of operation. Most of these in turn calibrate lower-level standards.



William Case adjusts the local oscillator in an experimental setup for evaluating the tensor permeability properties of ferrite materials. The ferrite (in cavity at center of electromagnet) is measured at 1,060 Mc.

quantities to measure accurately. Recently the Radio Standards Laboratory significantly improved impedance standards and measurement techniques in the microwave range.

Three types of fixed impedance (or reflection) standards have been developed: An adjustable sliding termination for rectangular waveguide, which can be arranged to have practically no reflection; very precise short-circuited sections having almost total reflection; and half-round obstacles whose reflections can be calculated from the dimensions and wavelengths.

The adjustable sliding termination has a voltage standing-wave ratio of less than 1.0002 or a return loss greater than 80 db. Extremely fine mechanical tolerances and controls provide a fine adjustment and minimum variation in reflection.

In the short-circuited sections of waveguide the input flange is a quarter wavelength from the short circuit. In a typical example a short-circuited section of X-band electroformed silver waveguide has a calculated VSWR at 10 kMc of approximately 5.140, corresponding to a voltage reflection coefficient of approximately 0.99961.

To test these short-circuited sections it was necessary to know the effective conductivity of the metal. This conductivity was obtained by making attenuation measurements of the sections. In these measurements, an attenuator was calibrated by modifying a system used in microwave power research. The lower range of the microwave variable attenuator was calibrated at approximately 9.4 kMc to accuracies exceeding 0.0001 db. Such accuracy exceeds that to which fine attenuators can be read. This development illustrates the interdependence of basic measurements. In this case, the need to evaluate impedance standards revealed a need for attenuation measurements that was met by a modification of a power measurement system.

From a theoretical analysis, inductive half-round obstacles have been built for use as impedance standards over a wide range of reflections. Measurements of these reflections have agreed with calculated values to better than 0.1 percent in VSWR.

The calibration and use of these standards required improvement in the measurement of microwave impedance. Accuracies of 0.1 percent in VSWR to 2.0 were achieved by using magnified response and modified reflectometer techniques. The development of the latter technique included a rigorous analysis of the microwave reflectometer. This analysis describes the correct adjustment of auxiliary tuners, and provides quantitative values for errors resulting from incorrect adjustments. Work is in progress on the extension of these impedance measuring techniques to other sizes of rectangular waveguide and to coaxial systems.

The above description of recent research and development in microwave impedance illustrates advances in a specific area of standardization. Progress is also being achieved in other basic quantities throughout the radiofrequency range.

Atomic Frequency Standards

The physical quantity most important to the electronic field is frequency. To make the national standards of frequency and time intervals readily available, radio broadcasts are made continuously from WWV, in Beltsville, Maryland, and WWVH in Maui, Hawaii. In addition, a 60-kc experimental station broadcasts from Boulder, Colo.

The Radio Standards Laboratory monitors WWV continuously. Its frequency is measured daily in terms of extremely accurate atomic standards. With recent improvements in technique, comparisons can now be made to a part in 100 billion.

Experiments in the search for more accurate standards of time and frequency have shown that standards based on unvarying properties of atoms are more precise than astronomical or quartz crystal standards. Atomic standards are also simpler and more completely understood. They do not have the secular variations inherent in astronomical time, nor do they suffer from the aging effects of quartz. In addition, they measure time and frequency very quickly, in contrast to delays of months or years necessary for evaluation of other systems.

Recent improvements in atomic frequency standards are opening up new possibilities in science and engineering. For example, atomic clocks provide high-resolution spectroscopic techniques that can be used to probe deeper into the molecule, atom, and nucleus. Also, more accurate time measurement will permit a closer study of the effect of land tides, sea tides, and the motion of air masses upon the rotation of the earth. It may even provide a means of detecting the effect of rarified gases and magnetic fields on the motion of planets or satellites. Another government agency is now planning to use atomic clocks in an experimental test of the special and general theories of relativity.

The atomic beam frequency standards under development in the Radio Standards Laboratory depend upon the transitions of cesium atoms from one energy state to another. These transitions can occur by the absorption or emission of an electromagnetic wave of a very definite frequency. This frequency is determined by the difference in energy of the two states involved in the transition. For an isolated atom the energy difference of these states—and consequently the emitted or absorbed frequency—is invariant. Of course, the apparatus used to observe the transition disturbs the atoms, and they can then no longer be considered isolated. However, the atomic beam technique creates the least such disturbance of all current methods. For this reason, it is thought to provide the most accurate frequency standard, although perhaps not the most precise.

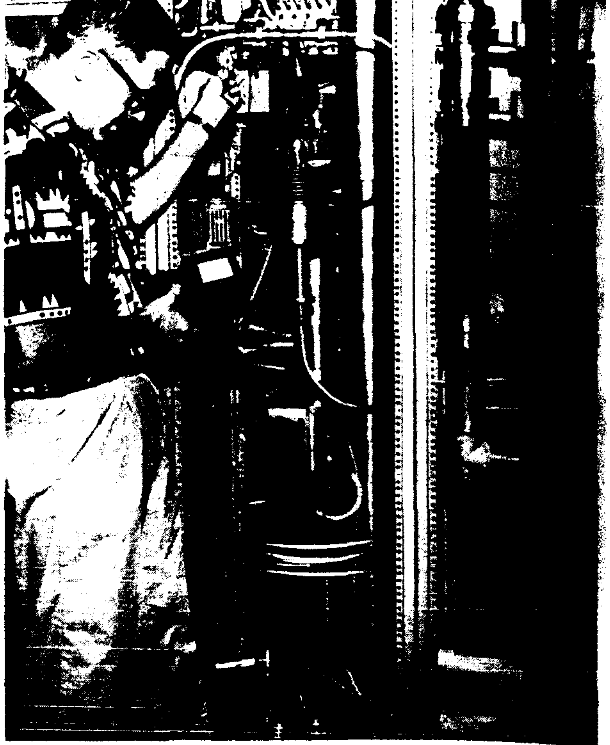
During the past 18 months a cesium beam atomic standard has been almost completely remodeled so that it now has a precision and accuracy of about 7 parts in 100 billion. A new cesium beam standard, designed to have a somewhat higher precision, has just been completed. These two cesium standards, an Atomicron, and an extremely stable crystal oscillator, are now being intercompared on a regular basis.

The new atomic beam is designed to use thallium as well as cesium (thallium has certain important advantages over cesium). Initially, however, cesium is being used and preliminary results (as of October 1, 1959) indicate that its precision and accuracy is 6 parts in 100 billion. The new machine compares in frequency with the old machine to 7 parts in 100 billion.

Two ammonia masers (microwave amplification through stimulated emission of radiation) are being used to study the character of the radiation which excites the cesium transition. At the same time they provide separate standards for frequency comparison. Frequency comparisons with atomic standards in other parts of the world are also made on a regular basis.

Electronic Calibration Center

For quantities other than frequency, the Radio Standards laboratory disseminates its standards and measurement techniques to the Nation mainly through its Electronic Calibration Center,[2] established in 1958. The primary mission of the Center is to calibrate interlaboratory standards for such quantities as voltage, power, and impedance in terms of the national standards maintained by NBS. These interlaboratory standards, in turn, are used to assure the accuracy of reference and working standards.

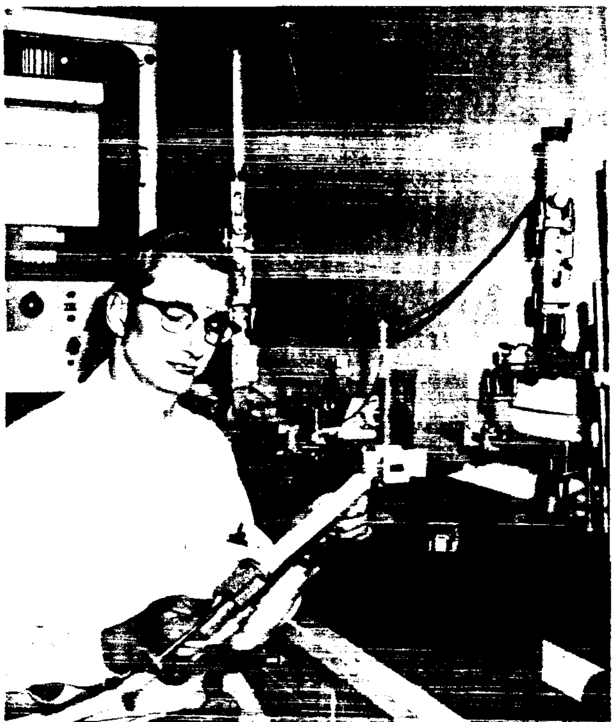


David Russell adjusts the "magic T" input to the detector of the new high-frequency piston attenuator (see also photo on facing page). On the right is the large trombone phase shifter used in this dual-channel system.

Although the Center was established primarily to meet critical needs within the Department of Defense, it is also designed to meet the needs of the electronics industry. Efforts are underway to increase the capacity of the Center to provide a larger number of individual calibrations each year.

Its calibration activities are divided into three units covering low, high, and microwave frequency measurements. Instrumentation is still incomplete but interim steps are used when necessary to help meet the calibration demand.

Low frequency (zero to 30 kc) instrumentation now provides for the calibration of resistors, bridges, potentiometers, capacitors, inductors, standard cells, electrical instruments, ratio devices, and instrument transformers. Within recent months the Center has received a transformer-type capacitance bridge, constructed by the Electricity and Electronics Division, that will extend the capacitance calibration range, for low frequencies, downward to 1 μpf. By modifying existing ratio sets and associated equipment, it is expected that the frequency range of current and potential transformer calibrations will be extended, within the year from 60 to 400 cps.



An accurate attenuation measurement technique was developed to evaluate new short-circuit types of microwave impedance standards. Wilbur Anson examines a silver section of waveguide used to transfer this measurement to the impedance standards.

Eugene Amrine uses the new NBS high-frequency piston attenuator to calibrate the unknown inserted in the lower-right panel.

To date, the saturated cells used by the low-frequency unit to maintain the volt have been kept at a reasonably constant temperature in an air bath. A new oil bath that is now being completed should increase certified accuracies five times over the current accuracy of 0.001 percent.

The high-frequency unit (30 kc to 300 Mc) is now equipped to calibrate standards of voltage (unbalanced), power, impedance, attenuation, and field strength. At the present time, these standards are limited to cw measurements. Calibration services for most quantities are at the fixed frequencies of 30, 100, and 300 kc. and 1, 3, 10, 30, 100, and 300 Mc. Continuous frequency coverage is being provided, however, as rapidly as stable and accurate equipment can be devised.

A new precision piston attenuator to operate at 30 Mc has just been completed by the Laboratory. This attenuator will measure a change in attenuation of less than than 0.001 db, and will allow calibration accuracies of 0.01 db. These same accuracies are expected to be offered within the next year at 100 and 300 Mc.

High-frequency voltage is now being calibrated at fixed frequencies ranging from 30 kc to 400 Mc. Consoles from 30 kc to 100 Mc cover from 0.2 to 500 v. The 300 and 400 Mc console covers from 0.2 to 100 v. A microvolt calibration console, which is nearly complete, will extend from 1 μv to 0.1 v, using the fixed frequency sources of the voltmeter consoles. Most of this hf voltage calibration is to an accuracy of 3 percent. The range from 30 kc to 10 Mc, however, is being calibrated to an accuracy of 2 percent, and it is hoped that during the next year this accuracy can be extended to 0.25 percent.

In the microwave range (above 300 Mc) calibration equipment for power, impedance, attenuation, frequency, and noise is being established or improved. Instrumentation using coaxial transmission line components is being prepared for the nominal frequency range 300 to 4,000 Mc, and instrumentation using waveguide components will cover the range of 2.6 to 40 kMc. For frequency measurements, this range is extended to 75 kMc.

Power calibrations in waveguide are now being made to an accuracy of 1 percent in the frequency range of 8.2 to 12.4 kMc. A setup for power measurements in the waveguide range of 2.6 to 3.95 kMc is nearly complete.

Apparatus for microwave impedance (VSWR) measurements in the waveguide range of 8.2 to 12.4 kMc is nearly complete. Initial accuracies are expected to be within at least 0.5 percent and ultimate accuracies may be 0.1 percent.

Microwave attenuation is being calibrated to 0.1 db in waveguide from 2.6 to 18.0 kMc. Equipment for waveguide calibration from 18.0 to 26.5 kMc should be completed during 1960. Attenuation measurements in coaxial line have been extended to 5.6 kMc.

A calibration project to measure microwave noise began in early 1959, and the calibration equipment for waveguide range 8.2 to 12.4 kMc is now almost complete.

During its first year of operation, the Center made 14,182 measurements on the 2,074 items which were calibrated. About two-thirds of these items were for the Department of Defense and about one-third was for the electronics industry.

Radio Materials

The work in measurement and determination of physical quantities at radio frequencies is being extended to measurement of the physical properties of matter with radio techniques. An understanding of the properties of materials at radio and microwave frequencies is important to advances in radio technology where new discoveries often depend on knowledge of the behavior of different substances. For this reason, the Radio Standards Laboratory has established a new facility to study the interactions between electromagnetic waves and matter.

This facility will use the most advanced radio techniques to conduct its research. Molecular beam techniques, radio and microwave spectroscopy, gyrators, nuclear resonance, ferromagnetic resonance, paramagnetic resonance, and microwave solid-state amplifiers are among some of the research tools. They will be used to investigate molecular, chemical, and liquid- and solid-state problems: dielectric, magnetic, and semiconductor phenomena; and determinations of new standards and physical constants.

The Laboratory has been studying magnetic phenomena for the Navy Bureau of Ships since 1952. This work began with the evaluation of powdered irons, and has since been expanded to include measurements of

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many other magnetic materials under static conditions and at microwave frequencies. For instance, a quasi-static hysteresis loop tester (Cioffi type) is nearing completion and will be used for studies of ferrites. Also a modified vibrating sample magnetometer has been designed to measure the maximum magnetic intensity in a material.

In the range from direct current to microwave frequencies, investigations are underway on magnetostriction (in the rf region only) on the total energy lost by magnetic cores when they are exposed to high-level magnetic fields, and on magnetic and dielectric spectroscopy techniques. Work in the third category includes extensive studies of coils, rf permeameters, and cavities.

Emphasis in the microwave region is being placed on a determination of the tensor permeability (directional properties) and dielectric properties of ferrites at about 1,060, 3,100, and 9,200 Mc. Studies are also being conducted on the tensor permeability of ferrites at low d-c fields. Such information is used to design many new microwave-ferrite devices such as isolators, phase shifters, modulators, and circulators.

Dielectric constants and dissipation factors are measured over a frequency range of 0.1 to 10^{10} cps at temperatures from $-100°$ to $+500°$ C. The Bureau has developed methods for measuring loss tangents as low as 0.000,001 at 1 Mc. Facilities for millimeter-wave work are now available, and studies have been made at the low-frequency end of the dielectric spectrum on frequencies so low that their periods are days in length.

A detailed study of polarization and conductivity in crystals of barium titanate has led to formulas that consider the presence of free charges near the domain walls. These equations explain variation in hysteresis loop shape, the dependence of conductivity on polarization, and the variation of switching time with various parameters.

In conductivity studies the Radio Standards Laboratory is investigating the tensor or directional conductivity of semiconductors such as single crystals of germanium at microwave frequencies under different physical conditions. These studies are expected to yield a better understanding of the crystal-lattice forces and processes.

[1] *For a detailed report on the Aerospace Industries Association report,* *see p. 222 of this issue of the Technical News Bulletin.*

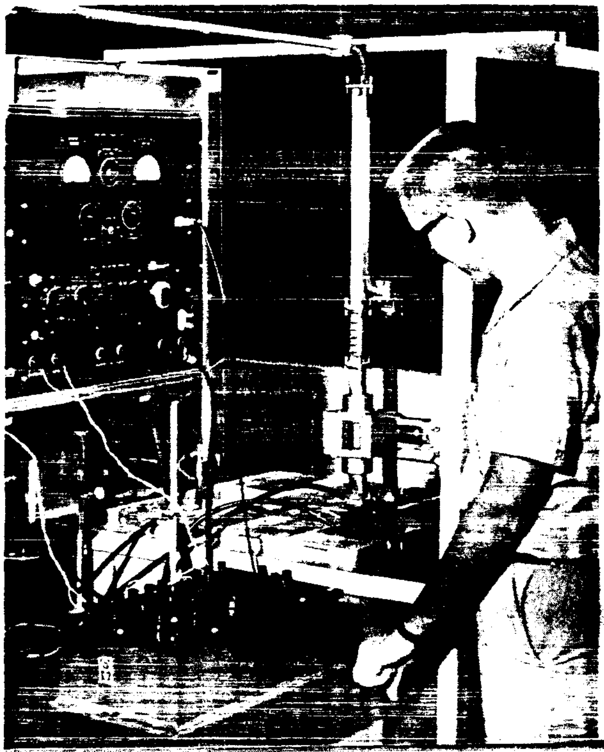
[2] *For further information, see* Services and facilities of the Electronic Calibration Center, *Tech. News Bul.* **223,** 42 (*Nov. 1958*).

ULTRAPRECISE ATTENUATION MEASUREMENT

A METHOD has been developed for calibrating the lower ranges of a microwave variable attenuator to accuracies better than 0.0001 db (10 microbels). This accuracy exceeds the precision to which available attenuators can be set and read, and is the most accurate measurement of microwave attenuation yet made at the Bureau's Radio Standards Laboratory, Boulder, Colo.

The work was carried out by the personnel of the microwave power standards project under the leadership of G. F. Engen, with assistance from members of the microwave impedance and attenuation projects. This work was done in connection with the Bureau's program to develop microwave standards and precision measurement methods at microwave frequencies. Calibrated microwave attenuators and directional couplers are used in such instruments as field strength meters and signal generators, and in alinement of radar transmitters and receivers. The use of attenuators for power measurements reduces high-power outputs by a known amount to a level that can be conveniently measured with milliwatt instruments. Manufacturers of microwave equipment need their transfer standards calibrated against a national standard to insure the accuracy of attenuators made for industry, military, and the Government. This present development provides the required accuracy in the lower ranges.

The improved accuracy was made possible by adapting a very stable power measurement system to attenuation measurements. The resulting calibration system consists of an amplitude-stabilized microwave signal source and a bolometer detector operated in a temperature-stabilized water bath. There are provisions for "tuning out" the reflections of the system at the place where the test attenuator is inserted, and for accurately measuring the d-c power supplied to the bolometer detector. A second bolometer detector forms part of the amplitude stabilization loop.[1]



Measuring attenuation to 10 microbels at microwave frequencies. James E. Gilbert changes the setting of the test attenuator during its calibration.