THIRD INTERNATIONAL CONFERENCE ON PRECISION ELECTROMAGNETIC MEASUREMENTS

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THE third International Conference on Precision Electromagnetic Measurements was held during August 14–17 at the Boulder Laboratories of the National Bureau of Standards, Boulder, Colorado. Sponsored by the Radio Standards Laboratory of the National Bureau of Standards, the Professional Group on Instrumentation, Institute of Radio Engineers and the Instrumentation Division, American Institute of Electrical Engineers, the conference was concerned with the advancement of standards and accurate measurement throughout the coherent frequency spectrum. Fifty-five papers were presented in 10 sessions. There were technical discussions during an informal evening session, and the work of the Radio Standards Laboratory was demonstrated.

Dr. Frederick W. Brown, director of the Boulder Laboratories, welcomed some 560 members from Australia, Belgium, Canada, England, France, Japan, New Zealand, Sweden, Switzerland and the United States, and gave background information on the activities of the National Bureau of Standards. Dr. John M. Richardson, chief of the Radio Standards Laboratory and chairman of the Conference, spoke on the Conference's organization and objectives, pointing out that the subject-matter of high-level precision and accuracy throughout the entire coherent frequency spectrum involves the national standards laboratories of the world and other laboratories and organizations in contact with them. Also, a closer relationship between the standards laboratories and those who are making the discoveries which lead to improved accuracy and precision in measurement seems to be required.

The technical programme, under the chairmanship of Dr. George Birnbaum (Atomics International), included papers about, and related to, accurate measurement in determining: (1) low-frequency electrical quantities; (2) high-frequency and microwave quantities; (3) properties of materials; (4) applications of quantum electronics to precision measurement, for example, frequency, time and the velocity of light; (5) use of statistics as an aid to measurement; (6) the precision measurement needs of space technology. About 20 per cent of the papers were from outside the United States.

Dr. Robert D. Huntoon, deputy director, National Bureau of Standards, set the theme of the Conference as co-operation in focusing on precision electromagnetic measurements at all coherent frequencies and in pushing for improvement in the state of the art. In his address, he told of how the Conference work is related to the mission of national standards laboratories, and of the need for very close collaboration between scientists and laboratories in keeping on a common basis as closely as possible in standards, and in keeping on a common basis in precision terminology. It seems that each time a new measurement idea comes about it is duplicated, improved and incorporated in a standard which is returned for calibration. The problem is to keep the standards laboratories ahead of measurement requirements.

Session I: Space Electronics

The sessions commenced with five papers on space electronics, relating to space explorations, and in keeping with the world-wide emphasis now placed on this subject. The chairman, Prof. Samuel Silver, University of California, referred to the objectives previously given, namely, a reporting of the precision measurement problems in space.

W. E. Brown, jun. (Jet Propulsion Laboratory), dealt with "Measurement Problems of Space Vehicle Experiments". He pointed out that the need for conducting remote measurements by use of experimental sensors on space-vehicles, in an environment where there is often a large uncertainty in the parameter to be measured, establishes a new area of endeavour for the research worker. The conditions peculiar to this problem are in many instances vastly different from those normally encountered in laboratory research, and are related to the over-all spacecraft design requirements. These new conditions attach a new significance to calibration philosophy, sampling-rates, conversion accuracies and reliability. Furthermore, the ground data handling problem of extracting information from the large quantities of data is extremely severe and usually requires careful planning by the experimenters several months prior to the actual measurement. The paper surveyed the present and future aspects of acquiring accurate and intelligible information from the spacecraft sensors by the utilization of techniques which tend to be more compatible with the spacecraft design requirements.

D. B. Holdridge (Jet Propulsion Laboratory) described the computations and "Error Sources in the Determination of the Astronomical Unit from Venus Radar Observations". Radar reflexions from Venus when it was near the 1961 inferior conjunction were detected using continuous-wave techniques (2,388 Mc/s) in the Doppler and time-of-flight data systems. The data were compared with theoretical values obtainable by use of the available planetary position–velocity ephemerides and yielded a value of 149,498,845 ± 250 km for the astronomical unit (A.U.), or a solar parallax of 8″.7,940,976 ± 147 based on an Earth radius of 6,378,145 m.

Computations of the A.U. were made separately from the 'Newcomb ephemerides' and the 'Duncombe-corrected ephemerides'. Reduction of the Doppler data disclosed a small residual error in the difference between the heliocentric longitudes of the Earth and Venus in Duncombe's corrections to Newcomb's theory.

D. D. McKibbin (Lockheed Missiles and Space Co.) reported results from an ion chamber carried on about 100 orbits through the *F*2 region of the ionosphere. The measurements were made from 73° N. to 73° S. over altitudes of about 210–510 km. Kinetic ion temperatures were found to be 1,500° K and higher. Ion concentrations varied from 5×10^3 to 10^6 particles/cm^3. Fluctuations in the ion chamber values, especially in the southern auroral zone, indicated the presence of large ionization irregularities.

T. J. Crowther (Lockheed Missiles and Space Co.) gave a paper on "Automatic Range Switching of Instrumentation in Space Vehicles for Increased Accuracy". He described a device for making accurate measurements of electronic signals from a space-vehicle using automatic range switching. The device controls an instrument which has many operating ranges or scales and automatically selects the proper scale. The readings are then telemetered back to Earth on two channels, one to indicate which scale is in operation and the second to give the actual reading within the scale. Results from an actual application were given where accuracies of 5–15 per cent were obtained over a dynamic range of 10^4.

E. M. Bollin (Jet Propulsion Laboratory) discussed "Lunar Surface and Sub-surface Magnetic Susceptibility Instrumentation". His paper is a description of the development and the changes necessary in the instrumentation and transducer configuration to adapt a standard field method of magnetic susceptibility measurement to the special restrictions of space-craft electronics, transmission systems, measurement environment, and the restrictions imposed by sample geometry and size.

One of the major considerations is to get accurate information to the scientific community concerning the specific need for these rather specialized measurements. Accurate instrumentation was not previously developed as there was no specific need and no easy way of overcoming difficulties inherent in the measurement.

Session II: Direct Current and Low-Frequency Measurements

Five papers in this basic area of precision electromagnetic measurements were presented under the chairmanship of Chester Peterson (National Bureau of Standards).

G. A. Candela and R. E. Mundy (both at the National Bureau of Standards) described the measurement of "Absolute Magnetic Susceptibilities by the Gouy and the Thorpe–Senftle Methods". Dr. Candela pointed out that most magnetic susceptibility measurements in the past were made by relative methods. These depend on knowing the susceptibility of a reference substance; however, there are very few substances the susceptibility of which is known to better than about 1 per cent. To-day the measurements can be made easily and on an absolute basis on small samples. This results largely from the developments described and from measuring magnetic fields with a proton resonance magnetometer. It was suggested that laboratories equipped with the Gouy and Faraday apparatus should use the absolute measurement methods.

J. J. Hill (National Physical Laboratory, Great Britain) spoke on "The Design and Performance of High Precision Audio Frequency Current Transformers". The principal factor governing the performance of current transformers at high audio-frequencies is the magnitude of the product value of total leakage inductance and total interwinding capacitance. When the equations governing these quantities are examined it is found that there is an optimum thickness for the insulation space between the primary and secondary windings. Further improvement is obtained if the winding resistances, leakage inductances, and capacitances are all symmetrically and uniformly distributed. It is suggested that these conditions can best and most easily be realized by the use of single layer primary and secondary windings on a toroidal core.

The National Physical Laboratory has constructed transformers on this design to measure currents up to 400 amperes in the frequency band 400 c/s to 20 kc/s. The maximum ratio error at any load throughout this frequency-range is 17 parts in 10^6 and the maximum phase error is 50 μradians.

The discussion brought out the need for international agreement on how transformers are tested and the manner in which errors are to be specified.

P. L. Richman (Rotek Instrument Corporation) described "A New Peak to d.-c. Comparator for Audio Frequencies", an adjustment-free transfer technique for making precision comparisons between audio-frequency a.c. voltages and a reference d.c. Limitations and errors were estimated at 50 parts in 10^6 for the worst case in the over-all a.-c.–d.-c. transfer. Experimental verification for many of the error estimates was described, and experimental over-all comparison against thermal calibration and against a modification of the Smith–Clothier calibration technique was given. Agreement in the latter case was of the order of 30 parts in 10^6, indicating good correspondence with calculated error predictions. The comparator was usefully employed at frequencies up to 100 kc/s.

Dr. William A. Geyger (U.S. Naval Ordnance Laboratory) discussed "Low-Power-Operated d.-c. Instrument Transformers". Recent research work has been conducted toward the development of low-power-operated direct-current types of instrument transformers. The term, "d.-c. instrument transformer", has gained acceptance as a general name for those types of saturable-core devices which permit the measurement of direct currents and low-frequency currents, with a high degree of accuracy, without the use of power-consuming shunt resistors.

Dr. Geyger's paper describes a miniaturized d.-c. instrument transformer which is 60 c/s-operated from a correspondingly miniaturized switching-transistor magnetic-core multivibrator. In a special application to the measurement of currents derived from solar batteries, this low-power-operated d.-c. instrument transformer (the power drain on the 6-V battery is about 5 mW) eliminates the considerable power dissipation (up to 5 W) in a 5-ohm shunt resistor carrying the direct current to be measured. The device is also quite valuable for other applications, where small size, light weight, and an extremely low-power drain are of prime importance.

R. P. McKnight (Sandia Corporation) discussed the development and performance of "A Direct Reading Voltage Divider with Standard Cell Reference", in which the output voltage is equal to that of a standard cell when the input resistance has been adjusted so that 1 m.amp of current is flowing through the divider. The range of measurement with direct reference to a standard cell is 2–1,100 V. The range may be lowered to 0·02 V with decreased accuracy by the use of a Lindeck potentiometer in place of the standard cell. Results indicate that accuracies of approximately 0·005 per cent may be obtained from 2 V to 1,100 V without applying corrections.

Session III : Data Reduction in Precision Measurements

This session of four papers was mainly devoted to professional advice on the statistical analysis of data.

The first paper, "Uncertainties in Calibration", by W. J. Youden (National Bureau of Standards), also chairman of the Session, presented striking examples of research values which were improperly given in the literature. He spoke of incorrect simplifying assumptions, for example, treating systematic errors as though they were random. He then described efficient methods of clearly revealing systematic errors. General rules were given: we must improve the meaningfulness of limits set on measurement results, we need to know more about our random and systematic errors, we need to recognize that in many cases the available knowledge to form an estimate of errors is not reliable information, we must not jump the elementary steps, and we must be sure of what the precision errors are.

A. G. McNish (National Bureau of Standards), with a paper entitled "The Speed of Light", complemented the foregoing remarks. He summarized the present state of our knowledge regarding this important physical constant, and in doing so explained methods and techniques of analysis applicable to practically all well-controlled experiments. The concluding value after analysis of the numerous independent or semi-independent measurements was given as $299,792.50 \pm 0{\cdot}10$ km/s.

The discussion brought out that there is no evidence either theoretical or experimental that the speed of light changes with frequency or with epoch.

The third paper, "Automatic d.-c. Data Logging System", was given by William Arnett (COHU Electronics, Inc.). He described a system which digitizes d.-c. voltages and records the values on punched cards for subsequent machine data reduction. The system has high precision, a few parts in 10^6, which is new in this field. Statistical analysis of the calibration data and information on stable voltage sources show the probable error to be about one part in 10^6. The speed of measurement, about 100 points in 6 min, and automatic self-calibration are also unusual with this type of system.

The last paper of this session, "Variance of Radio Frequency Caused by Atmospheric Turbulence in Line-of-Sight Transmissions", by K. A. Norton, E. C. Barrows, M. C. Thompson, jun., and H. B. Janes (all at the National Bureau of Standards), was given by Mr. Janes. This paper deals with the errors contributed by the turbulent lower atmosphere to standard radio frequencies transmitted over line-of-sight paths. Some measurements of these errors are discussed in terms of their effect on frequency and time-interval estimation. They are also compared quantitatively with the error contributed by transmitting oscillator instability.

The paper establishes the fact that, at the present state of the art, transmission of standard frequencies over a line-of-sight propagation path through the troposphere will not appreciably further deteriorate their accuracy relative to that available before this transmission.

Session IV : Properties of Materials

Recent developments in solid-state electronics and the increasing need for compact, light electronic devices with minimum power consumption for service in space-craft have focused scientific interest on the electromagnetic properties of materials. The examination of such properties requires the development of precise and convenient methods of measurement such as those explored by this conference. Prof. A. A. Oliner (Polytechnic Institute of Brooklyn) served as chairman and introduced the speakers.

Prof. L. M. Silber (Polytechnic Institute of Brooklyn) began the session with a paper prepared in co-operation with Prof. H. J. Juretschke (also of that Institute): "DC Effects Accompanying Ferromagnetic Resonance in Thin Films". The technique described permits the simultaneous measurement of several properties of a thin film: electrical conductivity, extraordinary Hall coefficient, magneto resistance anisotropy, permeability tensor and gyromagnetic ratio. Since all these properties can now be measured for a single film, their relationships can now be studied without the uncertainties of earlier methods which required the preparation of several identical films.

The second paper, "Microwave Faraday Rotation Using a Bimodal Cavity", by Dr. D. P. Snowden (General Atomic, San Diego, California), described the use of a TE_{111} bimodal cavity which is 1,000 times as sensitive as the direct method for measuring microwave Faraday rotation. Dr. Snowden pointed out that the same cavity can be used to measure the conductivity tensor or the susceptibility tensor of a material. During the discussion, Mr. H. E. Bussey (National Bureau of Standards) indicated that a bimodal TM_{110} cavity can be used in a similar way to measure the susceptibility tensor of a material with the added advantage that an exact mathematical analysis of the TM_{110} measurement is available.

Mr. A. D. Krall (U.S. Naval Ordnance Laboratory, Silver Spring, Maryland) spoke on "The Microwave Measurement of Narrow Line Width Ferromagnets by Radiated Fields". Mr. Krall showed that by placing a pick-up loop in the field radiated from a resonant sample the ferromagnetic line-width can be measured quickly, conveniently and with simple equipment. For narrow line-widths this method gives an accuracy of $\pm 0{\cdot}02$ œrsted. The first order anisotropy coefficient of the material can also be measured by this technique.

The final paper of session four was, "Measurement and Standardization of Dielectric Samples", by Mr. H. E. Bussey and Mr. J. E. Gray (both at the National Bureau of Standards, Boulder Laboratories). The introduction indicated that the art of measuring dielectric properties at microwave frequencies is maturing as is evidenced by the close agreement of different methods of measurement. Consequently, it now seems appropriate for the National Bureau of Standards to issue standard dielectric samples with specified dielectric constant and loss tangent. Mr. Bussey explained that accurate microwave dielectric constant measurements are made by correcting for the effects of all deviations from the ideal or perfect resonator or line. When this is done accuracies of 0·3 per cent for dielectric constant measurements and 5 per cent for loss tangent measurements become possible.

On August 13, the day preceding the Conference, an important meeting was held on high-temperature dielectric measurements. Attendance included representatives of about ten laboratories active in the field. Present-day methods were examined. A sample standardized to about 1,500° C is desired. To partially satisfy this need a round-robin comparison among interested parties will be conducted immediately.

Session V : Quantum Electronics in Precision Measurements

Seven advanced papers, under the chairmanship of Dr. R. C. Mockler (National Bureau of Standards), treated present and future possibilities of quantum electronics in precision measurements.

N. Bloembergen (Harvard University) discussed the new phenomena of non-linear optics which has become accessible to experiment by the advent of optical masers. The coherent nature of these new sources of light makes possible extremely high electro-magnetic fields within crystals which in turn reveal the non-linear behaviour of the medium. Maxwell's equations have been applied to this situation to obtain new laws of reflexion and refraction. The result is a theoretical basis for optical mixing, harmonic generation, and modulation with high intensity light beams.

A. Javan (Massachusetts Institute of Technology) presented evidence that the continuous-wave gas maser may achieve high reproducibility with the improvement of the mechanical resonator. He cited 3–4 sec stability of 1 part in 10^{13} and a reproducibility of 1 part in 10^{9} at present with a helium neon laser.

A. L. Bloom (Spectra Physics, Inc.) explained the use of optically pumped rubidium vapour as a precision magnetometer. This device is better known as a precision frequency source for atomic clocks. The sensitivity of the rubidium transition to magnetic field allowed a magnetometer to be constructed with a sensitivity of 10^{-8} gauss and a dynamic range of 10^{5}. Fast response and absolute accuracy were also claimed for the instrument.

J. P. Gordon (Bell Telephone Laboratories, Inc.) outlined the limitations of information-rate in communication channels due to quantum noise effects. The optimum signal should have the same statistical form as the noise. The differences between an amplitude sensitive receiver and a power sensitive receiver were explained. Each had advantages in some situations.

A. Ganssen (National Co., Inc.) discussed the advantages of a proton resonance oscillator in which the working substance could be water. This has advantages of room temperature operation and low-frequencies from -2 kc/s to 100 Mc/s. The disadvantage is the external magnetic field of high stability required. High spectral purity has been obtained along with stability of a few parts in 10^{10}.

Y. Beers and G. Strine (National Bureau of Standards) explained the use of the microwave Stark effect to measure high voltages to great precision. The instrument which was constructed consisted of a parallel plate microwave resonator of the Fabry–Perot type in which the Stark splitting of a molecular transition could be accurately measured. If the dipole moment of the molecule is known, the voltage across the parallel plates can be calculated with great accuracy. The instrument can also serve to determine the dipole moment if the voltage is known.

R. C. Mockler (National Bureau of Standards) outlined a proposed experiment to measure the velocity of light (γ-rays) using the Mossbauer effect. The source and detector are vibrated at high frequency in synchronism and the distance between them is varied to observe maxima in γ-ray absorption. This is a very difficult experiment but a measurement to a few parts in 10^{8} is expected to be possible.

Session VI : Atomic Frequency and Time (Hydrogen, Hydrogen Cyanide, Other Molecules)

This session with four papers and Dr. John T. Henderson (National Research Council) as chairman commenced the third day of the conference, a full day allotted to frequency and time.

A report on theoretical and physical properties of "The Atomic Hydrogen Maser", N. F. Ramsey and H. E. Peterson (Harvard University), was presented by Prof. Ramsey. He discussed effects of cavity pulling, wall coating of the hydrogen container within the cavity, magnetic fields, etc., which leads to shifts in the maser output frequency. From measurements made within the past week, the frequency difference between two independently constructed and independently adjusted machines was about 1 part in 10^{12}. A better agreement can be expected. In answer to inquiries he reported that instability in the electronic measuring apparatus (phase comparator) appears to be well under control, and is no longer a significant factor in evaluating the overall instability. The technique of looking at several nearby field-dependent transitions was described as the means of measuring the magnetic field actually seen by the atom in the maser itself.

The hyperfine frequency of atomic hydrogen, previously published as 1, 420, 405, 762. 415 $\pm$ 4·000 c/s (with reference to an atomichron), appears now to be known to about $\pm$ 0·030 c/s. Prof. Ramsey anticipates a hard push in obtaining a value known to 1 part in 10^{13} ; however, he is confident that such can be obtained.

R. F. C. Vessot and H. E. Peters (Bomac Laboratories, Inc.) summarized their work on "Design and Performance of an Atomic Hydrogen Maser". Two objectives were mentioned: (1) design of a compact unit; (2) fundamental investigations on maser theory and performance.

Dr. Vessot reported details on one completely sealed off hydrogen maser, using 'vac ion' pumps, which has operated more than two months and is expected to operate two or more years. It may be likened to a tube with a large capacity getter and could be designed for 20 years performance. With no special precautions, beyond an air-conditioned laboratory, the instability relative to a second hydrogen maser was about six parts in 10^{13} in 1 min and five parts in 10^{12} in 10 h. It was pointed out that as the work progresses a fundamental importance will be given to measurement of the ratios of frequency of masers and other devices operating with different atoms such as cæsium, hydrogen and rubidium.

Dr. D. Marcus (Bell Telephone Laboratories, Inc.) described his "Hydrogen Cyanide Molecular Beam-Type Maser". It is a close relative to the ammonia maser, the first maser ever operated successfully. However, it differs from the ammonia maser in two important points. (1) It uses a different transition. While the ammonia maser uses the inversion of the nitrogen atom perpendicular to the plane defined by the three hydrogen atoms, the hydrogen cyanide maser uses the rotational motion of the molecule as a whole. This is the first successfully operated maser using a rotational transition. (2) The frequency of operation of the hydrogen cyanide maser is more than three times as high as that of the ammonia maser. This maser oscillates at 88·63 Gc/s corresponding to a wave-length in vacuum of 3·4 mm.

The design of this maser is interesting in that it used a great number of molecular beams which emerge from a circular source and converge on the resonant cavity which is located at the centre of the circle. A system of electrically charged rods arranged in two planes below and above the molecular beams removes the lower state molecules from the beams, thus achieving population inversion.

The resonant cavity is of the confocal interferometer type which is at present used in many optical masers.

This maser can be used as a precision frequency standard in much the same way as the ammonia maser.

A study of the possibilities of an electric resonance molecular beam frequency standard, "Choice of a Molecule for a Beam Frequency Standard", was presented by Dr. F. S. Barnes (University of Colorado). The devices described are analogous to the cæsium beam machines except that they operate with electric fields and electric dipole moments instead of magnetic fields and magnetic dipole moments.

Such devices might give nearly exact reproducibility except for: (1) uncertainty in field measurements in the *C*-field region; (2) uncertainties due to residual magnetic fields and a small magnetic dipole moment of many of the molecules which may be chosen; (3) measurement errors inherent in all beam type devices resulting from the finite '*Q*' and electrical noise; (4) shifts in the resonance from nearby molecular transitions; (5) unequal phase in the two cavities required.

Three kinds of detectors were investigated: hot wire, electron bombardment devices, and the Pirani gauge using semiconductive films.

The various sources of instability are hard to evaluate and a device should be built and operated to be sure. A stability of one part in 10^{13} can be expected.

Session VII : Atomic Frequency and Time (Ammonia)

Dr. Henderson continued as chairman and introduced a series of three papers which showed that precision and accuracy are still being improved for ammonia masers. In a paper "Ammonia Masers", K. Shimoda (University of Tokyo) discussed the effects of cavity pulling, longitudinal and transverse Doppler effects, the pressure shift, the dispersion of nearby lines, the effect of unresolved hyperfine structure, and the effects of magnetic field.

Also from Tokyo, Y. Saburi presented a paper "Characteristics of the 3–2 Line Maser of $^{14}NH_3$ and the Precision of Frequency Comparison", by Y. Saburi, M. Kobayashi, and Y. Yasuda (Ministry of Posts and Telecommunication). They considered the effects of changes in experimental parameters such as ammonia pressure, focuser voltage and magnetic field, as well as possible fluctuations from the associated quartz oscillator and frequency multipliers.

The third paper, "$^{15}NH_3$ Double Beam Masers as a Primary Frequency Standard", was given by J. De Prins (University of Brussels). He discussed experiments where the symmetry of double beam masers was made use of to reduce the frequency sensitivity to experimental parameters. From these papers, numbers of the order of 10^{-9} were suggested for the accuracy and 10^{-11} for the resettability of single beam masers and an order of magnitude better for double beam masers.

In 1957, Prof. P. Kusch proposed that a thallium hyperfine structure line may yield a more precise standard of frequency than the use of the cæsium line. The first reported operation of a thallium standard was given at this conference by Dr. Jacques Bonanomi (Neuchâtel Observatory). In his paper, "Design and Performance of a Thallium Frequency Standard", the construction differs from cæsium standards in the following main points: a high (1,000° K) oven temperature, high (14,000 gauss) *A* and *B* fields, and an oxidized tungsten filament detector. In his preliminary attempt, an accuracy was attained which is already comparable to the best accuracy of other kinds of atomic frequency standards.

Dr. Bonanomi presented possibly the most interesting results of the Conference. He showed that the construction problems for a thallium beam machine are not insurmountable, and that there are good reasons to believe that the advantages of a higher frequency and smaller magnetic field sensitivity as compared with cæsium can be realized. Measurements were reported where the whole correction for the magnetic field *C*-field was about 2 parts in 10^{12}. With reference to the unit of time in which the cæsium frequency is 9, 192, 631, 770 c/s, the thallium line frequency was reported as 21, 310, 833, 945·1 c/s ± 1·0 c/s.

Session VIII : Atomic Frequency and Time (Rubidium, Cæsium and Other Matters)

This afternoon session under the chairmanship of Dr. L. Essen (National Physical Laboratory, Great Britain) continued the day's discussion on frequency and time.

A paper by M. E. Packard (Varian Associates), "The Optically Pumped Rubidium Vapour Frequency Standard", reported recent work on gas cell frequency standards and the physics of the quantum mechanical system. Carefully engineered systems have been demonstrated to have high stability with high reliability and small weight and volume.

Frequency stability, which is the important quality of a standard, has been studied over a wide range of averaging and measurement times. A plot of standard deviation of frequency stability shows a broad minimum of $2{\cdot}5 \times 10^{-12}$ for a run of 10 h (24 min averaging time for each measurement); 2×10^{-11} for a run of 10 min (1/4 sec averaging time); and $4{\cdot}5 \times 10^{-11}$ for a run of 160 days.

P. Kartaschoff (Swiss Laboratory for Horological Research) reported results on "Operations and Improvement of a Cæsium Beam Standard Having 4 Meters Interaction Length". By extending the length of an atomic beam frequency standard, the line width is reduced, allowing greater precision of measurement if the signal to noise ratio remains sufficiently high and if other length dependent errors such as *C*-field uncertainty and phase shift are not limiting. He found it possible by using demagnetizable Armco iron shields to reduce errors due to *C*-field uncertainty to $1{\cdot}2 \times 10^{-12}$. Cavity phase shift effects were below $1{\cdot}5 \times 10^{-11}$ and his accuracy was stated to be $\pm 3 \times 10^{-11}$. Two years of comparisons by VLF Standard Frequency Broadcasts showed agreement to about $\pm 1 \times 10^{-10}$ with the United States Frequency Standard.

Manual measurements of cæsium beam resonators are more straightforward and involve less equipment than servo methods, but are also more time-consuming and more dependent on the technique of the individual operator. Servo measurements, however, are potentially affected by many more parameters.

R. E. Beehler, W. R. Atkinson, L. E. Heim, and C. S. Snider (all at the National Bureau of Standards) presented "A Comparison of Direct and Servo Methods for Utilizing Cæsium Beam Resonators as Frequency Standards". This investigation showed that any inaccuracies added to the measurements due to the effects of their servo system parameters are less than several parts in 10^{12}. The precision of measurements has significantly increased to 2×10^{-12} for a 1/2 h average. The servo method is now used for measuring the U.S. Working Standards of Frequency on a regular basis.

William Markowitz (U.S. Naval Observatory), in a paper "The Atomic Time Scale", discussed the system of atomic time, *A*1, derived from the operation of cæsium-beam resonators located in nine laboratories about the world. A re-determination of the cæsium quantum transition frequency, found to be 9,192,631,770 c/s of ephemeris time in 1958, was made, using observations of the Moon through July 1962. This resulted in the same frequency but with the error of observation reduced from $\pm$ 20 c/s to $\pm$10 c/s.

The Bell Telephone Laboratories have a programme for improving quartz crystal oscillators. A report on their 2·5 Mc/s and 5 Mc/s oscillators used for standard frequency and time control, "Performance of Precision Quartz Crystal Controlled Frequency Generators", by R. A. Sykes, W. L. Smith and W. J. Spencer was given by Mr. Sykes. Recent improvements in oscillator, oven and crystal unit design have produced 5-Mc/s oscillators with drift rate less than 1×10^{-10} a day, while the 2·5-Mc/s oscillator drift-rate is less than 1×10^{-11} a day.

The short-time stability (10 msec) of both types of units when measured in the Gc/s range appears to be of the order of a few parts in 10^{10}.

Addition of a getter in the quartz crystal unit appeared to have a marked effect in reducing frequency shifts caused by oven and oscillator shut-off.

H. F. Hastings (U.S. Naval Research Laboratory) and P. B. King (Aircraft Radio Corporation), in a paper "Technique for Precise Measurement of Short- and Long-term Stability of Oscillators", discussed improvements in the error multiplication system of frequency measurement. In this system the unknown frequency and standard frequency, nominally the same, are multiplied by different factors, in this case 9 and 10. The resulting beat frequency is again multiplied, the resulting process of error multiplications being repeated until sufficient precision is attained.

In the last paper of this session it was shown that there are certain advantages in using relatively short cæsium beams for frequency standards, among them less difficulty in obtaining a uniform *C*-field over a short region and higher beam intensity, although the cæsium line width is made larger by the short interaction time. The performance of such a beam tube was reported by James George (National Company, Inc.) in his paper "Recent Advances in Cæsium Beam Technology and Characteristics of Rabi and Ramsey Cæsium Beam Tubes 17 Inches in Length". The tube uses a new hot wire ionizer relatively free of potassium with a response of 0–500 c/s. The line width is 1,000 c/s with only 1·5 μW necessary to excite the transition using a single Rabi type cavity. The standard deviation from the controlled output frequency of an 'Atomichron' using the 17-in. beam tubes (Rabi and Ramsey types) was a few parts in 10^{11} and in 10^{12} respectively. This development now permits the realization of 'Atomichrons' small in size, weight and power consumption for use in highly portable systems.

Unit of Time and Velocity of Light

Prof. N. F. Ramsey served as chairman of the informal evening session at which two subjects were discussed: "An Atomic Definition for the Unit of Time" and "Determination of the Velocity of Light".

William Atkinson (National Bureau of Standards) presented results which were of importance to the problem of keeping atomic time scales and to time and frequency comparisons by very-low-frequency broadcasts. He discussed how clocks driven by quartz oscillators would be subject to fluctuations which depend on the spectra of the phase fluctuations of the oscillators, and gave results of measurements on typical oscillators which show an increasing amplitude of fluctuation as the fluctuation frequency decreases. He presented results of comparisons by means of *WWV* of the National Bureau atomic time-scale and the Naval Observatory *A*1 atomic time-scale. He also pointed out that caution must be used in applying statistical treatment to data from very-low-frequency comparisons since his analysis showed that the data did not generally exhibit a gaussian distribution.

There was a considerable amount of discussion concerning what transition would be used for an atomic definition of the second as well as some of the problems in relating atomic time to astronomical time. The unit of time-interval, now identical with the second of Ephemeris Time, may be re-defined in 1966 in terms of an atomic transition by the General Conference of Weights and Measures. This would recognize formally the situation that now exists, that atomic clocks are used to provide the unit of time-interval where very high precision is required. However, the requirements for providing Universal Time along with the interval of atomic time will continue (Universal Time is a time-scale based on the rotation of the Earth). Prof. Ramsey, by way of summary, stated that in order that the Consultative Committee for the Definition of the Second may make a firm recommendation by 1966 to the International Bureau of Weights and Measures, the particular transition should be fairly well settled on in the next two years. Cæsium now appears to be a good possibility with a long head start, but there are still others in the running. The atomic transitions, thallium, cæsium and hydrogen, look a little more favourable than molecular transitions such as ammonia. In the meantime, astronomers are working hard to supply the best value for close agreement between the Ephemeris and Atomic Second.

When the Atomic Second is adopted it will very closely agree with the Ephemeris Second, but will be independent of the latter.

The second part of the evening discussion was devoted to experiments in progress, or proposed, for determining the velocity of light. The points were raised that such experiments should have as their aims an increase in the present accuracy of the value of *c* and a verification of the hypothesis that *c* is independent of frequency.

An experiment in progress at the National Bureau of Standards Boulder Laboratories and reported by Mr. R. C. Baird utilizes a micro-wave interferometer of the Michelson type to measure phase velocity of 50-Gc/s electromagnetic waves. The primary difference between this interferometer and earlier ones is the region of operation. The Bureau model operates in the Fresnel or near field region. This necessitates the use of a diffraction correction and this is calculated on the basis of a rigorous solution of Maxwell's equations. The accuracy of this determination will be about 3 or 4 parts per 10 million, which is equal to the best determination to date. One of the most useful results of this work is the analysis of the diffraction correction; another feature of value is that the experiment represents an independent determination at a different frequency and uses a different method from previous experiments.

Dr. Boyne of the National Bureau of Standards, Washington, analysed a novel method utilizing an optical maser as a source. The method would necessitate the measurements of the difference frequency of two gas laser lines of the helium–neon system. This frequency is about 1,600 Gc/s, and Dr. Boyne explained the use of a modified cathode ray-travelling wave tube using a photo cathode to measure this accurately.

Dr. Essen (National Physical Laboratory, Great Britain) commented on his experiments aimed at determining lengths in terms of frequencies, utilizing the velocity of light. He is of the opinion that their determination of *c* will be to a few parts in 10^8.

During this part of the discussion Mr. McNish made the point that present measurements of light speed are all less accurate than length and time-interval measurements. Hence attempts to define lengths in terms of a frequency standard and an assumed light speed would make length determinations more inaccurate than they ought to be in comparison with present techniques based on an independent length standard (wave-length of the krypton line). Dr. Ramsey stated also that since we have an *MLT* system, the value of the speed of light, although a theoretically invariant constant, must still be determined experimentally.

There was some discussion of the practical necessity for knowing the speed of light to a high accuracy, and Dr. Richardson expressed an interest in finding out just what are the present theoretical limitations, in concept, on the constancy of the light speed *c*. Dr. Shimoda noted that estimates of the limit of the deviation of the Coulomb law from the inverse square seem to yield a figure of 1 part in 10^{16} as an interesting region for investigation. Such a deviation would imply a non-zero photon rest mass and consequently a dispersion in the speed of light. Besides atomic effects of this kind, Richardson also had in mind a general relativistic limitation on our definition of standards.

Any co-ordinate systems, as a result of the curvature of space time predicted by general relativity theory, must also partake of this distortion. Hence, the co-ordinate speed of light will differ from point to point due to gravitating masses. However, the speed measured over short enough distances in a freely falling, that is, an inertial reference frame will always be the same invariant, *c*. A co-ordinate speed could differ, near the Earth by 1 or 2 parts in 10^9, from the co-ordinate value at a large distance from the Earth, or from the value measured in an inertial system. However, a suitable choice of the space and time co-ordinates can, of course, be made so that in any small enough region the co-ordinate speed and the proper light speed are equal. But this cannot be done everywhere simultaneously using only one co-ordinate system. Thus, methods of dissemination of time signals must take this limitation into account.

Such relativistic effects as this furnish us with additional reasons why an atomic standard for time, as well as one for length, should be adopted. Such standard units are definable over restricted regions of space and time in such a manner as to satisfy the conceptual requirements of relativity theory.

Session IX : Micro-wave Power and Attenuation

This session, presided over by K. Tomiyasu (General Electric Co.), had seven papers on microwave power and two on microwave attenuation. Each was concerned with precision measuring techniques and standards.

The session opened with an invited paper by Prof. H. M. Barlow (University College, London), who surveyed the instruments and techniques recently developed in Great Britain for measuring power. Some of these new measuring techniques are attractive in that they do not require absorption of the incident energy, as do ordinary bolometric techniques. The first device is an oscillating dipole, placed in a resonant cavity, and arranged with a fine suspension fibre and optical deflexion measuring system. Peak deflexion of the dipole in response to the torque that results when pulsed power is applied to the cavity can be related to the power-level.

Several of the difficulties inherent in present Hall-effect devices were discussed, and a new method which offers hope of eliminating some of these troubles was proposed. Finally, a new type of electrostatic torque wattmeter, developed by the speaker, was described. It offers the advantage of calibration in terms of mass, length and time, and is thought to be capable of correct power measurements regardless of the nature of the load.

S. Okamura (University of Tokyo) discussed the work being done in Japan on a device similar to the oscillating dipole type designed for use at 35 Gc/s. The basic unit has been refined by the addition of a special photoelectric deflexion-measuring system. Both transmission and cavity types of microwave wattmeters based on the magneto-resistance effect were also described.

Investigations into the use of Hall-effect devices to measure microwave power densities up to 1 W/cm^2 were reported in a paper by R. A. Leavenworth, J. Maczuk, and R. F. Schwartz (University of Pennsylvania). Their studies were primarily concerned with the use of such devices as broadband collectors and transducers of the microwave energy, operating without tuning over the range 0·1–10 Gc/s. Meaurements made covered the range from 0·3 to 3·4 Gc/s and sensitivities of about 1·28 μV/100 mW/cm^2 were obtained.

A paper by K. Sakurai and T. Maruyama (Electrotechnical Laboratory, Tokyo) described a mm-wave microcalorimeter of interesting design. The instrument uses a single load, as opposed to the thermally balanced type developed at the National Bureau of Standards, and uses an electronic servo system to maintain the temperature difference between the load (bolometer mount) and the reference (the shell of the calorimeter) less than 10^{-5} °C. This is accomplished by means of a Peltier thermoelectric cooler controlled by a differential thermopile between the two calorimetric bodies. The current of the cooler furnishes the data in the system. The system measures the effective efficiency of a bolometer mount with an absolute accuracy of 0·6 per cent, making possible accurate power measurement in the 35-Gc/s region.

The next two papers demonstrated the importance of microwave pulse power measurements. The first, by C. A. Denny, C. L. Mavis and C. J. Still (Sandia Corporation), described two systems in which a sample of the unknown pulse is compared with an identical sample of a known generator, using a coherent detector for level comparison. The two methods differ from each other in that one samples the unknown signal directly with a crystal switch while the other uses a heterodyne receiver with a pulsed intermediate frequency amplifier. The pulsed receiver system can be used down to −60 decibels referred to 1 mW with an accuracy of 5 per cent. Somewhat better accuracy is obtained at higher levels. The crystal switch is usable with pulse widths greater than 200 nsec, and the pulsed receiver may be used with pulse widths greater than 350 nsec.

The second paper dealing specifically with peak pulse power measurement was prepared by P. A. Hudson, W. L. Ecklund and R. A. Ondreika (National Bureau of Standards, Boulder). Their system is very similar to that described by C. A. Denny, but features a narrower sampling pulse, typically 100 nsec wide. This, together with the pulse delay and trigger circuitry of the system, permits resolution of the unknown pulse shape as well as measurement of the peak value for pulses longer than about 1 μsec. A special switch design affords greater than 70 db. isolation when open and 1·5 db. loss when closed. The high isolation is necessary to the accuracy of the system, which is given as plus or minus 2·5 per cent. The system is intended for application at levels up to 10 kW peak.

A highly refined and carefully analysed rotary vane attenuator was described by A. V. James (Sperry Gyroscope Co.), who proposed its use in primary calibration laboratories. The design discussed uses a tape wound around the circumference of the rotary drum in place of the usual gear drive. This eliminates the gear backlash and converts the rotary motion to translational motion, where it is measured by means of a dual micrometer mechanism. The translation amounts to 4·5 in. for a 90° rotation and is measured to within 250 μin. A check against an audio-substitution attenuation measuring system showed agreement to within 0·04 db over a 40-db range, in the *X* band. Calculated limits of error were plus or minus 0·095 db in the range 0–40 db.

A paper by R. F. Clark and B. J. Dean (National Research Council, Ottawa) discussed a precision *X*-band system capable of an accuracy of ±(0·010 db + 0·005 db/10 db), with a 40 db dynamic range. The *X*-band attenuator is compared with a calibrated 30-Mc/s reference attenuator by means of a linear superheterodyne detector. Both frequency and amplitude stabilization are used in the system to obtain for the standard a drift of less than ± 0·005 db per 5 min.

A new and unusual method of pulse power measurement was disclosed in a paper entitled "An Elastic Wave Method for the Measurement of Pulse Power Density", delivered by R. M. White (General Electric Co.). The method is based on pulse heating of the surface of a body which is mechanically coupled to a sensor such as piezoelectric crystal. The absorbed energy pulse produces a rise of temperature in the surface of the body which creates an elastic stress wave that propagates through the body to the sensor. Experiments have shown that the effect is due to heating and not to radiation pressure; indeed, the system is much more efficient than one designed to respond only to the radiation pressure. In an experimental *X*-band detector, an output of 6 mV was obtained from the sensor for a peak pulse power density of 12 kW/cm². Experiments were also made with different energy sources, including light pulses from a laser or stroboscopic lamp, and a pulsed beam of electrons in an evacuated chamber. It may be possible to obtain ultimate sensitivities of a few hundred microwatts per square centimetre by using resonant techniques.

Session X: Micro-wave Techniques

Session X on "Microwave Techniques", with Harold M. Barlow (University College, London) as chairman, consisted of six papers.

S. B. Cohn (Rantec Corporation, Calabasas, California) presented the first paper, entitled "Swept Phase-Measurement Techniques with CW and Pulsed Signals", in which he described recent advances in instrumentation for measuring phase shift versus frequency for linear two port devices and phase shift versus control voltage or drive power for non-linear devices. The instrumentation, for either continuous-wave or pulse-modulated signals, had a scale expansion such as to allow errors of only a few tenths degree around 90° for single frequency measurement.

The second paper, entitled "A Phase Measuring System for Short RF Pulses", presented by R. A. Sparks (Emertron, Inc., Silver Spring, Maryland), described a novel technique of measuring the relative phase characteristics of pulsed microwave amplifiers. The method utilizes a two-channel system and the principles of homodyne detection. The capability of handling very narrow radiofrequency pulses with high resolution is obtained through generation of an unusually high offset frequency and the use of a wide band intermediate frequency amplifier. A 100 Mc/s oscilloscope is utilized to display the undetected bipolar signal that contains the translated phase information of the pulsed carrier.

Paper three, "A Technique for Precise Measurement of the Radio Frequency Structure of Pulsed Signals", was given by W. D. Griffin (HRB-Singer, Incorporated, State College, Pennsylvania). The technique described here is capable of detecting a zero-beat to one one-hundredth of a cycle during a pulse. It is based on measurement of the instantaneous relative phase of the pulsed signal with respect to a stable local oscillator (stalo) at approximately the same frequency. This is accomplished by dividing the pulsed signal into two equal parts and heterodyning these in balanced crystal mixers with two equally divided continuous-wave signals from a stalo. Equal path-length is maintained throughout except for a 90° phase shift inserted in the path of one of the two oscillator signals. One mixer output is used as the vertical deflexion voltage on a cathode-modulated cathode ray oscilloscope, while the other is used as the horizontal deflexion voltage. This then produces a unique display of the relative phase of the pulsed signal with respect to the oscillator as a function of time.

The next paper, "Report on Standardization of High-Precision Coaxial Connectors", was presented by D. E. Fossum (Sandia Corporation, Albuquerque, New Mexico). In the present state of the art of coaxial measurement, errors due to connexion uncertainties limit the accuracy of nearly all quantities. The report briefly described the co-operative effort of the National Bureau of Standards and instrument manufacturers with university and foreign laboratories to recommend practices for precision coaxial connectors. Such connectors would be used on standard and high-quality instruments to ensure minimum loss of accuracy in transferring information with a small number of compatible connectors. Such connectors would be made to accuracies now used for precision wave-guide flanges giving voltage standing wave ratios ranging from about 1·002 at 1 Gc/s to 1·01 at 13 Gc/s.

D. Woods (Ministry of Aviation, London) presented the fifth paper, "Improvements in Precision Coaxial Resistor Design". Discussed were: (1) the successful development of cylindrical metal film resistors of uniform surface resistivity with an adjustment tolerance of 0·1 per cent; secular stability, 0·03 per cent; temperature coefficient less than 0·002 per cent/°C, suitable for use with a tractorial jacket in a coaxial mount up to 4 Gc/s; (2) the proposal to apply the technique to the manufacture of conical resistors for use with a cylindrical jacket. The advantages of this type of mount are pointed out, namely, the simplicity of the mechanical construction and the reduction of residual discontinuities to a bare minimum, even to the elimination of the dielectric support in a matched termination, provided a suitable coaxial connector is used, similar to one developed by the author; (3) a simple explanation of the principle of operation of the cylindrical resistor with a tractorial jacket and the conical resistor with a cylindrical jacket in terms of electromagnetic wave propagation over a resistor film surface; (4) the effects of field penetration through the resistive film into the resistor substrate and means for compensating the effect in a precision coaxial resistor.

The last paper, "Microwave Measurements at 150 Gc/s", was presented by J. B. Thaxter (Lincoln Laboratories, Lexington, Massachusetts). Mr. Thaxter discussed methods presently used at his laboratory for the measurement of frequency, power, and impedance in the two millimetre wave-length region of the spectrum. Frequency is measured by heterodyning the unknown with a signal obtained by multiplication from a highly stable low-frequency source. Power at 100–200 Gc/s in the fractional mW range is measured by a water-flow calorimeter utilizing a d.-c. comparison method. Impedance is measured by the usual bridge technique utilizing a hybrid T along with a calibrated attenuator and sliding short. Lack of standards in this frequency-range and the component sizes dealt with severely limit the accuracy of measurements in this new field.

Numerous persons, including many of the authors already mentioned, contributed to and reviewed this summary. Their efforts are greatly appreciated.

INTERPRETATION OF MICRO-STRUCTURES IN CARBONACEOUS METEORITES

By PROF. G. MUELLER

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THE considerable number and variety of microscopical objects within the Orgueil and several other carbonaceous stones were interpreted by some authors[1,2] as of likely organic origin. These conclusions have been contested[3] and critically discussed[4,5].

The aim of the present article is to attempt to cast more light on this controversy through additional evidence furnished from observations under the polarizing microscope of fifteen previously recognized and five new stones with a carbonaceous phase. It was found that the majority of the structures claimed as of organic origin could be readily and quite unequivocally identified as mineral grains.

From the point of view of types and abundance of micro-structures present, the meteorites so far investigated could be divided into three broad classes as follows:

Microstructure type 1: these include the two stones so far examined from compositional group I of Wiik[6]. They are characterized by the presence of troilite plates and abundant glass globules (Table 1). This group includes the Orgueil meteorite.

Microstructure type 2: includes mostly the compositional type 2 of Wiik. In these there are no troilite plates, and the glass globules are less abundant, whereas freely grown, cored olivines are the

Table 1. MICROSTRUCTURES IN CARBONACEOUS METEORITES

Type	Meteorite	Troilite plates	Limonite after troilite	Glass globules	Pele's hair	Opaque (Fe_3O_4, FeS NiFe) globules	Olivine globules	Cored olivine crystals	Cored felspar, enstatite, etc., crystals	Sintered and sheathed olivines
(1)	Orgueil	+	+	+ + +	+	+ + +	+ +	+ +	+	+ +
,,	Alais	+	+	+ + +	+ +	+ + +	+	+ +	+	+ +
(2)	Cold Bokkeveld	–	–	+	–	+	+ +	+ +	+	–
,,	Kaba	–	–	+ +	+	+ +	+ +	+ +	+	+ + +
,,	Karoonda*	–	–	+	–	+	+ +	+ + +	+ +	+ +
,,	Mighei	–	–	+ +	–	+ +	+ + +	+ + +	+	+
,,	Mokoia	–	–	+ +	+	+ + +	+ +	+ +	+ +	+ +
,,	Murray	–	–	+	–	+	+ +	+ + +	+	+ +
,,	Nagoya	–	–	+	+	+ +	+ +	+ +	+	+
,,	St. Caprais*	–	–	+ +	+ +	+ +	+	+ + +	+	+ +
,,	Staroye Boriskino	–	–	+	–	+	+ +	+ +	+	+
(3)	Bali*	–	–	+ +	+	+	+	+	+ +	+ + +
,,	Goalpara	–	–	–	–	+	+	+	+	+ + +
,,	Indarch	–	–	+	–	+	+	+ + +	+	+ +
,,	Lancé	–	–	–	–	+	+	+ +	+	+ + +
,,	Ornans	–	–	–	–	+ +	+	+	+	+ + +
,,	Renazzo*	–	–	+	+	+	+	+	+	+ + +
,,	St. Seveur*	–	–	–	–	+ +	+	+	+	+ + +
,,	Warrenton	–	–	–	–	+	+	+	+	+ + +
–	Erakote	–	–	–	–	–	–	–	–	–

* Carbonaceous stone recognized for the first time.

Approximate abundance of microstructures: + + +, above 10 per mg; + +, 1–10 per mg; +, below 1 per mg; –, not observed, less than 0·2 per mg.