PROGRESS IN RADIO SCIENCE 1960-1963

Volume I

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VOLUME I

RADIO STANDARDS AND MEASUREMENTS

PROCEEDINGS OF COMMISSION I ON RADIO MEASUREMENTS AND STANDARDS DURING THE XIVth GENERAL ASSEMBLY OF URSI, TOKYO, SEPTEMBER, 1963

edited by

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LIST OF ABBREVIATIONS

AGC – Automatic Gain Control
A – amperes
mA – milliamperes
CRO – Cathode Ray Oscilloscope
Cs – Cesium (caesium)
CW – Continuous Wave
Gc/s – gigacycles per second (10^9 cycles per second), also written GHz (gigahertz), and equivalent to KMc/s (kilomegacycles per second)
HFS – Hyper Fine Structure
IDOC – Inner Diameter of Outer Conductor
LASER – Light Amplification by Stimulated Emission of Radiation
km – kilometers, kilometres (10^3 meters)
m – meters, metres
mm – millimeters, millimetres (10^{-3} meters)
ODIC – Outer Diameter of Inner Conductor
r.m.s. – root mean square
s – seconds
ms – milliseconds (10^{-3} seconds)
μs – microseconds (10^{-6} seconds)
ns – nanoseconds (10^{-9} seconds)
ps – picoseconds (10^{-12} seconds)
S/N – Signal to Noise
Tc/s – teracycles per second (10^{12} cycles per second), also written THz (terahetz)
kV – kilovolts
V – volts
VSWR – Voltage Standing Wave Ratio
VTVM – Vacuum Tube Voltmeter
MW – megawatts (10^6 watts)
W – watts
mW – milliwatts (10^{-3} watts)
ω – symbol for angular frequency (2π times frequency)

Frequency Bands

VLF – Very-Low Frequency (3–30 kilocycles per second)
LF – Low Frequency (30–300 kilocycles per second)
MF – Medium Frequency (300–3, 000 kilocycles per second)
HF – High Frequency (3–30 Megacycles per second)
VHF – Very-High Frequency (30–300 megacycles per second)
UHF – Ultra-High Frequency (300–3, 000 megacycles per second)

National Laboratories

CNET – Centre National d'Études des Télécommunications (National Center of Telecommunications Studies) France
CSIRO – Commonwealth Scientific & Industrial Research Organization (Australia)
ETL – Electro Technical Laboratory (Japan)
FOA – Forsvarets Forskningsanstalt (Research Institute of National Defense) Sweden
LSRH – Laboratoire Suisse de Recherches Horlogères (Swiss Laboratory for Time Keeping Research) Switzerland

NBS – National Bureau of Standards (U.S.A.)
NPL – National Physical Laboratory (United Kingdom)
NRC – National Research Council (Canada)
PTB – Physikalisch-Technische Bundesanstalt (West Germany)

International Organizations

BIPM – Bureau International de Poids et Mesures (International Bureau of Weights and Measures)
CCIR – Comité Consultatif International des Radio-Communications (International Radio Consultative Committee)
IAU – International Astronomical Union

CONTENTS

GENERAL SUMMARY

The purpose of these "Progress Reports in Radio Science" is to collect together the information gathered in Tokyo at the technical sessions of Commission I. At these sessions, technical progress since the last General Assembly in 1960 was reviewed and discussions were held relative to present and future problems.

Included herein are the introductory and the summary reports of the Chairman of Commission I, the full texts of review papers relevant to the subject matter of the sessions, short abstracts of some papers reporting on special topics pertinent to the session, selected verbatim discussions of the sessions, and the resolutions and recommendations arising out of the sessions.

It is noteworthy that progress in some areas was so extensive as to require more than one review paper to cover it. Also developments are so rapid that some of the more recent ones occurred after the preparation of the review papers and were covered in special papers for which abstracts are given, the complete paper to be published elsewhere. In some cases, neither abstracts nor papers were available, and this material has been recognized by the inclusion of selected verbatim discussions of the sessions.

INTRODUCTORY REMARKS

1. Preparations for the XIVth General Assembly of URSI have suffered considerably due to the sudden death, in an accident at Geneva, of Vice-Chairman of Commission I, Mr. W. D. George, in February, 1963. His willingness and ability to partake in, and deal with, problems of all sorts, sudden or otherwise, is well known and will never be forgotten.

2. In May 1963, Mr. R. W. Beatty, also of the National Bureau of Standards, Boulder/Colorado, decided, fortunately, to take over the duties of Vice-Chairman as well as those of Scientific Editor of Commission I. The arrangements made for the sessions of Commission I at the General Assembly of Tokyo, September 1963, could be carried out, with the result that 6 scientific and 3 administrative sessions could be held.

3. The sessions were spread over the short period of ten days, during which time our Japanese hosts made every effort to show URSI scientists their well outfitted Laboratories and Institutions. A flexible organization was, therefore, necessary, and constantly applied. Besides the two Secretaries of Commission I, Prof. Wertheimer (France) and Dr. J. T. Henderson (Canada), many other scientists, including several from Japan, were kind enough to offer their specialized services for settling questions of organization, especially in connection with the drawing up of resolutions, or leading discussions, when necessary.

4. The topics indicated below, dealt with during the scientific sessions of Commission I at Tokyo, were in accordance with its assigned task of Radio Standards and Measurements. A certain selection was necessary ac-

cording to the urgency of the problems. The two sessions marked with an asterisk (*) were made jointly with Commission VII.

1. Atomic and Molecular Standards of Frequency and Time.
2.* Physics of Masers and Lasers.
3. Frequency and Time Broadcasts, Frequency Measurements, Quartz Clocks.
4. Radio Measurements and Standards to about 1 Gc/s.
5. Radio Measurements and Standards, Microwaves.
6.* Precision Measurements of Distance and Velocity of Light, using Lasers.

The first speaker in each session, having given considerable attention to the organization of same, presented the review paper as represented in this book.

5. The present Chairman of Commission I, expressing regret, made a request to be released from his duties for the coming period. The board of officers then elected, on the proposal of Commission I and through a proper vote, Dr. L. Essen as Chairman, Prof. Okamura as Vice-Chairman of Commission I, with Mr. R. W. Beatty remaining as commissioned Scientific Editor.

U. E. ADELSBERGER
Past Chairman, Commission I

BRIEF SUMMARY OF THE SESSIONS OF COMMISSION I

Commission I held three administrative sessions on September 9–10 and 19th, four scientific sessions on September 10, 11, 12 and 13th, and two scientific sessions jointly with Commission VII on September 11 and 16th, the first of these being organized by Commission VII, and the latter by Commission I.

The subject of the session on 9 September was Atomic and Molecular Standards of Frequency and Time. The speakers were

Dr. L. Essen
Dr. R. C. Mockler
Prof. N. F. Ramsey
Prof. K. Shimoda

After the papers were presented the discussion took place under the direction of Dr. John M. Richardson.

The Joint Session of Wednesday morning 10 September was a general one concerned with Space Research and is reported by Commission VII.

The session on Wednesday afternoon 10 September was devoted to Frequency and Time Broadcasts, Frequency Measurements, and Quartz Clocks. The speakers were

Mr. C. J. G. Åbom
Prof. U. E. Adelsberger
Dr. L. Essen
Mr. A. H. Morgan
Prof. H. Uyeda

The papers were followed by discussion under the direction of Mr. Åbom.

The session on Thursday 12 September was on Radio Measurements and Standards to about 1 Gc/s. The speakers were

Dr. F. Carassa
Dr. D. L. Hollway
Dr. B. M. Oliver
Dr. K. Posel
Mr. M. C. Selby
Mr. D. Woods

The papers stimulated later discussion.

The session on Radio Measurements and Standards for Microwaves on 13 September heard papers from

Mr. R. W. Beatty
Prof. A. L. Cullen
Mr. G. F. Engen
Dr. R. G. Fellers
Prof. S. Okamura

The discussion was directed by Prof. Okamura.

The Joint Session on Monday 16 September with Commission VII was on the subject of Precision Measurements of Distance and Velocity of Light, using Lasers. The speakers were

Dr. P. L. Bender
Dr. A. M. Prokhorov
Mr. B. S. Yaplee

SURVEY AND INTRODUCTORY REPORT OF THE CHAIRMAN, COMMISSION I

U. E. ADELSBERGER

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INTRODUCTION

Commission I has been involved in various subjects which are at different stages of development.

New designs and recent methods to extend progress in measurements sometimes show a rapid development beyond former estimation. Scientific progress has been achieved in frequency standards, maser and various caesium beam and gas cell designs. Nobody, at the last General Assembly, would have thought of such fast development of solid state or gas laser, whereby their essential effect of synchronous excitation now gives rise to a belief of future methods to bridge the gap between light and radio waves. The hydrogen maser might now be able to essentially contribute to a new definition of the second. This problem is of basic value in the domain of work covered by Commission I.

On the other hand certain intricate techniques as sampling or automation in measurements are slower in spreading than foreseen, until some means of simplification can be found. This holds true for fully transistorized and programmed frequency measurements of high precision including evaluation and data processing, further for determining with much better accuracy electric quantities at very fast operational cycles in the regions beyond Gc/s (or ns), domains of ultra-high-frequency or pulse techniques.

Thus, considering both points of view one may estimate the interval between two General Assemblies to be a long one concerning new approaches or ideas, but too short to match with the wish to solve at once in a thorough and laborious effort most details of some problems.

A more or less general survey necessarily not sufficient to mention all aspects of work will be presented as follows.

In December 1961, it was felt necessary to have a discussion based on some questions related one to the other by a future definition of the second. A meeting was held in London by the national chairmen of Commission I of the U.K. and Germany. The Chairman of Commission I had further informative discussions at NBS, Washington, D.C. and Boulder, Colorado (U.S.A.). The topics partly refer to time interval on one hand, and time and epoch on the other hand.

The time interval scale has no beginning; it is in common use and inherent with physicist's investigation of all sides of physical appearance. The modern equipment with quartz controlled standards operating for many years without failure and the means of determining by atomic standards the small rates of acceleration make possible a quite continued and constant operation for years. Thus, the starting point ("zero") of any measurement or public frequency transmission seems to be not so essential.

Another approach would be to find a definition of epoch usable for synchronization purposes and certain fields of application. Defining an epoch requires another outstanding and remarkable event—surely not easy with quartz or atomic clocks as a source of equally spaced intervals or oscillations. Out of these inherent reasons, accentuated by demands of metre convention, standard frequency and time interval transmissions are in discussion since the last General Assembly, London, 1960, while at the time an offset of frequency is used. Further to secure equal time throughout world-wide regions, a synchronization of (transmitted) time to about 1 μs has occasionally been established between the U.S. and the U.K.

Considerable efforts were devoted to the development and investigation of atomic and molecular standards. Here is an open field to investigate such transitions, to produce better atomic or molecular beams and develop frequency standardization. The question would be put this way: Which is the suitable standard of this kind to deliver the definition of the second in the near future? As usual this question is manyfold; it should include the practical handling, possible application, precision, and resettability. Many investigations first carried out in the U.S.A. are connected with the hydrogen maser having a spectral linewidth of only 1 c/s. From some points of view, one might believe this to be the best solution. But it is too early to give a final opinion.

Switzerland has a hydrogen maser in operation. In the last years, experimental caesium beam and other standards were also investigated in Italy, France, Poland as well as in Sweden and Germany. In Sweden and Germany, technical Atomichrons as reference sources of constant frequency were recently installed and further special investigations on better performance of quartz clock groups are reported. In the U.K., the 5 m caesium beam resonator works continuously with an estimated present accuracy of a few parts in 10^{11}, gas cells being developed there. The same results are reported from Switzerland. In Canada, the existing Cs-beam apparatus has been improved.

Several approaches were made for better intercomparison of frequency standards. The U.S. and the U.K. have been investigating the effectiveness of propagation links to about 1×10^{-10}. Best means for comparison are transmitters like NBA, GBR, and WWVL. Rubidium gas cells and thallium beam sets are in good progress. Double-beam resonant-cavity masers have been investigated; the aging of quartz crystals has been studied in the U.S.S.R. where a bridge-type quartz oscillator using transistors for better short term stability is in use. In the U.S. a frequency standard consisting of two caesium beam devices having a stability of 2×10^{-13} for 10 hours and an accuracy of 1×10^{-11} is reported.

Standard frequency transmissions were synchronized in Canada and Switzerland, and will be in the future in Sweden; such transmissions are carried on in Italy and Germany, where the relative frequency deviation of transmitter DCF 77 from nominal value with respect to caesium beam standards has attained about 1×10^{-9} in July, 1963. New Zealand reports observations made with several VLF transmissions. The implications inherent to long distance path have been studied in respect to day-to-day and seasonal variations.

During the time covered by this survey, radio frequency and microwave power equipment for tests and intercomparison were operated and exchanged according to the last General Assembly's resolution. At 300 Mc/s, the U.S. and the U.K. were within the limits of error of $\pm 0.5\,\%$, Japan being still 1.5 % off. Manyfold work essential for free space techniques was done in the new bands of mm and sub-mm. Consideration was given to arrangements for standards of variable attenuation, impedance, phase, pulsed and CW sinusoidal voltages. Different approaches lead to development of rotary vane or spirally wound wire type attenuator, phase difference meter with transistor flip-flop, absolute phase standard at 400 c/s to 0.01 degree, new bolometric, calorimetric or thermistor power meters including also ferromagnetic and semiconductor material, and coaxial capacitors as reference devices. Phase jitter and pulse comparison techniques attain resolutions of as much as 10 ps. Power sensitivities of 3×10^{-10} W are reported, they are characteristic of progress in this basic radio science.

According to the national reports, radio measurements and other standards have found special development and consideration in Canada, Italy, the U.K., the U.S.S.R., the U.S., Poland, Sweden and other countries. For power standards the Hall effect has been further discussed in the U.K.; cavity resonator techniques are being carried on there.

A Q-switched solid state laser in the U.S. is reported to have 50 MW in a narrow beam output at 10 ns, the gas laser a spectral purity of some 10^{-13}.

Now in honour of this hospitable island country in the far east, I would like to refer to other works of Japanese scientists. In the first place I mention the Vice-President and Chairman of the Japanese National Committee of URSI, organizer with his staff of XIVth General Assembly, known as a top scientist for many decades in the field of frequency standardization and quartz investigations, Isaac Koga. I. Koga and H. Fukuyo have published papers on the vibration of quartz plates. K. Shimoda and Y. Saburi are reported to have made progress in the work of ammonia masers to be used in the national standards of frequency, the transmission frequencies of JJY and the time signals being derived from a quartz oscillator monitored by the standard. The standard frequency transmitter JG2AR, on 20 kc/s, is operated to connect with Tokyo Astronomical Observatory. VLF transmissions as NBA and GBR (18 and 16 kc/s) are received, phase lags being thoroughly studied. Y. Saburi, Y. Yasuda, and K. Harada made a contribution concerning frequency multiplier phase variations, and K. Sakurai and T. Maruyama on a millimeter wave microcalorimeter.

Finally I want to indicate other related research in our field of interest as the development of automation and control for precise measurement. This trend is a very old one. One should also mention self-balancing electric bridges, servo controls, electronic gate circuits in connection with sampling and digital recording or printing and other devices.

As an example of automatically multi-operated electronic counter printing in numbers, the tests made in Germany on two digital sets have shown the result that low powered fully transistorized frequency counters are very reliable in the long run, the precision of each full operation cycle being about 2 ns. Thus, the output from inserted standard frequencies enables more precise evaluation of the resulting geometrical patterns of the print-out on a broad-carriage teletypewriter. Due to an internal storage register, no time is lost between any two of the exactly successive measurements. An exact mean value of 10 or 100 values, therefore, can be formed and printed out.

Furthermore, possibilities and approaches have been investigated to automate still broader fields of measurements where no personnel are needed and the operation cycles are according to the program, automatically repeated day and night.

CONCLUSION

In several places, the hydrogen maser is operating at a spectral linewidth of 1 c/s. Laser techniques are considered as an advanced knowledge offering better possibilities in laboratory research—also in the range of measurements, control and tracking at far distances on Earth or in the vast regions of space surrounding the Earth.

Atomic time is available for time interval determination. The accuracy for setting one clock to the other, with satellite methods, could be improved to approximately 1 μs. Accordingly, frequency comparisons by transmissions show better results in short periods of time.

The progress in developing atomic standards is marked by an advanced performance in precision, accuracy or resettability.

Standards of current, voltage, resistance, power, mutual inductance and all variable attenuators and phase shifters are being investigated from audio-frequency to microwave region, the former with high precision or sensitivity, the latter ranging from several hundred Gc/s especially in pulse applications.

Methods of sampling and a growing number of comparison techniques prevail in precise microwave measurement and investigation. Further progress was made in determining frequency, time interval and phase by digital procedures and, due to semiconductor techniques, in automation and control.