UNION RADIO SCIENTIFIQUE INTERNATIONALE

U.R.S.I.

Golden Jubilee Memorial

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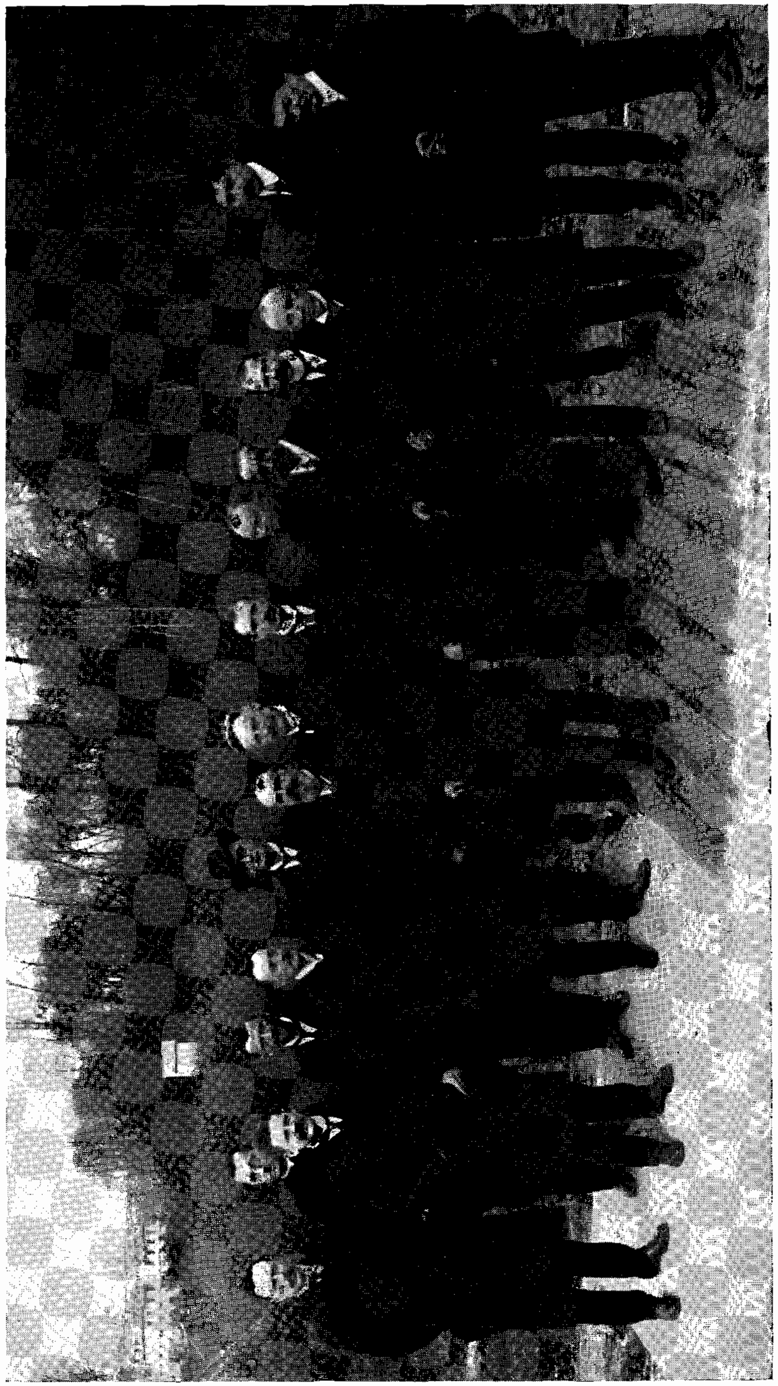
Constituting and first General Assembly of the Commission Internationale de Télégraphie Sans Fil Scientifique

Brussels, April 1914

from left to right : Prof. Marchant (U.K.), Father Wulf (Netherlands), Ing. Drumaux (Belgium), Comdt Ferrié (France), W. Duddell (U.K).

President, Prof. Schmidt (Germany), Prof. Abraham (France), Prof. Wien (Germany); Vice-President, Prof. Eccles (U.K.), Father Lucas (Belgium), Prof. Benndorf (Austria), Dr. Lutze (Belgium), Prof. Vollmer (Germany), Dr. Goldschmidt (Belgium); Secretary General, Ing. Braillard (Belgium).



U. R. S. I. Golden Jubilee Memorial

Preface

by E. V. APPLETON,
U.R.S.I. Honorary President

This Golden Jubilee Memorial Volume of U.R.S.I. is, at once, a story about people as well as about things. For it is not merely a record of progress in the field of scientific radio : it is also a history of the co-operative exploits of human beings in bringing that progress about. Like most institutions, U.R.S.I. still continues to benefit from the vision and imagination of its founders. There has been no change in its basic purpose, only an augmentation of the field of knowledge to which its objectives apply. To advance human knowledge and understanding in the field of scientific radio, by way of international association and co-operation, has always been, and still is, the declared quest of our Union.

Founded in 1913 when the techniques of radio were primitive and largely dependent on pioneer inventions, such as spark emitters and crystal detectors, U.R.S.I. has seen, and participated in, the harnessing of the free electron as the essential current component in high frequency circuits. But, above all, U.R.S.I. has been associated with the basic scientific eludication of the travel of radio waves, both in our terrestrial atmosphere and beyond it. It is this field of endeavour which led our members to invade the territory of other disciplines such as solar physics and meteorology, and, indeed, geophysics and astronomy generally, where applications of radio techniques have opened up entirely new lines of progress.

It was indeed our association with other subjects which led U.R.S.I. to draft the first formal proposal for an International Geophysical Year in 1957/8, a proposal which was immediately adopted, and implemented, by our parent body, the International Council of Scientific Unions. Again, it was our interest in the complex of electromagnetic radiations emitted by the sun which led our Union, in 1954, to draw the attention of the world's national academies to the possibility of mapping the solar spectrum by means of an « instrumented satellite », girdling the earth at a high level, and so escaping the absorption of the terrestrial atmosphere. It is no exaggeration to claim the circulation of this proposal as a pioneer step in the era of modern space research.

But the present and the future are always more important than the past. Today we stand on the threshold of new vistas and new opportunities. But it has been good to have surveyed the way we have come. We are naturally proud of past achievements. As for U.R.S.I. itself, our sentiments are simply expressed : we are sure of its worth and confident in its future.

Foreword

by R. L. SMITH-ROSE
U.R.S.I. President

It is very gratifying to have been associated with the preparation of this book published in celebration of the Golden Jubilee of U.R.S.I. The Proceedings of our thirteen General Assemblies record in detail the activities of the Union over the past fifty years. In addition, a series of Special Reports, Handbooks and Monographs have dealt with various sections of the wide range of subjects which fall under the heading of « Scientific Radio ». (See Appendix III, p. 157.)

It has, however, been considered appropriate that the Jubilee Year of 1963 should be marked by a special publication which is presented in this Volume.

After an introduction by the late Dr. J. H. DELLINGER, formerly an Honorary President of the Union, the first seven chapters review the histories of each of the seven Commissions, written by scientists who have been closely associated with the work of these Commissions. The remaining three chapters deal with other International activities, in which U.R.S.I. has played a leading part : the organisation and conduct of the special programmes of the International Geophysical Years; the Permanent Geophysical Services in which radio plays an essential part; and some of the special problems of Space Research.

The three Appendices present a factual record of : (i) the dates and places of the General Assemblies, and of the Officers associated therewith; (ii) the Officers of all the Commissions and Committees associated with U.R.S.I.; and (iii) a list of the publications of U.R.S.I.

The inspiration of this Jubilee volume was largely due to my predecessor, Dr. L. V. BERKNER, who presided over the General Assembly in London in 1960. Its successful realisation has been accomplished by the able and enthusiastic co-operation rendered by the authors of the individual chapters. Finally, I am particularly grateful to our Secretary General, Col. Ing. E. HERBAYS, who has been associated with the affairs of U.R.S.I. for so many years, and who, by his persistent advice and encouragement, has ensured the timely publication of this account of « 50 years of Radio Science ».

Introduction

History of U. R. S. I.

by J. H. DELLINGER,

Honorary President of U.R.S.I. (deceased December 1962)

The International Scientific Radio Union (U.R.S.I.) has existed for fifty years; a period which includes some three quarters of the entire history of radio science and communication. This is true even though the greatest single event in the history of radio science was its beginning just one hundred years ago. For it was in 1863, that James Clerk MAXWELL, a British mathematician, deduced from theoretical scientific reasoning that electromagnetic waves could be produced by electrical apparatus, and that such waves would travel through space with the velocity of light. It remained for a brilliant German experimenter, Heinrich HERTZ, to discover means of producing electric waves from an electrical discharge, and of detecting them by the small sparks they produced between conductors in the neighbourhood. Hereafter the difficulty was not the production of the waves but their detection and demonstration. Sir Oliver LODGE devised the coherer method of detecting electrical oscillations, and after improvement by BRANLY, this was used by MARCONI to demonstrate in 1896 the practical possibilities of wireless or radio signalling by means of electromagnetic waves freely transmitted through space or over the surface of the earth. Working independently Aleksandar POPOV, a Russian physicist, made some modifications to the coherer and used it in 1895 to detect the waves radiated from a lightning discharge. But while there was much experimental development of practical devices for the new means of communication, there was little in the way of scientific research in radio for about half a century after MAXWELL's classical theoretical research.

By 1913 it had become apparent that progress in radio science would require international cooperation in large-scale research. On October 13,

Prof. J. LUGEON (Switzerland), 1948-1950;
Dr. D. F. MARTYN (Australia), 1950-1954;
Dr. Ch. R. BURROWS (U. S. A.), 1952-1957;
Prof. B. D. H. TELLEGEN (Netherlands), 1952-1957;
Dr. L. V. BERKNER (U. S. A.), 1954-1957;
Dr. R. L. SMITH-ROSE (U. K.), 1954-1960;
Prof. I. KOGA (Japan), 1957;
Prof. G. A. WOONTON (Canada), 1957;
Mr. B. DECAUX (France), 1960;
Prof. A. Prokhorov (U. S. S. R.), 1960.

The aims of the U.R.S.I. are : (1) to promote international cooperation in the scientific study of radio, (2) to encourage and aid in the organization of radio research requiring cooperation on a large scale, (3) to promote the establishment and use of common methods and standards of radio measurements, (4) to encourage and aid the discussion and dissemination of the results of these activities.

These objectives are pursued on both the international and the national levels. Internationally, the Union holds meetings, called General Assemblies, usually at three-year intervals. These last about two weeks, are attended by about 500 people, and are devoted principally to papers and symposia in which the latest developments in radio science are presented. Commissions and Committees consider various fields of research and make recommendations on projects for the future. Not only do participants get a general view of world activity in their special interests; they also have an unique opportunity to promote personal acquaintance with those of like interests in other countries which helps greatly in subsequent collaboration across national boundaries.

Anticipating the meeting in Tokyo in September 1963, the Union will have held fourteen General Assemblies since the first one in Brussels in 1922. Details of the Assemblies are given in Appendix I.

The Commissions and their work

The technical work of the U.R.S.I. is carried forward on a continuing basis by permanent international bodies called Commissions. They conduct continuous studies of the major fields of radio research. At the inception of U.R.S.I., during 1919 to 1922; the following Commissions were established :

I. Measurement Methods and Standardisation
Chairman : Prof. H. ABRAHAM (France);

II. Wave Propagation
Chairman : Dr. L. W. AUSTIN (U. S. A.);

III. Atmospheric Disturbances
Chairman : Dr. W. E. ECCLES (England);

IV. Cooperation with Radio Amateurs
Chairman : Prof. G. VANNI (Italy).

These have been altered from time to time and are at present as follows :

I. Radio Standards and Measurements;
II. Radio and Troposphere;
III. Ionospheric Radio;
IV. Radio Noise of Terrestrial Origin;
V. Radio Astronomy;
VI. Radio Waves and Circuits;
VII. Radio Electronics.

Details of these, with their officers are given in Appendix II.

The Commissions function through correspondence, the work of Subcommissions, the holding of symposia, and also through discussion and planning sessions at the General Assemblies. All of these activities reinforce the personal contacts at meetings in the fructification of research and the accomplishment of mutual objectives in international projects. The work of the Commissions is described in succeeding chapters.

Finance

The U.R.S.I. is financed by contributions paid by the scientific Committees of the member nations and by grants from UNESCO. The cost of each General Assembly is paid, not by U.R.S.I., but by the National Committee of the country acting as host. A paid secretariat is maintained in Brussels, Belgium, which assists and coordinates the work of the Union, its Commissions and the National Committees. It operates mainly by correspondence. It also edits and manages the publications. The secretariat and the treasurer being located in Brussels, the Union's accounts are rendered in Belgian francs. This gives the organization the appearance of substantial wealth, as the figure denoting as a given sum of money is fifty times as great in Belgian francs as in American dollars.

The Union is financed from two sources : (*a*) contributions, according to a scale fixed in the Statutes, by the adhering countries, and (*b*) grants from U.N.E.S.C.O. The approximate income from these sources, for typical years, was :

Year	Contributions by adhering countries	Grants
1920	1 600	
1927	7 300	50 000
1930	38 000	
1939	39 000	
1947	285 000	250 000 (Unesco)
1950	486 000	
1960	1 365 000	700 000 (Unesco National) 600 000 Science Foundation 100 000

Members of U.R.S.I. - The National Committees

The national sections of the U.R.S.I. constitute its third mode of working, the first two being the triennial General Assemblies and the international Commissions for the seven technical fields. The following 28 countries have national sections, so-called National Committees, recognised by U.R.S.I. at the dates indicated :

Australia (1922)
Austria (1914) (1957)
Belgium (1913)
Canada (1952)
Czechoslovakia (1948)
Denmark (1930)
Finland (1954)
France (1913)
Germany (1938) (1952)
Greece (1957)
India (1952)
Italy (1922)
Japan (1922)

Morocco (1934)
Netherlands (1922)
New Zealand (1931)
Norway (1927)
Peru (1960)
Poland (1954)
Portugal (1927)
Spain (1952)
Sweden (1931)
Switzerland (1930)
Republic of South Africa (1928)
United Kingdom (1914)
United States of America (1921)
U. S. S. R. (1957)
Yugoslavia (1952)

The National Committees usually comprise from 10 to 30 people, and in many cases act as an Executive Committee for administering the activities of a much larger group engaged in promoting the technical objectives of the U.R.S.I. in their country. These activities, nationally, include the holding of national meetings for the discussion and promotion of radio science, the operation of technical groups called Commissions similar to the international ones, and the handling of the national phases of U.R.S.I. business such as the designation of national delegates to the triennial General Assemblies.

The National Committees are formed under the authority of each country's National Scientific Academy or National Research Council or similar body. Through that body the regular financial contribution for the support of U.R.S.I. is obtained. The same body in each country formally approves or appoints the membership and the procedures of that country's National Committee.

The formal organization and modus operandi of U.R.S.I. are controlled by its Constitution or « STATUTES », BYLAWS, and RULES for Commissions. The first version of the Statutes was prepared in 1919 and approved by the International Research Council when it approved the proposal to turn the T. S. F. S. into a body (U.R.S.I.) adhering to it. The Statutes etc. have been modified from time by the General Assemblies.

Publications of U.R.S.I.

The U.R.S.I. produces various classes of publications. The first was the Proceedings of the General Assemblies. This began with the second General Assembly, that held in Washington in 1927.

The next regularly issued publication was the Information Bulletin, which began in January 1938. It has at various periods been issued every one, two, or three months; it is bimonthly at present. At first it included a combined bulletin of the Ursigrams of cosmic data. It now gives comprehensive news of activities in the Commissions and National Committees, of U.R.S.I., in other related International Unions and scientific organizations, including the International Telecommunication Union : the proceedings of scientific meetings and symposia, etc., concerned with research in radio are also reviewed in the Bulletin.

The U.R.S.I. issues special publications from time to time. Among them are Special Reports summarizing knowledge in particular fields of radio science. There are also the U.R.S.I. Handbook of Ionogram Interpretation and Reduction, the I.G.Y. Calendar Record, detailed reports on international symposia, and the newly undertaken Monographs presenting the technical work of the Commissions as summarized in each General Assembly.

Special Projects and Services

The accomplishements of U.R.S.I. are mainly by and through the Commissions, which are considered in later chapters. An early project was the system of « U.R.S.I. signals » begun by the Radio Wave Propagation Commission in 1923. Special signals were transmitted by high-power stations in France, Italy, U. S. A., and Great Britain, on frequencies from 13 to 115 kc/s, to facilitate measurement of received field strength at great distances.

On the other hand, actions by National Committees sometimes develop into major U.R.S.I. projects. One of these is the « URSIGRAMS » service, in which coded daily bulletins of geomagnetic, ionospheric, solar and other cosmic data are broadcast by radio. Its purpose is to place useful data in the hands of radio transmitting services soon enough to aid in the selection of frequencies, times, and paths of transmission, and also to make widely available collections of data to research students of radio propagation and of geophysical and cosmic phenomena. It originated in actions of the French and American National Committees, especially by General FERRIÉ and Professor KENNELLY. The service began

with plain-language daily bulletins of geophysical and solar data from the Eiffel Tower in Paris, starting Dec. I, 1928. Then came coded daily bulletins from high-power stations of the U. S. Navy, starting Aug. 1, 1930, called Ursigrams. Through the use of special five-digit codes, these bulletins compressed a large amount of information into a short message. Later, English, Philippine, Japanese and Italian stations were added to the American and French stations to make the dissemination more nearly worldwide. Observing stations of many organizations provide data and the U.R.S.I. National Committees of the various countries provide means for collecting and forwarding the data to the radio transmitting stations. The Ursigram Service continues to the present time. The information broadcast includes ionospheric (critical frequencies, sudden disturbances, radio noise enhancements), solar (flares, corona, sunspots, radio noise), geomagnetic, and cosmic-ray data. The coded messages are transmitted daily at specified times from radio stations in France, Germany, Japan and India. Most are by radio telegraph, a few by radio telephone. As the data are broadcast in special five-letter codes, there is no difficulty over language in the various countries. The warnings of radio disturbance conditions broadcast by the U. S. A. National Bureau of Standards and others are based, in part, on data contained in the Ursigrams.

The U.R.S.I. now maintains a so-called Permanent Service : International Ursigram and World Days Service. Under the general auspices of the International Council of Scientific Unions (I.C.S.U.) the U.R.S.I. participates with other Unions in joint activities such as Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Science (I.U.C.A.F.), the Committee on International Geophysical Cooperation (C.I.G.), Committee on Scientific Space Research (C.O.S.P.A.R.), Scientific Committee on Antarctic Research (S.C.A.R.), etc.

The U.R.S.I. Committee on the International Geophysical Year (I.G.Y.) was formed in 1951, and was followed in 1958 by one on the International Collaboration in Geophysics.

Radio Astronomy

One of the most striking developments of science in recent years has been the emergence of radio astronomy. Stars, the sun, and other heavenly sources emit radiations at radio as well as optical frequencies. Techniques have been developed to detect and measure their intensity and whole new chapters of astronomical knowledge are opening up. Many things are being revealed to which optical telescopes are blind. Many astronomers consider that new knowledge is now coming faster from radio telescopes than from optical telescopes.

The beginning of this new science was first reported at an U.R.S.I. meeting; this was the paper of Karl JANSKY at a meeting of the U. S. A. National Committee in 1932. The U.R.S.I. established a Commission to specialize on radio astronomy in 1948. Its activities and the symposia at the General Assemblies have been a major guiding and coordinating force in this rapidly moving field. The U.R.S.I. has organised a programme of observation by observatories all over the world to ensure coverage at all times.

International co-operation in Geophysical and Space Research

The U.R.S.I. played a key role in the « Third International Geophysical Year » (1957-58). The word « Third » is interesting. The First International Polar Year, for intensification of geophysical research in polar regions, occurred in 1882-83, the Second in 1932-33 (50 years later). The U.R.S.I. was active in the planning and the conduct of the Second Polar Year. In 1950, U. S. A. members of U.R.S.I. evolved the idea that 25 years, rather than 50, would be a suitable interval nowadays, and also that such an undertaking should be worldwide and not limited to polar regions (hence the name should be « Geophysical »). They submitted these ideas to the International Joint Commission on the Ionosphere. Then the U.R.S.I. at its 1950 Ceneral Assembly endorsed the idea and in 1951 the International Council of Scientific Unions appointed an international committee to organise it. The programme of work all aver the world, with emphasis on polar regions, included observations on aurora and airglow, cosmic rays, geomagnetism, glaciology, ionospheric physics, meteorology, seismology and gravity, solar activity, latitude and longitude, oceanography, and rocket exploration of the upper atmosphere. Practically all nations participated in the programme. A vast literature resulted, describing the new knowledge obtained. A major U.R.S.I. publication on it was the Monograph entitled « Some Ionospheric Results Obtained during the International Geophysical Year », being the proceedings of a symposium at Brussels in September, 1959.

The U.R.S.I. is actively co-operating in the planning of the programme of international scientific observations for the International Year of the Quiet Sun (I.Q.S.Y.) to be made during the period 1964-1965.

The U.R.S.I. was the body which initiated international action looking toward the placing of artificial earth satellites in orbit. At its General Assembly in August 1954, the U.R.S.I. adopted the following resolution in connection with its planning for upper-atmosphere observations during the I.G.Y. : « U.R.S.I. therefore draws attention to the fact that an extension of present isolated rocket observations by means of instrumented earth satellite vehicles would allow the continuous monitoring of solar ultraviolet and X-radiation intensity and its effects on the ionosphere, particularly during solar flares, thereby greatly enhancing our scientific knowledge of the outer atmosphere ». Similar resolutions were subsequently adopted by the International Geophysical Union and by the International Council of Scientific Unions. In 1955 the governments of the U. S. A. and of the U. S. S. R. announced their intentions of launching such satellites. The resulting events are known to all.

General

Besides carrying on vigourously its own activities, U.R.S.I. collaborates with other organizations, such as other International Scientific Unions particularly the ones on geophysics (I.U.G.G.) and astronomy (I.A.U.), the World Meteorological Organization (W.M.O.). and the International Radio Consultative Committee (C.C.I.R.). Beginning in 1951, the U.R.S.I. has been represented by a delegation at the Plenary Assemblies of C.C.I.R. These refer specific questions to the U.R.S.I. for study. The questions are assigned to the appropriate Commissions and the resulting statements are contributed as documents for the next C.C.I.R. Plenary Assembly.

The history of U.R.S.I. has been one of steady growth, of effort to coordinate the international scientific foundations of the fantastically extending roles of radio and electronic applications. Our domain extends over the earth, throughout the solar system, and out among the galaxies. A historical account is not the place to examine the future. But we can be sure of one thing : when man reaches the outermost limits of the observable universe he will be materially assisted by means of radio for communications navigation and control using the electromagnetic waves envisaged by the genius of Clerck MAXWELL a hundred years ago.

Chapter I.

Radio Measurements and Standards

by L. ESSEN,

National Physical Laboratory, Teddington, Middlesex, England

1. — Introduction

In the course of the past 50 years the range of radio waves used in practical applications has been extended from about 1 Mc/s to 10^5 Mc/s and now in 1962 the « laser » light source having a frequency of the order of 10^8 Mc/s is being considered as a possible carrier wave for communication purposes. In the same time the precision of measuring the frequency of radio waves has increased from 1 part in 10^4 to better than 1 part in 10^{10}. Every extension of the band has involved the introduction of new techniques and often of new standards of measurement. These developments have all been discussed at the U.R.S.I. Assemblies and would find a place in a full history of the work of Commission I. This is clearly an impossible task, and the present account will be restricted to those aspects of the work to which U.R.S.I. has devoted particular attention and has encouraged experiments on an international scale.

The growth of U.R.S.I. and the increase in the numbers attending the Assemblies have made it impracticable to continue the early verbatim reports. It is however of interest to read these reports as they reveal not only the wisdom shown by the pioneers in the development of radio but also the spirit of great friendliness which characterised the discussions, the willingness to help, and the full interchange of information. The subjects selected for discussion in 1927 for example have formed the basis of most subsequent discussions (1). At this meeting and at the several succeeding meetings it was generally agreed that the unit of frequency was identical with the unit of time interval and that no independent definition should be given. This consideration is now relevant in the reverse sense. It is becoming necessary to define frequency in terms of an atomic spectral line; and when this is done it will also define the unit of time interval.

It was also agreed that although frequency was measured in terms of the astronomical unit of time it was nevertheless important to compare the national standards of frequency in order to check the techniques of measurement. This general philosophy has applied to other branches of the work of Commission I. Although measurements can be made in terms of the fundamental standards, international comparisons have done much to improve techniques and to bring them to a uniformly high level.

2. — Standards of frequency

Standards of frequency and their comparison have been an important item of discussion at U.R.S.I. throughout its history. A major advance reported at the 1927 Assembly was the continuous operation of a tuning fork, except for breaks of a few weeks, by J. W. Horton and W. A. Morrison. This was the beginning of a change in the pattern of frequency measurements. Instead of being measured in terms of the seconds impulses from a pendulum clock the frequency standards became clocks themselves. Tuning fork clocks were further developed by D. W. Dye and L. Essen but quartz oscillators were already being investigated and experiments at the Bell Telephone Laboratories indicated that a stability of 1 part in 10^6 should be attainable. The quartz bar oscillators developed by E. Giebe and A. Scheibe in the early 1930's and the ring oscillator developed by L. Essen in 1936 were stable to about 1 part in 10^{10} per day. These and other forms of quartz oscillator became time standards which enabled astronomical observations to be averaged over long periods of time with a great improvement in the uniformity of the unit of time itself. It is interesting to recall that in 1927 General Ferrié drew attention to the fact that the rotation of the earth might not be uniform although this was only of academic interest. By 1950 it was of practical importance and the non uniformity was detected and measured by quartz clocks. In 1956 a form of robust quartz clock stable to 3 parts in 10^{10} per day was described by A. W. Warner, and in 1960 he was able to claim a stability of 3 parts in 10^{11} per day.

(1) It should be noted that previous to that time measurements were more confined to transmission stations as mentioned in a paper by W. Duddell published in the first and unique number of the *Bulletin de la Commission Internationale de Télégraphie Sans Fil* (Brussels, May-June, 1914).

The first work on atomic standards by H. LYONS in the U. S. A. was reported to the General Assemblies of 1950, 1952 and 1954, and an account of the first operational atomic standard at the National Physical Laboratory (U. K.) was given at the 1957 Assembly. With the latter, L. ESSEN and J. V. L. PARRY had carried out an exhaustive series of tests to show experimentally that frequency, and time interval, could be defined in terms of a spectral line of caesium with an accuracy of $\pm$ 2 parts in 10^{10}. The first commercially available atomic standard, following the work of J. R. ZACHARIAS at MIT was reported at the same meeting, together with the Ammonia maser developed by C. H. TOWNES, and J. P. GORDON at Columbia University. By the 1960 meeting atomic or molecular clocks were also in use in Australia, Canada, France, Japan, Switzerland and the U. S. S. R.

The caesium beam atomic standards in the U. K., the U. S. A. and Switzerland were accurate to $\pm$ 3 parts in 10^{11}. It is clear that frequency could no longer be measured with the required precision in terms of the astronomical unit of time. An extended comparison between the astronomical and atomic units was made by the National Physical Laboratory (U. K.) in co-operation with the U. S. Naval Observatory and gave a value of 9 192 631 770 $\pm$ 20 c/s for the frequency of the caesium line in terms of the second of ephemeris time. This value with the smaller limit of $\pm$ 1 c/s has been widely used as a provisional atomic unit of time.

3. — The international comparison of frequency standards

Commission I of U.R.S.I. has been instrumental in arranging many series of comparisons by both the physical transport of standards and by the simultaneous measurement of the frequency of radio transmissions. In 1927 details were given by J. H. DELLINGER of the results obtained with two quartz oscillators measured at five laboratories. The variations of $\pm 2.5 \times 10^{-4}$ were considered excessive in view of the accuracies already required at that time. Improved oscillators were circulated in 1929 and the variations of results obtained again at five laboratories were reduced to $\pm 5 \times 10^{-5}$. Some further comparisons of this kind were made and in 1931 results obtained in the U. K. and France for a quartz oscillator agreed to 6 parts in 10^6 while the values obtained in the same two countries for a Giebe quartz resonator agreed to 1 part in 10^6.

By this time the improvement in the operation of transmitters and in particular their higher frequency stability made it more convenient and practicable to compare standards by using them to measure the frequencies of selected transmissions. Early attempts in 1924 had not been very successful, values obtained differing by 2 parts in 10^3. It was suggested at the General Assembly in 1928 that it might be useful to modulate the emissions from high power transmitting stations by the standard frequency, or a frequency derived from it. This method was employed extensively in Europe using first the Eiffel Tower station (carrier frequency 207,5 kc/s) and later the Daventry B.B.C. station (carrier frequency 193 kc/s). A modulation frequency of 1000 c/s on the Daventry station was measured at the National Physical Laboratory (U. K.), the Physikalisch-Technische Reichsanstalt (Germany), the Laboratoire National de Radioélectricité (France) and the Institut Radiotechniczny (Poland), and the results agreed to $\pm$ 2 parts in 10^7. During these modulation experiments many photographic records were obtained of the phase changes of the received signals, but the information they contained concerning the movement of the reflecting layers of the ionosphere was too complex for interpretation. The very stable Bureau of Standards transmission from Washington (W.W.V.) on 5 Mc/s enabled carrier wave measurements to be used with equal precision; and by this means the standards in U. S. A. and U. K. were compared in 1934 with an accuracy of 5 parts in 10^8, the actual precision of measurement being 2 parts in 10^8. It was concluded from these measurements that the sudden erratic changes observed in the frequency of the received signal must be caused by path changes with a resultant Doppler effect change. A steady drift during an hour was also observed but it was not concluded that this was due to the Doppler effect. Later measurements in the United Kingdom made over longer periods when the transmitted power of WWV was increased showed clearly a diurnal Doppler change of about 2 parts in 10^7 which limited the accuracy that could be achieved with this type of comparison. The introduction of atomic standards and the use of stable VLF transmissions for comparison purposes enabled the accuracy to be increased to $\pm$ 1 part in 10^{10} on a routine day to day basis. Such comparisons revealed a small systematic difference between the atomic standards in the U. K. and the U. S. A. and it was strongly urged at the 1957 Assembly that direct comparisons should be made. Two commercial caesium standards (Atomichrons) and one experimental model were sent to the NPL (U. K.) and for two years the deviations between them and the NPL standard were all within $\pm$ 3 parts in 10^{10}. The tests made by a combined U. K. and U. S. A. team gave a probable explanation of the small deviations that occurred.

The remarkable phase stability of the 60 kc/s and 16 kc/s emissions from the Rugby (U. K.) station was also discussed together with the plans that were being made for the world-wide co-ordination of atomic frequency and time signal services.

The striving for increased precision in the measurement of frequency has thus led to a revolution in the measurement and definition of time interval. The adoption of an atomic unit is under discussion by the International Comittee of Weights and Measures; and a provisional unit is already in wide use since it is indispensable for measurements of the highest precision.

4. — Standard frequency transmissions

The service of standard frequency transmissions with the call sign WWV and operated by the NBS since about 1932 has already been mentioned. Regular transmissions of limited scope were also made from the U. K. at this time, and a regular service from the Japanese station JJY operated from 1940. In 1947 at the Conference of the International Telecommunications Union the frequencies of 2.5, 5, 10, 15, 20 and 25 Mc/s were allocated to such services. A continuous service on three of these frequencies was started in 1950 in the U. K. with the addition of a short daily transmission on 60 kc/s. By 1962 there were about 15 different services of standard frequency transmissions in operation giving an effective world wide coverage. The transmissions are co-ordinated by the International Radio Consultative Committee (C.C.I.R.) with U.R.S.I. working on the more scientific aspects of the problem. The question of mutual interference and the possibility of time sharing were raised as early as the 1950 Assembly, but positive action is only now being considered. This may be because interference does not prevent the transmissions from being used for the main purpose of frequency calibration, although there might be difficulty in recognising the various 1 second timing pulses, which form a subsidiary part of the service. Moreover interference would prevent the transmissions from being used for field strength measurements or other propagation studies. To alleviate the situation most stations have a short off-period; the U. K. service for example operating under the call sign MSF has an off-period of 5 minutes each hour. Now that there are more stations in operation particularly in the European area, further time sharing might be introduced.

5. — The measurement of field strength

The field strength produced by a radio station is clearly a matter of fundamental international importance about which there must be

agreement between the manufacturer and buyer who may well be in different countries. There must be agreement, therefore, between the international standards and the methods of measurement. They were mentioned in a paper submitted by W. Austin to the 1928 meeting and in 1931 the British National Committee was asked to collect and co-ordinate information. As reported by R. L. Smith-Rose in a full review given to the 1948 Assembly a questionnaire was circulated and replies were received from some forty representatives in ten different countries. A review describing the existing methods of measuring field strength was presented to the 1934 Assembly in London, and it was recommanded that these studies should be continued, that several national laboratories should set up standards and that these should be intercompared. These comparison showed that further study was needed particularly at the highei frequencies.

At the 1938 Assembly attention was drawn to the advantages of the radiation method of calibrating field strength measuring sets at metre wavelengths. At the Paris Assembly in 1946 it was again recommended that the national laboratories should compare the methods which they used, and that the precision to be aimed at should be defined. R. L. Smith-Rose concluded that although measuring techniques had been developed and described for a large portion of the frequency spectrum, and where necessary for pulse modulated fields, there was some reluctance on the part of manufacturers to produce field strength measuring equipment. In the years following 1948 the position improved but the increasing experience showed that field strength is greatly dependent on the parameters of the site. In consequence it was decided in 1950 that an actual interchange of equipment between the national laboratories would be of doubtful value.

The U. S. A. national committee drew attention in 1957 to the confusion that sometimes arose between field strength and intensity; and in 1960 it was recommended that :

(1) Radio Field Strength refers to the magnitude of the electric or magnetic field vector (E or H) at a given location resulting from the passage of radio waves.

(2) Radio Field Intensity refers to the power density of electromagnetic waves through a surface normal to the direction of propagation.

Direct power measurements became of increasing importance especially with the development and exploitation of the microwave portion of the spectrum. Even at microwave frequencies however, field strength measurements remained important for special purposes. The problem is still receiving attention and at the 1960 Assembly in London the U. S. A. National Committee tabulated a comprehensive list of the accuracies required at various frequencies from 30 c/s to 140 Gc/s and magnitudes from 10^{-6} to 1 volt per metre.

6. — The measurement of radio frequency power

Another important measurement which has regularly formed a part of the programme of work of Commission I is that of radio frequency power. Perhaps the most valuable part of the work has been the interchange of information concerning rapidly developing techniques, the descriptions for example of the precautions that have to be taken in relating the heating of a bolometer wire by r. f. current and by direct current, and in the matching of the measuring instrument to the source. The reports of the U. S. A. and U. K. national committees have given much information of this kind. It is the general practice to calibrate the working standards of power by means of calorimeters and much work has been devoted to the development of calorimeters for high frequencies and low powers. Absolute measurements depending on the force exerted by an electromagnetic field on a small vane in a resonant cavity have also been carried out and the U. K. national committee reported in 1957 that such an instrument had possible systematic errors amounting to 7 % at a frequency of 3 Gc/s for power levels between 2 mW and 100 mW. Noise sources have also received much attention. In spite of the possibility of calibrating the working standards it was felt that international comparisons of standards would be a valuable additional check giving confidence in the methods used. In 1950 eight countries agreed to the interchange of equipment, the U. K. committee being made responsible for the detailed arrangements. At the next Assembly however in 1952 R. L. Smith-Rose had to report that no intercomparisons had been made and he offered to circulate two thermistor mounts developed in the U. K. for frequencies of 2.5 Gc/s and 9.8 Gc/s and calibrated against water calorimeters. J. F. Gaffney of the U. S. A. pointed out that although they had laboratory standards accurate to 1 %, the transfer standards were accurate to only 5 %. Even so it was felt that intercomparisons could be useful and the resolution of 1950 was re-affirmed specifying the two frequency ranges of 3 Gc/s and 10 Gc/s. The discussion at the 1954 Assembly followed similar lines and it was not until the 1960 Assembly in London that the results of comparisons could be given. The Japanese

Committee had devoted considerable effort to the subject, making and calibrating five bolomer mounts, two for comparisons in the U. K. and three for the U. S. A. Two mounts were supplied by the U. S. A. for the same purpose. The early comparisons revealed deficiencies in some of the mounts but after these had been rectified good agreement was obtained. The comparisons showed that measurements in Japan, U. K. and U. S. A. were in agreement to within 1 %.

7. — Fundamental electrical quantities

The importance of the measurement of capacitance, inductance, and resistance was stressed at one of the early Assemblies in 1927 and an interchange of apparatus between the NBS and NPL was suggested. These quantities however can be included among the basic units of measurement and international agreement has been secured through the International Committee of Weights and Measures. The primary standards of inductances, the values of which are determined from the dimensions are not of course interchanged directly but are used in the determination of the ohm and in the calibration of the working standards of resistance and voltage. The working standards are compared at the International Bureau of Weights and Measures, Paris. An interesting development was described by the Australian national committee in 1957. A new type of calculable capacitor was made in accordance with a theorem put forward by A. M. Thompson and D. G. Lampard. The capacitance is dependent on one length measurement only and it enables a unit to be realised with an accuracy at least as high as that achieves for the unit of inductance. Together with the value for the velocity of light it could give an independent check on the absolute value of the ohm.

Inductors, capacitors and resistors are incorporated into bridge circuits for the direct measurement of impedance and at the various meetings attention has been directed to bridges which can be operated at frequencies as high as 300 Mc/s, or even 1000 Mc/s with specially constructed circuits. At frequencies above about 200 Mc/s coaxial line and waveguide methods are convenient. In these the unknown impedance is compared with an impedance which can be calculated from the dimensions of the line or waveguide. In a similar way attenuation is measured by means of a waveguide the dimensions of which are below the cut-off value at the frequency concerned. These instruments are thus readily calibrated and it might seem that no purpose is served by the interchange of apparatus. The accuracy required with equipments used internationally has steadily increased and it has become important to compare directly the messuring techniques used in different countries. In 1960 the U. S. A. national committee suggested a comprehensive list of such comparisons which was incorporated in a recommendation approved by the Assembly.

8. — Properties of materials at radio frequencies

The measuring techniques developed to meet the requirements of radio engineering at higher and higher frequencies opened up the possibility of investigating the properties of materials at these frequencies. In particular the dielectric and magnetic properties of gases, liquids and solids have been studied, with far reaching consequences to physical theory and engineering practice. As an exemple might be mentioned the work of B. BLEANEY and his colleagues on paramagnetic substances, while of more immediate interest to radio engineers were investigations of the effect of moisture in soil carried out in a number of countries.

Measurement of the dielectric constant of air were also of direct interest to the problem of radio propagation. Measurements made by C. K. JEN reported at the Zurich, 1950 Assembly had a sensitivity of 1×10^{-5} and at the next Assembly details were given of the measurements of L. ESSEN and K. D. FROOME at 24 000 Mc/s. The accuracy of 1 part in 10^7 achieved in these latter results was needed for work then in progress on the velocity of radio waves.

Another physical measurement now made by radio techniques is that of magnetic field. P. GRIVET reviewed such measurements at BOULDER in 1957 describing the methods using the nuclear resonance effects discovered by E. M. PURCELL and R. BLOCH in 1948 and those using the electronic resonance effect discovered by E. ZAVOISKY in 1945. He mentioned also the ferromagnetic resonance discovered by J. H. E. GRIFFITHS in 1946 which had perhaps not been given adequate attention.

9. — The determination of physical constants

The new techniques of radio measurements made it possible to determine some important physical constants by new and more precise methods; and although U.R.S.I. may not have initiated such measurements it was quick to recognise their importance. The first of the new determinations of the speed of radio (or light) waves at the National Physical Laboratory using a cavity resonator was reported to the 1952 Assembly and a resolution was passed recommending the use of the value 299 792 $\pm$ 2 km/s for all scientific work. By the time of the next Assembly in 1954 several

other experiments, with light waves and radio waves supported this value and the earlier resolution was confirmed. The 1957 Assembly was able to take account of more recent and precise work at the National Physical Laboratory and recommended the value 299 792.5 $\pm$ 0.4 km/s. A radio method of measuring distance, using the commercially developed instrument, the Tellurometer, was now widely used, and it was necessary to apply a correction for the refractive index of air. At the 1960 Assembly a resolution was approved recommending the formula of H. BARRELL and J. E. SEARS (1) for light waves and that of L. ESSEN and K. D. FROOME for radio waves. These formulae had already been adopted by the International Union of Geodesy.

Another constant of great importance to radio standards is the gyromagnetic ratio of the proton, first determined precisely by H. A. THOMAS, R. L. DRISCOLL and J. A. HIPPLE in 1950. P. BENDER described the work at the NBS in this field to the 1960 Assembly, and J. E. P. VIGOUREUX reported that his results at the NPL agreed with the NBS value to 1 part

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(1) (*a*) For light waves (H. BARRELL and J. E. SEARS)

$$(n_G - 1).10^7 = 2876.04 + \frac{16.288}{\lambda^2} + \frac{0.136}{\lambda^4}$$

reduced to ambient conditions by

$$n_L = \frac{n_L - 1}{1 + \alpha t} \cdot \frac{p}{760} - \frac{0.000\ 000\ 055e}{1 + \alpha t}$$

where :

λ = the light group wavelengths in microns
n_L = refractive index in ambient conditions
n_G = refractive index in dry air with 0.03 % CO_2 at N. T. P. (0°C, 760 mmHg) for light of the group wavelength employed, calculated as above
t = temp. in °C
p = atmospheric pressure in mmHg
α = coefficient of expansion of air (0.003 661)
e = partial water vapour pressure in mmHg

(*b*) For radio frequency waves (L. ESSEN AND K. D. FROOME).

$$(n_{Tp} - 1) = \frac{103.49}{T} p_1 + \frac{177.4}{T} p_2 + \frac{86.26}{T} (1 + \frac{5748)}{T} p_3$$

n_{Tp} is refractive index at temperature T and atmospheric pressure p
p_1 is the partial pressure of dry air in mm of mercury
p_2 is the partial pressure of carbon dioxide in mm of mercury
p_3 is the partial pressure of water vapour in mm of mercury
T is the temperature $t + 273$, where t is the air temperature in °C.

The pressures are expressed in mm of mercury at 0° C and standard gravity.

760 mmHg = 1 013 250 dyne/cm²
= 1 013 250 millibars.

Chapter II.

Tropospheric Radio

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1. — Introduction

The present Commission II of U.R.S.I. « on Radio and the Troposphere » is one of the younger Commissions of the Union, though interest in the study of propagation through the lower atmosphere existed for many years before it was considered to justify the creation of a separate Commission. It was in fact from research on ultra-short-wave propagation in the late 1920s that it began to be realised that the influence of the troposphere would have to be considered, and at this time such topics fell within the scope of the original Commission II. « On Radio Wave Propagation ».

The increasing importance of the subject was appreciated by the Commission on Radiophysics (founded as a Vth Commission in 1927) when, in 1934, it proposed the following two resolutions : (i) « The Commission desires the study of the propagation of ultra-short waves (i.e.$\lambda < 10$ m), such study to include the determination of the effect of the atmosphere; and asks Dr. J. H. DELLINGER and Mr. T. L. ECKERSLEY to prepare a report on the subject », and (ii) « The Commission jointly with Commission II desires the further investigation of the theory of propagation and absorption of waves in the atmosphere, and of the conditions under which the propagation obeys the laws of geometrical optics and of those conditions under which the general laws of wave theory should be applied ». These resolutions helped to stimulate the research on tropospheric propagation and on its correlation with meteorology which began to gain impetus during the 1930s.

It was during the Second World War, however, with the experience of the use of metric, decimetric and centimetric waves for radar in many different climates throughout the world that it was first appreciated how extensive the influence of the troposphere on propagation is; and it was not surprising that, at the General Assembly in Paris in 1946, a Sub-Commission IIc was formed to deal with the subject. Finally, the reorganization of Commissions at the VIIIth General Assembly in Stockholm in 1948 resulted in the formation of the present Commission II.

It should, however, be mentioned that, in 1946, U.R.S.I. had suggested to its parent body, the International Council of Scientific Unions (I.C.S.U.) that a Joint Commission on Radio-meteorology should be constituted : this was agreed to by I.C.S.U. the other participating Unions being the International Union of Pure and Applied Physics (I.U.P.A.P.) and the International Union of Geodesy and Geophysics (I.U.G.G.), and the Joint Commission met for the first time in Stockholm in 1948. At the XIIIth General Assembly in London, 1960, the Joint Commission was reconstituted as the Inter-Union Committee on Radio-meteorology, and now only involves U.R.S.I. and I.U.G.G. The former Joint Commission and the present Inter-Union Committee, for which U.R.S.I. acted and still acts as the « Parent Union », had and have as their objective the fostering of combined activity between radio scientists and meteorologists in their field of mutual interest which, as far as U.R.S.I. is concerned, includes topics studied in Commissions II and IV.

It is now proposed to discuss in a little more detail some of the more important developments falling within the scope of tropospheric propagation and radio-meteorology; but it should perhaps first be pointed out that problems relating to the effects on propagation of the nature of the ground — its electrical properties and profile — or of obstacles on it are also appropriate to Commission II.

2. — Early work

It is in the records of the Generaly Assembly in Washington, 1927, that the first mention is found of discussion at an U.R.S.I. meeting of possible effects of the troposphere on radio wave propagation. These first reports seem actually to refer to short — and even medium — wavelength transmissions; thus according to a statement made by R. BUREAU : « There are reasons which have been worked out in France to suppose that we are dealing with effects not only of reflections and refractions in the upper atmosphere but also in the lower atmosphere. In regard to the lower atmosphere there have been sufficient experiments made, by taking simultaneous measurements at various receiving stations in France from a single transmitting station, to correlate the results with meteorological phenomena ». It was suggested that the differences in signal characteristics observed in different directions from the transmitter were related to the deviative properties of the air masses over the various paths. In view of later experience this interpretation of the results is perhaps open to doubt. At the same General Assembly, however, direct correlations between weather conditions and the reception of short waves were claimed.

It became clear in later years that significant tropospheric effects on propagation were to be expected mainly at wavelengths of the order of metres and less; but, whilst the propagation of such very short waves was discussed in Washington in 1927, it was only the effects of the ground which were described. Free-space transmission between high mountain peaks was demonstrated, and also the effects of diffraction by mountain ridges. The interfering effect of the ground-reflected wave and the resultant greater rate of attenuation with distance than in free space was also noted at this time.

In the years which followed, experiments with very short waves increased and it was apparent that communication beyond the horizon, sometimes appreciably beyond, was possible. Thus, by the time the General Assembly in London, 1934, was reached, it could be reported that MARCONI had been able to transmit waves even as short as 57 cm in wavelength over distances twice the optical range in the Mediterranean area, and the signals were shown to be subject to marked fading, particularly near or after sunset. Similar observations had been made at wavelengths up to 8 metres under conditions when it was considered there could have been no influence from the ionosphere, and it was therefore suggested that the explanation of the phenomena must be sought in terms of refraction in the lower atmosphere. It was realised that, because of the decrease of refractive index with height in the atmosphere as the density decreased, there would be a downward bending of the radio waves which would help in transmission beyond the geometrical horizon; but the calculated refraction appeared to be inadequate. However, the significant factor that water vapour has a greater refractive index for radio waves than for light waves was not properly appreciated and this would have accounted for some at least of the discrepancy.

Further experiments on metre wave propagation were made in a number of countries in the period between the General Assemblies in London (1934) and Venice (1938), and some of these were described in Venice.

Some interesting American measurements over a 70 mile ocean path at wavelengths of 1.0 and 1.6 metres yielded fading records which, it was suggested, were due to the combination of a ground wave and one or more waves reflected in the troposphere at air-mass boundaries. It was deduced that these boundaries were at heights between 1.9 and 5.5 kilometres, and there was some reasonable agreement between these deductions and meteorological measurements made in an aeroplane.

Progress in theoretical work on tropospheric propagation was also reported in Venice, and the concept of « effective earth radius » was introduced (by T. L. ECKERSLEY) for the modification of the theory of diffraction round the earth to allow for refraction in the lower atmosphere.

3. — War-time developments

Whilst very little was published in the period 1939 to 1945 it was in fact a most fruitful one in the study of tropospheric wave propagation. Intensive study, both theoretical and experimental, of propagation at very short wavelengths led to the identification of entirely new phenomena of refraction, reflection, absorption and scattering in the lower atmosphere — phenomena which are quite inappreciable at the longer wavelengths. Much of this work accompanied the development and widespread application of radar at wavelengths reaching down into the centimetric waveband.

For example, during the War it was discovered that the radar detection of ships was often possible, with very short waves, at distances much beyond the optical horizon. This effect was traced to the existence of powerfully refracting layers in the lowest levels of the atmosphere. Such refraction is associated either with temperature inversions or with conditions of marked humidity lapse rate, or with a combination of both. The incidence of this superrefraction is found to vary enormously from place to place on the earth's surface.

War-time experience also showed that centimetric wavelength radiation could be absorbed by oxygen and water vapour in the atmosphere, and absorbed and scattered by clouds and precipitation. These various phenomena formed the basis of the new subject of radio-meteorology which was later to develop greatly.

4. — Post-war work

When U.R.S.I. met again for the first time after the War, at the VIIth General Assembly in Paris in 1946, much of the war-time research on tropospheric propagation and radio-meteorology still had not been published. It was evident, however, that interest in these subjects was great and a sub-Commission of the then-existing Commission II with the title « Tropospheric Influences on the Propagation of Ultra-Short-Waves » was formed under the Chairmanship of Dr. H. G. BOOKER to review developments. It was further evident that, although the main activity in this field in the immediately preceding years had been in the U. S. A., Great Britain and countries of the British Commonwealth, notably Canada, Australia and New Zealand, interest would soon become much more widespread; and that, in view of the widely differing climates to be found in different countries, the subject was a most appropriate one for international collaboration through U.R.S.I.

A report at the Paris General Assembly submitted by the British National Committee described the development of radio meteorology up to that time and drew attention to the then known salient features of the subject : these included echoes from and attenuation by hydrometeors, attenuation by atmospheric gases and tropospheric refraction. This last topic had perhaps received the greatest attention during the War, and a good deal been learned about superrefraction; in particular the phenomenon of « duct » or « guided-wave » propagation was reasonably well understood both qualitatively and quantitatively.

Superrefraction phenomena are to a large extent explained by the fact that the potential temperature and specific humidity of the body of an air-mass resting on the earth's surface often differ to a marked extent from the values close to the surface itself. In the lower layers of such an air-mass marked gradients of temperature and humidity occur, and these produce marked gradients in the refractive index of the atmosphere for radio waves. In simple cases there is a region from the earth's surface up to a height that may vary from less than ten feet to more than a thousand feet in which the downward curvature of rays exceeds the curvature of the earth. It is such a region which is known as a radio duct, and a ray emanating horizontally from a point within the duct suffers successive reflections from the earth's surface and is « trapped » within the duct. A duct behaves much like a waveguide with a leaky upper boundary, and the longer the wavelength the deeper must the duct be to give efficient guiding of the waves. Sufficiently long waves respond only to a crude average of the overall refractive index gradient, but the propagation of sufficiently short waves is influenced by the fine structure of the index fluctuations.

The VIIIth General Assembly met in Stockholm in 1948, still in the form of four Commissions; but at the end of that Assembly a new structure

was adopted with a new Commission II devoted to studies of the troposphere and wave propagation and with Dr. C. R. BURROWS as its first Chairman. The increasing activity in the field of the new Commission became apparent from the reports of the various National Committees; and delegates were further able to have discussions in the light of the flood of papers on tropospheric research, conducted during the War, and which had been published in the period between the VIIth and VIIIth General Assemblies. Whilst the ground work of the subject — both theoretical and experimental — had in fact to some extent been laid before the War, it was now fully appreciated how great had been the impetus to work in this field by the war-time studies.

Further progress was reported at Stockholm in studies of refraction and of the physical properties of the lower atmosphere relevant to propagation and in relation to meteorological conditions. There was also discussion of problems connected with precipitation and consideration was given to some aspects of ground wave propagation. It was at this time too that radio amateurs were encouraged by U.R.S.I. to take an interest in tropospheric wave propagation by making regular observations on transmissions in the VHF and UHF bands.

5. — The new Commission II

The first meetings of the present Commission II were held at the IXth General Assembly in Zurich in 1950. Discussions continued on developments in the fields of radiometeorology, tropospheric propagation and ground-wave propagation, now well-established, and in addition a new and important topic appeared for the first time, namely the subject of tropospheric scatter propagation. With the advent of very high power transmitters, both for radar and broadcasting, it had been observed that the field strengths of very short wavelength transmissions well beyond the horizon were considerably in excess of those to be expected, even when it was known that no form of abnormal propagation due to non-standard conditions of refraction was occurring. The signals received were observed to fade rapidly and continuously, but they were nevertheless persistent. This form of propagation has become known as tropospheric scatter propagation and is considered to be due to irregular fluctuations in the refractive index structure.

Recently developed theories to explain the scattering process were proposed at Zurich by E. C. S. MEGAW and by H. G. BOOKER and W. E. GORDON. These theories were essentially the same in that they were based on the assumption that the fluctuations of the atmospheric refractive index were due to turbulence in the lower atmosphere. BOOKER and GORDON, however, described the turbulence in terms of a correlation function whilst Megaw used a method in which the turbulence was described in terms of a spectral distribution; these being alternative and interchangeable ways, of course, of looking at the same problem. The decade 1950 to 1960, embracing further General Assemblies at Sydney, The Hague, Boulder and London, saw many developments of scattering theory, based on one or other of these approaches, and other theories were advanced also : this, combined with many experimental investigations, maintained the subject of scattering as one of the major interests, and probably the one exciting the most vigorous discussions, at the meetings of Commission II during this period

In formulating Resolutions at Zurich to guide future work attention was focussed on the experimental data required to assist the development of scattering theory, and an appeal was made to meteorologists to provides as much information as possible about the variation of the atmospheric refractive index, and particularly its fine structure. Important progress on this latter problem was in fact soon made by the radio scientist himself. This resulted from the development of the microwave refractometer which first featured in U.R.S.I. discussions at the Xth General Assembly in Sydney in 1952. The instrument, initially used in the United States of America, is capable of measuring directly the refractive index of the atmosphere and its variations — in relatively fine scale — and extremely valuable information has resulted from its use, carried by aircraft or balloon, or mounted on high towers.

Another subject which expanded greatly during the decade 1950 to 1960, and assumed major importance, was the study of precipitation and cloud physics using radar techniques. This work has been described frequently at U.R.S.I. meetings, and it is a good example of the help which the radio scientist has been able to give to the meteorologist. Radar studies, for example, enable information to be gained about rain formation, rates of precipitation and drop-size distributions; also about the velocities of water droplets in clouds and their shapes. On the more practical side, radar observations of storms, frontal systems and areas of precipitation in general facilitate short-range forecasting of the weather and are a very useful aid to navigation both in the air and at sea.

In 1950 Reports from twelve National Committees were communicated to Commission II : by 1960 the number of such Reports had grown

to eighteen, clear evidence of the increasingly widespread interest in the work of the Commission.

The nature of the work of the International Radio Consultative Committee (C.C.I.R.) is such that close collaboration between it and U.R.S.I. is both desirable and inevitable, particularly since many who participate in the work of U.R.S.I. are also actively engaged in the studies of C.C.I.R. This collaboration, which is discussed in a little more detail in Section 7 in so far as it affects Commission II, officially started in 1948; and in 1954, at the XIth General Assembly in the Hague a « Committee on C.C.I.R. Work », having Dr. J. H. DELLINGER as its first Chairman, was formed in order to co-ordinate and facilitate studies carried out by U.R.S.I. for the C.C.I.R.

Also at The Hague, Commission II, looking forward to the International Geophysical Year, and with the needs of radio scientists in mind, defined a programme of meteorological observations which it was considered should be carried out as widely as possible during the I.G.Y. This programme asked for the fullest exploitation of both radio sondes and microwave refractometers in an attempt to gain as much detailed information about tropospheric refractive index variations as possible.

Dr. R. L. SMITH-ROSE became Chairman of Commission II at the end of the General Assembly in 1954; and when the work of the Commission for the next three years was organized, two working groups were formed to report on the existing knowledge and likely future trend of studies of tropospheric propagation (i) within the horizon and (ii) beyond the horizon.

The General Assemblies in Boulder (1957) and London (1960) saw in the main a continuation of the pattern of the discussions at The Hague, and the controversial arguments on the nature of tropospheric scatter propagation reached their peak during this period. It had become realized that an explanation simply in terms of turbulence effects was inadequate and that some account must also be taken of partial reflections from transitory layer formations; and a serious attempt was made to devise critical experiments which would help to determine the relative importance of the various possible propagation mechanisms.

It was felt in London, however, that the great attention devoted over a number of years to the subject of tropospheric scatter propagation had perhaps prevented Commission II from keeping properly up-to-date with some of the other topics within its terms of reference, particularly in such fields as cloud and precipitation physics and ground wave propagation, including the effects of irregular terrain; and it was decided that more emphasis should be given to these subjects at the XIVth General Assembly in Tokyo, when the Commission would be meeting under the Chairmanship of Mr. J. VOGE.

At London, too, it was appreciated that Commission II would have a part to play in space research, since many of the frequencies likely to be used in such research — and in fact now being so used — would be susceptible to tropospheric influences. In this connection refraction effects are of particular importance, as are also absorption at very short wavelengths and the associated noise radiation. Indeed in due course Commission II may well find itself concerned with propagation problems on the moon and in non-ionized planetary atmospheres.

6. — Inter-Union activity in radio meteorology

The Joint Commission on Radio Meteorology, already referred to in the Introduction to this Chapter, met four times, in Stockholm (1948), Brussels (1951 and 1954) and New York (1957), before its re-constitution in London (1960) as the Inter-Union (U.R.S.I.-I.U.G.G.) Committee on Radio Meteorology. Both the Joint Commission and the Inter-Union Committee have been concerned with matters related to the work of Commission II and also that of Commission IV. Activities relevant to the latter Commission are discussed in Chapter IV.

Concerning the work of interest to Commission II the proceedings of the Joint Commission up to 1960 followed closely parallel to those of Commission II, and were directed specifically towards a better understanding of the meteorological factors relevant to tropospheric propagation and to the use of radio techniques in meteorological studies. There was discussion of the control of the atmospheric refractive index by such meteorological processes as turbulence, subsidence, radiation and advection. The attenuation of microwaves by atmospheric gases and rainfall was also considered, especially in the early meetings, and at all times considerable attention was devoted to radar studies in the field of cloud and precipitation physics.

With the development of the microwave refractometer interest increased in the study of measured refractive index profiles and the associated meteorology; and when tropospheric scattering became a very live topic the Joint Commission discussed theories of atmospheric turbulence in some detail. By the time of its last meeting in 1957 interest had also extended to the study of meteorological « angel » radar echoes and of convective processes in the atmosphere as revealed by weather radar. Dr. C. R. BURROWS was the Chairman of the Joint Commission until the end of its third meeting, when he was succeeded by Dr. E. G. BOWEN.

Immediately on its formation in London in 1960 the new Inter-Union Committee on Radio Meteorology held a preliminary meeting at which Professor J. S. MARSHALL was appointed Chairman, and arrangements were made to hold the first full meeting of the Committee in Paris in the Spring of 1961, when it was planned that the agenda should include a discussion of the work of the Committee, the presentation of scientific papers on work in France and visits to conveniently located centres of research.

At the Paris meeting it was agreed that, whilst atmospheric phenomena at ionospheric levels do fall properly within the scope of the Committee, in the first instance consideration would be given mainly to matters relating to the troposphere. It was further agreed that the general scope of the Committee's activities would be similar to that of the former Joint Commission, and that this would embrace (*a*) aspects of meteorology which affect radio propagation, and (*b*) applications of radio techniques to meteorology. Under (*a*) it would be appropriate to discuss : (i) systematic and random patterns of the atmospneric refractive index; (ii) the distribution of attenuating media, water vapour, cloud, rain; (iii) tropospheric and stratospheric winds, severe storms; (iv) the correlation of satellite weather data with radio propagation; and (v) lightning (by the interference it creates). Under (*b*) the following topics would be considered : (i) radiosondes, rawinsondes and microwave refractometers; (ii) radar observations of the precipitation pattern, the dielectric pattern, winds and lightning; (iii) radio-location of lightning by normal reception techniques or using radar receivers; (iv) microwave radiometers; (v) meteorological interpretation of propagation performance in terms of the dielectric pattern; (vi) meteorological interpretation of attenuation in terms of water vapour, clouds and precipitation; and (vii) planetary atmospheric experiments and their testing with earth satellites.

Of these topics, *a*(v), *b*(ii) (lightning), and *b*(iii) are relevant to the work of Commission IV, whilst all the rest are of interest to Commission II of U.R.S.I. The Committee then reviewed the present state of knowledge in these fields and considered what research should be undertaken to achieve further progress.

Concerning its own future activities the Inter-Union Committee decided to seek permission from the Parent Unions to hold two meetings : (i) a general scientific conference to bring together all kinds of radiometeorologists, and (ii) a specialized colloquium, in which a limited number of experts would take part, on the fine structure of the atmosphere relevant to radio propagation problems. It was considered that, in view of the great development in, and ramifications of, the whole field of radio-meteorology, a general meeting of the kind proposed above would serve a most valuable purpose. It was further felt that at this meeting an attempt should be made to get together a representative international gathering of people interested in the broad aspects of radiometeorology, and that every effort should be made to avoid a division of the conference into small groups discussing narrow sectional interests. The Committee hoped to be able to hold this conference in the period between the General Assemblies of U.R.S.I. and I.U.G.G. in 1963.

The intention with the specialized colloquium was to get together a quite small group of experts to discuss in detail clearly defined problems : attention was to be focussed on what is meteorologically sound in the theory of radio wave propagation, and on where radio and meteorological experiments are failing to yield the information required. It was originally hoped to hold the colloquium in 1962, but this eventually proved impossible; and although it has not yet been held it remains clear that such a colloquium would still serve a valuable purpose in providing a guide for further research. There is little doubt that there will continue to be many important problems to occupy the attention of the Inter-Union Committee for some considerable time

7. — Collaboration with C.C.I.R.

There are parallel interests between a number of Study Groups of C.C.I.R. and the various Commissions of U.R.S.I., but this is perhaps particularly evident in the field of radio wave propagation; and this means that C.C.I.R. has frequently sought the advice of Commission II on fundamental problems of tropospheric and ground wave propagation.

From 1952 onwards, in formulating recommendations for further research, Commission II has regularly borne in mind the needs of the appropriate Study Programmes of C.C.I.R., in particular those concerned with long-distance propagation whether resulting from scattering or abnormal refraction, and with the correlation of propagation characteristics with meteorological parameters. The Commission has also given attention to the problems of transmission over irregular terrain and of multipath propagation through the troposphere. All of these topics are of major importance to the C.C.I.R. in its planning of broadcasting and communication at very short wavelengths.

Finally it may be mentioned that, at London in 1960, Commission II drew up a report, in response to a request from C.C.I.R., which outlined

the various influences of the troposphere on propagation at the frequencies likely to be used for telecommunications with and between space vehicles.

8. — Future work of Commission II

Many of the problems which have been discussed by the Commission since it was formed, and by the Joint Commission and Inter-Union Committee on Radiometeorology, have still not been finally solved, and their importance is such that continued work on them will be required. This is made clear by the programme which has been arranged for the meetings of Commission II at the XIVth General Assembly in Tokyo. It is certain, however, that the new problems raised by space research and communications will loom increasingly large in the years ahead, and for the first time in the history of the Commission an entire session will in fact be devoted to such problems in Tokyo.

Chapter III.

Ionospheric Radio

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This chapter is intended to present the story of the study of the ionosphere as seen through the eyes of U.R.S.I. In writing it an attempt has been made to show how ideas on the subject have changed and how the advance of the subject of ionospheric radio has been helped from time to time by the action which U.R.S.I. took, either by initiating discussions or by the Resolutions which it passed.

Between the first General Assembly in 1922 and the second in 1927, the subject of Ionospheric Radio Science had developed rapidly, indeed it might almost be said that it had come into being. It was in 1925 that APPLETON and BARNETT in England, and BREIT and TUVE in America, showed for the first time that radio waves could be reflected from the ionised portion of the atmosphere and, from then onwards, scientists began to realise that, on the one hand, radio provided them with a powerful tool for exploring the upper atmosphere and, on the other hand, that a study of upper atmospheric physics would help them to understand the propagation of radio waves. The year 1927 was most auspicious for the Union for another reason : it was near a time of sunspot maximum when, as we now know, many important phenomena revealed themselves to the Radio Scientist.

The Ionosphere in 1927

AUSTIN, the Chairman of the Commission on Radio Wave Propagation, in summarising the Proceedings of the 1927 Assembly said :

« A considerable portion of the time of the Commission was given to the theory of wave propagation in the upper atmosphere, the proof

of the existence of the KENNELLY-HEAVISIDE layer and its probable nature and position. No definite new conclusions were drawn but within fairly wide limits there seems to be a general agreement as to the height of this layer and as to the probable general theory of the bending of the radio waves. Among the points brought out was the evidence of the existence of more than one reflecting layer, which is one of the most interesting of the more recent conclusions. The long wave work was discussed at one meeting. There was considerable discussion of the phenomena observed in transmission over moderate distances, on the relation of the intensity of signals to solar activity, and also on that curious variation in the intensity with distance which has been observed in England in which the intensity did not fall off regularly with the distance as had been generally believed but showed maxima and minima, apparently proving the existence of interference phenomena. This exists in England in the daytime, it appears, while in America we observe similar phenomena at night, but nothing of the kind in the daytime, and it seemed a matter of considerable importance to discover just what the difference in conditions are which produce the difference in behaviour of the waves in the two countries (1).

The transmission over greater distances was also discussed. The question of the possible difference in the transmission from east to west and from west to east was mentioned, but apparently there is a considerable amount of conflicting evidence on this point and no conclusions were reached. In conclusion it was agreed that all of the work at great distances proves the great need of improvements in our methods of measurement and in our understanding of the degree of variation which is to be expected in the field intensity in different portions of the earth and under different circumstances of transmission and that the long distance problems can only be solved by a very large increase in the number of observing stations. It seems, therefore, desirable that all pressure possible should be brought to bear on the organizations which have funds at their disposal to establish such stations for a more speedy solution of our radio problems. »

It is interesting to read the specialist papers presented at the 1927 General Assembly in an attempt to recapture the frame of mind of radio scientists at that time. One of the most important experimental papers entitled « The Existence of more than One Ionised Layer in the Upper Atmosphere » was by APPLETON. In this he said :

(1) This peculiar difference between America and England does not seem to have been mentioned anywhere else in the literature. It would be interesting to know a little more about the circumstances which gave rise to the statement.

« The experimental evidence leaves little doubt that in the period before dawn the ionisation in the Kennelly-Heaviside layer (layer E) has been sufficiently reduced by recombination to permit of its penetration by waves of this (fixed) frequency. Reflection however takes place at an upper layer (F layer) which is richer in ionisation. With the advent of sunrise at a height of 100 km or so, the Kennelly-Heaviside layer (layer E) is formed again and deviation by this layer is suddenly established. The normal fall of its under boundary proceeds under the influence of solar radiation. As the day further proceeds the experimental results show that another region of ionisation (D layer) is formed below the Kennelly-Heaviside layer which while causing attenuation of the waves does not materially affect the height at which they are deviated. Occasionally reflected waves are detected from this layer. Its main function is however to absorb the waves which are only slightly bent in passing through it and which are finally deviated by layer E. It is suggested that layer D is the same as the ozone discovered by LINDEMANN and DOBSON. »

Here for the first time we have a discussion of the detailed structure of the ionosphere, the introduction of the nomenclature of the D, E and F layers, and the recognition that it is the D layer which plays the major part in absorption. The suggestion that the D layer should be identified with the ozone layer sounds a little odd at the present time.

In another paper entitled « Measurements of Effective Heights of the Conducting Layer and the Disturbances of August 19th 1927 », DAHL and GEBHARD gave an account of some of the earliest pulse experiments and earliest radio observations of an ionospheric disturbance. The oscillographic records of these experiments, published in the U.R.S.I. Proceedings, remind us that techniques in those days were somewhat crude, indeed it was only just possible to resolve a pulse reflected from the height of the F layer.

At the time of this General Assembly short waves had only recently been extensively used and there were still many long wave commercial transmitters at work. In a paper « On the Influence of Solar Activity on Radio Transmission », AUSTIN and WYMORE summarised the way in which the average strength of the signal received in Washington, from a long wave transmitter in Germany, had varied throughout the time from 1915 to 1926, and they showed in a most striking way how the signal strength followed the sunspot number. It was most fortunate that these observations had been made continuously since 1915, so that they covered a large part of the sunspot cycle. The effect of the solar cycle was so marked that it stood out clearly, even in the observations which had been made in the early

years by the elementary « shunted telephone » technique. The observations provide the first clear indication that the transmission of signals by way of the ionosphere varied through the sunspot cycle.

In another important paper entitled « Apparent Night Variations with Crossed Coil Radio Beacons » Harraden PRATT showed how radio direction finding errors varied from night to day. The subject does not appear to have been well underrstood and in summarising the experimental results the author referred to the disconcerting way in which the behaviour of a radio beacon became unreliable at night. As a result of several night flights he concluded that the indications of the radio beacon were reliable up to a distance of about 25 miles, but that they became progressively less accurate at greater distances and were so inaccurate as to be useless beyond 125 miles. He said that « several variables being involved, no conclusions had been reached as to the relative contribution of each factor, except that more steady signals were observed at fixed points on the ground than in the air at similar distances from the beacon. » It is clear that the existence of separate ground and downcoming waves, capable of producing errors by their superposition, had not yet been fully appreciated.

Accompanying the above-mentioned experimental contributions there were two historically important theoretical papers. One, by APPLETON, entitled « The Influence of the Earth's Magnetic Field on Wireless Transmission », gave in summary form his results for what is now known as the generalised magneto ionic theory. Lorentz had dealt with the two cases of longitudinal and transverse propagation, and APPLETON, using the same nomenclature, derived an expression for propagation in a generalised direction. For many years this was the only available expression to represent the full magneto ionic theory. It was not until 1932 that APPLETON published a full account of what he had given in summary form in 1927.

Another important theoretical paper was presented by HULBURT on « Ionisation in the Upper Atmosphere. » He wrote :

« Because of the diurnal variation in the ionization we choose the ultraviolet light of the sun as being the ionizing agency deserving first consideration. In order to make an explicit calculation of the ionization, the temperature, the pressure, and the constituent gases and their partial pressures must be known at each height in the upper atmosphere. These we may take as given completely in the classical thermodynamic isothermal equilibrium theory of Humphreys, Jeans and others. ... The law of the recombination of the electrons with the positive ions must be known.

For this we have J. J. Thomson's theory of recombination, and complete formulas are available. We must also recognise the possibility of the electron attaching itself to a neutral molecule, for when it does this, thereby producing a negative ion, it is no longer an energetic refractor of the wireless rays. The oxygen molecule is the only important one in this connection, and the values of the attachment coefficient measured in the laboratory for pressures of 10 mm of mercury and above must be extrapolated to pressures below 10^{-2} mm, perhaps a questionable extrapolation. The diffusion of the electrons and ions must be considered, this is a very important influence. Using all these things it is concluded that the solar ultra-violet light is a necessary and sufficient cause of the Kennelly-Heaviside layer, and that hypotheses of other agencies of ionization, such as charged particles from the sun, penetrating radiation, etc., are uncalled for except perhaps in unusual cases. Assuming the solar ultra-violet energy to be that of a black body at 6000° K and using known, or estimated, absorption cœfficients of the atmospheric gases for ultra-violet waves below λ1300 A which cause photo-electric ionization, the electron curve for the sun overhead, i. e. for high noon in summer in the temperate zone, has a maximum of 3×10^5 electrons per cm^3 at a height of 190 km. Below this the ionization can not be calculated exactly, because of the lack of many facts which future laboratory experiments may supply, but a density of 10^4 to 10^5 electrons per cm^3 or 10^9 to 10^{10} ions per cm^3 (or a suitable mixture of ions and electrons) seems possible down to, say, 100 km. This ionization is shown to explain quantitatively many facts of wireless telegraphy, i. e., the skip distances, overhead absorption coefficients, limiting waves, ranges and the apparent heights reached by the waves. Taking into account the seasonal changes in the upper atmospheric pressures and the altitude of the sun, the electron layer for winter noon is found to have a maximum of 1.42×10^5 at a height 147 km, and the ionization below this is less than the summer values by a factor of 2 or so. After sunset the maximum ionization is found to decrease by a factor of about 6 in the small hours of the morning; below the maximum the decrease is greater. The seasonal and diurnal changes in the ionization are shown to be in agreement with the corresponding variations in wireless wave propagation phenomena. »

« The potential energy of the daytime ionization in a 1 cm^2 column of the atmosphere is found to be at least 1 erg and the assumption that less than 1 % of this is liberated as light will account for the light of the night sky, or the non-polar aurora, as Rayleigh calls it. Due to diffusion of the ions along the lines of magnetic force upper ionic spray of the ionized layer diffuses to the magnetic poles, concentrates there and causes the

aurora. Calculation indicates that the ozone of the atmosphere is perhaps not directly connected with the foregoing ionization, but is formed by longer wave-lengths of ultra-violet light from λ 1300 to 1800 A. »

This remarkable paper represents one of the first attempts to consider in detail how the ionosphere was produced. It could used today as a summarising account with only small alterations in detail.

The period 1928-34

Not much new material was introduced at the third General Assembly in 1928, but we find a rapidly increasing understanding of some of the phenomena which proved puzzling in 1927. In particular there was now a greater stress on the correlation between radio transmission and solar activity. The newly observed phenomenon of skip distance was repeatedly referred to but does not seem to have been completely understood. Austin, who was again Chairman of the Commission on Radio Wave Propagation, raised a subject which, in the light of present day knowledge, was a little unexpected. He said :

« ... we should, I think, discuss certain fundamental questions as to our methods of determination of field strength. For example, how much do we really know in regard to the accuracy of the absolute measurements which we are making. In all these measurements we go back I believe, fundamentally to the reception on a loop. How sure are we that we know that we are correct ? The reception formula is easy enough to determine theoretically, but are we to consider that this reception is perhaps modified by the presence of the earth ? I think that is really an important thing to take up. It may be that our assumption have been perfectly correct but if they are not we ought to know it. I would like therefore to put this question in the hands of a small subcommittee... »

At the end of the meeting this subcommittee reported in the following form :

« The usual procedure of measuring signal intensities at the ground may be justified on theoretical grounds. The presence of the loop does not distort the field acting on the loop, though it does distort the field acting on some circuit in the vicinity. The field acting on this third circuit may be regarded as the vectorial sum of that due to the incident waves together with the waves generated by the receiving loop. »

It seems a little surprising to us nowadays that it was necessary to set up a subcommittee to get this matter straight.

At this meeting Smith-Rose presented an important paper on Radio Direction Finding, in which he gave an account of an extensive series of measurements on night errors and described several types of equipment intended to avoid them. From the clear explanation which he gave of the cause of these errors it appears that between 1927 and 1928 there had been a considerable advance in our understanding of the effects of the ionosphere.

The French National Committee made extensive proposals concerning the measuring of signal intensities received in many parts of the world from a number of specified stations. A Sub-Commission, set up to discuss the matter, recommended that certain transmitters should be observed wherever possible, and that the results should be circulated among the members of the union and should be published.

A detailed discussion of the phenomenon of skipped distance indicates that, at the time, it was not very fully understood. For example, APPLETON said :

« When the theory of skipped distances was first put forward it appeared to fit the facts. The explanation, in its simplest terms, was that there is a limited electronic concentration in the upper atmosphere and that the waves could only be deviated by the layer to a limited extent. But further work showed that signals were observed within the skipped distance and that the intensity of these signals exhibited a diurnal variation as if they were due to the downcoming waves. It seems to me important to find out whether waves are received from the atmosphere within this region... With regard to the theory of the subject Mr. T. L. ECKERSLEY has suggested that the increase of signal at the edge of the skipped distance is due to the lower absorption consequent on the increase of the angle of incidence. My own view is that we must regard the layer as a kind of rough surface and that within the skipped distance we get only scattered or diffusely reflected rays. As we go out further we pass from the region of diffuse reflection to that of true reflection and get stronger signals. Such an explanation gives the correct relations between skipped distance and wave length. »

In reporting the progress which had been made since 1927, AUSTIN drew attention to work which had been done on a detailed study of the nature of waves reflected from the ionosphere when the wavelength was about 400 metres. He referred particularly to measurements of the angle of incidence of the downcoming wave and to the fact that this angle had been found to change rapidly. It had been suggested that such rapid changes were probably caused by reflections from an uneven surface rather than by changes in the height of the Kennelly-Heaviside layer. From measurements of the sense of rotation of the elliptically polarised downcoming wave it had been shown that the reflection was caused by electrons rather than by positive ions.

In a search for round-the-world signals, on a frequency of 20 Mc/s, some workers had noticed what appeared to be retarded signals which had reached them by some shorter path than the great distance circle round the world. An entirely satisfactory explanation of this phenomenon had not been found, but it had been tentatively suggested that it was the result of reflection from a heavily ionized region near the magnetic pole, or by scattering from mountainous regions in the zones of reception beyond the skip distance. Other experiments on broadcasting wavelengths had indicated that signal strength was probably related to the temperature of the atmosphere and the barometric pressure. There had been many detailed observations or waves with great wavelength, of the order of 10,000 m.

In view of the fact that this year 1928 was one of maximum sunspots, it is not surprising that particular attention was paid to the relation between solar activity and radio wave propagation In his introductory remarks, the President of the Union stressed the need for a new mixed Commission in Geophysics to bring the astronomers and the ionospheric radio men together.

The next General Assembly was in 1931. It concerned itself largely with extending the arrangements for international collaboration and for planned experiments, particularly with relation to the forthcoming polar year in 1932. It was resolved that National Committees should organize the measurement of the height of the Kennelly-Heaviside layer, either by the method of frequency change or by that of pulses : a Sub-commission was set up to study the consequences of these results : the French National Committee undertook to collect information from its Administrations and private companies arising from measurements made on ordinary radio traffic : a Sub-commission was set up to deal with the preparation of work for the Polar Year : and arrangements were made to obtain special transmissions from NAUEN, particularly suited for the investigation of long-delayed echoes. Sub-commissions were set up to prepare programmes for special observations on the occasions of eclipses and to study the interaction of radio waves in the ionosphere. An important recommendation was to the effect that, in view of relations between the radio phenomena and terrestrial magnetic variations, values of magnetic activity for period shorter than 24 hours should be measured by magnetic observatories and should be made available to other interested workers.

Much attention was paid to the international sharing of information about the ionosphere and discussions were held leading to the setting up of the Ursigram Service. A Resolution was passed to standardize the terminology and definitions for ionosphere measurements and a list of International Days was compiled. It was further suggested that authority should be sought for an international frequency for ionosphere measurements, particularly for continuous P'(t) recording.

An interesting light is thrown on the state of our knowledge in 1931 by the discussion which preceded the setting up of the arrangements for recording the height of the Kennelly-Heaviside layer. Thus APPLETON is recorded as saying :

« It would be very desirable to carry out the measurements on two waves round 80 and 170 metres, with a view to obtaining data on the two Kennelly-Heaviside layers. »

General FERRIÉ supported this proposal but, since he believed there were not always two distinct layers, but rather a medium in which the ionization varied continuously, he thought it would be better to vary the length of the wave used, continuously back and forth around a mean value. APPLETON thought that :

« this method would be too laborious for general use, and that it was unnecessary for the following reason. In his own experiment he had already shown that a continuous variation of frequency shows only very small variations of the effective height until a critical frequency is reached near which a very small change of wavelength shows a very considerable increase in effective height, this new height being about twice the original height. If the frequency is still further reduced, the variations of this new height are again very small. »

VAN DER POL thought that each of these points of view could be defended and since the nature and disposition of the layers might vary with latitude, he suggested that both methods should be used.

The subject of long delayed echoes, which had been observed by VAN DER POL and others, was raised at this meeting and attracted a considerable amount of attention.

There was much interest in comparing the results of transmissions on long and on short waves. APPLETON asked why short waves were so advantageous and recalled

« the curve given by TAYLOR and HULBURT for the ranges of a wave as a function of its frequency for a given antenna power. This curve shows a minimum round the frequency of 1500 kc/s (200 metres) and it has been

thought that this minimum was due to the terrestrial magnetic field which might produce a resonance, but he does not think that this is the true cause of the phenomena. If however this is not the cause, then what is the cause ? »

At the 1934 General Assembly sub-commissions were set up to discuss the subjects of ionospheric measurements, including measurements made during eclipses, the results of observations made during the Polar Year of 1932, the subject of long delayed echoes and the interaction of radio waves in the ionosphere. It was recommended that for future eclipses charts should be prepared to indicate the nature of the eclipse as observed at different heights in the ionosphere.

There was for the first time discussion of the « full wave » theory of wave propagation through the ionosphere and VAN DER POL discussed the « W. K. B. solution » which is now so well known, but which in those days was new to ionosphere workers although familiar to atomic physicists. One Resolution of particular interest introduced the word « ionosphere » and defined it as that part of the upper atmosphere which is sufficiently ionized to affect the propagation of radio waves.

World-wide study of the ionosphere

In his report to the 1938 General Assembly DELLINGER, the Chairman of the Commission on Radio Wave Propagation, stated :

« Since 1934, experimental work has standardized upon the pulse echo method. The automatic multifrequency technique, formerly used in only one laboratory, is now in regular use at several widespread locations. Ionosphere measurements are regularly made in a large number of laboratories throughout the world. Extension of the number of points at which observations are made continuously is highly desirable, particularly in the polar regions. It appears that ionosphere vagaries and radio transmission difficulties are increasingly severe and frequent as the magnetic pole is approached, hence the need for consistent observation in polar regions. »

« The importance of ionosphere date in the realms of radio communication service and the cosmic sciences suggests the need of regular, prompt and widespread dissemination of such data. The time is envisaged when such a service will be analogous to the present meteorological service ..... The Report of a C.C.I.R. Committee on Radio Wave Propagation, prepared in November 1937 illustrates well the progress which has been attained in the application of ionosphere data to practical radio transmission problems.

That report recognized that long-distance radio transmission depends entirely on ionosphere conditions, and indeed presented a set of radio transmission graphs for various times of day, season, and year, based entirely on vertical-incidence ionosphere observations. The possibility of thus determining radio transmission conditions for various distances in terms of vertical-incidence observations depends on reliable calculation procedure connecting vertical-incidence with oblique-incidence transmission. Such calculation procedures have been developed and published in the past two years. Not only single but multiple-reflection transmission can be accurately computed. »

« An outstanding result of systematic observations of ionosphere and radio transmission conditions, which have now been completed for half a sunspot cycle, is that annual average curves of the critical frequencies of all layers, maximum usable frequencies for radio transmission, and sunspot numbers, all closely parallel one another. From the sunspot minimum in 1933 to the present maximum, critical frequencies and maximum usable frequencies increased by a factor of 1.25 for the E layer ans 2.0 for the F and F2 layer. This corresponds to increases of the ionization densities for these layers by factors of 1.6 and 4.0 respectively. »

« A good beginning has been made in establishing the characteristics of the three types of ionosphere disturbances : ionosphere storms, prolonged periods of low-layer absorption, and sudden disturbances causing radio fadeouts. The term « ionosphere storm » has been coined to describe the type of disturbance characterized by a diffuse and turbulent ionosphere, high virtual heights, low critical frequencies, large skip distances, increased absorption, and usually accompanied by a terrestrial magnetic storm. Its effects are primarily on the F or F2 layer. The low-layer absorption periods and sudden disturbances, on the other hand, have their seat below the E layer and are limited to the day hemisphere. »

« Efforts to study the causative solar disturbances have been generously rewarded, particularly as regards the sudden disturbances. Valuable correlations with visible eruptions on the sun have been established. Resulting research on ionizing effects of solar radiations gives promise of yielding and understanding of the mechanism of production of ionization in the earth's atmosphere causing not only the disturbances but the regular layer conditions as well. This work is of benefit to solar science as well as to radio research, since the radio observations are the only means we have of studying these ionizing solar radiations which are unable to penetrate down to the surface of the earth. »

« The French National Committee has taken a valuable initiative in correlating research work on the sudden disturbances, preparing and distributing a monthly bulletin of observed instances of the effect. This work should be continued and extended. The time is envisaged such work will be done by organization at least as extensive as that for studies of the sun which now publishes the Zurich Bulletin for Character Figures of Solar Phenomena. »

At the immediately Radio Conference of C.C.I.R., held in Cairo, the U.R.S.I. resolution of 1931 had been acted upon and an international frequency for ionosphere measurements had been allotted in the band 2925-2930 kc/s. The American group of magnetic observatories had adopted the recommendation that terrestrial magnetic variations should be recorded more frequently than at 24 hour intervals and U.R.S.I. now published separate magnetic character figures for each half-day.

A valuable report on ionosphere results obtained during eclipses was published in the Proceedings of the 1938 General Assembly. It contained a list of twenty-seven ionosphere observatories and a map of their location and it is intersting to note that most of them were run by private scientists who were not in the habit of taking routine observations.

Post-war activities

The next General Assembly was held in 1946. Of the eight years which separated it from the previous General Assembly, the war occupied six and during that time the two contestants had each, separately, realised how important a detailed knowledge of the ionosphere was for their radio communications and had established widespread networks of ionospheric observatories. In his Presidential address, APPLETON said :

« During the war, many new ionospheric stations were instituted in different parts of the world to serve the operational requirements of the Allied Forces. As accurate a picture of the ionosphere as possible was required, in certain parts of the world, in order that optimum ranges of radio frequencies for practical communication could be predicted in advance of their use. There was thus developed the subject of Ionospheric Forecasting. But, naturally, at the same time much scientific information of great value was accumulated, not all of which has yet been interpreted. But enough has been done to disclose the remarkable result that, while ionospheric events in the E and F1 layers are similarly reproduced at the same local time on the same day at all locations on a line of constant geographic latitude, the same is by no means the case for the F2 layer.

It appears, at any rate for conditions when the sun is high in the heavens, that the ionization in the F2 layer is subject to some form of geomagnetic control. This is a result which was certainly suspected in pre-war days ».

« Now that the war is over, and it is no longer necessary to plan the siting of ionospheric stations throughout the world on strategic conditions, it should be possible to site our stations more nearly according to scientific requirements. Only in that way can we hope to acquire the accurate picture of the F2 layer which is required. Our knowledge of F2 layer morphology is, for example, much more complete for the northern hemisphere than for the southern hemisphere and, in view of the shortage of land sites in the latter, it may be necessary to send out a sea expedition to get observations at the scientifically important latitudes and longitudes. »

« Two other ionospheric phenomena I might mention on which we lack world data are (*a*) ionospheric absorption and (*b*) ionospheric tides. Measurements of these quantities have been made at one or two sites but we have not got enough information to tell us how the magnitudes (and in the case of (*b*), the phase also) of these quantities vary with latitude. »

At the meeting immediately before the war, JOUAUST had been nominated Chairman of a Sub-Commission charged with studying ionospheric perturbations. When he reported in 1946, he explained that it had been impossible during the war to obtain collaboration from other countries and that attempts had therefore been made to discover how ionosphere perturbations affected naturally occurring radio atmospherics. BUREAU, in France, had made a remarkable series of measurements of this kind on what he called « perturbations ionosphériques à début brusque » (P.I.D.B.). (We should now call these events Sudden Ionosphere Disturbances (S.I.D.s.).) He emphasized that these P.I.D.B.s. occured suddenly and simultaneously over the sunlit hemisphere and at the same time as visible chromospheric eruptions and he pointed out that their formation must be due to an exceptionally strong and sudden ionization in the D region.

At this meeting attempts were made for the first time to explain the quiet-day magnetic variations in terms of what was known about the ionosphere. It was shown that the ionospheric conductivity, calculated from radio estimates of the electron concentration, was too small to explain the magnetic variations in terms of what was then known of the tidal motions of the atmosphere. It was not until later that this descrepancy was cleared up by investigating in more detail how the earth's magnetic field modified the conductivity.

The theory of the formation of the ionosphere was carried considerably further by some of the early work of BATES and MASSEY, who considered the ionization and loss processes at work in the ionosphere. For the first time since the early work of HULBURT, they inserted numerical values into the theory and showed the sort of ray in which a solution must be found to this problem.

It was at this meeting in 1946 that a long run of measurements of ionospheric absorption, made by the British Ionospheric Observatory at Slough, was first reported and attention was drawn to the « winter anomaly », in which there is an increased absorption on some days in winter months.

Several papers attempted to relate the propagation characteristics of long distance communication circuits to what was known of the ionosphere from vertical incidence sounding.

At the conclusion of the meeting, sub-Commissions were set up to organize simultaneous observations on an international scale and to study the interaction of waves in the ionosphere. Recommendations were passed that each country should establish at least one vertical ionospheric sounding station; that measurements should be made on long waves, particularly for the purpose of showing up any eleven year variation of signal strength; that observations, particularly of sudden fade-outs, zones of silence, etc., should be made by official services, by private companies and by amateurs; and that special attention should be paid to the effect of eclipses on the region F2. The International Astronomical Union (I. A. U.) was asked to arrange that records of disturbances on the sun should be made in such a way that they could be related to the corresponding observations with radio waves.

Ionospheric measurements during solar eclipses were discussed in a third report presented by the British National Committee. After drawing attention to the results achieved during several eclipses, this report stressed the need for further study of the effect of eclipses on the F region with particular reference to the possibility of a « corpuscular eclipse » effect. It also called for further study of the ionisation produced by active areas on the sun; and emphasised the need to decide whether there was any eclipse effect on abnormal E.

The Mixed Commission on the Ionosphere

The Mixed Commission on the Ionosphere was formed in 1945 by a Resolution of the International Council of Scientific Unions (I.C.S.U.) as a joint body representing the Unions on Scientific Radio, Geodesy and

Geophysics, Astronomy, and Pure and Applied Physics. It held its first meeting in 1948. From that time onwards its discussions had considerable influence on the proceedings of the Ionosphere Commission of U.R.S.I. and since U.R.S.I. was the parent Union of the Mixed Commission it is convenient to include an account of that Commission's work in this history.

At its first meeting the Mixed Commission considered what information of importance for ionospheric studies might be obtained from observation of the sun, of atmospherics, of aurorae and of geomagnetism and in addition it considered the nature of atomic and molecular processes in the ionosphere. A valuable list of unsolved problems of the ionosphere was presented by APPLETON and BEYNON, its Chairman and Secretary respectively. They asked :

« (1) What is the precise solar source of the ultra-violet light which causes the E and F1 layers ?

(2) How far do we need to invoke the additional action of corpuscles in the formation of the F2 layer ?

(3) What is the detailed explanation of the stratification of the ionosphere into several layers ?

(4) What are the nature of the atomic processes by which electrons disappear in the various layers ?

(5) Why does the scale-height of the atmosphere increase with increase of height above 100 km ?

(6) Why is the F2 layer exceptionally subject to a geomagnetic control ?

(7) What is the cause of the F2 layer changes during ionospheric and geomagnetic storms ?

(8) What is the influence of atmospheric oscillations on the ionosphere ?

(9) How far do ionospheric currents give rise to Hall effect phenomena due to the influence of the earth's permanent magnetic field ?

(10) What is the evidence suggesting the existence of ionospheric winds ?

(11) What are the ionospheric levels of the currents responsible for the quiet day magnetic variations ?

(12) What are the ionising agencies responsible for the production of sporadic or abnormal E layer ionisation in different latitudes ? »

It is interesting to notice that, 15 years later, in 1963, it is generally believed that the answers to questions 1,3,4,9, 10 are known, that the answers to questions 2, 5, 6, 8 are partially known and that questions 7, 11 and 12 remain as outstanding problems in ionospheric physics.

The Mixed Commission passed Resolutions which suggested, amongst other things, that an international network of radio observing stations should be organized during the solar eclipse expected in 1952 : that the scaling and publication of ionospheric data should be standardised : that the observations of winds and drifts in the ionosphere and the observation of sporadic E ionization should be encouraged. Two of the Resolutions were particularly important. One stressed the value of upper atmospheric research by means of rockets at places distributed widely over the earth : the other called for the early organizing of observations during the forthcoming international Polar Year in 1957 to 1958. It was this latter Resolution which led ultimately to the establishment of the International Geophysical Year, which is dealt with in Chapter VIII.

At the General Assembly of U.R.S.I. held in the same year (1948) the very numerous scientific papers covered most aspects of ionospheric science. It is noticeable that there was a considerable increase in the number of papers dealing with observations on long and very long waves and that for the first time some papers were concerned with hydromagnetic waves in a plasma and, by implication, in the ionosphere. A Report on Tides in the Ionosphere was presented and was later published as a Special U.R.S.I. Report (No. 2).

Ten Years of Progress (1950-1960)

The General Assemblies held between 1950 and 1960 were attended by large numbers of workers to whom the subject of ionospheric was new, and who represented an increasing number of new research centres. The papers presented ranged widely over the whole subject. No attempt will be made here to describe in detail what was discussed at each meeting, instead it will be shown how new topics in the science of ionospheric physics came to the notice of U.R.S.I. and how the Resolutions of U.R.S.I. encouraged new aspects of ionospheric research.

The Assembly of 1952 was noticeable as being the first at which the topic of ionospheric forward scatter was discussed : this topic continued to interest U.R.S.I. at succeeding General Assemblies. Also in 1952 there were, for the first time, papers dealing with the tensor conductivity of the ionosphere and the whole problem of the relation of the ionosphere to the regular magnetic variations was beginning to be sorted out. Ionospheric storms were, also for the first time, analysed in the same way as magnetic storms into two parts known as the solar variation (SD) and the storm-time variation (Dst) respectively.

Resolutions passed in 1952 encouraged the world-wide study of movements in the ionosphere; the measurement of ionospheric absorption through observation of the strength of galactic noise; and observation of the aurora by radio.

At the meeting of the Mixed Commission which immediately followed the General Assembly of 1952 the morphology of ionosphere storms and the tensor conductivity of the ionosphere were discussed in considerable detail. An account was given of the results of ionosphere measurements made during the solar eclipse of February 1952. The Resolutions of this Assembly called for measurements on magnetic gradients for the purpose of determining the height of the auroral electrojet, and made the far-seeing suggestion that suitably trained theoretical and experimental physicists were needed in the field of ionosphere research, and that they should have a knowledge of the electro-dynamics of ionized media.

In 1954 attention was mainly concentrated upon the behaviour of the ionosphere at high latitudes, the morphology of the D layer, and rocket investigations of the ionosphere. The following important and far-reaching Resolution was passed :

« Study of Solar Radiation in the Upper Atmosphere. — U.R.S.I. recognises the extreme importance of continuous observations, from above the E region of extra terrestrial radiations, especially during the forthcoming A.G.I. »

« U.R.S.I. therefore draws attention to the fact that an extension of present isolated rocket observations by means of instrument earth satellite vehicles would allow the continuous monitoring of solar ultraviolet and X radiation intensity and its effects on the ionosphere, particularly during solar flares, thereby greatly enhancing our scientific knowledge of the outer atmosphere. »

This Resolution played a large part in initiating the ionospheric satellite experiments made during the I.G.Y.

Other Resolutions put forward by the Commission were largely intended to make the reporting of world I.G.Y. results more uniform. An important recommendation which led to a considerable improvement in the correlation of magnetic and ionospheric data was that magnetic disturbance indices Kp should be determined at quarter-hourly intervals during the I.G.Y.

A Sub-Commission was set up to standardize the nomenclature in magnetoionic theory. At the associated meeting of the Mixed Commission it was arranged to hold a special symposium on the subject of solar eclipses and the ionosphere. This symposium, held in London in August 1955, was highly successful and resulted in one of the most valuable of the U.R.S.I. publications (1956).

In 1957 the Mixed Commission proposed that a joint study group should be set up between those concerned with electromagnetics, hydromagnetics, and fluid mechanics, to study the problems of irregularities in the ionosphere. As a result, an International Symposium on Fluid Mechanics in the Ionosphere was held at CORNELL in July 1959. The chief outcome of that conference was the suggestion that ionospheric irregularities need not necessarily be the result of « turbulence » in the normally accepted sense, and it was suggested that they could be caused by gravity waves in the atmosphere.

It was at the General Assembly of 1957 that U.R.S.I. first realised the scientific value of curves showing electron-density height-distributions deduced from ionograms (the so-called « electron-density profiles ») and a working group was set up to recommend the best procedures for calculating them. In 1957 also there was much discussion of the ionospheric phenomena accompanying the large solar flare of February 1956. These phenomena had been surprising, and together with the equally surprising cosmic ray phenomena they formed the first observed example of what is now called a Polar Cap Event. The Event of 1956 happened to be an exceptionally large one, its consequences had been widely observed, and ionospheric investigators were stimulated to make a detailed study of similar events during the I.G.Y.

At the Assembly of 1960 a joint session was held with Commission IV (Radio Noise) on the subject of naturally occurring radiations of very low frequency, their origin, and their propagation. These radiations, which include « whistlers », « chorus », and other phenomena, are of fundamental importance to the theory of the ionosphere, but it had been tacitly agreed at the Assembly of 1953 that they should be considered by the Noise Commission (IV). It was, however, now becoming clear that the subject of ionospheric physics covered a much wider field than had sometimes been supposed. Whistlers and associated phenomena provided information about the upper parts of the ionosphere, above the peak of the F region. So did rocket soundings, and the elegant method of « incoherent scatter », described for the first time at the 1960 meeting. It was realised that some changes in the organisational structure of U.R.S.I. were necessary if these wider implications of ionospheric physics were to be represented properly, and the Chairmen of Commissions III and IV were invited to make suggestions. In case the subject of radio noise of terrestrial origin might be related, organisationally, to that of tropospheric physics, the Chairman of Commission II was also to be consulted.

At the 1960 meeting a Special Report on Radio Observations of the Aurora was presented and was published in 1961. At the same meeting an important Resolution concerned the sunspot minimum year (later the International Quiet Sun Year (I.Q.S.Y.)) : it urged all National Committees to participate as fully as possible in organising ionospheric investigations.

Apart from the formal proceedings of the Commissions at the London General Assembly a « Monograph on Ionospheric Radio » was published in 1962 containing the principal scientific papers and discussions thereon presented at the Assembly. Among others these included a review of rocket and satellite observations related to the ionosphere, which resulted from the proposal first made by the Mixed Commission in 1950, and developed to a practical achievement during the International Geophysical Year, 1957-58.

Retrospect and Prospect

How has the subject of ionospheric physics been seen by members of U.R.S.I. over the last 50 years, and what might possibly be its future? Up to 1939 U.R.S.I. saw a gradual growth largely due to the efforts of a few workers in no more than five or six research centres. The main facts concerning the E and F1 layer became clear, and it was beginning to be realised how complicated was the behaviour of the F2 layer. It was realised that disturbances of the ionosphere were related to disturbances in the sun and the distinction between sudden ionosphere disturbances (S.I.Ds.) and ionosphere storms was realised.

The war brought with it world wide networks of ionospheric observatories from whose results it became clear that the earth's magnetic field played a key role in controlling the F region. After the war many new groups of experimental and theoretical investigators became interested in ionospheric physics and brought to it new ideas and techniques. Theories of the atomic and molecular processes in the ionosphere were elaborated; the role of the earth's magnetic field in influencing the ionosphere's conductivity became clear, and there was progress in linking our knowledge of the ionosphere to our ideas about the dynamo theory of terrestrial magnetism. Methods were found for deducing electron density height

variation (« profiles ») from ionograms of the type made by ionospheric observatories. Advances in techniques led to measurement of ionospheric irregularities and their movements, to studies of ionospheric scatter, and to the use of rockets.

The International Geophysical Year, which was organised at the time of the greatest solar activity so far recorded, was the occasion for an intensive study, particularly of the ionosphere in the Polar Regions. The existence, and the nature, of « Polar Cap Events » were established. Towards the end of the period under review methods were developed for studying the « topside » of the ionosphere, above the peak of the F layer. These include the use of rockets, the observation of whistlers, and the method of incoherent scatter.

Ionosphere research in the immediate future might be expected to concern itself more and more with « topside sounding » by the methods already mentioned and by means of ionosondes carried in satellites. The results might be expected to throw light on the constitution and temperature of the highest parts of the atmosphere and the way in which it merges into the outer parts of the solar corona. The part played by charged particles in producing, or influencing, the ionosphere should soon become clearer. It is to be hoped that the glamour of some of these newer problems will not entirely distract attention from unsolved problems of the lower (« bottom side ») ionosphere, amongst which are some of those listed at the first meeting of the Mixed Commission.

Theories in the immediate future are likely to be concerned more and more with the ionosphere considered as a plasma, and with the propagation through it of hydromagnetic waves and of gravity waves.

In the near future U.R.S.I. will find it necessary to reconsider its organisation into Commissions. The subject of Ionospheric Radio is already too wide to be covered by one Commission of the size normal for the Union.

Chapter IV.

Radio Noise

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1. — General Survey

When the possible formation of an international radio union was first discussed in 1913, eighteen years had elapsed since Professor POPOV had started to record the electrical disturbances from lightning discharges. In this period, much effort and ingenuity had been expended in attempts, usually based on fallacious arguments, to mitigate the interference caused by these discharges to the long-wave radio-services then in use, but little progress had been made towards an understanding of the nature of the disturbances, commonly known as atmospherics, strays, or (operationally) X's. In 1902, Captain (later Admiral Sir) Henry JACKSON had reported that nearly all lightning discharges caused atmospherics, whether or not they were visible at the receiving station. The phenomena were found to be less prevalent in temperate than in subtropical regions and, in the Mediterranean area at least, were more prevalent in summer and autumn than in winter and spring. He also maintained that the occurrence of lightning discharges, in addtion to producing interference, could affect the propagation path of a radio circuit, usually adversely but sometimes enabling a signal to be received at greater distances than was normally possible.

This, then, was the state of knowledge in 1913 and in the provisional programme of international co-operation which was drawn up, the necessity for a better understanding of the nature of atmospherics was recognised by the inclusion of an item :

« simultaneous measurements, at the various receiving stations, of disturbances due to atmospherics ».

The structure of the Union, as formulated in 1919, included a Commission (N° III) on Atmospherics. A programme of research was drawn up at the 1922 Assembly, initially relating to the « periodicity » (rate of occurrence) of disturbances. Suggestions for a more comprehensive programme then emanated from National Committees, particularly those of France and the United Kingdom, where studies af atmospherics were being most actively pursued. The proposals were discussed in detail in Washington (1927) and the work then recommended included listening tests, recording of atmospherics, direction finding, delineation of waveforms, and studies of the energy spectrum, nature and location of sources, distance of propagation and temporal variations. This comprehensive and somewhat ambitious programme set the pattern of work for the next thirty years.

In Brussels (1928) the Commission concentrated on the details of a proposed programme of measuring noise at a number of frequencies, to determine the energy distribution, and discussed rules to ensure that observation techniques were standardised as far as was necessary.

The Copenhagen Assembly (1931) reaffirmed the programme previously agreed, and emphasised its relevance to the forthcoming second Polar Year. In the event, the incidence of the Polar Year did not result in any marked expansion of the noise programme, although some measurements were made at high latitudes. However as this Assembly agreements for co-operative work were extended, for example by providing for simultaneous recording of waveforms and the reporting of visible lightning. The close assaciation between the radio and meteorological aspects of this field of study were recognised and possible collaboration between U.R.S.I., the International Meteorological Committee (later to become the World Meteorological Organisation) and the International Union of Geodesy and Geophysics (U.G.G.I.) was discussed.

In London (1934) various new fields of study were added to those already adopted. These included detailed photographic and visual recording of lightning flashes and simultaneous recording of the electrical field changes in their vicinity, and a study of the newly-discovered extra-terrestrial sources of noise. Whistling atmospherics, or whistlers, were also discussed but it was considered premature to recommend any collaborative or standardised measurements.

The next Assembly, in Venice and Rome (1938) found that it still remained to be proved that all atmospherics of terrestrial origin originated in thunderstorms, and recommended further simultaneous recording of waveforms and directions of arrival, at locations near to the storm areas, to be carried out on designated « International Days ». This Assembly stressed the value of thunderstom location, by direction finding, to meteorology, and also recommended that observations of whistlers should be organised. The recording of integrated noise at VLF, previously recommended as a means of determining the energy spectrum, was now recognised as useful for studying ionospheric disturbances.

Much of the work on atmospherics ceased during the war but some continued and even intensified. For example studies of waveforms of atmospherics were continued in France, where only work involving reception was possible, while in England the difficulty of obtaining meteorological data from continental Europe and from the Atlantic Ocean resulted in renewed interest in direction finding of atmospherics for locating thunderstorms. Requirements for data on atmospherics as a source of interference to radio services led to a survey of existing information and to the production of the first charts showing estimates of the world-wide distribution of noise.

On the resumption of U.R.S.I. activities in Paris, in 1946, Commission III once again formulated a programme in broad terms. Proposed activities were in three categories :

(*a*) origins of terrestrial atmospherics and relations with meteorological phenomena ;

(*b*) Propagation and world distribution of atmospherics ;

(*c*) Extra-terrestrial radio noise.

The last of these categories, which had arisen originally from a study of atmospherics, developed into radio-astronomy which was to become the subject of a separate commission in 1948. Its development therefore, is not within the scope of this review. Indeed, noise from extra-terrestrial sources soon ceased to be known as atmospherics.

As an indication of the topics of interest at that time the subject matters of the papers presented at the Paris Assembly may be listed. They included propagation, location of sources, waveforms, nature of lightning discharges and other meteorological factors, spectrum of noise and use of atmospheric noise levels as an indication of the occurrence of ionospheric storms.

At the Stockholm Assembly in 1948, an attempt was made to restart co-operative experiments by recommending simultaneous measurements with standardised techniques. Integrated noise, single atmospherics and directions of arrival were to be studied. A common system of classification of waveforms was considered desirable and the need for co-

ordinating the relevant activities of U.R.S.I. and W.M.O. were re-affirmed. W.M.O. had expressed an interest in the electrical properties of dust-storms, which had received little attention. A further venture in co-operation was the formation in 1946, of a Joint Commission on Radio Meteorology, between U.R.S.I., U.G.G.I., and the International Union of Pure and Applied Physics (I.U.P.A.P.), the first meeting of which took place in 1948.

It was at this Assembly that the Commissions were reorganised and radio noise became the responsibility of Commission IV, on Terrestrial Atmospherics.

In 1950, in Zurich, the ties between U.R.S.I. and the International Radio Consultative Committee (C.C.I.R.) were strengthened, and this was particularly apparent in the subject of terrestrial noise. C.C.I.R. were in fact studying, for communications purposes, some of the noise problems which had been discussed over the years by U.R.S.I., and they sought the advise of U.R.S.I. on the question of what parameters of the noise were most relevant to interference.

Two other important landmarks occurred in this Assembly. The first was the discussion of proposals for measuring the detailed structure of atmospheric noise (as distinct from single atmospherics) and specifying the results in terms of a series of statistical parameters. The second was the presentation of spectrograms of whistlers, in a form which was to become familiar in the next few years.

By 1952, preliminary plans were being made for the proposed International Geophysical Year, 1957-58, and discussions took place at the Sydney Assembly. An event of considerable importance to the programme was the presentation of the theory of whistler propagation along magnetic-field-aligned paths in the Earth's outer atmosphere. A programme designed to verify this theory was an important I.G.Y. activity. At this meeting, also the topic of man-made noise was introduced.

The Hague Assembly, in 1954, gave more detailed consideration to the I.G.Y. programme. The need for the measurement of more statistical noise parameters was emphasised and a continuing working party was given the task of preparing, by the next Assembly, recommendations on what parameters should be measured in order to assess the probable interference to radio services. Another working party was set up to exchange waveform records of atmospherics and to seek agreement on their interpretation.

About this time there was renewed interest in propagation at very low frequencies and much theoretical work was being done. The analyses of waveforms of atmospherics were largely aimed at checking the various theories which were propounded.

The working party set up to consider the parameters of noise presented its report to the Boulder Assembly (1957) and it was recommended that the findings should form the basis of an U.R.S.I. Special Report. Commission IV then also gave attention to the terminology used in atmospherics work appreciating that in the study of whistlers and other VIF noise phenomena particularly, rapid developments had led to the need for many new terms. The Boulder Assembly gave detailed consideration to the measurements which were being done during the I.G.Y.

The London Assembly (1960) was concerned largely with a review of the results obtained during the I.G.Y. In the studies of atmospherics, along traditional lines, attempts were being made to integrate more closely the work on the meteorological characteristics of the source, on the nature of single atmospherics, on means for estimating the numbers of lightning discharges and on the integrated noise from many sources. Means were discussed for using the more comprehensive noise data which were becoming available, particularly as a result of the I.G.Y. In work on whistlers there was an increasing field of interest common to Commission III and IV and a joint session was held to discuss the exosphere. There was also a joint session on the rapidly growing subject of hydromagnetic waves and ELF propagation. The text for the special report on the measurement of noise was approved and was published early in 1962 (Special Report no. 7).

2. — Measurement of the intensity of atmospherics

The early work on atmospherics was designed to help communications engineers to assess the interference likely to be experience at different frequencies. Before long it was realised that an understanding of the physical processes involved, including the mechanisms of generation and propagation, was required, and the work branched into various interesting new lines. However, the assessment of the energy spectrum remained an important part of the programme.

The initial suggestion in 1928 was for measurements to be made in a fixed bandwidth of 25 c/s at frequencies of 20, 65, 130, 1500, 4000 and 12 000 kc/s. The parameter to be measured was the mean field strength, absolute values being derived by using a calibration circuit. It was envisaged that one station for every 100 000 square kilometres would be needed to give the overall world picture, and uniformity of equipment, particularly aerial characteristics, was emphasised. It was intended that world charts of atmospheric noise intensities would be drawn from the results of this survey.

The General Electric Company of America offered to provide thirty-six equipments to start this survey, the design to be the responsibility of U.R.S.I. Unfortunately the prototype apparatus undergoing tests at the factory was, somewhat ironically, struck by lightning, and the 1929 depression stopped the work. Altough it was hoped that the stoppage was reported at the end of 1930 that « business is still rather dull » and there is no more than passing reference to this project in later U.R.S.I. proceedings. The situation was aggravated by the fact that the British equipment which had been used for this type of measurement had been destroyed by fire in 1927, and the production of new equipment was slowed down in the expectation that the standardised equipment would become available soon. Some data were available from the early measurements and showed diurnal seasonal and annual variations. Surprisingly they also indicated a minimum of the noise intensity spectrum at a frequency of about 60 kc/s, a characteristic which has not been revealed by any later measurements

In the meantime further consideration was being given to the form which the measurements might take. The opinion was expressed that the proposed international programme was over-ambitious, and more modest proposals for measurements on only three frequencies, 12, 50 and 90 kc/s were agreed. It appears, however, that the various workers had acquired experience with their own designs of apparatus and that the prospects of universal standardisation of techniques were not bright. In particular, methods based essentially on counting the number of atmospherics exceeding a specified amplitude were current in France, while elsewhere the average field strength was measured. Comparisons between the two methods were essential step towards standardisation. There was considerable controversy even on the precise frequencies to be used, partly because some workers were reluctant to change and partly because interference from station transmissions was already becoming a problem. Arguments between the protagonists of the various systems of measurement became heated at times, to the point where one worker referred to another (not at U.R.S.I.) as « the arch-offender in disregard of quantitative specification. »

At the London Assembly in 1934 it was deemed opportune to pass a resolution increasing again the number of recommended frequencies of observation to nine, covering the range 12 kc/s to 20 Mc/s, but there is no evidence that even the more modest programme previously agreed had made any significant progress. The reasons were probably, first, that other aspects of atmospherics research, notably direction finding and the study of the source characteristics, were claiming greater attention and, second, that the increased use of hight frequencies for long distance communication, with their relative freedom from atmospherics, may have raised some doubts as to the practical need for further measurements of noise intensities. However some measurements were made by operators of radio services.

During the war, regular recording of noise amplitudes was continued in some countries, for example, France and Switzerland, but more with the object of studying the ionosphere than the noise itself. The emphasis in this work was placed on low frequencies.

The need for operational data on noise led to a plan for measurements by a so-called subjective method and a network of stations was set up, soon after the end of the war, under the joint auspices of Australia, the United Kingdom and the United States. Standardised equipment operating at high frequencies was used and the technique was to compare the noise, picked-up on an aerial, with a locally generated radio-telegraph signal of adjustable intensity. The strength of this signal required to provide a specified standard of intelligibility was taken as a measure of the noise.

Another wartime activity had been the collection af all the available noise data and the compilation of world charts showing noise distribution. Subsequent measurements were often designed to check the validity of these charts, and in Zurich, in 1950, attention was drawn to some discrepancies. This period showed a marked increase in collaboration between C.C.I.R. and U.R.S.I.; C.C.I.R. asked for advice on what were to be regarded as the most significant parameters of noise from which interference could be deduced, and U.R.S.I. encouraged research on this question. It was agreed that the adequate description of noise required the measurement of more than one parameter, and the amplitude probability distribution was suggested as a means of presenting more complete information on the amplitude characteristics of the noise.

In the meantime the network of stations for measuring noise was being extended. A station in Greenland was operated by Denmark, and measurements in Japan, previously carried out at low frequencies, were extended to the high frequency range. The so-called mean level recording in France was given more quantitative significance by defining the threshold levels of the equipment. In measurements in general, more care was being taken in the precise description of the important characteristics of measuring equipment, for example, the bandwidth and the effects of automatic gain control, when used.

Attention was then again paid to the possibility of introducing standardised equipment which would measure, preferably automatically, parameters of the noise which could be defined unambiguously in simple mathematical terms. However, for the time being the subjective method was continued at HF and the technique was even extended by the use of new equipment operating in the range 15-500 kc/s. Some work was done using the interference to radio-telephone and teleprinter services as a criterion of the noise intensity.

The period from about 1954 was marked by one or two definite trends. One was the gradual adoption of mean noise power as the characteristic of the noise on the basis of which different results could be compared in absolute terms. As a step in this direction the world-wide noise data which had been collected and plotted during and just after the war, and expressed in terms on interference to various types of radio service, were converted to give the first estimates of the distribution of received noise power. New curves and charts were published under the auspices of the C.C.I.R. Where the average field strength was being measured, studies of the noise structure were made to enable noise power to be deduced, and the more difficult task of converting quasi-peak measurements and direct measurements of interference into noise power was attempted. Another trend was an increase in the recording of amplitude probability distributions as a means of specifying the amplitude characteristics more completely. The « time of occupation » or the percentage time for which a given field strength was exceeded by the noise was another measured parameter compatible with the amplitude distributions, in that it gave one point on the distribution curve, and another related parameter was the number of times per second that the noise envelope crossed a given threshold, or a series of thresholds. Noise power, average noise field strength and amplitude probability distributions were the main characteristics which were recommended for measurement by the Working Group set up in 1954 to consider what parameters were most relevant to interference, and they became the main objective during the I.G.Y.

Some studies were being made of the relative importance of atmospheric and man-made noise, to determine particularly how free from man-made noise a site needed to be for the measurement of atmospherics. Some tests on a very remote site in the United States showed that at some frequencies and times, measurements of atmospherics could be invalidated by power lines at distances of the order of a mile.

The I.G.Y. provided additional stimulus for the noise programme and the number of stations was greatly increased. A network of 16 stations for measuring noise power automatically, on eight frequencies, was set up, using equipment designed in the United States, and at many of these stations the average field strength and the mean logarithm of the field strength were also recorded, providing some indication of the noise structure. Other countries concentrated on recording amplitude probability distributions and the U.S.S.R. set up a network of stations for this purpose. At some stations, notably in Singapore, as part of the United Kingdom programme, measurements of probability distributions were made in parallel with automatic measurements of noise power, to provide a comparison between the techniques. In the United States studies were made of the effect on the probability distributions when the receiver bandwidth was varied, and in Japan, Sweden and the United Kingdom comparisons were made between objective and subjective methods. Measuring programmes were carried out in India using various techniques.

One of the difficult problems in atmospheric noise work is the presentation of a large quantity of data in a simple, summarised form which preserves the main features of the changes with frequency and time. This is particularly true in considering amplitude probability distributions, where the results of a measurement are in the form of a curve rather than a single parameter. Many attempts have been made to represent a typical curve by a simple mathematical function which can be defined in terms of a few (usually two or three) parameters. None of these attempts has been wholly successful when applied to a wide range of frequencies, but considerable empirical knowledge has been accumulated on the most probable form of a distribution at a given frequency and time.

In atmospheric noise investigations long-term synoptic measurements are required, and many of the stations set up for the I.G.Y. are continuing observations over a period of many years. In addition attention has recently been turned to some additional statistical parameters of the noise, such as the distribution of the durations of noise bursts and of the intervals between them.

All the intensity measurements referred to so far have related to the noise resulting from the combined effects of all received atmospherics, irrespective of the location of the sources. There have also been many measurements of the amplitudes of single atmospherics. Most of these have been made with wide band receivers, but sometimes the records have been Fourier-analysed to determine the spectrum. In other instances, particularly in the last few years, amplitude measurements of single atmos-

pherics have been made in narrow band receivers tuned to different frequencies distributed through the radio spectrum. Estimates of the distances of the sources have been made so that results can be normalised to the same distance and compared, and even interpreted in terms of an effective radiated power from the source. In this way the distribution of energy through the major part of the spectrum is now known, to a first approximation, and a start has been made on correlation of data on single atmospherics with noise from all sources.

3. — Counting Atmospherics

Counting atmospherics can be regarded as a form of intensity measurement, but has been given long and special attention. Professor Popov's experiments, started in 1895, were designed to count the number of received atmospherics and counting techniques have been widely used ever since. Intensity recording, based on counting has long been used, particularly in France and Switzerland, to show relative changes, and more recently has been given absolute quantitative significance. The early British work involved the determination of the number of atmospherics exceeding various defined thresholds. The atmospherics were those recorded in a wide bandwidth, including most of the VLF and LF ranges, and it was reported at the 1928 Assembly that the number was approximately proportional to the inverse square of the threshold. With a threshold of 10 mV/m the number received at locations in Europe and North Africa varied between 20 and 300 per minute, depending on place and time, while in the Red Sea area, with a threshold of 1/2 mV/m there was a diurnal variations from 100 per second in the early morning to about 300 per second in the afternoon. In Khartoum, counts were often greater than 1000 per second at night. It is not clear whether these could all be regarded as separate atmospherics, from different sources, or whether they were peaks, of which several could occur in one atmospheric, but in 1925 it was estimated from meteorological studies that a normal incidence of lightning was 100 flashes per second, in 1800 thunderstorms, in the world as a whole. These figures have not yet been seriously disputed.

The statistical amplitude measurements in recent years have included records of the number of times per second that a given threshold is exceeded by the noise envelope. The measurements have been made with narrow band receivers and while the results at low frequencies represent, approximately, the number of separate atmospherics, this is not so at higher frequencies where the atmospherics consist of bursts rather than separate impulses.

Many radio engineers, power engineers and meteorologists have designed instruments for counting near lightning flashes. Their instruments have nearly all consisted of wideband, low-frequency receivers with a counter operating at some specified threshold level. Comparisons between them bave been undertaken in many countries and one oı two designs have come into widespread use. One particular design was recommended for use during the I.G.Y. and was adopted by several countries, but progress towards establishing a world-wide network is slow.

4. — **Waveforms of Atmospherics**

It is not entirely appropriate to discuss the recording of waveform of atmospherics as a separate topic. The technique has been used for studying the nature of the source, the propagation medium, for locating sources, etc, and it is logical to discuss these various applications in other sections concerned with these objectives. Nevertheless, waveform recording has played such a prominent part in atmospherics programmes that some general comments should be made particularly as many waveform investigations yielded data on a variety of topics.

The waveform of an atmospheric is simply the record of the time variation of the field. The atmospheric will have been modified by the characteristics of the receiver, especially if the pass-band is restricted, but nearly all so-called waveforms have been recorded with wide band receivers, accepting most of the energy with frequency components below 100 kc/s.

Waveform studies can be regarded as having started with the recognition that there were at least two types of disturbance, clicks and grinders, which had quite different characteristics. Rapid progress in understanding the structure of these disturbances began to be made when the cathode ray oscilloscope became available in the 1920's. At first it was necessary to record the oscillograms by handtracing, and only the main features were discernible. A general division of waveforms was made into those which were essentially unidirectional and those which were oscillatory. There were many arguments about whether the interference to radio was caused by the energy represented by these main field changes or by that associated with the smaller but rapid variations which could be seen, but not recorded accurately with the techniques then available.

By 1934, techniques, including photographic recording, had been developed to the stage where the detailed fluctuations could be studied, and attention was turned to the variations in waveform with the distance

of propagation, and to the explanation of features of the waveform in terms of the known electrical characteristics of lightning discharges. Notable work was done in South Africa where the Boys camera was used to photograph the different components of the lightning flash. Waveforms were classified into various types, in which account was taken of features resulting from both source and propagation effects. The search for a classification acceptable to most experts continues to the present day.

At the 1938 Assembly, simultaneous recording of waveforms at a range of distances from storms was recommended, one object being to determine whether there were terrestrial sources other than those in the storms.

After the war the recording of waveforms was resumed with enthusiasm. It was revealed at the 1946 Assembly that considerable work had been done in France. The fine structure had been studied and various details attributed to leader strokes, return strokes and strokes in the cloud.

The influence of propagation was shown to be of great importance, and one interesting type was shown to result from multiple reflections, of an initial short pulse, between the earth and the ionosphere, now known as a reflection-type waveform. This was essentially a night-time phenomenon and both the height of reflection (75-90 km) and the distance of source could be deduced from suitable waveforms.

The pre-war U.R.S.I. recommendation for simultaneous recording of waveforms was reaffirmed, for various purposes and a plea was made for greater standardisation of recording techniques. One fundamental difference in methods was that some recorded variations in electric field while others recorded the rate of change of this field. Agreement as to which is more valuable has not yet been reached, but some workers have recorded both parameters. One advantage of recording the field itself was that components having the lowest frequencies were not obscured. For example the « slow tail », having frequency components of the order of 500 c/s, and having a different apparent speed of propagation from the components of higher frequency, could be studied.

Efforts to record waveforms simultaneously at several places were given added stimulus during the I.G.Y., and several networks were installed. The main objective was low frequency propagation research, which is described in section 6.

The early work on waveforms was concerned largely with the larger and more rapid field changes recorded at low frequencies. As these became reasonably well understood, interest extended both downwards and upwards in frequency. With recorders responding to lower frequencies, it became evident that the atmospherics consisted of slow changes in field of long duration (up to a second or more) with the more rapid changes superimposed. Waveform records at high frequencies showed that energy was often radiated more or less continuously through both the slow and more rapid low frequency changes. The later stages of this work have been facilitated by the adoption of magnetic-tape recording, first at low frequencies and then, by the use of frequency-change techniques, to studies of high frequency waveforms.

It is interesting to note that the use of magnetic methods of recording atmospherics was foreshadowed in the following suggestion by Dr. (now Sir EDWARD) APPLETON, recorded in the account of the 1927 Assembly.

« It is proposed that each country within signalling range of a broadcasting station should record by telegraph and send (telegraphone records) to a central bureau. The telegraphone is an apparatus in which an iron wire moves between the poles of an electromagnet so that the incoming signals are recorded magnetically on the iron wire. The iron wire may be made to reproduce the sound again. »

5. — Identification and location of sources of atmospherics

Altough from the earliest days of radio it was recognised that lightning discharges produced atmospherics, there was, at the first meetings of U.R.S.I., considerable divergence of opinion on the question of whether all, or even most atmospherics were caused by lightning. Another question of controversy was whether atmospherics were received only from near sources or whether they could travel over long distances.

The first step towards resolving these problems was the organisation of tests in which a number of listeners to broadcast talks were provided in advance with copies of the text and were asked to mark on the scripts the words, syllables or intervals which were interfered with by atmospherics. It appeared that observers up to 2000 miles apart could hear the same atmospherics, but the results were considered by some not to be conclusive. One suggestion made was that lightning discharges near the broadcasting transmitter affected the aerial in such a way that the disturbances were radiated, together with the programme. Later stages of the argument centred around the differences between « clicks » and « grinders ». One school of opinion stated that clicks were from nearby sources and that grinders were from greater distances, while others thought that the opposite was true.

The development of the cathode-ray direction-finder for atmospherics research helped to settle these arguments, for it was found possible to plot the locations of sources and to correlate these with the occurrence of thunderstorms. In Japan, directional observations showed that grinders came from one predominant direction irrespective of season, while clicks were larger and showed a greater variability in occurrence and direction, suggesting that their sources were nearer than those of grinders. The conclusions from the directional work were that noise could be received in temperate regions from the main equatorial regions but these sources could be obscured by nearer thunderstorms.

In retrospect it seems probable that the differences of opinion on the estimated ranges of atmospherics were caused largely by differences in receiver sensitivity. The use of insensitive receivers would naturally decrease the chances of recording atmospherics from distant sources and give a false impression that only nearer sources were effective. By 1932 nearly all workers were in agreement that atmospherics could be received at low frequencies from ranges of several thousand kilometres. It was also agreed that lightning discharges were an important source of atmospherics, but there was still controversy on whether there were other sources of comparable importance. The situation is clouded to some extent by uncertainly regarding the definition of lightning. If the term was restricted to discharges which were visible from the ground, there vould undoubtedly be atmospherics from discharges obscured by clouds, and these may not have been regarded as lightning. Nevertheless it does seem that there was a strong belief, by some, in an entirely different mechanism. Thus in 1931 it was stated that a proportion of sources of atmospherics could not be placed in the neighbourhood of storms, or even of cumulo-nimbus cloud. Even in 1938 the results of a long programme of research in Italy were said to show that most atmospherics did not originate in storms. There was some evidence that as recording techniques improved, the proportion of atmospherics which could not be positively associated with storms decreased, but there is no doubt that many workers up to the war and even afterwards believed that there were instances of atmospherics being received from areas free from storms. This question has not yet been finally resolved, but there is little doubt that with the exception of purely local corona effects, any natural terrestrial noise other than that from lightning discharges must be comparatively insignificant.

Whatever doubts were expressed on the mechanism of generation, work proceeded apace on the location and tracking of the sources on the assumption that most of the atmospherics came from storms and that methods of location were of potential value to meteorology as well as to radio-communication. Two broad types of direction-finder were in use in the 1930's. One first suggested in 1916 was the cathode-ray direction-finder which enabled directions of individual atmospherics to be recorded. By the co-ordinated use of several such instruments in a network, the source of each atmospheric could be located. The second type was a recorder with a rotating beam aerial, which enabled the directions of received atmospherics to be recorded on a pen chart. Early models had broad aerial beams but in the later « narrow sector recorder » a narrow beam was achieved effectively by superposing differentially the patterns of loop and rod aerials.

All these instruments were subject to errors which became more evident as the work proceeded, but they enabled the main sources to be identified and showed how these moved with time of day and with season. Both types of direction-finder embodied loop aerials which were known to suffer from polarisation errors and work was started on a cathode-ray direction-finder based on vertical rod aerials (Adcock). Considerable technical difficulty was experienced however and the work fell into abeyance.

It was hoped that a world-wide network of direction finders could be set up and that by co-ordinated observations all the important sources could be mapped. Many countries did indeed install direction finding equipment, and some collaborative measurements were made, but the task of correlating the results of all installations was very great and did not progress far.

Networks for tracking sources of atmospherics, and therefore thunderstorms and associated fronts, became particularly valuable during the war, when many sources of meteorological information ceased to be available. Marked advances in instrumental technique were made, but after the war, when comparison between the results of the various countries became possible, it was observed that the locations plotted by the different networks were not always in agreement, and co-operation efforts between U.R.S.I. and W.M.O. were recommended to resolve these differences. Directional errors were particularly noticeable at short ranges, and the influence of site irregularities on accuracy was found to be much larger than had previously been supposed.

By 1950 considerable interest was being shown in the possible location of thunderstorms from a single station, by measuring both distance and direction of arrival. The studies of waveforms had suggested two possible techniques, one depending on the increase with distance, in the time separation between the high frequency and low frequency (slow tail) components of the atmospheric and the other on the analysis of waveforms in wich « echoes » occurred owing to multiple reflections between the earth and the ionosphere. Another possible technique depended on the observation of the highest frequency (in the HF range) on wich an atmospheric was received, and the correlation of this with ionospheric information to give the distance. In France and Switzerland information on the broad distribution of sources was obtained from a study of the behaviour of the received noise as the sun rose and set along the propagation path. All these techniques were shown to be feasible under certain conditions but none was considered capable of providing regular and reliable information sufficiently rapidly for meteorological forecasting purposes, as did the purely direction finding methods.

To obtain more information on the world-wide distribution of sources, a series of direction finding measurements was made by France on board ship, mainly in the southern hemisphere. These experiments confirmed that the main sources were in the equatorial land masses and also showed that the Pacific Ocean was a large diffuse source. It was reported that no atmospherics were observed from the direction of the Antarctic continent.

For many years no further significant advances were made in techniques for locating thunderstorms at a distance, although the number of stations using cathode ray direction finders or narrow sector recorders gradually increased (to upwards of 100 by 1957) mainly under the auspices of meteorological services. There had been a widespread feeling, however, that a location system based on measurement of differences in times of arrival of atmospherics at several stations might provide more convenient and possibly more accurate. A test of such a system was reported at U.R.S.I. in 1960 and high accuracy was claimed. Although the technique has not been fully explored, particularly at relatively short ranges, it is an intersting new development.

6. — VLF Propagation

Interest in propagation as a factor in atmospherics research stemmed from a desire to understand the whole life history of an atmospheric from its source to the receiver, and was given impetus by the arguments which developed on whether the important components of atmospherics were of local or distant origin. The close association of propagation and atmospherics studies has, however, been given more lasting importance by the fact that lightning discharges are powerful and widespread sources of energy at frequencies lower than any on which transmitters operate.

TESLA, as early as 1899 had observed a regular standing wave pattern in the strength of atmospherics as the distance of a storm increased. ECCLES, in 1912, reported regular variations in the rate of occurrence of atmospherics near sunrise and near sunset and advanced a theory that these were caused by changes in the state of ionisation of the atmosphere. Nevertheless, only casual references to the possible importance of propagation variations in affecting atmospherics was made before 1930. There was a suggestion in 1927 that the propagation of short impulses might be quite different from that of continuous waves, particularly in respect of polarisation, and the increase in the intensity of a atmospherics on short wavelengths at night was mentioned. Another report was to the effect that atmospherics had been found to be propagated best in directions both parallel to and normal to the earth's magnetic field.

An early reference to the variation of field strength with distance occurred in the United Kingdom report of 1928, when the relationship was stated to lie between an inverse distance law and inverse square root of distance law over distances of hundreds of kilometres at 10 kc/s. Possible solar influences on propagation were also mentioned about this time. The field strength was later (1938) stated to be proportional to d^{-1} up to 100 km and to $d^{-1/2}$ from 100 to 1000 km.

In 1934 a subcommission was set up to consider the propagation of atmospherics. One of the topics discussed was a method of investigating the ionosphere by observing the changes in the intensities of atmospherics at dawn. The time of increase indicated sunrise in the relevant part of the ionosphere and thus the height of reflection. This method was used extensively in Switzerland.

Nearly all the propagation work, using atmospherics, has been at frequencies below 100 kc/s. One of the first observations was that at distances of about 2000 km there was energy at 500 c/s and above 5000 c/s but very little in the intermediate range. In 1934 it was stated that « it is still a matter of investigation whether there is very small content of intermediate frequencies, say 1000 to 5000 c/s in the original impulse or whether dispersive action includes specially heavy selective absorption in this band. » An interesting suggestion was that the absorption might be caused by ionised hydrogen in the earth's magnetic field, but no good reason could be advanced for the existence of free hydrogen. This « absorption band » has been the subject of many subsequent investigations.

In 1938 observations of VLF atmospheric noise were recommended as a means of studying ionospheric changes, particularly the sudden changes caused by solar disturbances. Routine recordings with this objective

were carried out by France during the war and, subsequently, regular bulletins of sudden enhancements were issued as a result of this work.

By 1948 considerable throught was being given to the mechanism of propagation of atmospherics in the earth-ionosphere duct. Previous work on reflection type waveforms had shown that if the atmospheric was regarded as a short pulse of energy, reflected between the earth and the ionosphere, the effective height of reflection was about 90 km at night and 75 km during the day. Only a small proportion of waveforms, however, could be explained in terms of this simple mechanism. By 1952 it was evident that the type of waveforms often depended on the direction from which it was received, but it was not clear whether the differences were due to the source, to the nature of the terrain (land or sea) along the path, or to other differences in propagation. Observation on GBR, on 16 kc/s, had also shown that propagation depended on direction. Another observation in the United Kingdom and the United States was that partial reflection often appeared to take place from two layers, some 5 km apart. The effective height of reflection also appeared to depend on the angle of incidence.

These experimental observations stimulated theoretical work on the mechanism of propagation and a theory based on waveguide modes was developed which showed how a reflection type atmospheric could change to a smoother form with change in distance of propagation and also how slow tails could arise. Although there was argument on the details of the theory, it soon became firmly established, and further developed by taking account of the earth's magnetic field and the use of more realistic models of the ionosphere.

The I.G.Y. programme included the recording of waveforms simultaneously at several locations to see what changes took place during propagation. An important conclusion from the data concerns non-reciprocal propagation; at VLF, attenuation in a west-east direction is less than in an east-west direction. This effect has been shown theoretically to be related to the earth s magnetic field.

Not all the propagation data derived from noise measurements have been based on observations of single atmospherics. For example in Germany the amplitude variations of integrated noise, particularly early in the day, have been used to deduce the properties in the D region and used to study ionisation and recombination processes, and many workers have studied the influence of solar flares on the ionosphere by observing noise. Recent interest in VLF propagation has centred on phase stability at long ranges, in view of the potentialities of these long wavelengths for standard frequency services and navigational aids.

There is now considerable interest in extending measurements of noise downwards in frequency, through the ELF range. Observations have been made at frequencies less than 1 c/s, and at the 1960 Assembly there was a discussion of the reported detection of a resonance in the earth-ionosphere cavity, at about 8 c/s.

It is interesting to note that, following a calculation by Lodge of the natural resonance frequency of the earth in free space, yelding a figure of 17 c/s, FITZGERALD, in 1893, deduced that the resonance would be at 10 c/s it there were a concentric conducting shell at a height of 100 km. TESLA, in 1905, suggested making use of this resonance for long-range signalling.

7. — Interfering properties of noise

Early discussions on noise were concerned very largely with the interference, actual or potential, to radio services, and many experiments were designed to measure this interference directly. Numerous laboratory tests were carried out to discover what noise was tolerable for different types of services, particularly for broadcasting where many of the factors were subjective. Measuring circuits were developed which were intended to take into account some of these subjective factors. During the war, the first world-wide maps of noise were presented in terms of the field strength required for a stated quality of radio-telephone service, with conversion factors for other types of service, and an immediate post-war network of stations measured the field strength required for a given quality of slow-speed radio-telegraph service. At the Zurich Assembly, similar measurements with high speed telegraph services were reported. Much recent work in India has been concerned with the interference of atmospheric noise to broadcasting.

A disadvantage of this type of measurement is that the results depend not only on the form and intensity of the noise but often, also, on the characteristics of rather specialised receiving equipment, and possibly on subjective factors. Results are therefore difficult to compare, and there has been a growing feeling that the properties of the noise should be expressed in terms of parameters which can be formulated in unambiguous mathematical terms, and that the question of interference should be treated separately,

Some of the problems of interference appeared to lie within the field of interest of Commission VI, and at the Hague Assembly, a joint meeting

between the two Commissions was organised. This served to clarify some of the issues, and led to some theoretical work, in France and Japan based on concepts of information theory. However, in view of the mathematical difficulty of interference problems involving fluctuation noise, and the much more complex nature of atmospheric noise, the prospects of a satisfactory theoretical solution did not seem good, and no further joint meetings were arranged.

The working party set up to consider what parameters should be measured, if the interfering properties were to be deduced, concluded that noise power was probably the best single parameter, but others were required in addition, since noise power alone did not differentiate between highly-impulsive and relatively smooth types of noise. It was decided that amplitude characteristics were sufficient for most purposes, variations in the instantaneous phase being of secondary importance. The amplitude probability distribution of the noise envelope was therefore recommended for measurement, with various time functions (e. g. lengths of noise bursts) as useful additional parameters.

There remained the problem of relating the additional information to interference. It was demonstrated from work in the United States, Japan and France that a curve showing the amount of interference (for example percentage errors in a teletype system) as a function of signal strength was similar to the amplitude probability distribution of the noise, so if this could be described by a limited number of parameters, these could also serve, with appropriate conversion factors, to describe the interference to a particular type of service.

Attention is now being turned to describing time-functions in statistical terms, and some measurements were reported to the 1960 Assembly.

8. — Atmospherics and Meteorology

By the time that U.R.S.I. programmes on atmospherics became active it was well known that there was a close relationship between atmospherics and meteorology, but there were very divergent views on the precise nature of the connection. It was clear that thunderstorms were one source of atmospherics and that there were two main types of storms, those caused by local heating of the earth's surface, and those caused by the interaction between cold and warm masses of air at meteorological fronts. However some thought that most atmsopherics originated in thunderstorms, while others thought that only a small proportion could be explained in this way. With the passage of time the first of these views gradually prevailed and attention was turned to the use of atmospherics recording to study the nature of the lightning discharge and to provide an index of meteorological conditions.

Many efforts were made in the early days to correlate the occurrence of atmospherics with the variations in the various meteorological parameters being measured on a routine basis. Claims were made that there were correlations with pressure and with wind, but as the widespread nature of the sources became more obvious, it was apparent that these quantities could correlate with atmospherics only to the extent that they were indicative of large scale features such as the movements of masses of polar air. However the tracking of sources of atmospherics soon became a recognised technique for following the movements of meteorological fronts and other unstable conditions such as tornadoes.

Some connection was claimed also, at times, between the general level of atmospheric noise and the weather, but wrong conclusions were sometimes drawn because changes in propagation, particularly from day to night, were neglected.

During the 1930's many meteorological situations were analysed and correlated with sources of atmospherics, and a study of the movements of typhoons was undertaken in Japan. The different types of waveform were also ascribed, to some extent, to different types of meteorological source; for example, arising out of the waveform recording in France, during the war, it was claimed that the type of waveform recorded from Mediterranean storms depended on the type of meteorological situation giving rise to the storms and even on the phase of the storm's development.

Tornadoes were given special attention in Japan and the United States. Atmospherics from these were said to have different frequency spectra from those originating in ordinary storms, for example, relatively large numbers of atmospherics were recorded at a frequency of 150 kc/s. Waveforms from discharges in snow squalls were recorded in Sweden and Japan, and showed characteristics significantly different from those from thunderstorms.

Another close relationship between radio and meteorology has existed in the study of the discharge processes in thunderstorms. Much of the existing knowledge of these processes has resulted from observations of the electromagnetic field changes near to the source; and this work has been pursued in many countries. A combination of field measurements and photography of flashes has led to a reasonably satisfactory understanding of the discharges to ground, including the leader strokes and the main return strokes. The early waveforms, in which only major changes in the high amplitude parts of the atmospheric were recorded, were associated with these processes or with similar processes in those discharges which did not reach the ground. The properties of discharges within the cloud, however, had to be inferred almost entirely from the field changes. Studies were carried out in many countries, notably in Japan, South Africa, Sweden and the United Kingdom.

After the war, the extension of the response of waveform recorders to lower frequencies, and longer times, showed that an atmospheric, near the source, was a long-duration phenomenon, with slow field changes lasting up to a second or more, on which were superimposed the more rapid changes which had been the subject of previous studies. Further examination of the slow changes revealed additional rapid changes of small amplitude, and when waveform recording was extended to high frequencies, it appeared that these were one of the main sources of the high frequency atmospherics. The leader processes were found to be more complicated than had previously been supposed, with several recognisable types, and there were also so-called junction processes, between main discharges, which were associated with the tapping of higher accumulations of charge in the cloud. There is now a reasonably good understanding of the general nature of these more complicated discharge processes, and the way in which they give rise to noise, but a satisfactory quantitative model for the currents involved, their rates of change, and the lengths of the discharge channels exists only for the return stroke. The noise-generation process is still an active topic of discussion in U.R.S.I.

With the development of high power radar equipment it became possible to study lightning discharges by virtue of the fact that they reflect radio waves. Most work of this kind has been done in South Africa and in the United States. The reflections are believed to be from the ionisation produced by the discharges and of particular interest is the evidence of discharges in the higher parts of the thundercloud or even upwards from the top of the cloud. There have been reports that such discharges have also been observed visually. One serious difficulty in using the radar technique, especially if quantitative results are required, is to ensure that the radar beam is directed towards the discharge when it occurs, and that the pulses are radiated sufficiently frequency to explore the rapidly changing conditions in the discharge channel. Nevertheless valuable results have already been obtained and the method seems capable of further exploitation.

9. — Whistlers and related VLF noise phenomena

According to a report presented to the Boulder Assembly in 1957, the musical types of low frequency noise known as whistling atmospherics or whistlers were observed on line-telegraph equipment in Austria in 1886. However, the modern work on the subject dates from about 1930, and the report of an U.R.S.I. sub-commission set up in 1934 showed that the main characteristics of whistlers, including their dispersion and the existence of « echoes », were then known. It was surmised that the dispersion occurred over long ionospheric paths, but the nature of these paths was not known. A programme of observations was recommended in 1938, but it was not until after the war that the work gained impetus. An important contribution was the announcement, at the Sydney Assembly in 1952, of Storey's theory that the long ionospheric paths followed the lines of the earth's magnetic field to large distances from the earth, and back again to the conjugate magnetic point. The mode of propagation which enabled the low frequency energy to penetrate the regular ionospheric layers was formulated mathematically and became known as the whistler mode.

Whistlers could originate in lightning discharges either near to the observing point (long whistlers) or near the conjugate point (short whistlers), and echoes could be observed after multiple journeys between these two points. Whistler recording thus became a tool for exploring the outermost regions of the ionosphere. Many observing stations were set up, especially by the United States, one objective being to observe the same whistler at both ends of a magnetic field line, and so prove the Storey theory beyond doubt. Large numbers of whistlers were recorded on magnetic tape, and their frequency spectra determined by the use of sound spectrographs.

Much of the recording was for synoptic purposes, to study diurnal and seasonal variations, to look for correlations with disturbed ionospheric conditions, to discover whether whistlers could be observed simultaneously at well-separated stations, and so on. Several workers experienced difficulty in establishing a connection between whistlers and lightning discharges in local storms, but eventually this was done. Correlations were also established, for example by work in France, between whistlers and discharges observed near the conjugate point.

For the I.G.Y. programme two networks of stations were set up, roughly along meridians, one through the eastern part of the American Continent and another through the Pacific Ocean. In addition there were several other stations, some in pairs near mutually conjugate points. The I.G.Y. results confirmed the basic theories of the origin of whistlers and much progress was made in explaining the detailed features and using them to study the ionosphere.

A natural extension to the whistler work was an attempt to receive man-made transmissions over a field-aligned path by the whistler mode. This was done first by receiving a 15.5 kc/s transmission from the United States at a receiving point near Cape Horn. A pulse system was used and the time delays provided additional support to the propagation theories.

In 1957 « nose whistlers » were also discussed. These were discovered when the frequency range was extended above the limit of audibility. They contain a note of ascending pitch in addition to the more usual descending tone, the two components starting at the same « nose frequency » which was shown to be related to the magnetic field at the highest part of the transmission path. Other detailed investigations of the whistler spectrograms showed evidence of multiple paths, and the effects of ions at the lowest frequencies.

There was some speculation on whether the prevalence of whistlers depended on particular characteristics of the causative lightning discharges. Evidence was presented to show that whistlers originated in discharges with especially strong spectral components in the region of 5 kc/s, and in France they were also said to be associated with discharges giving rise to reflection-type atmospherics. In Sweden and the U.S.A. it was reported that storms in some locations were more likely to produce whistlers than those of comparable intensity in other places.

One of the important results of the whistler work was the derivation of the distribution of electron density in the outer ionosphere. The data also have led to the conclusion that the distribution is of a fibrous nature with a pattern of electron density variations aligned with the earth's magnetic field. It has been shown that relatively small changes in density are sufficient to produce guidance of waves along the directions of the field lines.

At the 1960 Assembly a report was presented of an experiment in the United States in which high frequency energy (13 Mc/s) was said to have been propagated over a long field-aligned path. This report gave rise to considerable discussion, some sceptical.

An interesting theory, advanced at the same assembly, suggested that enhanced, field aligned ionisation, favourable to the propagation of a whistler, might be formed by a lightning discharge just prior to that responsible for the whistler energy.

One of the instrumental limitations in whistler analysis has been the slow rate at which spectrograms could be obtained from whistlers recorded on magnetic tape, and improved methods of analysis are now being introduced.

Associated with whistlers are various other low-frequency noise phenomena, such as those which became known as chorus and hiss. At the Boulder Assembly it was suggested that these forms of noise originated not in lightning discharges, but in the ionosphere, and that hiss, for example, could be generated by the interaction of solar-corpuscular streams with the earth's magnetic field. There was some correlation in occurrence with periods of magnetic disturbance, and with periods of high absorption of atmospherics propagated by normal modes below the ionosphere. Hiss in the Antarctic was associated with aurora.

Whistlers and other forms of low frequency noise are considerable interest to both Commission IV on Radio Noise and Commission III on Ionospheric Radio. This common interest has been served in recent Assemblies by arranging joint meetings. One such meeting, held during the London Assembly dealt with the exosphere, or the outermost ionospheric regions, and much of the discussion centred on the way in which electron density and temperature decrease with increase in height. It seems likely that while lightning discharges continue to be the main source of energy for experiments at these very low frequencies, both Commissions will have an interest in the field.

10. — **Man-made noise**

Although man made noise is considered to be within the terms of reference of the Commission on Radio Noise, it has been given little attention, compared with natural noise. The probable reasons are that many of the associated problems are regarded as technological rather than scientific, and that other international organisations are very active in this field. Nevertheless man-made noise has been recognised as of importance to U.R.S.I., since it sets a limit to many scientific radio measurements, for example in radio astronomy, and an understanding of the relative importance of man-made and natural noise is required in many practical problems.

There is little mention of man-made noise in U.R.S.I. Proceedings until 1948 when the President of Commission IV listed « industrial noise » as one of the four main noise sources causing interference to communications. In 1950 there were several relevant contributions. A survey of medium frequency noise in the United States had shown the relationship between the noise from a city and its population, and measurements at 2 Mc/s in Australia had shown that noise radiated by a city, and propagated by the ionosphere, could be a limiting factor on an otherwise quiet

site. There were also accounts, from the United States, of the development of specialised equipment for measuring man-made noise, part of a long-term programme in this field. In the next years there were only occasional reports relating to man-made noise. Charts of city noise in Japan had been prepared by 1957 and the report on noise, published by the C.C.I.R. in 1956, contained curves showing the expected intensity of man-made noise on typical sites.

At the London Assembly in 1960 a session was devoted to man-made noise, with the object of deciding whether there were any scientific problems which required investigation. A review was made of the main sources, and the ways in which the radiated noise can reach a radio receiver. One of the main conclusions from the discussion was that there was a need for measurements of the mean power of man-made types of noise and that in furtherance of this aim there should be close liaison between U.R.S.I. C.C.I.R. and C.I.S.P.R. (Comité International Spécial des Perturbations Radioélectriques). For U.R.S.I. purposes special emphasis was required on the relatively low but still significant intensity of man-made noise on good sites.

11. — **Conclusion**

In the review of the early days of atmospherics research it was stated that the objectives were described in such broad terms that they formed the basis for much of the work which was to follow. To what extent have the aims been achieved, what additional advances have been made, and what remains to be done ?

Regarding the origins of atmospherics, all doubts that thunderstorms are the main source have been removed, but there is still inadequate knowledge of the geographical distribution of the numbers of lightning discharges at different times, and the proportions of different types are known only approximately.

The spectra of the radiation fields from discharges have been measured over a wide frequency range, but there is a need to extend the measurements down to frequencies of the order of a few c/s. There have been only limited attempts, and these confined to the VLF range, to determine the individual spectra of different types of discharge, for example those which strike the ground and those which do not. Very few results are available to indicate whether discharges of the same general type in different parts of the world have similar spectra. The spectra of the integrated noise from all significant sources are now reasonably well-known, at frequencies in the VLF range and above.

Early advocates of international cooperation expressed the desire to see networks of stations established for two purposes. The first was the measurement of noise intensities by a standardised technique, and the second was the location of sources. Networks for both these purposes now exist in many parts of the world, but there are still large areas where no measurements have been made.

Methods of measuring the detailed characteristics of noise and describing them in statistical terms are a relatively new development; they have proved of great value and can be exploited further.

Experimental observations using atmospherics have provided both a stimulus for theoretical work on VLF propagation and also a means for testing the developing theory, and for determining the relevant ionospheric parameters. Similar advances may be expected at lower frequencies.

Atmospherics research can also be said to have given rise to two new branches of radio science, neither of which was foreseen in the discussions at the earliest U.R.S.I. assemblies, and each having implications far beyond the scope of the work in which it originated. The first is radio-astronomy, which rapidly developed to a stage justifying the formation of a separate Commission. The second is the subject of whistlers, starting as a study of a special type of atmospherics, but opening up a new phase in the exploration of the upper atmosphere. With these two examples in mind, who would venture to forecast with confidence what will be the important developments of the next fifty years ?

Chapter V.

La Radioastronomie et l'U. R. S. I.

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L'immense majorité des informations dont nous disposons sur les phénomènes célestes nous parvient sous la forme d'ondes électromagnétiques. Il y a trois décades à peine, nous ne pouvions observer que des ondes *lumineuses* s'étendant sur un intervalle spectral très étroit déterminé essentiellement par les propriétés absorbantes de l'atmosphère terrestre. Maintenant, un domaine spectral beaucoup plus large a pu être exploré, celui des ondes *hertziennes* d'origine extraterrestre.

Il est surprenant de constater que, malgré l'étroitesse de la fenêtre optique, l'astronomie et l'astrophysique nous ont déjà fourni une image cohérente du monde. Ce même Univers, que nous croyions connaître bien que nous ne puissions pas toujours en expliquer les phénomènes, présente dans le domaine hertzien une physionomie étrange et des propriétés parfois singulières, qui viennent jeter une lumière nouvelle sur la nature profonde des mécanismes qui s'y développent. Aussi la constatation que des ondes hertziennes extraterrestres peuvent être observées à partir de la Terre a-t-elle ouvert un nouveau chapitre de la science astronomique. La radioastronomie est l'une des grandes découvertes de notre époque. Comme elle implique des moyens d'observation nouveaux, elle revêt également une grande importance technique, tant il est vrai que la recherche pure est toujours à bref délai suivie d'applications fécondes.

Premières observations

La radioastronomie est née de la curiosité, dans le sens le plus élevé du terme. Elle résulte aussi d'une longue patience. C'est en 1931 que K. C. JANSKY, étudiant aux laboratoires de la Bell Telephone Co à Holmdel, New Jersey, l'intensité et la direction d'arrivée des parasites radio-électriques que l'on croyait d'origine atmosphérique, observa pour la première fois le retour périodique d'un faible signal de bruit se répétant tous les jours avec une légère avance sur l'horloge moyenne. La période de récurrence, 23 h 56 m était celle de la journée sidérale. Il fallut 5 ans d'observations et l'utilisation d'antennes directives et orientables pour confirmer le fait que la source observée correspondait à la région du centre de la Galaxie. Ainsi, une source ou un ensemble de sources radioélectriques situées à 25000 années-lumière avait été mis en évidence.

Il est frappant aussi de constater que la radiation hertzienne de la Galaxie a été découverte avant celle du Soleil. Dans le domaine hertzien, le Soleil n'est pas la source brillante que cet astre représente dans le domaine optique.

Très tôt après la théorie électromagnétique de MAXWELL et sa vérification par HERTZ, l'idée d'une radiation solaire sur ondes longues s'était fait jour dans l'esprit des physiciens. En 1894, Sir Oliver LODGE prévoyait, dans une communication à la Royal Institution de Grande-Bretagne, certaines expériences destinées à déceler cette radiation. On savait que le Soleil est un puissant émetteur d'ondes lumineuses; il serait bien étrange que son spectre ne contienne pas d'ondes radioélectriques. La couronne solaire elle-même tirait son nom des phénomènes électriques. Il semble bien que LODGE procéda à ces expériences jusqu'en 1900. Dès 1896 SCHEINER et WILSING en Allemagne et, en 1902, NORDMANN en France, firent des tentatives déjà plus poussées. Ces expériences n'eurent aucun résultat et l'idée fut abandonnée jusqu'en 1942. Rappelons pourtant les observations de ARAKAWA (1936), de DELLINGER, NEWTON et BARTON (1937), de HEIGHTMAN (1938), de NAGAKAMI et MIYA (1939), sur l'apparition de bruits radioélectriques intenses précédant immédiatement les évanouissements brusques des ondes courtes et les ruptures de télécommunications, que l'on savait résulter d'un influence temporaire du rayonnement des éruptions chromosphériques sur l'ionosphère.

Effet Mögel, Dellinger, Jouaust et radiation solaire

Il est regrettable que ces observations n'aient eu à cette époque aucun écho sur le plan astronomique. Mais du 21 au 28 février 1942, les radars de l'armée britannique opérant sur 4 à 6 m de longueur d'onde, ceux de la R.A.F. sur 7 et 13 m, et ceux des bateaux de guerre dès le 23 février, furent sévèrement perturbés par une radiation électromagnétique d'origine solaire. Simultanément, on observait le 28 février à 12 h 15 m, une éruption chromosphérique au sein d'un groupe étendu de taches couvrant

2000.10^{-6} hémisphère, elle fut accompagnée de 12 à 20 h d'un évanouissement des ondes courtes, et à 12 h 01 d'un crochet magnétique. Avec un certain retard apparurent un orage géomagnétique intense le 1er mars à 07 h 27 m, et de brillantes aurores polaires. Après le 28 février, le groupe de taches commença à décroître et les phénomènes radioélectriques s'estompèrent progressivement. Ces diverses circonstances furent décrites dans l'article d'APPLETON et HEY, paru dans *Phil. Mag.* (**7**, 37, p. 73) en 1946.

Depuis cette époque, les observations radioélectriques solaires furent nombreuses et, à l'heure actuelle, on distingue couramment les observations radioélectriques du « Soleil calme » et celles du « Soleil actif ». Les observations du Soleil calme prolongent au domaine radioélectrique celles faites dans le domaine optique et intéressant spécialement les modèles de photosphère et de chromosphère. Elle présentent l'avantage de rendre la couronne solaire constamment visible (en fait, dans le domaine radioélectrique, la couronne n'est pas ce milieu transparent, à faible épaisseur optique, que montrent les observations sur les longueurs d'onde lumineuses, en particulier lors des éclipses totales ou au moyen d'instruments spéciaux, coronographes, coronomètres, etc.). Les observations radio nous permettent d'accéder continuellement à la couronne à des distances considérables du limbe solaire et fournissent ainsi la possibilité d'établir de précieux modèles coronaux. L'étude du disque se complète par une gamme étendue d'investigations portant sur les phénomènes associés dans les couches supérieures de l'atmosphère solaire et annonçant généralement l'activité. Dans le domaine radioélectrique, le Soleil s'est révélé être une étoile très variable, les régions supérieures observées sur ondes longues ne présentant nullement cet état de calme que montreraient les observations optiques.

Actuellement, les divers sursauts radioélectriques du Soleil ont pu être classés par leurs spectres dynamiques. Des théories explicatives ont déjà été abordées, mais elles ne présentent pas encore un caractère synthétique. On commence pourtant à comprendre les mécanismes de génération de quelques-uns de ces sursauts, ainsi que les relations avec certains phénomènes géophysiques associés.

Ainsi les observations radioélectriques solaires sont venues jeter une lumière entièrement nouvelle sur tout le mécanisme de production des hautes couches atmosphériques de l'étoile, ainsi que sur le mécanisme général de son activité. Un grand nombre d'entre elles sont effectuées à fréquence fixe, au moyen de radiotélescopes peu résolvants. Un certain pourcentage des observations analysent le Soleil par bandes, au moyen d'interféromètres à deux ou plusieurs antennes. Les grands miroirs, les interféromètres à bases croisées, permettent l'étude de détail de la source apparente. Assez peu d'observations, mais d'une grande valeur, ont trait à l'étude spectrale des sursauts au moyen de spectrographes dynamiques. Rares sont les mesures de polarisation qui revêtent cependant un réel intérêt pour les théories. La calibration des instruments pour les mesures absolues, et pour les événements intenses, reste difficile. L'obtention de radiospectrohéliogrammes sur diverses fréquences convenablement étagées est souhaitable et permettrait d'étudier la distribution centre-limbe pour les diverses radiations, la directivité et le mouvement des sources transitoires. Les enregistrements rapides du flux, à fréquence fixe, permettraient d'étudier le profil des sursauts, ce qui donnerait une estimation des divers paramètres qui interviennent dans leur mécanisme. La polarisation (elliptique, circulaire ou rectiligne) est essentiellement liée au mode de production de la radiation dans les plasmas magnétisés, qu'il s'agisse de mouvements électroniques désordonnés ou coordonnés. Les polarimètres mesurant simultanément les 4 paramètres de Stokes, avec une résolution spatiale suffisante, pourraient donner des indications de grande valeur sur les phénomènes d'émission. Beaucoup d'évènements intéressants échappent encore à la faible sensibilité des radiospectrographes. Enfin de meilleures interprétations théoriques, plus cohérentes, s'imposent. L'homogénéisation des résultats d'observation et la correction des erreurs instrumentales sont aussi fondamentales. Mentionnons pour finir, l'intérêt des corrélations entre phénomènes solaires et terrestres : phénomènes optiques, radioélectriques, corpusculaires, de radiopropagation terrestre, phénomènes géomagnétiques, auroraux, ainsi que le spectre de rigidité des corpuscules solaires mesuré hors de la magnétosphère. De telles études sont nécessaires pour l'établissement de l'indice solaire de base demandé à l'U.R.S.I. depuis une dizaine d'années par le C.C.I.R.

Radioastronomie galactique et extragalactique

Depuis JANSKY, l'étude du rayonnement de la Voie Lactée et des radiosources discrètes galactiques et extragalactiques a fait bien des progrès. Certaines études de la Galaxie sont certainement le siège de phénomènes comparables à ceux constatés pour le Soleil. En particulier, la radiation radioélectrique essentiellement temporaire et variable d'étoiles à éruptions (flare-stars) a été détectée. A part cela, aucune autre étoile radioélectrique n'est connue avec certitude. Par contre, la radioastronomie nous a révélé une nouvelle classe d'objets célestes, celle des « radiosources discrètes » plus ou moins étendues angulairement et plus ou moins proches de notre observatoire terrestre.

Parmi ces radiosources, certaines appartiennent à notre Galaxie : restes de supernovæ comme Tau A (la Crab Nebula), régions A_{II} et vastes enveloppes stellaires, nébuleuses planétaires, nuées turbulentes de plasma galactique, enfin, radiosources du disque galactique, radiation du halo galactique et certaines structures montrant bien le caractère non thermique du rayonnement du halo. La « source centrale » elle-même située au centre de notre système stellaire, pourrait bien être un phénomène lié à toute la structure spirale de la Galaxie.

La plupart des radiosources discrètes ont cependant un caractère nettement extragalactique : la plupart d'entre elles n'ont pas été identifiées à des objets optiques et ne le seront probablement jamais, vu leur distance.

Les galaxies spirales ordinaires (comme la Nébuleuse d'Andromède) ne sont que des émetteurs faibles, comparables à notre Galaxie. Au contraire, les galaxie anormales, comme la Nébuleuse de la Vierge (NGC 4486), la radiosource du Cygne, sont des émetteurs considérablement plus puissants (10^6 fois la radiation lumineuse). Ceci en fait d'excellents laboratoires pour étudier la physique des plasmas magnétiques et la radiation de synchrotron. Les radiosources comparables, situées à d'énormes distances de notre Galaxie, sont aussi d'excellents jalons pour étudier la structure de l'Univers et à cet égard se pose le problème cosmologique.

Ici encore, c'est à la patience, à l'ingéniosité et la curiosité scientifique d'un amateur que l'on doit les premières cartes galactiques. Dès l'origine, il fallut créer de toutes pièces les moyens d'observation. On relira longtemps, avec grand intérêt, l'article publié par G. REBER dans les P.I.R.E. (Janv. 1958, Vol. 46, N° 1, p. 15-23), dans lequel l'auteur relate avec humour ses premières tentatives. Si la découverte de la raie spectrale radioélectrique de l'hydrogène interstellaire sur 21 cm a permis des sondages d'une profondeur inespérée dans la Galaxie, elle a ouvert simultanément un nouveau domaine, celui de la radiospectroscopie astronomique, domaine qui n'attend pour se développer que la sensibilisation des instruments. La raie 21 cm est encore la seule observable. D'autres possibilités sont pourtant réservées (raies spectrales de radicaux, raies de structure fine et hyperfine d'éléments). Mieux encore, l'observation des radiosources lointaines pose directement le problème cosmologique. Il s'agit de choisir, dans les modèles d'univers établis par les mathématiciens, celui qui correspond le mieux à la réalité observable. Il s'agit donc d'accroître le profondeur des sondages dans l'univers extragalactique. La construction d'instruments de très grandes dimensions doit permettre d'obtenir un pouvoir résolvant suffisant pour la discrimination des sources dans une telle étude. Elle doit permettre également d'obtenir une séparation suffisante pour l'étude de détail des radiosources proches. L'étude des spectres de radiosources et de leur polarisation présente aussi un intérêt considérable, et ces observations restent à la portée des radiotélescopes plus petits. Beaucoup reste à faire dans ces domaines, et aucun double emploi n'a jamais été constaté.

Radioastronomie du système planétaire

Le système planétaire n'a pas échappé aux investigations radioastronomiques. Nous n'insisterons pas sur la radiation propre des planètes (radiation thermique de la Lune, Vénus, Mars, Jupiter, Saturne; radiation non thermique sur ondes décamétriques et décimétriques de Jupiter), nous contentant de dire que Jupiter a fourni sans doute les résultats les plus spectaculaires dans ce domaine : radiation en sursauts sur ondes décamétriques, radiation continue sur ondes courtes provenant des « ceintures de van Allen » joviennes, phénomènes ionosphériques sur Jupiter, etc., en relation avec le fait, constaté par les observations optiques, que la période d'activité de Jupiter est la même que la période undécennale d'activité solaire.

Nous voudrions plutôt attirer l'attention sur la méthode des échos radioélectriques sur les corps célestes. La méthode des échos lunaires est intéressante en ce qu'elle fournit des informations sur les rugosités du globe à l'échelle de la longueur d'onde. La méthode des échos sur Vénus a permis d'améliorer d'un facteur 10 la précision de la parallaxe solaire, et cela malgré la faiblesse du signal d'écho. L'élargissement dopplérien des échos, résultant de la rotation de l'objectif, doit permettre d'obtenir une information sur la période de rotation de Vénus. On pourrait ainsi faire le départ entre les périodes longues (de l'ordre de 200 jours) et les périodes rapides (de l'ordre de 23 h). Actuellement, de telles données sont obtenues par autocorrélation, le signal d'écho étant noyé dans le bruit. Il est très probable que l'amélioration des techniques d'émission et de réception ainsi que l'usage des sondes spatiales lèvera bientôt la difficulté.

Etude des météores

C'est dans l'étude des météores que la technique des échos a permis les plus grands progrès. Si d'une part elle conduit à percevoir le mécanisme de la formation d'une traînée ionisée, de sa déformation sous l'effet des vents ionosphériques, de la cohérence des mouvements électriques requis, d'autre part elle permet, par sa sensibilité et par son indépendance

vis-à-vis des conditions de jour et de nuit, de résoudre la question de l'origine interplanétaire ou interstellaire des météores. Beaucoup d'essaims diurnes, actifs durant la journée, ont été découverts et mis en relation avec des essaims nocturnes correspondants. Tous les essaims décrivent des orbites du type cométaire, dans le sens direct, avec une forte concentration écliptique. La comète existe, ou n'a jamais été perçue. Il est probable que certaines comètes responsables des météores d'essaims se sont désagrégées depuis longtemps. De toute manière, les météores d'essaims sont certainement (à part une faible fraction résultant des perturbations planétaires) des objets d'origine interplanétaire et non interstellaire. L'hypothèse suivant laquelle les météores sporadiques sont d'origine interstellaire reposait sur le concept d'homogénéité spatiale de leur distribution et le fait que, visuellement, ils apparaissent plus nombreux la nuit, et en hiver. Les échos radar, qui ont permis d'atteindre les météores sporadiques plus faibles et les météores diurnes, ont montré qu'au contraire, ils sont plus nombreux en été. D'autre part leur concentration écliptique est grande, et les orbites sont aussi parcourues en majorité dans le sens direct. De tels météores pourraient s'être formés à partir des essaims sous l'effet des perturbations, ou bien constituer les vestiges du nuage interplanétaire initial. En tout cas, il existe un pourcentage extrêmement faible de météores sporadiques ayant, au voisinage de la Terre, une vitesse supérieure à la vitesse critique d'éjection du système solaire. Comme l'énergie est conservative en l'absence de collisions, il s'ensuit que nulle part sur leurs trajectoires, de tels météores ne doivent avoir une énergie totale positive. En d'autres termes, il s'agit ici d'objets interplanétaires et non interstellaires. Une évaluation de la densité, basée sur la loi de distribution des masses accessible aux observations, conduit à la valeur provisoire 1.10^{-23} gr/cm^3, parfaitement en accord avec celle de la densité dans un nuage interstellaire typique de la Galaxie. Il n'y a donc aucune raison de supposer que le Soleil et son cortège de planètes se sont formés dans une région bien particulière de la Galaxie.

L'U.R.S.I. et la Radioastronomie

Quel a été le rôle de l'U.R.S.I. dans la réalisation du programme radioastronomique ? L'Union a été très vite intéressée par ces développements. En fait, il s'agissait d'une nouvelle branche, aux confins des recherches radioélectriques pures et des recherches astronomiques. La radioastronomie s'est d'abord développée grâce aux efforts des radiophysiciens; les astronomes ne s'y sont intéressés qu'ensuite. Mais dès la naissance de leur intérêt, la branche a connu des progrès considérables. Remarquons encore que la sensibilité d'un radiotélescope peut être, malgré le faible pouvoir résolvant, plus élevée que celle d'un télescope optique. Ainsi les premières identifications optiques de radiosources ont été faites à partir des positions suggérées par les mesures radiointerférométriques. Enfin, l'intérêt des mesures solaires pour ce qui concerne l'état de l'ionosphère et des radiopropagations a conduit l'U.R.S.I. à envisager très tôt la question. Comme toute Union, elle fournit aussi un forum permettant les discussions au sens large, le résumé des résultats acquis au cours d'une certaine période, la coordination de certains problèmes à l'échelle internationale, et le tracé des voies d'avenir. Comme les progrès des observations sont le plus souvent liés aux progrès des techniques, il était naturel que l'U.R.S.I. s'attache à un tel domaine, où l'aspect technique est souvent prédominant.

D'autre part, il était naturel que l'attention de l'U.R.S.I. fût attirée par l'étude des phénomènes parasites qui troublaient la réception des signaux radioélectriques. A cette époque, l'origine des perturbations était mal connue, ce qui peut expliquer les différents noms donnés à la commission qui chargée de leur étude. En 1921 elle prit le nom de Commission III des « Parasites ». En 1922 il fut décidé de l'appeler Commission des « Perturbations atmosphériques », nom qu'elle devait garder jusqu'en 1948 quand l'ancienne Commission III devint la Commission IV ou des « Atmosphériques d'origine terrestre ».

Origines de la Commission V

Au cours de l'Assemblée Générale de Paris en 1946, considérant l'état actuel des connaissances et pour attirer l'attention sur les problèmes nouveaux, la Commission III proposa la création de trois Sous-Commissions sur les sujets suivants :

a) origine des atmosphériques terrestres et leur relation avec les phénomènes météorologiques,

b) propagation et distribution mondiale des atmosphériques terrestres,

c) bruits radioélectriques d'origine extraterrestre. La création de cette Sous-Commission qui devait bientôt donner naissance à une nouvelle Commission (la Commission V) marque l'intérêt consacré par l'U.R.S.I. aux problèmes posés par la découverte des radioémissions solaires. Cet intérêt fut souligné par deux vœux, l'un recommandant l'observation continue du Soleil pendant les périodes d'activité intense, l'autre invitant

les Comités Nationaux à encourager les observations des amateurs sur les bruits radioélectriques et, en particulier, sur la corrélation entre les bruits d'origine solaire et l'activité undécennale.

A l'Assemblée Générale de 1948, chacune des trois Sous-Commissions constituées en 1946 présenta un rapport. L'Assemblée Générale décida de publier comme Rapport Spécial nº 1 de l'U.R.S.I. le document établi par la Sous-Commission des bruits d'origine extraterrestre (par Sir Edward V. Appleton) et intitulé « Rapport sur les bruits radioélectriques solaires et galactiques ». C'est au cours de cette Assemblée que la Sous-Commission devint la Commission V des « Bruits radioélectriques d'origine extraterrestre ». En 1950, lors de IX^e Assemblée Générale tenue à Zurich, la Commission établit son premier programme de recherches coordonnées en proposant d'effectuer des observations solaires continues sur 200 et 3000 MHz.

La Commission proposa d'établir une chaîne mondiale d'observatoires radiosolaires et créa à cet effet une Sous-Commission V*a*, pour la conseiller au sujet des améliorations à apporter à la chaîne : standardisation des équipements, possibilité d'éviter les interférences des émetteurs, etc. En 1952, lors de la X^e Assemblée Générale de Sydney, 17 Comités Nationaux présentèrent des rapports sur les recherches radioastronomiques. La Sous-Commission V*a* annonçait que 12 pays participaient à la chaîne mondiale d'observations. Deux autres Sous-Commissions V*b* (terminologie et unités) et V*c* (indice solaire de base) étaient instituées et établirent des rapports. La publication des trois Rapports Spéciaux sur les sources discrètes d'émission radioélectrique, sur la distribution de brillance du disque solaire et sur l'hydrogène interstellaire fut décidée. En 1945, lors de la XI^e Assemblée Générale de La Haye, 15 rapports furent présentés par les Sous-Commissions et les Comités Nationaux; des réunions mixtes furent tenues avec la Commission III pour l'étude de l'influence des phénomènes solaires sur l'ionosphère, avec la Commission IV pour l'étude de cette influence sur la propagation des atmosphériques et avec la Commission VI pour l'étude des équipements. Cette collaboration avec d'autres Commissions s'est confirmée en 1957, lors de la XII^e Assemblée Générale de Boulder. D'autre part les résolutions de la Commission V adoptées par l'Assemblée Générale portent sur l'adoption d'une séquence étalon de radiosources et sur la précision des observations galactiques et extragalactiques, sur la nécessité de disposer d'une protection efficace des bandes observées vis-à-vis des interférences, et sur l'institution d'une nouvelle sous-commission à cet effet.

Symposium U.R.S.I.-U.A.I. 1958

Pour donner ses effets à la dernière recommandation, un Comité fut formé afin d'organiser en commun avec l'Union Astronomique Internationale un symposium U.R.S.I.-U.A.I. sur la radioastronomie.

Ce symposium a été tenu à Paris, en juillet-août 1958, et ses comptes rendus ont été publiés sous forme d'un volume de 612 pages. 162 radioastronomes appartenant à 17 pays y participèrent. 106 communications y furent présentées. C'est dire l'immense développement pris en quelques années par les recherches que nous décrivons. Les sujets traités couvrent : la radioémission et les échos des planètes, les radioémissions du Soleil calme et du Soleil actif, l'étude radioastronomique d'objets individuels en dehors du système solaire, l'étude radioastronomique des structures microscopiques de la Galaxie, l'étude des radiosources discrètes en relation avec les problèmes cosmologiques, les théories sur les mécanismes de l'émission radiosolaire et cosmique.

Activités récentes

L'Assemblée Générale de Londres en 1960 montra une fois de plus l'intérêt pris par l'Union dans les recherches radioastronomiques. Les termes de référence de la Commission V y furent établis : activités concernant *a*) les Radiosources dans l'espace, *b*) l'étude des Météores, du Soleil, de la Lune, des Planètes et des autres objets du système solaire par la technique des échos. La Commission étudie et tend à promouvoir le développement des méthodes techniques, en relation avec les sujets décrits, et s'efforce de protéger les observations contre les interférences. Elle travaille conjointement avec les autres Commissions de l'U.R.S.I. dans le domaine de leurs intérêts communs, et elle coopère avec la commission 40 de Radioastronomie de l'U.A.I. pour le choix des matières à discuter afin d'éviter les doubles emplois. Elle formule des recommandations à l'U.R.S.I. sur tous les sujets radioastronomiques de manière que ces questions puissent être étudiées par les Commissions de l'Union ou d'autres organismes internationaux. D'autres résolutions adoptées ont trait au fonctionnement des Sous-Commissions, aux bibliographies sur la Radioastronomie, au catalogue des évènements remarquables dans la radioémission solaire (en coopération avec l'U.A.I.).

Depuis longtemps, l'U.R.S.I. s'est efforcée d'obtenir la protection des bandes de fréquence utilisées pour les observations radioastronomiques. Elle fut secondée dans ses efforts par l'U.A.I. et le C.C.I.R., et par une série de mémoranda émis par les institutions des divers pays intéressés.

Lors de la Conférence Administrative de l'U.I.T. à Genève en 1959, un succès partiel fut enregistré : la Radioastronomie figure maintenant au tableau des fréquences et a été reconnue par l'U.I.T. comme un service jouissant d'une certaine protection. Lors de l'Assemblée Générale de Londres, un Comité Inter-Unions U.R.S.I.-U.A.I.-C.O.S.P.A.R. a été créé pour poursuivre cette action. Ceci montre que l'action combinée et coordonnée du C.C.I.R., de l'U.R.S.I., de l'U.A.I., du C.O.S.P.A.R., avec l'appui efficace de plusieurs délégations nationales et les efforts généreux d'un grand nombre de personnes a mis en lumière l'importance de la protection des fréquences, sans laquelle le développement de la Radioastronomie risque d'être arrêté à bref délai.

Chapter VI.

Radio Waves and Circuits

by Samuel SILVER,

Professor of Engineering Sciences and Director, Space Sciences Laboratory, University of California, Berkeley, California

Commission VI was instituted together with other new Commissions after World War II at the Stockholm General Assembly of 1948. The action taken by the U.R.S.I. at the 1948 General Assembly can be regarded as the maturation of interests and scientific activities in which U.R.S.I. had been engaged for many years prior to World War II. The Proceedings of the General Assemblies from 1927 until 1938 point clearly to many aspects of modern electronics and communications and it is quite appropriate for Commission VI to claim the scientific meetings and activities of those years as its lineage and its heritage.

The starting point of this history is taken to be 1927 when, at the General Assembly held in Washington, D. C., the U.R.S.I. consisted of four commissions. One cannot help but view those days with a mixture of regret and sadness at their passing. The number of participants was small and the interaction between the Commissions was strong and effective. Many of the subjects that loom large today in scientific programmes were then in a formative and embryonic stage. For example, radio waves having wavelengths of 50-80 metres represented short waves and the report by R. MESNY of researches conducted in collaboration with MM. BEAUVAIS and DAVID on wavelengths of 2-4 metres was in the frontier of the radio science of the day. At the same meeting, Prof. Balth. VAN DER POL discussed the nonlinear behaviour of feedback amplifiers to explain the dependence of gain on signal strength. This paper is representative of the impetus that Prof VAN DER POL gave to U.R.S.I. activity in the field of nonlinear systems.

The beginnings of the present Commission VI can be perceived in the minutes of the administrative sessions of the 1927 Assembly. Prof. VAN DER POL called attention to the need for a separate commission for such subjects as the general theory of triodes, new developments in the general theory of complex functions, modulation theory, and the theory of oscillations (of linear and nonlinear systems). It is to be noted that each of these topics became of foremost importance in the ensuing five years. The organization by U.R.S.I. of the new commission — then Commission V — in accordance with Prof. VAN DER POL's recommendation certainly contributed to the growth of interest and research in those fields.

This new Commission, designated as Radiophysics, began its separate existence with the 1931 General Assembly. Among the topics covered at the meetings two are worthy of special mention : (1) the interrelation of Nyquist's theory of noise and the Einstein-Smoluchowski theory of Brownian motion; (2) the theory of the reciprocity between the transmitting and receiving characteristics of antennae.

The period 1930-1938 was one of rapid growth in the U.R.S.I., corresponding to that of the entire field of radio sciences. The scope of the Commission on Radiophysics broadened while at the same time its importance and effectiveness became increasingly apparent. The timeliness of its programme can be demonstrated no better than by quoting the set of resolutions submitted by the then Commission V to the plenary session of the Assembly in September 1934 :

« 1. The Commission desires the further investigation of the mechanism of generation of electrical oscillations of ultra high frequency, by means of electronic tubes, for example, Barkhausen-Kurz, Pierret oscillators, etc.; and asks Prof. MESNY and Dr. WAGNER to prepare a report on the subject for the next meeting of the U.R.S.I.

2. The Commission desires the study of the propagation of ultra short waves, (i. e. below 10 m) such study to include the determination of the effect of the atmosphere; and asks Dr. J. H. DELLINGER and Mr. T. L. ECKERSLEY to prepare a report on the subject.

3. The Commission desires the further theoretical and experimental study of the Brownian movement of electrons in conductors, and of the shot effect in thermionic tubes. The Commission asks Messrs. LLEWELLYN, MOULLIN and Dr. VAN DER POL, to prepare a report on these subjects.

4. The Commission desires the further study of the theory of nonlinear oscillations, and asks Dr. VAN DER POL to prepare a report on the subject.

5. The Commission jointly with Commission II, desires the further investigation of the theory of propagation and absorption of waves in the atmosphere, and of the conditions under which the propagation obeys the laws of geometrical optics and of those conditions under which the general laws of wave theory should be applied. The Commission asks Mr. T. L. ECKERSLEY and Prof. MANNEBACK to prepare a report on the subject. »

It is recognized that the foregoing resolutions touch upon virtually every major area of interest in that decade. Prof. VAN DER POL was the guiding spirit of the Commission throughout the period. He directed special attention to the subject of nonlinear systems which was then starting to develop. By virtue of his world-wide eminence he was informed on the developing Russian school on nonlinear systems and, thereby, served as the bridge between the U.S.S.R. and the scientists of western Europe and the United States. The calling of attention to Russian work and, more generally, to the importance of the field of nonlinear systems is a recurrent theme in the discussions at the General Assemblies of the prewar period.

Another important development was set into motion at the General Assemblies of 1934 and 1938, namely, the examination of the geometrical optics approximation to solutions to Maxwell's equations. The subject rose to prominence later, as we shall see, put the prewar stimulus is indicative of the contributions of the U.R.S.I. to the growth of radio science. The programme of the 1938 General Assembly was marked further by a series of discussions on rather general mathematical aspects of the theory of wave propagation and solutions to the Maxwell equations; this subject was to engage major attention in the programmes of Commission VI when scientific research was resumed after the war.

At the reconvening of the U.R.S.I. in Paris in 1946 the programme of the Commission in Radiophysics displayed an interest in the new area of information and communication theory. Some of the war period developments in microwaves, their generation and transmission, and in communication systems began to emerge from the confines of security and classified information. These new scientific and technological contributions pointed to an even greater scope for the Commission and thought was given to creation of a new commission to take over the fields of electronics.

The Commission on Radiophysics began to lay the more definitive lines for the future Commission VI at the 1948 General Assembly. It was decided to separate the subject matter covered by the title « Fundamental Theory of Waves and Circuits » from that designated by « Electronics and Properties of Matter at Radio Frequencies. » The former encompassed the work on information and communication theory, circuits and network theory, and electromagnetic theory applied to antennas and waveguides. The 1948 General Assembly actually reorganized all the Commissions and created three new commissions one of which is the present Commission VI - Radio Waves and Circuits. This Commission was given the area referred to previously as Fundamental Theory of Waves and Circuits. Prof. VAN DER POL who had been the leader of the Commission on Radiophysics for its many years of existence was elected chairman of the new commission and the stage was set for a new period of growth and development. It was characteristic of his genius that he could foresee the far reaching implications of the new field of information theory and directed the special attention of the new commission to it.

Two contributions to the 1948 General Assembly are particularly noteworthy of mention. One was the paper by Prof. B. D. H. TELLEGEN on gyrators, the theory of which later played so important a role in the development of ferrites as circuit elements. The other was the paper by Dr. C. J. BOUWKAMP on the problem of « optimum » current distributions in antennae. The latter resolved a basic theoretical question about the realization of supergain antennae.

The General Assembly of 1950 inaugurated the new Commission VI with a programme of technical sessions devoted to information theory, linear circuits, nonlinear circuits, and applied electromagnetic theory. It was about 1950 when declassification of the major portion of the wartime research in the United States and the United Kingdom had been achieved and, consequently, the General Assembly in Zurich (1950) was most lively and vigorous. The sessions on information theory were given to establishing basic concepts, rigorous formulation of basic theorems and some consideration to practical applications. The French school led by Prof. FORTET was especially prominent in this meeting.

Another exciting area of discussion at the Zurich meeting was that of scattering and diffraction of electromagnetic waves. The study of diffraction on a rigorous basis as a class of boundary value problems in electromagnetic theory was stimulated by the microwave antenna work carried on in various countries during the war and now for the first time the scientists were able to compare ideas, methods of solution, and experimental investigations. The salient problem of the day on the subject was the set of boundary conditions required to specify an exterior electromagnetic boundary value problem. The discussion — a lively one in which Drs. BOUWKAMP, CHU and SILVER participated — arose from recent work by Prof. MEIXNER and his colleagues on the edge conditions pertinent to situations such as the Sommerfeld problem on diffraction by an opening in a thin plane screen. Those discussions stand out in the writer's memory both because of their stimulus to further work and because of the lasting friendships that grew out of the hours of exchange of views and ideas.

The following General Assembly held in Sydney, Australia in 1952 led to several significant developments. At Zurich, the lines seemed to be drawn rather sharply between those interested in information and communication theory, those specializing in circuit theory and networks, and those specializing in electromagnetic theory. In fact, the Commission was broken down into three subcommissions, one for each of the aforementioned areas. There seemed to be little common ground for the three subcommissions. At the Sydney meeting Dr. SPENCER (U. S. A.) called attention to recent work on the application of information theory to microwave optics and urged that special attention be directed by Commission VI to these new developments. An ad hoc subcommittee for the study of information theory and microwave optics was created under the chairmanship of Dr. SPENCER. During the next five years the work of the ad hoc committee did much to bring a whole new regime of problems into focus; the following two General Assemblies were marked by a strong interplay between the subcommissions and expressed by such work as that of Dr. GABOR and Prof. A. BLANC-LAPIERRE on the analogy between optical systems as spatial frequency filters and networks as temporal frequency filters. Major contributions were made by GABOR and BLANC-LAPIERRE to the mathematical theory and to the physics of optical systems. The work of Commission VI may be credited with the upsurge of interest in this interdisciplinary study in the United States and other countries as well. The subject became increasingly prominent in the semiannual technical meetings of the U. S. A. National Committee and was the forerunner of a more practical development in the form of data processing antennas.

At Sydney, also, there came into being the Electromagnetic-Wave Theory Symposium. It was during a most delightful weekend excursion arranged by our Australian hosts that the idea of holding a major symposium on microwave optics evolved; Prof. WOONTON of MCGILL University agreed to act as host and shortly after the Assembly the date for the Symposium was set for June 1953. That meeting brought together virtually all of the major contributors to microwave optics in western Europe and the United States and Canada. The importance and effectiveness of the Symposium was evidenced by the interest and extensive researches in the subjects of scattering and diffraction and the theory of partial coherence which ensued in the following years.

The MCGILL symposium was the first of a series which has become recognized as one of the major international meetings on applied electromagnetic theory. It was followed by the Michigan symposium of 1955, a Paris symposium in 1958, and most recently by the Copenhagen symposium of 1962. Commission VI has had the prime responsibility for these symposia. The theory of diffraction and scattering of electromagnetic waves has advanced enormously under these stimuli. Special mention must be made of the work of Prof. FRANZ (Germany) and his school on creeping wave theory and of Prof. KELLER (U. S. A.) and his co-workers on diffracted ray theory for the treatment of the asymptotic behavior of solutions to Maxwell's equations and of approximate solutions for configurations for which exact solutions are not possible.

In accordance with a new ruling of the Statutes on the terms of service, a new chairman was elected for Commission VI at the Sydney meeting. Dr. L. C. VAN ATTA (U. S. A.) was elected but, unfortunately, he found it necessary to resign the following year. Prof. SILVER (U. S. A.) was then named by the Board as acting chairman and was subsequently elected to the position by the 1954 Assembly. He held the chairmanship until and including the 1960 Assembly when Mr. J. LOEB (France) was elected to succeed him.

It was possible to obtain release of a large body of the work done in the United States on information and communication theory for the 1954 Assembly. Drs. W. TULLER and P. ELIAS gave comprehensive surveys of U. S. work on information theory and coding and a number of topics of rather practical importance were discussed. There is one sad memory associated with the Assembly : Dr. TULLER lost his life in an airplane accident over the Atlantic on his way back to the United States.

There were several very active discussions on circuit theory and the definition of areas appropriate to the objectives of Commission VI. Attention was directed particularly by Prof. ZADEH and Dr. WEINBERG to subjects of switching circuits and digitizing circuits and computers and the related subjects of data processing. While the implementation of a programme on these subjects has been slow in developing it is of interest to note how important they have become in the field of space communications.

The General Assembly of 1954 was also marked by joint sessions of Commission VI with other commissions of U.R.S.I. One such session was with Commission V — Radioastronomy — on the subject of large antennas. It was motivated by the ad hoc Committee on Microwave Optics and Information Theory and led to a consideration of antennas from another point of view. The subject of data processing antennas began to take shape then and in the following six years it grew steadily. Another joint session of Commission V and VI was held at the 1960 Assembly in London emphasizing data processing antennas. By this time practical realization of the theoretical ideas had been achieved. Prof. M. RYLE reported observations made with the aperture synthesis antenna at Cambridge and Mr. BLUM of the Meudon Observatory presented the operational aspects of a data processing array at the radio astronomy station at Nançay and results obtained by himself and his co-workers.

The activities and importance of Commission VI in promoting exchange of ideas and information grew with each succeeding Assembly. The entrance of the U.S.S.R. into U.R.S.I. in 1957 made possible direct personal exchanges of information with Russian scientists and the sessions of Commission VI may be described as opportunities of getting to know one another. It was most interesting to observe the correspondence of interests in the U. .S. S. R. with those in western Europe and the United States and Canada.

The technical programme of Commission VI at the 1957 and 1960 General Assemblies were marked by the integration of the three subcommissions and stronger interaction with the other Commissions by means of joint sessions. The combined sessions of Commission VI and V were noted previously. The Commission held also, at the 1960 Assembly, a joint session with Commission VII on the subject of solid state devices. The program dealt, on the one hand, with the general theory of equivalent circuit representations of many new types of semiconductor devices and, on the other hand, with the basic physics of devices such as the Esaki diode and their utilization in various types of systems. In another session, of Commission VI itself, the subject of propagation in randomly varying media was treated from a field-theory standpoint as a multiple scattering problem and from a communication theory standpoint as a randomly varying channel. The discussion that took place in this session emphasised the need for a more general theory using the arbitrarily time depen-

dent field equations to deal with propagation and communication through highly turbulent media such as may be encountered in some planetary atmospheres.

The broadening interests of the Commission showed themselves also in the Electromagnetic Wave Theory Symposium held in Copenhagen in June, 1962. The sessions on anisotropic media constitute a case in point. The programme for this subject area was devoted largely to propagation in plasmas immersed in a uniform constant magnetic field. The papers ranged over a variety of topics, some pertaining to plasma devices and some to the ionosphere. In the session on general theory the subject of waves in plasmas was treated from three different points of view : (*a*) modal analysis, an extension of the methodology of wave guide theory, (*b*) wavefronts and dispersion relations, and (*c*) magneto-ionic theory. These papers brought together techniques used in treating three different regimes of plasma phenomena and showed the complementary relationship of one to the other. The importance of understanding this relationship was made striking by a subsequent session on the subject of the characteristics of an antenna in a plasma. The problem was treated by several workers using the various methodologies presented under general theory. They arrived at results somewhat at variance with one another which could be understood only in the light of the general analysis which had preceeded. The problem of the antenna in a plasma is perhaps the singly most important subject in the antenna field today. It is of primary importance in the whole field of telemetry and space communications; it is also fundamental to the interpretation of those experiments designed to determine the structure of the ionosphere and the magnetosphere from the variations in the radiofrequency impedance of an antenna mounted on a space vehicle (rocket or satellite). It is, therefore, of paramount importance to obtain a correct and physically understandable treatment of the problem.

The subjects which have been referred to in the foregoing review of the activities of Commission VI at General Assemblies and in the specialized Symposia are but examples of the range of interests of the Commission. They have been chosen to show interaction between our Commission and others, and to point up how the Commission has stimulated research and provided the seed for new fields. The roles of commissions such as those on tropospheric and ionospheric radio as international organizations are easily understood, for many researches in those fields must be carried out on a world-wide basis and require international collaboration in the actual conduct of the research. The subject matter of Commission VI, however, requires no such collaboration in the conduct of the research and the international role of the commission may be questioned. But as one reviews the history of the U.R.S.I. and sees how the discussions at the General Assemblies were so often the precursors of new research as well as renewed interest in a classical field the contributions of the international Commission VI to scientific progress is strikingly evident.

Any effective organization is the product of the people involved in it. It would be difficult to list the names of all who participated actively in the programmes of Commission VI and did much for its development and growth. However, the writer would be especially remiss in his duty if he omitted to note the roles of Dr. F. L. H. STUMPERS, Prof. B. D. H. TELLEGEN, Prof. G. SINCLAIR and Mr. J. LOEB who served as subcommission chairmen and vice-chairmen of the Commission over the past decade and who carried many of the responsibilities for the organization of the scientific programmes.

The Commission as well as U.R.S.I. as a whole suffered a great loss with the death of Prof. VAN DER POL in October 1959. He had played an active part in the Commission throughout. Following his tenure of office as chairman of the Commission he served for a period as chairman of the subcommission on information and communication theory and until his death gave freely of his time and energy to the scientific interests of the Commission. His guiding genius and great humanitarian spirit remain an inspiration to the future growth and strength of Commission VI.

Chapter VII.

On Radioelectronics

by G. A. WOONTON,

Vice-President of U.R.S.I.; Department of Physics, McGill University, Montreal

Commission VII, on Radio Electronics came into existence in 1948 at the Assembly at Stockholm and met for the first time in Zürich in 1950. In the previous chapter, it was made clear that both Commissions VI and VII had their source in a commission on Radiophysics proposed and fathered by Professor VAN DER POL as early as 1927.

By 1948, U.R.S.I. was ready for and needed the new Commission. Research and development, starting in 1939 and forced at an unparalleled rate by the necessities of war had created profound changes in the science of electronics; a stock of new techniques awaited exploitation in the interests of scientific radio. The magnetron and the klystron had been brought to a high state of perfection and this in turn had made possible a whole new microwave technique. A vigorous, war-time development programme had produced many new microwave components and these already found application in scientific measurements by 1948. Physicists, now skilled in radio techniques but anxious to return to their proper field had invented microwave spectroscopy. Solid-state spectroscopy in the form of nuclear magnetic resonance, pure nuclear quadrupole resonance and electron paramagnetic resonance soon followed.

Solid state physics may be said to have grown up in the war years. Researches in nuclear physics or associated with the techniques of that subject were complemented by intensive work aimed at the development of microwave, converter diodes. By 1948 is was clear that there existed a bright future for a new field of solid state electronics which might have important effects on scientific radio. At that time the ground work was being laid for the transistor and the many developments in solid-state circuits which are now being made.

Directly within the province of U.R.S.I., micro-wave radar techniques were soon applied to the investigation of clouds in the troposphere and to the investigation of discontinuities in the ionosphere; such techniques made possible the investigation of tides and winds in the upper atmosphere. Radio astronomy had also found new life in radar techniques. The increase in noise which occured when a radar antenna pointed at the sun was now well known; and by the end of the war, galactic noise had been observed with radar equipment. The phenomena of noise in circuits had been studied intensively; noise in electron beams, as the result of work on microwave tubes, was partly understood. These facts and others set the stage for the creation of a new commission whose business it would be to study new electronic phenomena and to bring these phenomena to the attention of the other Commissions.

Commission VII met for the first time at the IXth Assembly (Zürich 1950) and there discussed its future programme. In the opinion of the Commission, its purpose was the discussion of fundamentals rather than devices and to this end, the Commission recommended for discussion at the Xth Assembly, the following subjects :

The fundamentals of vacuum tubes.

The fundamentals of gas discharge.

The fundamentals of semi-conductors with application to radiophysics.

Microwave spectroscopy including magnetic resonance absorption.

The Xth Assembly (Sydney 1952) in many ways was to be the test of the vitality of the new commission but distance and the wartime restrictions on publication which were still in effect conspired to curtail the attendance of Commission VII members to a very small number point. It is apparent that most of the adhering countries had tried to organize research around the list of fundamentals set forth at the Zürich meeting. In the March-April Information Bulletin no. 74 for March-April 1952, it is reported for example that the Japanese Commission VII had organized its work in this fashion; in fact from the « Proceedings of the General Assembly » Volume IX, Part 8, it is clear that a very large proportion of fifty-five papers submitted to Commission VII for the Sydney meeting were by Japanese authors. Wartime regulations however prevented the Japanese members from attending the meeting and the cost of the trip to governments still suffering from wartime financial difficulties made it impossible for many other members of Commission VII to appear. The

following two extracts from a letter written by the Chairman of the Commission to the official members (Information Bulletin no. 79 May-June 1953, is pertinent :

« Commission VII, Electronics, is a very new commission and cannot be said to have proved its value to U.R.S.I. In fact, in Australia, it was suggested that the 1954 meeting would be a test of its value and that if it were not shown to have the same international reason for existence as some of the other Commissions, it should be dissolved. My opinion is that Commission VII is valuable insofar as it is able to co-operate with the other Commissions by bringing to their attention fundamental advances in the physical basis of electronics ».

« In Australia last year, only one of all the authors was present (at the Assembly) who had submitted papers to be read in Commission VII. I suggest that the authors of papers should be present at our meetings and should be prepared to consider their paper only as a basis for discussion. For this reason, would you consider which of your countrymen are apt to attent the 1954 U.R.S.I. meetings and would you suggest a list of topics, which they would be willing to discuss ».

There were at Sydney, however, a few interested members of Commission VII and this small group, lacking authors and indeed papers or even an audience, turned to the staffs of the Australian universities and to interested members of other Commissions for help. Three meetings were held :

1. On vacuum tubes.
2. On physics of the solid state.
3. On fundamentals of gas discharge.

Although they were held on a completely impromptu basis, these meetings lacked nothing in scientific merit or in interesting discussion. Sir K. S. Krishnan gave an exceedingly interesting paper on his new method of determining the thermionic contact of metals. At the same meeting a series of interesting papers on the dielectric constants of liquids and solids were given by members of the C.S.I.R.O. Division of Industrial Chemistry, Melbourne.

It would be fairer to describe the meeting on the fundamentals of gas discharge as a joint meeting; authorities from other commissions, such as Sir Harry Massey (London), Professor L. G. Huxley (Adelaide), Dr. M. Laffineur (Paris) and many others, all contributed to make an interesting and informative colloquium.

The Assembly at the Hague in 1954 provided the first real opportunity for the members of Commission VII to become acquainted and to organize their programme. A rather extensive correspondence had been carried on by a group of members during the two-year period between the meetings in Sydney and in the Hague; decisions had been made concerning the proper subjects of the Commission and the manner in which the Commission desired these subjects to be presented.

The topics for discussion were, in part, decided by the course of research in electronics at that time. The transistor, as a device was now well known and being widely applied in radio circuits. The travelling-wave tube was well established but phenomena associated with it had renewed interest in electron emission and in gaseous electronics. The behaviour of plasmas was receiving attention in the literature both from the point of view of laboratory physics and as a mechanism responsible for both geophysical and radio-astronomical phenomena.

A series of nine, well attended scientific sessions were held on the subjects of electron emission, solid state electronics, microwave electronics and particularly on gas discharges and gaseous electronics. As at Sydney, the discussions of gaseous electronics resulted in a very successful joint meeting with Commission V on Radio-Astronomy.

Also at the Hague, Commission VII held a business meeting at which discussions took place resulting in the prefix Radio being added not only to the name of Commission VII, which up until that time had been designated « Electronics », but also to the name of all the other Commissions. The following is an extract from the minutes of that business meeting :

« A letter advocating the formation of a new Union on the subject of Electron Physics within the I.C.S.U. or at least the formation of a joint Commission between U.R.S.I. Commission VII and I.U.P.A.P. was read. The main argument was that the field of electronics and therefore of Commission VII was too wide for said commission to be dependent only on U.R.S.I. which is concerned mainly with Radio Science. Professor KOTANI has discussed the question with the U.R.S.I. National Committee (Japan) and with the Executive Committee of I.U.P.A.P. but had not obtained a commitment or a recommendation from any of these groups.

« Professor KOTANI then explained his point of view again. He was seconded by Sir KRISHNAN (India) who also developed the same thesis. »

« Both however were strongly opposed by Professor LEHMAN of France who recalled that all these questions were debated several years ago before the formation of Commission VII and that said Commission was

nevertheless formed in view of the strong link between the radio engineers and the people working in electronics. He recalled that in a large measure the science known today as electronics was historically a part of radio engineering and that even today the tremendous development of electronics is fostered by the demands of the scientists interested in the domain of communication. In consideration of these strong relations he recommended that Commission VII should stay entirely and uniquely within U.R.S.I. »

« Professor KOTANI then remarked that such things as electron microscopy are hardly included in Commission VII of U.R.S.I. and also that I.U.P.A.P. would welcome a joint commission. »

« There arose a few questions as to what, exactly, could be the working mechanism of such a joint commission but no definite answer was offered or even suggested. Professor LEHMAN remarked that if one wants to generalize, the whole of U.R.S.I. could be transferred to I.U.P.A.P. »

« Then, following the previous discussions, it was moved : »

« (A) By Professor SHEPHERD that the name of the Commission be changed to that of Radio Electronics. His proposal was voted on and carried against Professor LEHMAN's vote, who had a mandate from the French Committee to try to keep the name in its most general form.

» (B) By Professor SHEPHERD that « U.R.S.I. Commission VII » recommends the formation of a joint commission with I.U.P.A.P. in the field of physical electronics. It is the desire of Commission VII that this should not be construed as a limitation of the area of interest of Commission VII.

The motion was seconded by Professor SAYERS, voted on and carried. »

At Boulder, Colorado in 1957 and in London in 1960, the meetings of Commission VII produced in the members a feeling that the Commission had matured, an impression that had been lacking in the earlier meetings. The Boulder meeting took place in an atmosphere of great scientific interest : the Maser had been conceived a few years earlier and by 1957 promised to be a device that could revolutionize measurements in scientific radio. During the intervening three years research on beam type vacuum tubes had also made great strides as had the subject of solid-state physics. By no means least in its effect on the scientific sessions was the fact that the members now knew one another and in many cases had carried on a steady correspondence over a period of five years.

The following quotation from a letter to Officials Members of the Commission makes clear another matter to which Commission VII owed much for its interesting meetings at Boulder :

« It is fortunate for Commission VII that this Assembly of U.R.S.I. is located in the United States of America. The extensive research in the field of electronics which is in progress here has made it possible for us to find many distinguished people who were willing and able to help us with our meetings. Through the kindness of the Officers of the American National Committee of U.R.S.I., and with the never-failing help of our Honorary President, Dr. DELLINGER, it has been possible for us to invite outstanding Americans to chair some of our meetings and to make contributions to our sessions, even though in many cases these gentlemen are not official delegates to U.R.S.I. »

In fact, world authorities led the discussions at five scientific meetings. The topics discussed were oscillation phenomena in gas discharges, the physics of the cathode, the source and nature of noise in electron beams, the physics of semi-conducting devices for radio application and the maser. The discussion of the maser was led by Professor C. H. TOWNES of Columbia University, N. Y. and was the first session held by Commission VII jointly with all commissions of U.R.S.I.

At London in 1960, the Commission still found much to discuss on the subject of molecular and parametric amplifiers. It is interesting to record that two of the earliest contributors to the conception and development of the maser, Professor PROKHOROV of the U.S.S.R. and Professor BLOEMBERGEN of the U. S. A., took an active part in this discussion. As at all previous Assemblies, one scientific session was devoted to the discussion of plasmas; it is pleasant to record that Sir Harry MASSEY who, in no small measure, had been responsible in Sydney for the success of the joint meeting on this subject was again in the chair. Two subjects, not discussed before, « Ferrites in Microwave Circuits », and « Energy Conversion by Thermionic and Thermo-electric Devices » provided the bases for two interesting and well-attended meetings in London.

Commission VII has had a legal existence of fifteen years but an operating life of only nine years. During this short life, its members have seen many phenomena, which were dimly understood in 1948, developed and used as the basis of devices now in every day use in radio measurements. Solid-state electronics is an offshoot of solid-state physics and in turn solid-state electronics has led to the concept of solid-state circuits. This

natural progression is well illustrated by the fact in London the joint session on « Solid-state Circuits » was organized by Commission VI and that another session on « Very High Sensitivity Receivers » joint with Commission VII was organized by the Commission on Radio Astronomy.

Chapter VIII.

U. R. S. I. and the International Years

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In the course of the last eighty years three major international scientific enterprises have been organised. These were the so-called « Polar Years » of 1882-3 and 1932-3 and the « International Geophysical Year » of 1957-8. In reviewing the part which U.R.S.I. has played in international science, and in particular the part it has played in these international cooperative projects, it will be convenient to divide the account into three broad sections :

(i) The period before, and up to, the Second Polar Year of 1932-3.

(ii) The period before and including the International Geophysical Year.

(iii) The period since the I.G.Y.

1. — **The period before the Second Polar Year** (1932-3)

The First International Polar Year was organised in 1882-3, some five years before Hertz had generated, detected and studied radio waves. Man-made radio waves thus played no part in the scientific programmes of that Year although, as Dr. W. H. ECCLES put it in his address to the 1934 U.R.S.I. General Assembly, « atmospherics were doubtless moving about the globe and the ionosphere was present and awaiting investigation ».

The International Commission for Radio Telegraphy (from which U.R.S.I. originated) was constituted in October 1913, and at its first meeting it formulated a programme for radiating test transmissions from the radio station which had been established two years previously at Laeken by Dr. GOLDSCHMIDT (the first Secretary General of U.R.S.I.). During this same meeting a tentative programme was drafted for the « simultaneous measurements of atmospheric disturbances by various stations ». The three National Committees then constituted were invited to cooperate in this work and also invited to investigate « the best methods for recording atmospheric disturbances ».

Although not directly concerned with U.R.S.I., it is worth noting that an attempt to establish an international coordinated study of radio propagation phenomena was that made by the British Association in 1912 when a committee under the Chairmanship of Sir Oliver LODGE organised a programme of world-wide observations to study the possible effect of atmospherics and radio wave propagation of the total solar eclipse of 21 August 1914. The path of totality lay across Europe and special observations were planned but unfortunately nothing came of the plan since the outbreak of the first World War prevented all observations in Europe and the only observations which were made were in parts of the world too remote from the path of the eclipse to produce any observable effect. After the war the same Committee organised a similar set of observations for the eclipse of 29 May 1919 and many cases of increased signal strength on long wave radio transmissions (wave lengths of 500 metres) were reported during the eclipse period.

In the years following the 1914/18 war, there was a very rapid expansion of interest in all aspects of radio and especially in the propagation of waves of medium and short wave lengths. In 1919 the Radio Telegraphy Commission was constituted as a Scientific Radio Union and the international character of its tasks, and the need for cooperation with other scientific disciplines, was emphasised within U.R.S.I. right from the start. Thus in the First General Assembly in Brussels in 1922 there was established a « Commission of Cooperation with the Operators, Practitioners, Amateurs and connected Sciences ». This Commission continued in existence until 1946 and at the Third Assembly in Brussels in 1928, it resolved « that, in view of the complexity and interdependence of the phenomena of radio transmission and those of geophysics, solar physics and meteorology, the mutual collaboration between the workers in these sciences is necessary for their satisfactory development, It is considered that simultaneous observations of phenomena in these fields will be of great mutual assistance in solving many important theoretical and practical problems. The Commission desires therefore to instruct the Secretariat to take such action as may be suitable to bring about cooperation with the corresponding international organisations ». At the same Brussels Meeting this Commission recommended « that radio broadcasts concerning geographical and astrophysical phenomena, possibly capable of effecting the propagation of radio waves, should be emitted daily from a certain small number of radio transmitting stations, so as to permit specialists to become speedily informed concerning the same ». This recommendation was carried out some two months later when, on the 1 December 1928, the first daily « URSIgram » was broadcast from the Eiffel Tower at Paris. The data broadcast in these URSIgrams were based on observations made each morning at observatories near Paris, and consisted in summary statements on terrestrial magnetic and electron field variations, and astrophysical data on the activity of sunspots, faculae and protuberances. This early recognition by U.R.S.I. of the need for integrating radio studies with related fields, ensured that in the planning and preparation for subsequent international geophysical enterprises U.R.S.I. would be well to the fore.

2. — The Second Polar Year

The President of the International Polar Year Committee was the Danish physicist Dr. LA COUR and it was indeed a fortunate coincidence that in 1931 the year immediately preceding the start of the Second Polar Year the Fourth General Assembly of U.R.S.I. was held in Copenhagen. Dr. LA COUR attended the various Commission meetings and participated in the discussions which took place on the forthcoming Polar Year. At a meeting of Commission II (Radio Wave Propagation) he suggested the formation of an « U.S.R.I. Polar Year Sub-Commission ». This Sub-Commission was duly formed and at the concluding session of the Assembly it reported as follows :

« 1. The Sub-Commission, consisting of the following members (1) :

Prof. E. V. APPLETON (President); Prof. LA COUR; Commandant R. BUREAU; Dr. B. VAN DER POL; R. A. WATSON-WATT (Secretary), was asked to consider the advisability of making wireless observations during the Polar Year, and, if agreeing that such measurements were desirable, was entrusted with the task of formulating definite proposals concerning the nature of the work. »

« 2. (*a*) The Sub-Commission strongly recommends that scientific radio observations should be made during the Polar Year.

(*b*) The Sub-Commission recommends that measurements of KENELLY — Heaviside layer heights and ionization should be made during the Polar Year at stations as far North as possible, and suggests the following places :

Tromsö
Scoresby Sound

(1) Dr. J. H. DELLINGER was later added to the membership.

Thule
Angmagssalik
A station in Northern Canada
A station in Alaska.

The Sub-Commission notes with satisfaction that the establishment of a station at Tromso for making such observations has already been contemplated by the British National Committee, and that the Danish National Committee, and the Dutch Committee for the Polar Year have similar projects for such work at Thule (Greenland) and Angmagssalik respectively.

(*c*) The Sub-Commission recommends that all stations capable of making Kennelly-Heaviside height and ionization measurements, wherever these stations are situated, should carry out such measurements as regularly as possible during the Polar Year and in particular on the « International Days » of the Polar Year.

(*d*) The Sub-Commission recommends that all stations capable of recording the intensity of atmospherics, wherever these stations are situated, should carry out such measurements as regularly as possible during the Polar Year and in particular on the « International Days » of the Polar Year. It is particularly desirable that the network of such stations should include stations situated as far north as possible.

(*e*) For aural and other measurements of radio signal intensities the Committee recommends that a long wave station and a short wave station in Europe and a similar pair of stations in America should provide special transmissions. Transmissions would be made at each hour during the International Days of the first order, long wave emissions taking place at the even hour and short wave emissions at odd hours G.M.T. The European stations would transmit from 0 *n* 00 to 0 *n* 10 and the American station from 0 *n* 05 and 0 *n* 15 G.M.T. (*n* being an integer).

It is also recommended that observations should be made on the special Polar Year signals which are to be emitted daily by Pontoise-sur-Oise on 28.5 metres and by Bordeaux on 18 000 metres at 0810 and 2010 G.M.T. immediately after the time signals.

It is further recommended that observations be made on signals emitted every Tuesday from Washington at from 1900 to 2100 G.M.T.

(*f*) The Sub-Commission recommends that once per hour, whenever possible, estimates of atmospheric intensity and counts of the number of atmospherics heard per minute should be made on a wavelength of 6,000 metres or above, all observations at the same station being made on the same wavelength throughout the Polar Year. In the case of stations equipped only for short wave reception the observations should be made on a wavelength as near to 60 metres as possible, such wavelengths likewise being maintained throughout the Polar Year.

(g) For the purpose of these recommendations the International Day is to be understood as beginning at 1600 G.M.T. Wednesday and ending 1600 G.M.T. Thursday. »

« 3. The Sub-Commission asks that in the event of its proposal being confirmed by the U.R.S.I., it may be continued in office in order that it may carry out the detailed organization of the programme and the collection and preliminary reduction of the resulting data. »

At this Copenhagen Assembly Polar Year Radio observations were also discussed in Commission III (Atmospherics) and on the proposition of Mr. BUREAU, the Commission adopted proposals for special and exceptional observations in addition to recording programmes during the Polar Year. The Commission also called for the selection of « International Radio Days » which could be linked with the International Days of the Polar Year. (It was reported at the meeting that a Polar Year Calendar of International Days had already been fixed).

At the discussions of Commission IV (the 1922 « Commission of Cooperation » referred to earlier) there was an interesting reference to the possible influence of artificial and natural (volcanic) explosions on upper atmospheric ionisation and on radio wave propagation and it was suggested that studies on the influence of man-made explosions might be undertaken on International Days in the Polar Year. In this the Commission IV of 1931 seems to have anticipated, in a remarkable way, the now well established effect of large explosions on the ionosphere.

Following upon the general plan presented at the Copenhagen Assembly, the Chairman and Secretary of the Polar Year Sub-Commission drafted a more detailed international programme which was circulated to National Committees. The following extract is taken from this document :

« On International Days of the First Order, i. e. on one day per month, the following measurements will be made within the quarter-hour periods ending at midnight and noon, local mean time, viz. :

« Using central frequencies of 4 Mc/s and 2 Mc/s (wavelengths of 75 m and 150 m), determination of the equivalent height of the ionized regions effective in returning these emissions to earth at substantially vertical incidence (i. e. over base lines not exceeding 25 km). The observations on 4 Mc/s are most important, those on 2 Mc/s next in importance. »

« On International Days of the Second Order, i. e. on one day per month displaced by fourteen days from the day of the First Order, the following measurements will be made throughout the 24 hr :

» Using the one central frequency of 4 Mc/s (wavelength 75 m), determination at each hour of local mean time, throughout the 24 hr, of the equivalent height of the region returning emissions of this frequency to earth at substantially vertical incidence (base lines not exceeding 25 km). »

» On International Days of the Third Order, i. e. on the Wednesdays to Thursdays of the weeks intervening between weeks containing First and Second Order days, determinations of the following general type will be made, viz., measurement of the approximate ionization density, near noon local mean time, in the ionized regions, by the method of APPLETON, which involves essentially the determination of the critical frequencies for the lower (E) and upper (F) ionized regions. Attention will be concentrated on the upper and on the lower regions respectively on alternate days of the Third Order. »

It was stated that the proposed international programme was deliberately restricted in scope so that it could readily be undertaken by all participating countries, and that in countries where additional effort was available this programme could then be supplemented by a national effort directed to the study of particular problems. In considering this programme of observations, it is relevant to note that the Second Polar Year came at a time when ionospheric studies and measurement techniques were progressing very rapidly, and that even during the year itself, workers developed new and improved methods of recording echo signals from the ionosphere. Until about 1931, two main techniques were employed viz., the « frequency change » method and the « pulse » method. For rapid routine sounding of the ionosphere the pulse method had many advantages and was universally employed for radio soundings during the Polar Year. At the beginning of the Year (August 1932), the $h'(f)$ technique of ionospheric sounding was still in its infancy, and although the U.R.S.I. Polar Year Sub-Commission suggested a very limited programme of critical frequency measurement, most of the Polar Year sounding were of the $h'(t)$ type, and these could only yield a very restricted amount of information on peak electron densities in the layers. The International Programme recommended noon measurements of critical frequency on a total of 31 days during the Polar Year (sixteen noon measurements of the E-layer critical frequency and fifteen of the F-layer critical frequency). The enormous expansion in the scale of ionospheric measurements since 1932 is emphasized when this modest programme is compared with that recommended 25 years later for the I.G.Y., when each of the 170 observing stations was recommended to make 1/4 hourly observations on a normal day, and at still more frequent intervals on World Days and Special World Intervals.

The Second International Polar Year ended on 31 August 1933 and reports on the principal ionospheric and other radio studies were presented at the Fifth General Assembly in London in September 1934. Preliminary accounts of Polar Year radio work carried out by Britain, Russia, Germany, Poland, Holland, Japan, U. S. A., France, India and Italy were presented at this Assembly. Dr. LA COUR (President of the International Polar Year Committee) also gave a resumé at this Assembly of Polar Year magnetic work. A summary account of the Polar Year radio investigations has been given in volume 1 of the Annuals of the I. G. Y.

The U.R.S.I. Polar Year Sub-Commission was dissolved at the London Assembly in 1934 and in its place U.R.S.I. established a Permanent Committee with the following terms of reference.

« (*a*) to keep a list of stations making ionospheric measurements;
(*b*) to issue agreed programmes of work;
(*c*) to assist the interchange of data;
(*d*) to arrange special observations on the occasion of eclipses, meteor showers, magnetic disturbances, etc.;
(*e*) to collect data on commercial circuit operation for comparison with ionospheric data ».

In its final report the Polar Year Sub-Commission made a number of recommendations on ionospheric nomenclature and symbols and also drafted a long-term International Ionospheric Recording programme to be carried out on a pre-arranged schedule of « International Days ». The International Days were taken as beginning at 1600 G.M.T. Wednesday and ending at 1600 G.M.T. on Thursday and there were four « Orders » of such days. Those of the First Order were the first Wednesday-Thursday of each calendar month, those of the Second Order fourteen days later, those of the Third Order were between the First and Second and those of the Fourth Order fourteen days after Days of the Third Order. Special observations were also scheduled for the Solstice and Equinox periods. For many years following the Polar Year this programme of observations was faithfully carried out by the small number of ionospheric sounding stations then operating regularly, and the data so acquired formed the basis for much of the very considerable advance in ionospheric knowledge which was a feature of that period.

3. — The International Geophysical Year

The main contributions of U.R.S.I. to the I.G.Y. were effected through many channels the principal ones being the U.R.S.I.-I.G.Y. Committee and its associated Sub-Committee on World Wide Ionospheric Soundings; the work of the Commissions and especially that of Commission III, at the General Assemblies; U.R.S.I. representation on the Mixed Commission on the Ionosphere and U.R.S.I. representation on the International I.G.Y. Committee (C.S.A.G.I.). Some idea of the overall magnitude of the effort contributed by U.R.S.I. in the various phases of the I.G.Y. is afforded by the following facts. Between 1950 and the end of the I.G.Y. U.R.S.I. representatives were concerned in the formulation of more than seventy resolutions referring to one of other aspect of the I.G.Y. Over the same period reports of meetings, memoranda etc. relating to U.R.S.I.-I.G.Y. activities accounted for some 2000 pages in the U.R.S.I. Information Bulletin, and General Assembly Proceedings, Volumes in the « Annals of the I.G.Y. » series and other Volumes.

Hence in attempting the present short survey of the part played by U.R.S.I. in the International Geophysical Year it will not be possible to do more than refer briefly to some of the more important tasks undertaken and achieved.

3.1. — *The Mixed Commission on the Ionosphere.*

The « Mixed Commission on the Ionosphere » was formed in 1947 by the International Council of Scientific Unions (I.C.S.U.) with representatives from the four Scientific Unions concerned in ionospheric studies viz. I.A.U., U.G.G.I., I.U.P.A.P. and U.R.S.I. U.R.S.I. was nominated parent Union and, throughout its existence of ten years or so, the M.C.I. acted in very close cooperation with U.R.S.I. and in particular with Commission III. The Chairman (Sir EDWARD APPLETON) and the Secretary (Dr. W. J. G. BEYNON) were two of the U.R.S.I. representatives on the Commission and all meetings of the Commission were held in association with the General Assemblies of the Union. All the resolutions of M.C.I. were also brought before Commission III.

The proposals for organising a « Third International Polar Year » in 1957-58, some twenty-five years after the Second, was made in 1950 by Dr. L. V. BERKNER at an informal meeting of a small group of scientists in the U. S. A. Professor Sydney CHAPMAN and Dr. BERKNER later submitted the proposal to the M.C.I. at its Second Meeting in Brussels on 4 September 1950. The proposal was warmly welcomed and, on the basis of its discussion at that Meeting, the Commission prepared a memorandum which was transmitted to I.C.S.U. and other Scientific Unions. The full text of this memorandum has been published in the proceedings of the M.C.I. and in the « Annals of the I.G.Y. » but a few extracts from it may be quoted here.

The memorandum starts with the following resolution :

« That, for the reasons attached, the Third International Polar Year be selected for 1957-58 and that, in view of the length of time necessary for adequate organisation of the complex physical equipment now potentially available, an International Polar Commission be appointed in 1951 to supervise planning. This resolution is transmitted by the Mixed Commission on the Ionosphere for the approval of the Unions affected and sponsoring this Commission and for action by I.C.S.U. ».

Then follows a brief statement setting out the reasons for suggesting that the enterprise be held at a period of sunspot maximum and after an interval of twenty-five years, rather than fifty years, from the date of the Second Polar Year.

The principal objectives for the Third International Polar Year were stated as follows :

« To provide information for understanding :

(i) The physics of magnetic and ionospheric storms and other disturbances peculiar to Polar Regions (such as magnetic bays and giant pulsations).

(ii) The physics of aurorae.

(iii) The structure and circulation of the atmosphere in the Polar Regions where absorption and radiation of the energy by the atmosphere play important roles ».

Although these objectives refer to Polar Regions, the document states « it should perhaps be explained that the expression « Polar Year » in the document implies not only a year in which special observations would be made in Polar Regions but also one in which observers in all latitudes would cooperate to the maximum extent so as to give as complete a picture as possible of world-wide geophysical phenomena. It is also assumed that the Antarctic Region would receive its full share of attention ». (Later the title of the enterprise was changed to « International Geophysical Year »). The meorandum then made a series of brief preliminary suggestions for observations in various fields — radio, magnetic aurorae,

rockets, ozone, cosmic rays, troposphere and solar observations. Finally the M.C.I. recommended I.C.S.U. to establish a Polar Year Commission in 1951 « so as to give at least five full years of preparation and trial ». It further recommended that a permanent secretariat should be formed to operate during the most active period of the Commission's work from about two years prior to the Polar Year until about three years after it.

This memorandum was transmitted by the Mixed Commission on the Ionosphere to the four Unions represented in its membership and also to the International Council of Scientific Unions. The resolution and memorandum were endorsed by Commission III and by the General Assembly of U.R.S.I. meeting in Zurich in September 1950.

The M.C.I. « Third International Polar Year » memorandum was considered at the Washington meeting of the Executive Board of I.C.S.U. 1951 and arising from this meeting a special Committee of I.C.S.U. was formed to organise the project. The General Secretary of U.R.S.I., Colonel E. HERBAYS, was nominated Provisional Secretary and he convened the first meeting of « C.S.A.G.I. » (Comité Spécial de l'Année Géophysique Internationale) at the U.R.S.I. Secretariat in Brussels in October 1952. Following this meeting the nations adhering to I.C.S.U. were invited to form « National I.G.Y. Committees » and at a further meeting in July 1953, again in Brussels, the Provisional Secretary reported that twenty-three such Committees had been formed.

3.2. — *U.R.S.I.-I.G.Y. Committee.*

At the Xth General Assembly held at Sydney in August 1952, U.R.S.I. formed the « U.R.S.I.-I.G.Y. Committee » to deal with all aspects of radio investigations during the I.G.Y. and to work in close cooperation with C.S.A.G.I. The full membership of this Committee was established at the following General Assembly in The Hague in 1954, Sir EDWARD APPLETON being nominated President and Dr. W. J. G. BEYNON, Secretary. Between 1954 and 1959, this U.R.S.I.-I.G.Y. Committee met annually and detailed reports of its activities have been published in the U.R.S.I. Information Bulletins. Throughout its existence, the Committee worked in close cooperation with the two other bodies closely connected with I.G.Y. ionospheric observations (U.R.S.I. Commission III and the M.C.I.) and the resolutions and suggestions of all three bodies were often submitted as a joint document to C.S.A.G.I. Among the multitude of I.G.Y. topics considered by the U.R.S.I.-I.G.Y. Committee over a period of 6 years, the following may be mentioned.

In 1954 recommendations were made on « World Days », tropospheric radio measurements, radio observations of the aurora, ionospheric observations (vertical soundings, absorption and drift studies), meteor observations, radio noise studies, solar radio emissions and I.G.Y. publications. In the same year, at the General Assembly, Commission III drafted resolutions relating to the I.G.Y. and at least one of these merits special mention here. This reads :

« Study of Solar Radiation in the Upper Atmosphere » — U.R.S.I. recognises the extreme importance of continuous observations, from above the E region of extra terrestrial radiations, especially during the forthcoming I.G.Y. U.R.S.I. therefore draws attention to the fact that an extension of present isolated rocket observations by means of instrumented earth satellite vehicles would allow the continuous monitoring of solar ultraviolet and X-radiation intensity and its effects on the ionosphere, particularly during solar flares, thereby greatly enhancing our scientific knowledge of the outer atmosphere ».

This resolution, formulated more than three years before the first successful satellite launching, is perhaps the earliest reference by a scientific body to the special value of earth satellite projects.

In 1955 the U.R.S.I.-I.G.Y. Committee, meeting in Brussels, revised and brought up to date maps and lists of stations planning to carry out ionospheric observations of all types during the I.G.Y. At that meeting it was reported that there would be at least 150 vertical sounding stations, that absorption measurements would be made at 25 to 30 stations and drift observations at a further 15 to 20 stations. The Committee received a report on some pre-I.G.Y. test experiments in which an intercomparison had been made between absorption measurements at various stations in Europe, and plans were made for a similar intercomparison of drift measurements. At the same meeting a Sub-Committee was formed, under the Chairmanship of Mr. A. H. Shapley, to deal with all aspects of ionospheric vertical soundings. This Sub-Committee later became known as the World Wide Soundings Sub-Committee (W.W.S.C.) and was responsible for very considerable detailed planning of all aspects of the I.G.Y. vertical soundings programme. The uniform high standard of vertical sounding recordings during the I.G.Y. at more than 170 stations was almost entirely due to the detailed planning and coordination undertaken by the W.W.S.C. Among the twenty resolutions formulated at this 1955 meeting, proposals were adopted for the rapid production of « instruction manuals covering all the principal I.G.Y. ionospheric studies ». The first manual was

to deal with vertical incidence recordings and subsidiary manuals were planned to cover more specialised studies. Authors were nominated for each section and an editor appointed, and at the same time arrangements were made for the preparation of French and Russian translations of the manuals. The content of these manuals was later considerably expanded so as to include a great deal of background information on the ionosphere which it was hoped would stimulate the interest of routine operators in the fundamental aspects of the subject. They appeared as Volume III of the « Annals of the I. G. Y. » and due largely to the early planning of the U.R.S.I.-I.G.Y. Committee, the ionosphere Volume was the first to be published in the series.

One other feature of the 1955 meeting merits attention. The Committee prepared a memorandum on the « Publication, circulation, etc. of I.G.Y. ionospheric characteristics ». the first proposal in this memorandum read as follows :

« Four « Regional Centres » shall be established by C.S.A.G.I. in the longitudes of America, Western Europe, Russia and Japan/Australia. The principal functions of these centres will be :

(i) to collect all I.G.Y. ionospheric tabulations and copies of selected ionograms; these to be available to research workers at the Centres;
(ii) to meet requests from bona fide users for purchasing microfilm copies of tabulations or ionograms;
(iii) to maintain a complete index of all these ionospheric data ».

Then followed seven proposals detailing procedures to be adopted and setting out responsabilities of stations and of Regional Centres for ensuring the interchange and collection of I.G.Y. ionospheric data. The « Regional Centres » proposed in the Resolutions were later to be termed « World Data Centres » those for the ionosphere being located at Washington, Moscow, Slough and Tokyo.

The 1956 meeting of the U.R.S.I.-I.G.Y. Committee was the final meeting before the start of the I.G.Y. and the principal tasks accomplished were :

(*a*) A full review of the world network of I.G.Y. ionospheric stations.
(*b*) Further development of proposals for World Day Centres.
(*c*) Detailed proposals made for I.G.Y. absorption, drift, whistler studies.
(*d*) Plans drafted for a gazetteer of all ionospheric stations, together with appropriate tables of solar zenith angle.

(*e*) Plans for the preparation of an atlas of ionograms.

(*f*) Preparation of the first report of the World Wide Soundings Sub-Committee which covered, in great detail, schedules of observations, parameters to be scaled, presentation of data, interchange of data, accuracy, symbols, etc.

The 1957 meeting of the U.R.S.I.-I.G.Y. Committee was held at Boulder, Colorado, during the XIIth General Assembly of the Union. On this occasion, in addition to its normal meetings, the Committee organised a very successful open session on the I.G.Y. at which the U.R.S.I. reporters for the various sections of the radio field presented short reviews of progress.

Two major recommendations from the Boulder meeting may be quoted here. The first refers to plans for post-I.G.Y. publication.

At earlier meetings the Committee had formulated plans for publications connected with the planning stage and for publishing volumes of selected I.G.Y. ionospheric data. At this meeting the Committee agreed

« to sponsor the preparation by suitable authors, within a period of about three years after the conclusion of the I.G.Y. of volumes of an interpretative character in which a connected survey might be given of published I.G.Y. results in the radio field ».

The second proposal refers to « I.G.Y. Fellowships and Studentships » and appears in the report of the meeting in the following terms :

« The Committee is well aware of the plans already formulated in many institutions throughout the world for the scientific elucidation of I.G.Y. radio observations by way of theoretical study. Nevertheless, in view of the vast and unique opportunity for geophysical comprehension which such observations provide, the Committee invites all bodies which sponsor scientific research to consider the possibility of instituting special I.G.Y. Fellowships and Studentships — of all ranges of seniority, from professorial downwards — for the prosecution of such theoretical research in I.G.Y. World Data Centres, universities and similar institutions on an individual or group basis.

» The Committee warmly commends the action of Unesco in instituting special studenships for the operational phase of the I.G.Y., and trusts that the same body will continue to support individual scholars, in the same way, during the post-I.G.Y. stages of scientific elucidation ».

In July 1958, the Committee met at Edinburgh and much of the discussion at this meeting centred on plans for continued ionospheric observations in the immediate post-I.G.Y. period. At this time the Committee

had before it a proposal for the extension of the I.G.Y. by a further year but after much discussion the Committee declared itself against the proposal on practical grounds. (Subsequently C.S.A.G.I. decided on a further year of enhanced geophysical investigations — the so-called « International Geophysical Cooperation 1959). The Committee re-affired its earlier decision on the publication of a limited number of ionospheric data (monthly mean hourly values of twelve selected parameters) in the « Annals of the I.G.Y. ». It also supported strongly the proposal for the preparation of an « I.G.Y. post-facto calendar » which would give, for each day of the I.G.Y., the degree of activity manifested in geomagnetism, aurora, ionosphere, solar activity and cosmic rays. The question of suitable ionospheric indices was discussed and it was agreed that for each Greenwich day two such indices should be included, one based on the normal Region E and the other on Region F2. The former was intended to provide an index of the day to day variability in the intensity of the solar radiation responsible for Region E, and the latter the measure of disturbance of Region F2. (The « I.G.Y. Calendar Record » was subsequently published as Volume XVI, Part I of the Annals).

The Committee also warmly supported a proposal for a permanent I.C.S.U. Special Committee on « World Geophysical Days ». (This subsequently developed into the present « International URSIgram and World Days Service »).

4. — The post-I.G.Y. period

At the 1958 meeting in Edinburgh the U.R.S.I.-I.G.Y. Committee decided that the next meeting should be devoted to a preliminary discussion of I.G.Y. ionospheric results.

Accordingly in Brussels in September 1959, some 9 months after the termination of the I.G.Y., a symposium was held at which some 60 papers were presented covering the following aspects of I.G.Y. radio observations.

F2 layer phenomena, high latitude studies, ionospheric irregularities, N(*h*) profiles, absorption, drifts, noise, whistlers, rocket and satellite observations. The proceedings were subsequently published as a special volume by U.R.S.I. under the title « Some Ionospheric Results obtained during the International Geophysical Year ».

With the close of the I.G.Y. and of the International Geophysical Cooperation of 1959, I.C.S.U. replaced its I.G.Y. Committee (C.S.A.G.I.) by an International Committee for Geophysics (now known as C.I.G.). At the same time the tasks of the U.R.S.I.-I.G.Y. Committee were largely completed and at the London General Assembly in 1960 the Committee was formally terminated. In its place U.R.S.I. established the U.R.S.I.-C.I.G. Committee with the following terms of reference :

« (i) to cooperate with C.I.G. in all matters relating to U.R.S.I. in the field of geophysics;

(ii) to coordinate the activities of those U.R.S.I. Commissions which are especially concerned in the field of geophysics;

(iii) to deal with all matters referring to the I.G.Y. formerly considered by the U.R.S.I.-A.G.I. Committee including the flow of data to W.D.Cs. and the publication of I.G.Y. and I.G.C. data in the field of radio science;

(iv) to integrate U.R.S.I. special programme of research to be planned under C.I.G. and to hold meetings and symposia in conjunction with the Commissions to further scientific progress under such plans. »

(By a strange coincidence it was also in London, some 26 years earlier, at the General Assembly in 1934, that the Second Polar Year Sub-Commision was deemed to have completed its tasks and was replaced by a Permanent Ionosphere Committee.)

The first meeting of the new Committee was held during the London Assembly and part of the discussions were devoted to further consideration of the publication of I.G.Y. data, to the preparation of critical surveys of I.G.Y. radio investigations and to the future of World Data Centres. At the same meeting preliminary consideration was also given to what was then known as the « Sunspot Minimum Programme ». It will be recalled that the I.G.Y. was planned for a period of high solar activity but even at the planning stage it became clear that the full fruits of the I.G.Y. would only be forthcoming if data, comparable in both quantity and quality with that of the I.G.Y. were available for a period of minimum solar activity. This matter was fully discussed by the U.R.S.I.-I.G.Y. Committee at its 1958 meeting and the Committee then expressed the view that « it would be desirable to have intensive ionospheric observations during the period of the next sunspot minimum ».

In the summer of 1960 C.I.G. adopted a proposal for a « Sunspot Minimum Programme » in those disciplines which are affected by solar activity. The two year period 1964-65 has been selected for the project which is now known under the title « The International Year of the Quiet Sun » (I.Q.S.Y.).

In the course of his address to an I.G.Y. meeting at the XII General Assembly Dr. L. V. Berkner (then President of U.R.S.I. and Vice-President of C.S.A.G.I.) said

« The work of U.R.S.I. typifies, in its highest form, the collaboration of Scientific Unions in the international research efforts of the I.G.Y. The example of the role played by U.R.S.I. in the planning of the I.G.Y. might well be considered as the ideal example of the appropriate relationships between the Unions and the Special Committees of the I.C.S.U. in future efforts of this kind ».

A positive assurance of the continuing role of U.R.S.I. in international scientific enterprises is afforded by the fact that in the forthcoming I.Q.S.Y. enterprise the present U.R.S.I.-C.I.G. Committee will again be responsible for the ionospheric programme. The Committee is already actively cooperating to the full with the central C.I.G.-I.Q.S.Y. Committee to ensure that the many radio studies to be carried out during the International Quiet Sun Year of 1964-65 are again of the highest possible scientific value and in the best traditions of U.R.S.I.

Chapter IX.

Services permanents de l'U. R. S. I.

par E. HERBAYS,

Secrétaire Général de l'U.R.S.I.

Introduction

Certaines sciences peuvent baser leurs théories et leurs études sur des expériences faites en laboratoire, tandis que pour d'autres le laboratoire est la Terre, les espaces qui l'environnent et même les espaces interplanétaires. Si, pour certaines de ses activités, l'U.R.S.I. appartient à la première catégorie, pour d'autres, elle partage, principalement avec l'Astronomie et la Géophysique, le laboratoire sans limites de l'Univers. L'exploitation de ce laboratoire suppose que les résultats des observations aient une diffusion universelle. Ceci fut compris par les précurseurs de l'U.R.S.I. qui, dès le début, s'efforcèrent de favoriser l'échange de renseignements livrés par les recherches et les observations. De là naquit dans l'U.R.S.I. une tradition qui alla en se développant avec l'essor de l'Union : celle d'échanger le plus rapidement possible les résultats d'observations faites à l'occasion d'événements remarquables. Cette tradition donna naissance aux Ursigrammes.

D'autre part, les radio-physiciens, tout comme les astronomes et les géophysiciens, se rendirent compte que si l'échange rapide de données leur était utile, il ne permettait pas toujours une comparaison efficace des résultats obtenus en des endroits et à des moments différents, mais qu'il convenait d'effectuer les observations simultanément en différents points du globe, d'où l'idée des Journées Internationales.

Service des Ursigrammes

Le désir d'étudier les relations pouvant exister entre la propagation des ondes et les phénomènes solaires, magnétiques et météorologiques amena l'U.R.S.I. à s'intéresser, dès ses débuts, aux moyens permettant l'échange rapide des données observationnelles. C'est ainsi que lors de l'Assemblée Générale de l'U.R.S.I. tenue à Bruxelles en 1928, plusieurs laboratoires de radioélectricité signalèrent qu'ils avaient pris des arrangements avec des stations magnétiques pour que celles-ci les avertissent du début des orages magnétiques. De même des relations avaient été établies entre des expérimentateurs en radioélectricité et des observatoires solaires. A la même époque, la Commission de Liaison avec les Opérateurs, Praticiens et Amateurs se préoccupait d'obtenir la participation d'amateurs qui effectueraient des observations en différentes parties de la Terre. Une des difficultés consistait dans la façon dont ces amateurs seraient averti en temps utile des conditions du milieu dans lequel s'effectuait la propagation des ondes. Il semblerait que le Général FERRIÉ pensât à la fois aux professionnels et aux amateurs lorsqu'il émit la proposition ci-après concernant la diffusion des données solaires et géophysiques.

« Je propose que la Commission émette un vœu à transmettre à l'Assemblée Générale, pour que des bulletins soient émis par radio dans différents pays sur l'activité solaire et les phénomènes radiophysiques, afin de permettre de réunir des observations sur la nature des orages magnétiques et sur les phénomènes qui les accompagnent. Ces bulletins seraient donnés, par exemple, en même temps que les bulletins séismologiques et autres qui suivent les signaux horaires. »

« Je demande au Président (de la Commission) de nous soumettre le texte d'un vœu et je propose que quelqu'un soit chargé d'établir un code pour la transmission des bulletins. » (1)

Les Ursigrammes étaient nés. En effet, dès le 1er décembre 1928, la station de la Tour Eiffel (207.5 kHz) émit chaque jour des messages rédigés en langage clair et transmis en code Morse; ils comprenaient une partie « géophysique » (variations magnétiques et électricité atmosphérique) et une partie « astrophysique » (activité des taches solaires, facules et protubérances).

L'année 1930 est marquante dans l'histoire des Ursigrammes. C'est en effet au cours d'une réunion de la Commission de Liaison tenue à

(1) Comptes rendus des Assemblées Générales de l'U.R.S.I., vol. II, fasc. 3, p. 25, mai 1929.

Stockholm que pour la première fois le nom « Ursigramme » fut employé par le Général FERRIÉ. A partir du 1er février de la même année, la station de Bordeaux (15.7 kHz) retransmit les messages émis par la Tour Eiffel qui, à cause d'une puissance trop faible, ne pouvaient être reçus aux Etats-Unis. Le 1er août 1930, à l'initiative du Prof. A. E. KENNELLY, commencèrent des émissions américaines d'Ursigrammes.

A l'Assemblée Générale de 1931 (Copenhague), le Comité National Français présenta un code pour l'émission des Ursigrammes français. Au cours des années qui suivirent des services d'Ursigrammes furent instaurés dans des stations anglaises, italiennes, philippines, japonaises et autres.

En 1934 l'Assemblée Générale adopta une résolution demandant à chaque pays qui préparait des Ursigrammes d'en envoyer copie au Secrétaire Général de l'U.R.S.I. qui, à son tour, enverrait chaque mois à tous les Comités Nationaux les textes des Ursigrammes reçus. Le Secrétariat Général commença alors la première publication régulière de l'U.R.S.I., le « *Bulletin des Ursigrammes* », qui, en quelque sorte, fut le prédécesseur du *Bulletin d'Information*; les Ursigrammes furent publiés dans le Bulletin jusqu'en 1950.

La plupart des stations émettrices d'Ursigrammes utilisaient des codes différents, ce qui présentait de sérieuses difficultés pour les chercheurs. Pour porter remède à cette situation, l'Assemblée Générale de 1938 créa un Sous-comité des Ursigrammes chargé de procéder à l'unification des codes; la deuxième Guerre Mondiale mit fin aux activités de ce sous-comité.

Dans l'entretemps d'autres Unions scientifiques, et notamment l'U.G.G.I. et l'U.A.I., avaient ressenti l'intérêt des Ursigrammes. Leur réseau constituait en quelque sorte un « système nerveux » unissant tous les organismes compétents. La Commission de Liaison avait été dissoute en 1946 et en 1950 l'Assemblée Générale de Zurich créa un Comité Permanent des Ursigrammes sous la présidence du Père Lejay; ce comité commença la normalisation des différents réseaux d'Ursigrammes.

En 1955, les Commissions 10 et 11 de l'U.A.I. reconnaissaient l'importance des Ursigrammes pour l'Année Géophysique Internationale alors en préparation, prévision que l'avenir justifia pleinement.

Lors de l'organisation pour l'A.G.I. du Service de Prévision d'Alertes et d'Intervalles Mondiaux Spéciaux, le Comité Permanent des Ursigrammes fut placé devant des perspectives nouvelles. A la XIIe Assemblée Générale de l'U.R.S.I. à Boulder, une réorganisation du Service des Ursigrammes fut proposée afin de donner à ce service les possibilités exigées par son activité croissante. Au cours de l'Année Géophysique Internationale 1957-1958, les centres émetteurs d'Ursigrammes ainsi que les stations participantes

jouèrent un rôle essentiel dans la transmission et la diffusion des données. On peut estimer en 1959, à plus de 140 le nombre des stations participantes dans les domaines de l'activité solaire, de l'ionosphère, du géomagnétisme, des courants telluriques, des aurores, des rayons cosmiques, des sifflements, etc.

Conformément aux décisions prises à la XIIe Assemblée Générale de l'U.R.S.I. à Boulder en 1957, le Service des Ursigrammes fut constitué de la manière suivante :

a) *Le Comité Central des Ursigrammes* (C.C.U.) comprenant en principe 4 membres (les Présidents des Comités Régionaux au nombre de quatre : Eurasie, Europe et Afrique, Pacifique Occidental et Hémisphère Occidental) et le Secrétaire Général de l'U.R.S.I.

b) *Les Comités Régionaux* comprenant des membres représentatifs de leurs pays (un membre par pays) suivant une liste définissant le groupement géographique propre à chaque Comité et établie par ce Comité lui-même.

La tâche principale du comité directeur, (C.C.U.) et des Comités Régionaux du Service des Ursigrammes était définie comme suit :

1. procéder à l'examen et au perfectionnement des codes utilisés par les observateurs, en tenant compte du progrès des connaissances et des besoins des utilisateurs, publier les codes et susciter leur distribution et leur emploi par les organismes intéressés;
2. stimuler le rassemblement des données et favoriser leur mise en sommaire;
3. améliorer l'échange des données et l'utilisation des résultats d'observation, en faisant connaître, sous forme d'Ursigrammes, ces données à toutes les stations et organismes intéressés;
4. faciliter la diffusion des données entre organismes par voie radiotélégraphique, télégraphique et/ou postale);
5. examiner les moyens de perfectionner les échanges et la diffusion (rapidité et efficacité), d'améliorer les communications et d'étendre le réseau.

Il convient de signaler que dès la constitution de la Fédération des Services Permanents d'Astronomie et de Géophysique (F.A.G.S.), le *Service Central des Ursigrammes*, dirigé par le Comité Central des Ursigrammes, fit partie de cette nouvelle organisation. L'appui financier qu'elle apporte au Service des Ursigrammes permit la publication du Manuel des Codes d'Ursigrammes.

Service International des Journées Mondiales (I.W.D.S.)

La nécessité de coordonner les observations effectuées sur le plan mondial au cours de l'Année Géophysique Internationale amena le Comité Spécial de l'A.G.I. (C.S.A.G.I.) à créer un service chargé de fixer les jours et les périodes pendant lesquels auraient lieu des observations simultanées pour certaines disciplines participant au programme de l'A.G.I.

Au mois de juillet 1958, le Comité de l'U.R.S.I. pour l'A.G.I. réuni à Edimbourg approuva une résolution rédigée comme suit (*Bulletin d'Information* nº 111, sept-oct. 1958) :

« *Proposed Commission on World Geophysical Days.* — The U.R.S.I./ A.G.I. Committee strongly supports the proposal for the formation of a Commission on World Geophysical Days. It suggests that the Commission takes the form of a Special Committee of the International Council of Scientific Union (U.R.S.I.) with representatives of interested scientific Unions. »

Cette proposition, appuyée par l'U.R.S.I., fut présentée en octobre 1958 à l'Assemblée Générale du Conseil International des Unions Scientifiques (I.C.S.U.) qui décida la constitution d'un *Service* International des Journées Mondiales (International World Days Service) et délégua son autorité à l'U.R.S.I. pour la formation et le fonctionnement ultérieur de ce nouveau service permanent. (Celui-ci adhéra très rapidement à la F.A.G.S.) Le Comité Directeur de ce Service devait comprendre un représentant de chacune des Unions participantes : U.R.S.I., U.G.G.I., U.A.I.

Le mandat de ce Service fut défini comme suit par l'I.C.S.U. :

« The I.W.D.S. will continue some of the work done under the I.G.Y. World Days Programme, including :

1. the advance specification of Regular World Days and World Meteorological Intervals in a World Geophysical Calendar;
2. the specification of a current schedule of solar activity Alerts, and occasionally, Special Observational Intervals;
3. the preparation of a post facto calendar of immediate significance to geophysical research. »

L'I.C.S.U. avait prescrit que le nouveau service devait être formé et fonctionner à partir du 31 décembre 1958. Le cours délai imparti explique pourquoi certaines activités de l'I.W.D.S. en 1959 ont été mentionnées dans les publications de l'A.G.I.

Service International des Ursigrammes et des Journées Mondiales (I.U.W.D.S.)

Dès le rattachement de l'I.W.D.S., le Comité Directeur de ce Service ainsi que celui du Service des Ursigrammes, considérant que ces deux organismes avaient des buts communs envisagèrent la possibilité de réunir ces deux services en un seul, ce qui explique que dès le mois de mai 1959 les réunions des deux Comités Directeurs eurent lieu simultanément. Ces premières réunions mixtes eurent pour but d'établir des contacts entre les membres des deux organismes et des programmes d'action des deux services. Dans ces programmes figuraient en bonne place l'établissement des Calendriers Géophysiques ainsi que la rédaction, la simplification et l'unification des divers codes utilisés pour l'émission des Ursigrammes.

L'Assemblée Générale de Londres avait approuvé en 1960 la fusion des deux services, ce n'est qu'en octobre 1962 que, grâce à l'aide financière de l'Unesco, les comités directeurs purent se réunir pour établir la constitution et le mandat du Comité Directeur unique.

Le compte rendu de cette réunion importante pour l'avenir du service a été publié dans le Bulletin d'Information de l'U.R.S.I. (nº 156, janv.-févr. 1963). Il paraît intéressant de reproduire ici le mandat du Service ainsi que la composition du Comité Directeur.

« *Terms of reference.* — The service aims to provide information rapidly to the world scientific community to assist in the planning, coordination and conduct of scientific work in the relevant disciplines.

These aims will be achieved by the :

(*a*) Advance specification of Regular World Days, World Geophysical Intervals and other periods of geophysical interest, which will be published annually in World Geophysical Calendars.

(*b*) Collection, coordination, interchange and distribution by rapid means of selected current observations and information of immediate significance to geophysical and space research and the provision of suitable interchange synoptic codes.

(*c*) Specification, on a current schedule, by a World Warning Agency, of solar activity and geophysical alerts and occasionally special World Intervals.

(*d*) Preparation and publication of periodic post facto Calendar Records of significant indices and outstanding solar and geophysical events.

(*e*) Undertaking of similar activities in cooperation with the participating scientific Unions or other international scientific bodies.

« *Steering Committee* :

1. The I.U.W.D.S. shall be administered by an I.U.W.D.S. Steering Committee consisting of :

(*a*) One representative from each of the following scientific Unions : U.R.S.I., I.A.U., I.U.G.G.

(*b*) One representative from each of the Regional Ursigram and World Days Committees.

(*c*) The I.U.W.D.S. Secretary and I.U.W.D.S. Deputy Secretary.

(*d*) The Secretary General of U.R.S.I. (ex officio).

2. In addition the Steering Committee shall have the power to seek cooperation, by direct representation or otherwise, with other international bodies interested in the work of the service.

3. The Steering Committee shall elect its Chairman and appoint the two Secretaries; the position of these officers will be reviewed at the occasion of each General Assembly of U.R.S.I.

4. The Steering Committee shall be responsible for the worldwide and interregional aspects of the service, for overall plans and guidance, and for the necessary central publications.

5. The Steering Committee shall designate the World Warning Agency from among the existing Regional Warning Centers. »

Au cours de cette réunion, le nouveau Comité Directeur étudia les possibilités de contacts directs avec d'autres organismes auxquels il pourrait apporter une aide efficace, et tout particulièrement avec le Comité pour les Années Internationales du Soleil Calme (I.Q.S.Y.).

L'Année Géophysique Internationale a permis une extension rapide et importante du Service des Ursigrammes et a donné naissance à l'I.W.D.S. L'Année du Soleil Calme offrira à l'I.U.W.D.S. toutes les possibilités pour affirmer son efficacité.

Chapter X.

U. R. S. I. and Space Research

by H. W. S. MASSEY,

Professor, University College London, Department of Physics

There is a very close association between radio science and space research. Without very advanced development of radio and electronics techniques generally, space research would not be possible. On the other hand such research is of great importance for radio communications, for the study of the ionosphere and for many other scientific disciplines of interest to U.R.S.I. It was to be expected therefore that members of U.R.S.I. would become interested and involved in activities made possible or required by the availability of space vehicles, either vertical sounding rockets, earth satellites or deep space probes.

The first explicit reference to the new possibilities in the U.R.S.I. proceedings arose from the meeting of the Mixed Commission on the Ionosphere held at Brussels in August 1954. At this meeting 13 Resolutions were submitted for endorsement by Commission III of U.R.S.I. at the XIth General Assembly at The Hague in 1954. The ninth of these resolutions was as follows.

Rocket Research and the Ionosphere

« The Mixed Commission on the Ionosphere strongly reaffirms its earlier resolutions (1) on the importance of rocket research investigations of the ionosphere and urges that the maximum use be made of rockets for this work during the A.G.I. (I.G.Y.) particularly in the zones (polar and equatorial) already recommended for special studies. »

(1) Resolutions of the Meetings of the Mixed Commission in 1950 and 1952.

« The Commission stresses the need for increasing the number of rocket firings and for immediately extending the scope of this type of research to other parts of the world. The Commission feels that the ultimate objective in this matter should be synoptic rocket observations. »

This resolution was not only endorsed but was supplemented by the following.

« U.R.S.I. suggests that small inexpensive sounding rockets released from aeroplanes and balloons would provide an approach to this objective and one which is within the means of many nations. »

The General Assembly at The Hague in 1954 also adopted the following Resolution, the first in which earth satellites were mentioned by any Scientific Union.

Study of solar radiation in the upper atmosphere

« U.R.S.I. recognises the extreme importance of continuous observations, from above the E region of extra terrestrial radiations, especially during the forthcoming A.G.I. (I.G.Y.) »

» U.R.S.I. therefore draws attention to the fact that an extension of present isolated rocket observations by means of instrumented earth satellites would allow the continuous monitoring of solar ultraviolet and x-radiation intensity and its effect on the atmosphere, particularly during solar flares, thereby greatly enhancing our knowledge of the outer atmosphere. »

The importance of these Resolutions remains as great today as at the time they were recommended. A great deal of progress has been made in the last few years in the study of solar-terrestrial relations both with the use of rockets and satellites but an immense amount must still be done before a complete supply service of solar radiation data at all relevant wavelengths is maintened. With such a service we can hope to understand and interpret upper atmospheric phenomena in range and depth to a degree never imagined before space vehicles became available.

While it is clear that earth satellite observatories are more effective for systematic observations of the solar radiation and other quantities of interest in atmospheric physics it is not possible to operate such observatories in orbits at distances from the earth much less than 200 km. For the study of the lower ionosphere it follows that reliance must continue to be placed on vertical sounding rockets. The resolution mentioned above and endorsed by Commission III in 1954 is therefore still very appropriate and it is gratifying that more and more emphasis is now being placed on the development and use of cheap rockets which may be launched much more frequently and from a variety of locations. Increased international cooperation in the use of small rockets for atmospheric research has been achieved during the past few years and has the strong encouragement and assistance of the Special International Committee on Space Research (C.O.S.P.A.R.).

Rocket and satellite programmes

Emphasis was also maintained, on the importance for U.R.S.I. of rocket and satellite programmes, at the XIIth General Assembly held in Boulder, Colorado, U. S. A. from August 22nd-September 5th, 1957. In addition to a resolution encouraging member nations to undertake rocket and satellite programmes of research on the earth's environment, Commission III also endorsed a Resolution formulated by the Mixed Commission on the Ionosphere at its meeting in New York in August 1957. This recommended that a more intensified small rocket programme should be carried out in auroral latitudes to study particle and other radiation at levels below 90 km.

Considerable contributions towards this objective were made during the I.G.Y. by American and Russian scientists and there are now prospects of an even more intensive attack on the problem of interpreting the phenomena which occur in polar atmospheres. A working group to study cooperative projects for Arctic rocket research was set up by C.O.S.P.A.R. and it is hoped that coordinated launching of rockets from ranges at Fort Churchill, Kiruna (to be established by the European Space Research Organization) and elsewhere will provide valuable information. This will be enhanced by observations made in the Antarctic by the U. S. A. and the Soviet Union.

Space research at the XIIIth General Assembly

Space research occupied an even more prominent place at the XIIIth General Assembly held in London from 5th-15th September 1960. The Goldschmidt Memorial Lecture was given by Dr. L. V. Berkner on « Science in Space ». Commission III devoted a session to the consideration of rocket and satellite data for the ionosphere, and on the 9th September all Commissions met in a discussion of « Space Radio Research ». In this case, the morning session was concerned with the subject of satellite relay (both active and passive) techniques and orbit scatter communications systems; while in the afternoon papers were presented on the results of space experiments on solar ionizing radiations, the ionosphere, cosmic radio noise at 4 Mc/s and the exosphere.

Committee on Space Radio Research

A further important development in connection with U.R.S.I. and space research was the establishment of a Committee for Space Radio Research under the chairmanship of Prof, L. G. H. HUXLEY. This consists mainly of representative from each of the U.R.S.I. Commissions concerned directly with space research. The Committee is charged with the responsibility of coordinating the interests of U.R.S.I. in space radio research and of organizing between General Assemblies, such specialist symposium as may be desirable.

Following the establishment of the Committee a symposium was organized on scientific and research problems associated with satellite radio communication systems. This was held in Paris in September 1961 and was attended by 116 delegates and about 50 observers from some 12 countries. In accordance with the policy of U.R.S.I., C.O.S.P.A.R. was kept fully informed of the arrangement and the President of C.O.S.P.A.R. was present at the meeting.

A wide range of topics was discussed including the launching, attitude control and tracking of communication satellites, problems of radio frequency allocation, radio equipment (both ground based and on-board) for communication satellites, modulation systems and specific communication systems. The proceedings have now been published by ELSEVIER as a monograph on « Space Radio Communications ».

A further symposium on the problem of determining the most efficient transmission of information in space experiments is being planned.

Space Research at the XIVth General Assembly

There will be even greater emphasis on space research in the forthcoming XIVth General Assembly at Tokyo. Almost all Commissions will discuss some aspect or other in their programmes. So much new data on the ionosphere is forthcoming from satellites such as Ariel and Alouette (the first to sound the ionosphere from above) and so much progress is being made in the development of communication satellites through the experience gained with Telstar and Relay that there will undoubtedly be plenty to discuss. At the same time need for continued progress in the radio and electronics technology necessary for the successful carrying

out of space experiments of increasing complexity as well as for the processing of the flood of data coming from space observations, calls for the special interest and attention of the members of Commissions VI and VII.

Radio frequency allocation

During the General Assembly of U.R.S.I. in London in 1960, a meeting was held with representatives of the International Astronomical Union (I.A.U.), and the Committee on Space Research (C.O.S.P.A.R.), to discuss means to be taken to secure a more generous allocation and a better protection of the radio frequencies assigned to both radio astronomy and space science. As a result, an Inter-Union Committee on the Allocation of Frequencies for Radio Astronomy and Space Science (I.U.C.A.F.), was formed with equal membership from the constituent bodies, U.R.S.I., I.A.U. and C.O.S.P.A.R. This Committee has secured recognition as a participating observer body at Assemblies of the International Radio Consultative Committee (C.C.I.R.) of the International Telecommunications Union (I.T.U.); and it has already participated effectively at the European Broadcasting Conference in Stockholm in 1961, and at meetings of the C.C.I.R. in 1962 (Washington) and 1963 (Geneva). As a result, some progress has already been made in the securing of greater freedom in the use of radio frequencies for space research, quite apart from those allocated for communications, navigation and telemetry in the operational use of earth satellite systems.

U.R.S.I. was one of the first Scientific Unions to take cognizance of the possibilities of space research. It is gratifying to note that this interest is being maintained and extended to the benefit of all concerned.

APPENDIX I.

ASSEMBLÉES GÉNÉRALES
GENERAL ASSEMBLIES

Année Year	Endroit Place	Président President	Secrétaire Général Secretary General
(T.S.F.S.) 1914	Bruxelles	W. Duddell	Dr. R. B. Goldschmidt
1922	Bruxelles	Général G. Ferrié	Dr. R. B. Goldschmidt
1927	Washington D. C.	Général G. Ferrié	Dr. R. B. Goldschmidt
1928	Bruxelles	Général G. Ferrié	Dr. R. B. Goldschmidt
1931	Copenhagen	Général G. Ferrié	Dr. R. B. Goldschmidt
1934	London	Dr. W. E. Eccles (Vice-Président)	Dr. R. B. Goldschmidt
1938	Venice and Rome	Prof. E. V. Appleton	Prof. M. Philippson
1946	Paris	Sir Edward V. Appleton	Ing. A. Dorsimont Ing. E. Herbays
1948	Stockholm	Sir Edward V. Appleton	Ing. A. Dorsimont, Ing. E. Herbays
1950	Zurich	Sir Edward V. Appleton	Ing. E. Herbays
1952	Sydney	Sir Edward V. Appleton	Ing. E. Herbays
1954	The Hague	R. P. P. Lejay	Ing. E. Herbays
1957	Boulder, Colorado	R. P. P. Lejay	Ing. E. Herbays
1960	London	Dr. L. V. Berkner	Ing. E. Herbays
1963	Tokyo	Dr. R. L. Smith-Rose	Ing. E. Herbays

APPENDIX II.

COMMISSIONS ET PRINCIPAUX COMITÉS
COMMISSIONS AND OUTSTANDING COMMITTEES

MESURES ET ETALONS RADIOELECTRIQUES.
ON RADIO MEASUREMENTS AND STANDARDS.

Présidents — Chairmen :

H. ABRAHAM (France) (1923-1927),
D. W. DYE (U. K.) (1927-1932),
E. H. RAYNER (U. K.) (1934-1946),
J. H. DELLINGER (U. S. A.) (1946-1952),
R. L. SMITH-ROSE (U. K.) (1952-1954),
B. DECAUX (France) (1954-1960),
U. ADELSBERGER (Germany) (1963-).

Vice-Présidents — Vice-Chairmen :

R. L. SMITH-ROSE (U. K.) (1948-1952),
W. D. GEORGE (U. S. A.) (1954-1963).

Secrétaires — Secretaries :

P. ABADIE (France) (1954-1960),
C. W. OATLEY (U. K.) (1954-1957),
E. WEBER (U. S. A.) (1957-),
F. WERTHEIMER (France) (1960-).

Rapporteurs — Reporters :

B. DECAUX (France) (1946, 1950),
R. L. SMITH-ROSE (U. K.) (1946),
G. LEHMANN (France) (1948),
M. RYLE (U. K.) (1948),
VOS (Sweden) (1948),
P. ABADIE (France) (1950),
F. G. GAFNEY (U. S. A.) (1950, 1952),

M. J. E. GOLAY (U. S. A.) (1950),
F. J. LEHANY (Australia) (1952),
J. VOGE (France) (1952).

Rédacteur Scientifique — Scientific Editor :

B. DECAUX (France) (1960).

PROPAGATION DES ONDES.

ON RADIO WAVE PROPAGATION.

Présidents — Chairmen :

L. W. AUSTIN (U. S. A.) (1922-1933),
J. H. DELLINGER (U. S. A.) (1934-1946),
E. V. APPLETON (U. K.) (1946-1958).

Vice-Président — Vice-Chairman :

NEWBERN SMITH (U. S. A.) (1948).

Rapporteurs — Reporters :

G. ABETTI (France) (1938),
M. PHILIPPSON (Belgique) (1938),
R. L. SMITH-ROSE (U. K.) (1938),
W. A. S. BUTEMENT (U. K.) (1946),
A. HAUBERT (France) (1946, 1948),
H. G. BOOKER (U. K.) (1948),
R. NAISMITH (U. K.) (1948).

Radioélectricité et Troposphère.

Troposphère et Propagation des Ondes (1948-1952)
Propagation Troposphérique (1952-1954).

On Radio and Troposphere.

Troposphere and Wave Propagation (1948-1952).
Tropospheric Propagation (1952-1954).

Présidents — Chairmen :

Ch. BURROWS (U. S. A.) (1948-1954),
R. L. SMITH-ROSE (U. K.) (1954-1960),
J. VOGE (France) (1960-   ).

Vice-Présidents — Vice Chairmen :

H. G. BOOKER (U. S. A.) (1948-1954),
C. G. P. AURELL (Sweden) (1954-1957),
J. B. SMYTH (U. S. A.) (1957-   ).

Secrétaires — Secretaries :

T. J. CARROLL (U. S. A.) (1954-1957),
J. VOGE (France) (1954-1957),
F. DU CASTEL (France) (1957-   ),
J. A. SAXTON (U. K.) (1957-   ).

Rapporteurs — Reporters :

E. C. S. MEGAW (U. K.) (1950),
J. VOGE (France) (1950, 1952),
A. H. CANNON (Australia) (1952).

Rédacteur Scientifique — Scientific Editor :

J. A. SAXTON (U. K.) (1960).

Radioélectricité Ionosphérique.

Ionosphère et Propagation des Ondes (1948-1952).
Propagation dans l'Ionosphère (1952-1954).

On Ionospheric Radio.

On Ionosphere and Wave Propagation (1948-1954)

Présidents — Chairmen :

E. V. APPLETON (1948-1954),
D. F. MARTYN (Australia) (1954-1960),
J. A. RATCLIFFE (U. K.) (1960-   ).

Vice-Président — Vice Chairman :

L. V. BERKNER (1954-   ).

Secrétaires — Secretaries :

W. J. G. BEYNON (U. K.) (1954-   ),
D. LEPÉCHINSKY (France) (1954-   ).

Rapporteurs — Reporters :

W. J. G. BEYNON (U. K.) (1950, 1952),
D. LEPÉCHINSKY (France) (1950, 1952).

Rédacteur Scientifique — Scientific Editor :

W. J. G. BEYNON (U. K.) (1960).

PERTURBATIONS ATMOSPHERIQUES.

ATMOSPHERIC DISTURBANCES.

Présidents — Chairmen :

E. V. ECCLES (U. K.) (1922-1928),
E.V. APPLETON (U. K.) (1928-1946),
R. BUREAU (France) (1946-1948).

Vice-Président — Vice Chairman :

H. NORINDER (Sweden) (1946-1948).

Rapporteurs — Reporters :

R. B. BUREAU (France) (1938),
R. A. WATSON-WATT (U. K.) (1938),
R. A. SMITH (U. K.) (1946),
R. RIVAULT (France) (1946, 1948),
F. W. CHAPMAN (U. K.) (1948),
J. STRANSKY (Czechoslovakia) (1948).

Perturbations Radioélectriques d'Origine Terrestre.

Atmosphériques d'Origine Terrestre (1948-1954).

On Radio Noise of Terrestrial Origin.

On Terrestrial Atmospherics (1948-1954).

Présidents — Chairmen :

H. NORINDER (Sweden) (1948-1952),
J. A. RATCLIFFE (U. K.) (1952-1957),
R. A. HELLIWELL (U. S. A.) (1957-).

Vice-Président — Vice Chairman :

F. H. DICKSON (U. S. A.) (1954-1960).

Secrétaires — Secretaries :

F. HORNER (U. K.) (1954-1960),
R. RIVAULT (France) (1954-1957),

G. FOLDÈS (France) (1957-1962).
E. H. DINGER (U. S. A.) (1960-).

Rapporteurs — Reporters :

F. W. CHAPMAN (U. K.) (1950),
R. RIVAULT (France) (1950, 1952),
P. W. A. BOWE (South Africa) (1952),
G. H. MAINRO (Australia) (1952).

Rédacteur Scientifique — Scientific Editor :

F. HORNER (U. K.) (1960).

RADIOASTRONOMIE.

ON RADIO ASTRONOMY.

Bruits Radioélectriques d'Origine Extra-Terrestre (1948-1952).

On Extra-Terrestrial Radio Noise (1948-1952).

Présidents — Chairmen :

D. F. MARTYN (Australia) (1948-1952),
M. LAFFINEUR (France) (1952-1957),
A. C. B.LOVELL (U. K.) (1957-).

Vice-Président — Vice Chairman :

J. P. HAGEN (U. S. A.) (1954-).

Secrétaires — Secretaries :

J. L. PAWSEY (Australia) (1950-1952),
R. HANBURY BROWN (U. K.) (1954-),
M. NICOLET (Belgique) (1954-1956),
R. COUTREZ (Belgique) (1956-).

Rapporteurs — Reporters :

M. LAFFINEUR (France) (1950, 1952),
J. L. PAWSEY (Australia) (1950, 1952).

RADIOPHYSIQUE.

RADIOPHYSICS.

Président — Chairman :

B. VAN DER POL (Netherlands) (1927-1948).

Vice-Président — Vice Chairman :

O. E. H. RYDBECK (Sweden) (1948).

Rapporteurs — Reporters :

W. P. WILSON (U. K.) (1938, 1948),
E. B. MOULLIN (U. S. A.) (1938),
P. DAVID (France) (1946),
E. C. S. MEGAW (U. K.) (1946),
P. BAUDOUX (Belgique) (1948),
H. BREMMER (Netherlands) (1948),
O. E. H. RYDBECK (Sweden) (1948).

Ondes et Circuits Radioélectriques.

On Radio Waves and Circuits.

Présidents — Chairmen :

B. VAN DER POL (Netherlands) (1948-1952),
L. C. VAN ATTA (U. S. A.) (1952),
S. SILVER (U. S. A.) (1953-1960),
J. LOEB (France) (1960-).

Vice-Présidents — Vice-Chairmen :

J. LOEB (France) (1954-1960),
N. MARCUVITZ (U. S. A.) (1960-),
F. L. STUMPERS (Netherlands) (1960-),
L. WEINBERG (U. S. A.) (1960-).

Secrétaires — Secretaries :

P. MARIE (France) (1957-1960),
H. MEINKE (Germany) (1957-1960).

Rédacteur Scientifique — Scientific Editor :

S. SILVER (U. S. A.) (1960).

Radioélectronique.

On Radioelectronics.

Présidents — Chairmen :

G. LEHMANN (France) (1948-1952),
G. A. WOONTON (Canada) (1952-1957),
W. G. SHEPHERD (U. S. A.) (1957-).

Vice-Présidents — Vice-Chairmen :

O. E. H. RYDBECK (Sweden) (1948-1952),
J. L. H. JONKER (Netherlands) (1954-1957),
G. A. WOONTON (Canada) (1957-1960),
R. E. BURGESS (Canada) (1960-).

Secrétaires — Secretaries :

H. P. KOENIG (Canada) (1954-1957),
J. L. H. JONKER (Netherlands) (1957-1960),
C. M. HATOYAMA (Japan) (1960-),
M. BERNARD (France) (1960-).

Rapporteurs — Reporters :

R. MERCIER (Suisse) (1950),
J. SAYERS (U. K.) (1950),
N. SCHAETTI (Suisse) (1950),
A. BLANC-LAPIERRE (France) (1952),
L. W. DAVIES (Australia) (1952).

LIAISON AVEC LES AMATEURS.

ON CO-OPERATION WITH AMATEURS.

A. E. KENNELLY (U. S. A.) (1927-1934),
G. VALLAURI (Italy) (1938-1946).

Rapporteur — Reporter :

Ing. E. HERBAYS (1938).

COMITÉS — COMMITTEES

Comité de l'U.R.S.I. pour l'Année Géophysique Internationale.
U.R.S.I. Committee of the International Geophysical Year.

Président — Chairman :

Sir EDWARD V. APPLETON (U. K.) (1952-1960).

Secrétaire — Secretary :

W. J. G. BEYNON (U. K.) (1952-1960).

Comité de l'U.R.S.I. pour le Comité International de Géophysique.
U.R.S.I. Committee for the International Committee on Geophysics. (U.R.S.I.-C.I.G.)

Président — Chairman :

W. J. G. BEYNON (U. K.) (1960-).

Secrétaire — Secretary :

G. M. Brown (U. K.) (1960-   ).

Comité pour la Recherche Radioélectrique Spatiale.

Committee on Space Radio Research.
(S.S.R.)

Président — Chairman :

L. G. H. Huxley (Australia) (1960-   ).

Secrétaire — Secretary :

W. J. G. Beynon (U. K.) (1960-   ).

Comité de l'U.R.S.I. pour les Travaux du C.C.I.R.

U.R.S.I. Committee for C.C.I.R. Work.

Présidents — Chairmen :

J. H. Dellinger (U. S. A.) (1954-1962),
B. Decaux (France) (1962-   ).

Comité de l'U.R.S.I. pour les attributions de Fréquences pour des buts scientifiques.

U.R.S.I. Committee on Frequency Allocations for Scientific Purposes.

Président — Chairman :

J. A. Ratcliffe (1960-   ).

Secrétaire — Secretary :

J. W. Findlay (1960-   ).

Publications

RECUEILS DES TRAVAUX DES ASSEMBLEES GENERALES

Langue Française

Vol. I. — IIe Assemblée Générale, Washington, août 1927 :

Fasc. 1. — Mémoires scientifiques (textes originaux).

Fasc. 1*bis*. — Traduction (en langue anglaise ou française) du fascicule 1.

Fasc. 2. — Comptes rendus de l'Assemblée Générale. Rapports du Secrétaire Général et des Commissions (Textes originaux).

Fasc. 3. — Travaux de la Commission des Méthodes de Mesures et Etalonnage (Textes originaux).

Fasc. 4. — Travaux de la Commission de la Propagation des Ondes (Textes originaux).

Fasc. 5. — Travaux de la Commission des Perturbations Atmosphériques (Textes originaux).

Fasc. 6. — Travaux de la Commission de Liaison avec les Opérateurs, Praticiens et Amateurs.

Vol. II. — III[e] Assemblée Générale, Bruxelles, septembre 1928 :

Fasc. 1. — Mémoires scientifiques (Textes originaux).

Fasc. 2. — Comptes rendus de l'Assemblée Générale (Textes originaux).

Fasc. 3. — Comptes rendus des travaux des Commissions (Textes originaux).

Vol. III. — IV[e] Assemblée Générale, Copenhague, mai-juin 1931 :

Textes originaux des séances de l'Assemblée Générale et des Commissions ainsi que des rapports des Comités Nationaux et de Commissions.

Vol. IV. — Ve Assemblée Générale, Londres, septembre 1934 :

Comptes rendus, en langue originale, des séances de l'Assemblée Générale et des Commissions; texte complet ou résumés des mémoires scientifiques.

Vol. V. — VIe Assemblée Générale, Venise et Rome, septembre 1938 :

Fasc. 1. — Mémoires scientifiques. Textes originaux avec résumés.

Fasc. 2. — Comptes rendus des séances de l'Assemblée Générale et des Commissions (Textes originaux).

Vol. VI. — VIIe Assemblée Générale, Paris, septembre-octobre 1946 :

Comptes rendus des séances de l'Assemblée Générale et des Commissions; textes originaux des mémoires scientifiques et rapports des Comité Nationaux et Commissions.

Vol. VII. — VIIIe Assemblée Générale, Stockholm, juillet 1948. — Comme pour le Vol. VI.

Vol. VIII. — IXe Assemblée Générale, Zurich, septembre 1950 :

1re Partie. — Comptes rendus des séances de l'Assemblée Générale et des Commissions. Rapports des Comités Nationaux. Cette partie a été publiée également en langue anglaise.

IIe Partie .— Textes originaux et résumés des mémoires scientifiques.

Vol. IX. — Xe Assemblée Générale, Sydney, août 1952 :

Fasc. 1. — Compte rendu administratif et rapports des Comités Nationaux.

Fasc. 2. — Travaux de la Commissions I des Méthodes de Mesures et d'Etalonnage.

Fasc. 3. — Travaux de la Commission II de la Propagation Troposphérique.

Fasc. 4. — Travaux de la Commission III de la Propagation Ionosphérique.

Fasc. 5. — Travaux de la Commission IV des Atmosphériques d'Origine Terrestre.

Fasc. 6. — Travaux de la Commission V de Radio-Astronomie.

Fasc. 7. — Travaux de la Commission VI des Ondes et Circuits.

Fasc. 8. — Travaux de la Commission VII de l'Electronique.

Vol. X. — XIe Assemblée Générale, La Haye, août-septembre 1954.

Fasc. 1. — Travaux de la Commission I des Mesures et Etalons Radioélectriques.

Fasc. 2. — Travaux de la Commission II, Radioélectricité et Troposphère.

Fasc. 3. — Travaux de la Commission III, Radioélectricité Ionosphérique.

Fasc. 4. — Travaux de la Commission IV, Perturbations radioélectriques d'origine terrestre.

Fasc. 5. — Travaux de la Commission V de Radio-Astronomie.

Fasc. 6. — Travaux de la Commission VI, Ondes et Circuits Radioélectriques.

Fasc. 7. — Travaux de la Commission VII, Radioélectronique.

Fasc. 8. — Compte rendu Administratif.

Vol. XI. — XIIe Assemblée Générale, Boulder (Colorado), août-septembre 1957 :

Fasc. 1 à 8, comme pour le volume X.

Vol. XII. — XIIIe Assemblée Générale, Londres, septembre 1960 :

Fasc. 1 à 8, comme les volumes X et XI, mais le fascicule 8 porte le titre « Administration et Activités diverses ».

Les volumes IX à XII ont été publiés également en langue anglaise; le volume XII contient un fasc. 6bis *publié uniquement en langue anglaise, comme supplément au fascicule* 6.

PROCEEDINGS OF GENERAL ASSEMBLIES

(English language)

Vol. I. — IInd General Assembly, Washington, August 1927 :

Part. 1. — Scientific papers (Original texts).

Part 1*bis*. — Translation (in French or English language) of Part 1.

Part. 2. — Proceedings of the General Assembly. Secretary General and Commission Reports (Original texts).

Part. 3. — Minutes of Commission on Measurements and Standardization (Original texts).

Part. 4. — Minutes of Commission on Radio Wave Propagation (Original texts).

Part. 5. — Minutes of Commission on Atmospherics (Original texts).

Part. 6. — Minutes of Commission on Cooperation with Amateurs (Original texts).

Vol. II. — IIIrd General Assembly, Brussels, September 1928 :

Part.1. — Scientific Papers (Original texts).

Part. 2. — Proceedings of the General Assembly (Original texts).

Part. 3. — Proceedings of Commissions (Original texts).

Vol. III. — IVth General Assembly, Copenhagen, May-June, 1931.

Original texts of the General Assembly and Commission Sessions, and of National Committee and Commission Reports.

Vol. IV. — Vth General Assembly, London, September 1934.

Proceedings, in original languages, of the General Assembly and Commission sessions, full text or summary of scientific papers.

Vol. V. — VIth General Assembly, Venice and Rome, September 1938 :

Part. 1. — Scientific papers, full text and summary.

Part. 2. — Proceedings of the General Assembly and Commission sessions (Original text).

Vol. VI. — VIIth General Assembly, Paris, September-October 1946. :

Proceedings of the General Assembly and Commission sessions; original text of scientific papers and of National Committee and Commission Reports.

Vol. VII. — XIIIth General Assembly, Stockholm, July 1948, as for Vol. VI.

Vol. VIII. — IXth General Assembly, Zurich, September 1950 :

Part. 1. — Minutes of the General Assembly and Commission sessions. National Committee Reports (This part has also be published in English language).

Part. II. — Original text and summary of scientific papers.

Vol. IX. — Xth General Assembly, Sydney, August 1952 :

Part. 1. — Administrative Proceedings and National Committee Reports.

Part. 2. — Proceedings of Commission I on Measurement Methods and Standards.

Part. 3. — Proceedings of Commission II on Tropospheric Propagation.

Part. 4. — Proceedings of Commission III on Ionospheric Propagation.

Part. 5. — Proceedings of Commission IV on Terrestrial Atmospherics.

Part. 6. — Proceedings of Commission V on Radio-Astronomy.

Part. 7. — Proceedings of Commission VI on Waves and Circuits.

Part. 8. — Proceedings of Commission VII on Electronics.

Vol. X. — XIth General Assembly, The Hague, August-September, 1954.

Part. 1. — Proceedings of Commission I on Radio Measurements and Standards.

Part. 2. — Proceedings of Commission II on Radio and Troposphere.

Part. 3. — Proceedings of Commission III on Ionospheric Radio.

Part. 4. — Proceedings of Commission IV on Radio Noise of Terrestrial Origin.

Part. 5. — Proceedings of Commission V on Radio-Astronomy.

Part. 6. — Proceedings of Commission VI on Radio Waves and Circuits.

Part. 7. — Proceedings of Commission VII on Radio-electronics.

Vol. XI. — XIIth General Assembly, Boulder (Colorado), August-September 1957 :

Parts 1 to 8, as for Volume X.

Vol. XII. — XIIIth General Assembly, London, September 1960.

Parts 1 to 8, as for Volumes X and XI; the title of Part 1 is « Radio Standards and Measurements Methods » and of Part 8 « Administrative Proceedings and Miscellaneous Activities ».

Volumes IX to XII have also been issued in French language; volume XII contains Part 6 bis issued only in English language, as a supplement to Part 6

RAPPORTS SPÉCIAUX DE L'U.R.S.I.

U.R.S.I. SPECIAL REPORTS

1. On Solar and Galactic Radio Noise (1951).
Bruits radio électriques solaires et galactiques (Traduction).

2. On Tidal Phenomena in the Ionosphere (1951).
   Les phénomènes de marée dans l'Ionosphère (Traduction).
3. On Discrete Source of Extra-Terrestrial Noise (1954).
   Les sources discrètes d'émission radio électrique extra-terrestre (Traduction).
4. On the Distribution of Radio Brightness on the Solar Disk (1954).
   Distribution de la brillance radioélectrique sur le disque solaire (Traduction).
5. On Interstellar Hydrogen (1954).
   L'Hydrogène interstellaire (Traduction).

Special Reports n° 4 and 5 have been issued in a single booklet.

Les Rapports Spéciaux n° 4 et 5 ont été publiés dans une seule brochure.

6. Radio Observations of the Aurora (1961).
7. The Measurement of Characteristics of Terrestrial Radio Noise (1962).

Special Reports n° 6 and 7 have been issued in the U.R.S.I. Monograph Series; they contain a summary in French language.

Les Rapports Spéciaux n° 6 et 7 ont été publiés dans la séries des Monographie de l'U.R.S.I. et contiennent un résumé en francais.

MONOGRAPHIES DE L'U.R.S.I.

U.R.S.I. MONOGRAPHS

Some Ionospheric Results obtained during the International Geophysical Year, W. J. G. Beynon, Symposium held in Brussels, September 1959.

U.R.S.I. Handbook of Ionogram Interpretation and Reduction, W. R. Piggott and K. Rawer (1961).

On Radio Measurements and Standards (XIIth General Assembly) — Sur les Mesures et Etalons Radioélectriques (XIIe Assemblée Générale), B. Decaux (1961).

Radio Wave Propagation in the Troposphere, J. A. Saxton (1962).

Ionospheric Radio, W. J. G. Beynon (1962).

Radio Noise of Terrestrial Origin, F. Horner (1962).

On Radio Waves and Circuits, S. Silver (1963).

Space Radio Communication, G. M. Brown — Symposium held in Paris, September 1961.

COMPTES RENDUS DE RÉUNIONS DE COMMISSIONS MIXTES

PROCEEDINGS OF JOINT COMMISSIONS MEETINGS

Commission Mixte de l'Ionosphère.

Mixed Commission on Ionosphere.

1. Bruxelles, juillet 1948.
2. Bruxelles, septembre 1950.
3. Canberra, August 1952.
4. Bruxelles, août 1954.

Commission Mixte de Radio Météorologie.

Joint Commission on Radio Meteorology.

1. Stockholm, July 1948.
2. Bruxelles, août 1951.
3. Bruxelles, août 1954.
4. New-York August 1957 (Published in *Journal of Atmospheric and Terrestrial Physics*, Vol. 15, n° 3, 4, October 1959).

BULLETINS

Bulletin de la Commission Internationale de Télégraphie Sans Fil Scientifique n° 1 (numéro unique), Mai-Juin 1914.

Bulletin d'Information (Tous les deux mois).

Information Bulletin (Bi-monthly).

n° 1-57. — En deux langues — Bilingual.

n° 57-122. — Une édition anglaise et une édition française.

A French issue and an English issue.

A partir du n° 123, édition bilingue.

From n° 123, a bilingual issue.

AUTRES PUBLICATIONS

OTHER PUBLICATIONS

Manuel des Stations Ionosphériques — Ionospheric Stations Manual.

Manuel des Codes des Ursigrammes — Ursigram Codes Manual.