Canadian Satellite: The Topside Sounder Alouette

The United States and Canadian national committees of the Union Radio Scientifique Internationale (URSI), together with Professional Groups of the Institute of Radio Engineers, recently sponsored the second United States-Canadian technical meeting of URSI. The meetings were held on 15, 16, and 17 October in Ottawa, the hosts being the Canadian National Research Council and the Defence Research Board.

At this meeting Canadian scientists announced the preliminary results of a spectacularly successful scientific space venture involving the "Alouette" satellite. The Alouette, also known as the Topside Sounder S27 and as 1962 Beta Alpha One, was developed by Canadian scientists of the Defence Research Board. It has the distinction of being the first space craft to be designed and constructed by a nation other than the United States or the U.S.S.R. It was launched by the American National Aeronautics and Space Administration (NASA) from the Pacific Missile Range on 29 September 1962, the first orbital flight attempted by NASA from this particular site. A 600-mile high circular orbit was asked for and achieved almost exactly. In fact, this particular launching represented the most accurate orbit yet achieved in the U.S., the height of perigee and apogee differing by only 22 miles. The Alouette was launched by a Thor Agena B vehicle into a polar orbit (inclination 80.5 degrees). Its period is 105 minutes.

The satellite itself is an oblate spheroid (Fig. 1) of spun aluminum (diameter, 42 inches; height, 34 inches) weighing 319 pounds. Its power is derived from some 6500 solar cells covering the outer shell of the vehicle which convert energy from sunlight incident on the cells into electrical energy to trickle charge the satellite's 12 nickel-cadmium batteries.

A unique feature of the Alouette is its 150-foot (tip-to-tip) antenna, the longest aboard any space vehicle to date. This, together with an additional 75-foot antenna, enables the satellite to receive and transmit radio waves over a wide frequency range extending from 0.45 to 11.8 Mcy/sec. The deployment of such long antennas raised some interesting problems which were solved in a brilliantly original way. Both antennas are made of thin heat-treated steel and are stored on drums within the vehicle rather like a carpenter's steel tape rule. After the satellite has separated from the launch vehicle, the antennas are extended and the steel tape assumes a circular cross section very much in appearance like, and as rigid as, a thin cylindrical tube. Antenna tests and preliminary experiments to test the feasibility of topside soundings were carried out at NASA's Wallops Island Station by rocket firings in June 1961.

A number of different experiments, conducted by the Canadian Defence Research Telecommunications Establishment and the National Research Council, are aboard the Alouette. The main experiment is concerned with measurements which have become known as "ionospheric topside soundings."

This experiment is a natural extension of one first carried out by Breit and Tuve in 1926 in the United States. Essentially, Breit and Tuve's equipment consisted of a variable-frequency, vertical-incidence radar capable of measuring the time delays between radio wave pulses received via a direct path from a transmitter on the ground close to the receiver and those received after they had traveled up into, and had been reflected down to earth by, the ionized regions of the earth's upper atmosphere. The depth to which the radio waves penetrate into the ionosphere depends on the frequency of the radio wave, and these observations are therefore known as ionospheric "soundings." Automatic equipment to record the echo time-delays as a function of frequency is called an ionosonde, and the record obtained is called an ionogram. The penetration depth also depends on the electron density in the ionosphere, and ionograms made at observatories all over the world have been widely used as starting data for the determination of the electron density-height profile of the ionosphere and to provide information about the maximum electron density in the different layers of the ionosphere. Ground based ionograms, however, have the serious limitation that they can provide no information about the ionosphere at levels above that at which the electron cloud reaches its maximum density (300 to 400 km) corresponding to a "critical" probing frequency. Radio waves of frequency greater than this critical value penetrate the ionosphere and are not reflected to earth.

The Alouette carries an ionosonde at altitudes well above the level of maximum electron density (Fig. 2) so that the delay time of echoes reflected from the *topside* of the ionosphere as a function of frequency may be recorded (Fig. 3*a*) and used to give the electron density distribution in the upper F region (Fig. 3*b*). The technical problems to be overcome in designing a sweep frequency satellite-borne radar system weighing less than 300 pounds and occupying a volume of less than 3 cubic feet are tremendous.

The sounding transmitter and receiver in the Alouette are completely transistorized. The sweep frequency sounding takes about 11 seconds to complete; during this time the satellite travels approximately 55 miles. The transmitter has a peak pulse power of 100 watts. The ionograms already recorded by this equipment number over 70,000; the quality of the recordings is extremely good. Furthermore, data recorded by Alouette, together with simultaneous soundings made by ground-based ionosondes, may be fitted together to produce a complete ionospheric electron density profile extending from about 100 kilometers above the earth into the exosphere (Fig. 4).

Thus, for the first time, the distribution of free electrons throughout the ionosphere may be monitored on a simple routine basis, and the way in which the ionosphere changes through

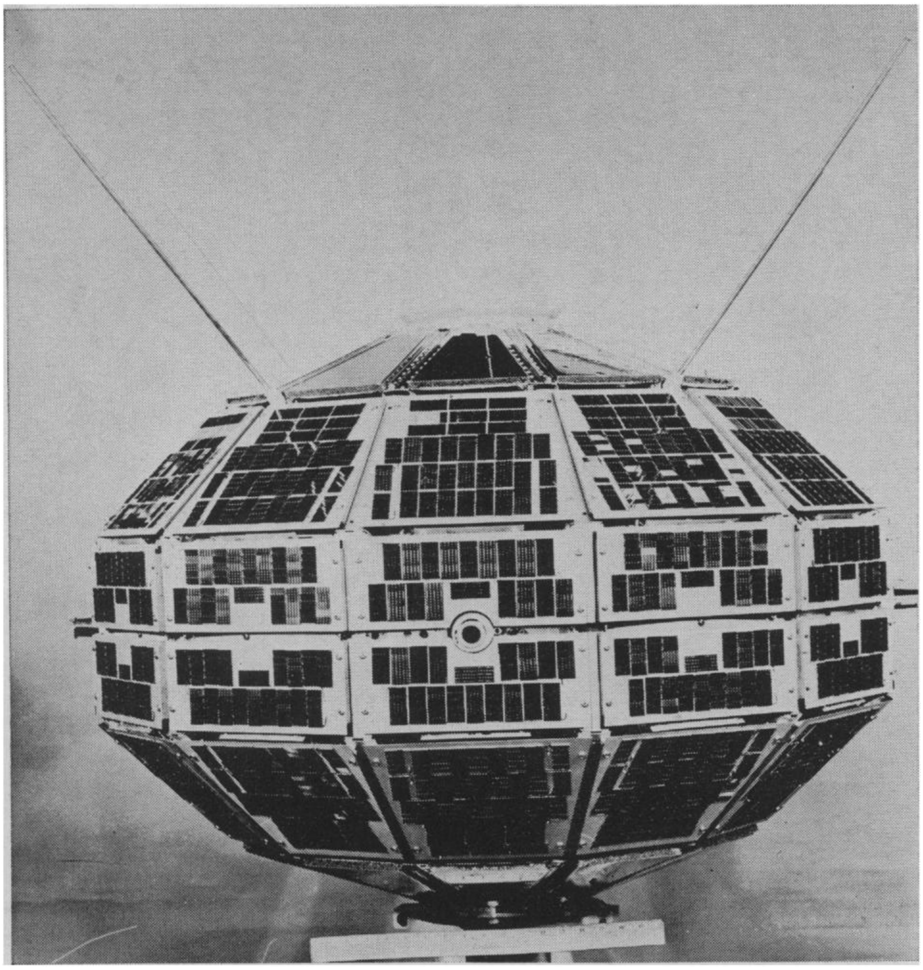

Fig. 1. The Canadian Topside Sounder Satellite "Alouette."

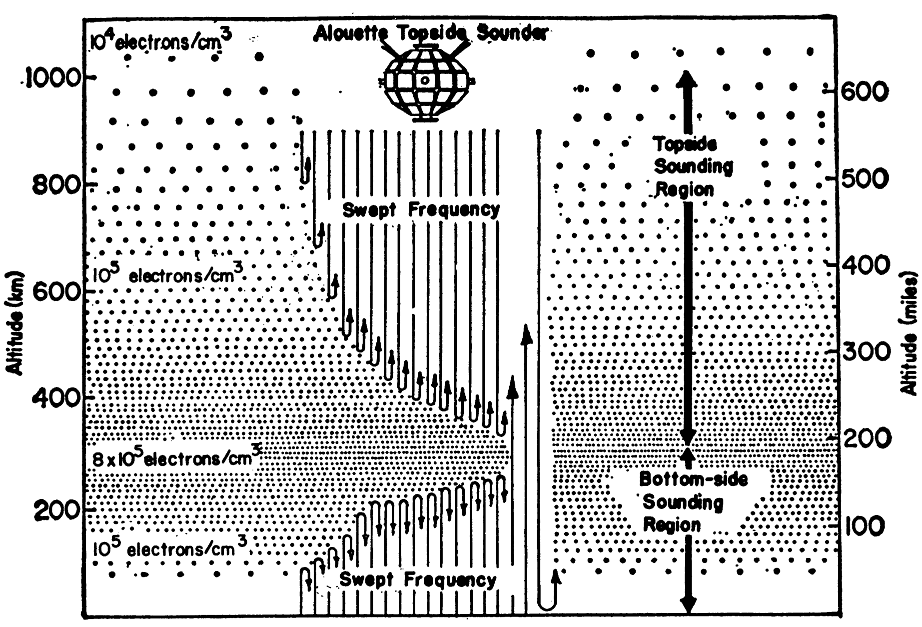

Fig. 2. Ground-based ionosondes are widely used to probe the part of the ionosphere lying below the level of maximum electron density at about 300 km. The Alouette satellite carries an ionosonde well above this level and can make similar observations of the extended upper reaches of the ionosphere. The number of electrons per cubic centimeter at different levels is represented schematically by the density of dots and is also indicated numerically.

the day and night at different latitudes may be observed. From these profiles, it is possible to derive information on the temperature of the ionosphere and on the mean molecular mass of its constituents. A paper presenting preliminary data on these subjects was read at the meeting. Scientific data recorded by the satellite are being telemetered to 12 ground stations. Three of these in Canada (Resolute Bay, Prince Albert, and Ottawa) were constructed by and are manned by Canadian personnel of the Defence Research Board. Seven of NASA's world-wide Minitrack stations are also recording data and tracking the satellite. Two stations are being operated by Great Britain—one at Singapore and the other on an island in the South Atlantic. These observations will be continued for at least a year, and it is planned ultimately to store copies of the data at the world data center at Boulder, Colorado, where they will be available on request, to scientists from anywhere in the world who may be interested in them.

The topside ionograms recorded to date show some extremely interesting features, and many of the sessions at Ottawa were concerned with their interpretation. In addition to the ordinary and extraordinary traces corresponding to the reflection of waves from the topside of the ionosphere, echoes are observed at frequencies greater than the "critical frequency" of the F2 layer. These correspond to waves which pass through the ionosphere, are reflected at the ground, penetrate the ionosphere again and are finally received at the satellite. A bifurcation of the traces is sometimes observed, and this has been attributed to the existence of a ledge (or perhaps a layer) above the F2 layer peak. Diffuse reflections similar in form to the familiar "spread F" echoes observed on ground-based ionograms have also been seen near the satellite and near the peak of the F2 layer. It seems likely that irregularities in the ionosphere at levels not previously studied will now be observable.

In addition to the ordinary and extraordinary wave traces mentioned above, some additional traces, including some called "plasma spikes," are observed. These spikes may be used to determine the electron density at the satellite very accurately. The detailed appearance of the ionogram traces pose many interesting new problems in the field of radio wave propagation in an ionized medium, and these are being worked on extensively by the Canadians as well as by scientists elsewhere. It is already clear that these features will provide a great deal of information about the properties of the ionosphere and about the earth's magnetic field at great heights above the earth.

The Alouette satellite carries a number of experiments in addition to the topside sounder experiment. Some of these, in which electron, proton, and α-particle fluxes are measured at the satellite, are concerned with the intensity of radiation in the horns of the outer Van Allen belt and with the variations of intensity which occur outside the belt and are associated with solar flares and auroras. The ar-

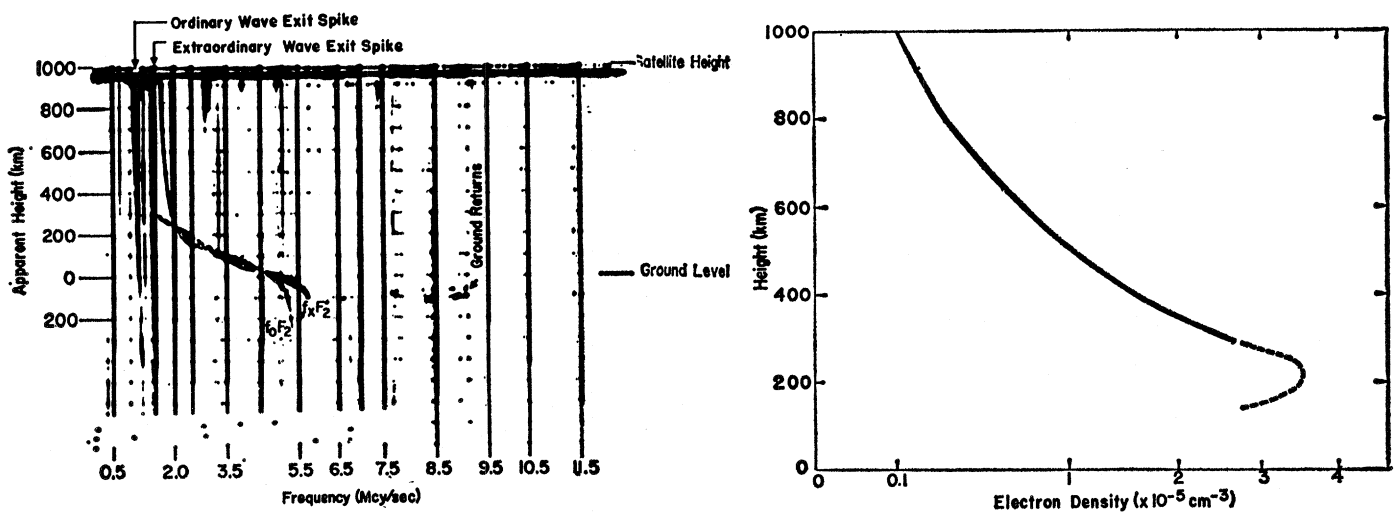

Fig. 3*a* (left). Alouette Topside Sounding made about midday above Ottawa, 29 September 1962. (Reproduced from Alouette Satellite 1962 Beta Alpha One, published by the Canadian Defence Research Board, Ottawa, October 1962.) Fig. 3*b* (right). The author has calculated that the electrons in the upper ionosphere must be distributed approximately in the form shown to account for the Alouette Topside Sounder observations reproduced in Fig. 3*a*.

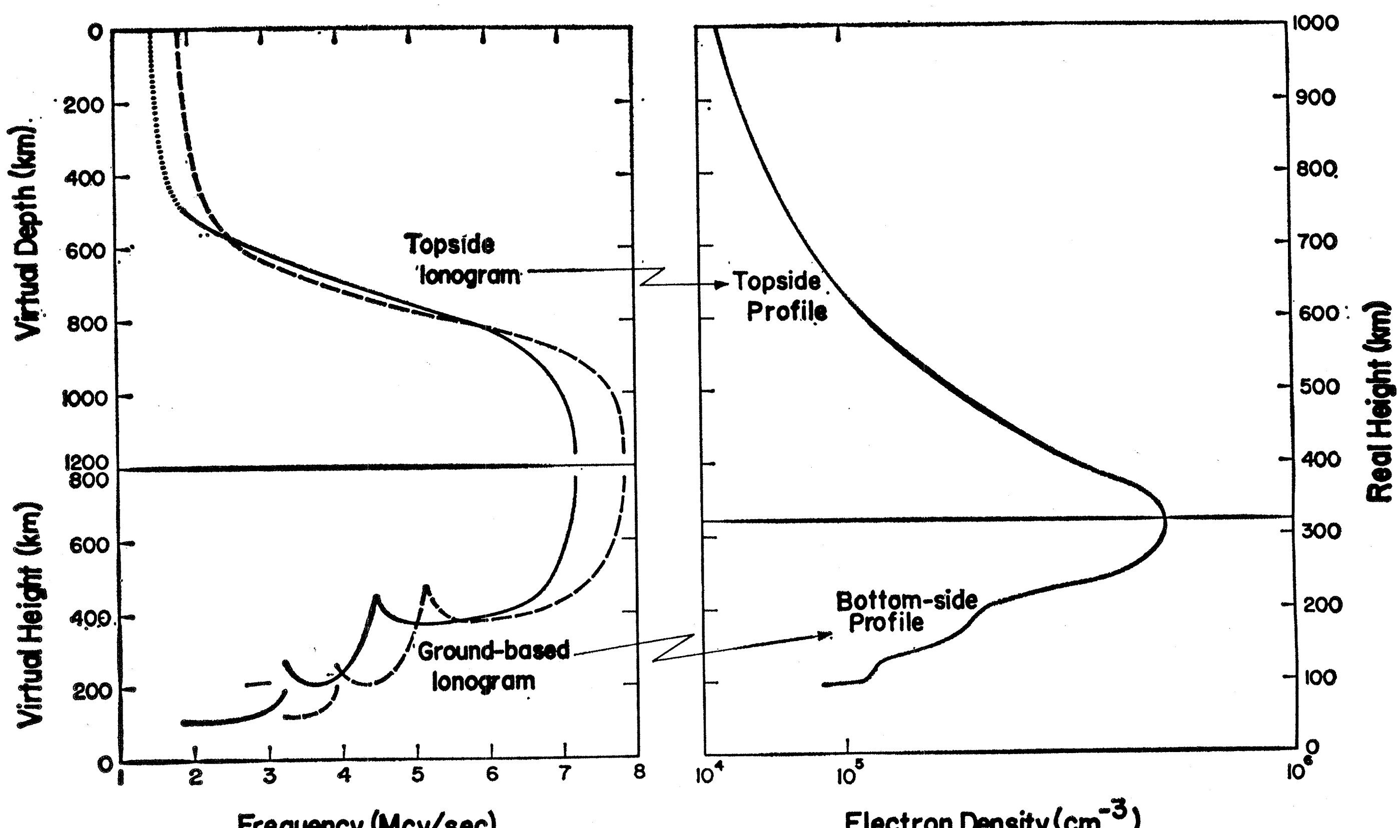

Fig. 4. Schematic diagram to illustrate how a complete ionospheric electron density-height profile may be obtained by using a topside ionogram to give the profile above the level of maximum electron density and a ground-based ionogram to give the profile below this level.

tificial radiation belt produced by a recent nuclear explosion at great altitude is also being observed. The instruments in the satellite also measure galactic radio noise and the intensities of very-low-frequency radio emissions in the range 1 to 10 kcy/sec.

The design and construction of the satellite was carried out by the Canadian Defence Research Telecommunications Establishment with assistance from NASA (which was responsible for the final testing and launching of the equipment) and from Canadian industry.

The Alouette satellite represents a brilliantly successful effort in which international cooperation in scientific experiments in space may be seen working at its best.

J. O. THOMAS
Radioscience Laboratory, Stanford University, Stanford, California

Bibliography and Notes

E. S. Warren, "Sweep frequency radio soundings of the topside of the ionosphere," *Can. J. Physics* **40**, 1692 (1962).
"Alouette satellite 1962 Beta Alpha One" (Canadian Defence Research Board, Ottawa, 1962).
"Space Systems: Canada's Alouette. . . .", *Missiles and Rockets* (24 September 1962), p. 35.

The following papers were included among those presented at the URSI-IRE meeting: G. E. Lockwood, "Plasma and cyclotron spike phenomena observed in topside ionograms"; G. L. Nelms, "Scale heights of the upper atmosphere from topside soundings"; G. L. Nelms and E. S. Warren, "Diffusing electromagnetic radiation."
This paper is based on information presented in papers read at the URSI-IRE meeting in Ottawa, 15–17 Oct. 1962, by a number of Canadian scientists, and on discussions with J. H. Chapman, G. L. Nelms, J. S. Belrose, and G. E. Lockwood. Goddard Space Flight Center (NASA) provided Fig. 1 and a slide from which Fig. 2 was adapted.

Forthcoming Events

February

10–15. **Management** Function in Research and Development, conf., Pasadena, Calif. (Management Development Section, Industrial Relations Center, California Inst. of Technology, Pasadena)

11–14. American Soc. of **Heating, Refrigerating, and Air-Conditioning Engineers,** New York, N.Y. (R. C. Cross, 345 E. 47th St., New York 17)

11–14. Industrial **Lubrication,** intern. conf. and exhibit, London, England. (E. V. Paterson, Scientific Lubrication, 217a Kensington High St., London W.8)

11–15. Quantum **Electronics,** intern. symp., Paris, France. (Secrétariat, Troisième Congrès International d'Electronique Quantique, 7 rue de Madrid, Paris 8e)

12–14. **Lysozomes,** symp. (by invitation), London, England. (Ciba Foundation, 41 Portland Pl., London W.1)

13–15. **Electrochemistry,** 1st Australian