THE UNIVERSITY OF AUCKLAND

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The last six months have seen a considerable increase in the amount and variety of information being recorded, and some valuable new techniques have been developed. This is due primarily to the fact that, for the first time, good signals are available from a number of different satellites in useful orbits. The number of people engaged on the work has also been increased since four research students are undertaking theses in this field.

Signals being recorded on a routine basis are from the Polar Ionosphere Beacon satellite S-66 (launched in October 1964), the Ionosphere Beacon Satellite BE-C (March 1965) and the communications satellite Syncom 3 (August 1964). The first of these, in an approximately north-south orbit, is recorded at a chain of six stations extending from a latitude of 21°S to 79°S. BE-C provides east-west, near-overhead transits at Auckland, and these are recorded for comparison with the north-south transits of S-66. The 136 Mc/s signal from the geostationary satellite Syncom 3 is recorded continuously at Auckland and at Invercargill. Equipment has been developed which uses this signal to provide a continuous, detailed and accurate record of the total electron content of the ionosphere. Recording of the satellite Transit 4A at Auckland and at Invercargill has been discontinued. These records have provided four values of total content at each station every day for over two years, but are now replaced by the continuous records from Syncom 3. A brief description of the major projects under way at the present time is given below.

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(1) ROUTINE RECORDING OF THE POLAR IONOSPHERE BEACON SATELLITE (S-66)

The amplitudes of the 20, 40 and 41 Mc/s signals from this satellite are being recorded during five transits each day at Auckland and at Invercargill. These signals are also being recorded during 14 transits each day at Scott Base in the Antarctic. The Department of Scientific and Industrial Research is recording the 20 and 40 Mc/s signals at Wellington and at Campbell Island, and these records will be available for Faraday rotation studies at Auckland. All these stations have been operating continuously since the satellite was launched in October 1964.

Equipment for recording the 20 and 40 Mc/s signals at Rarotonga was constructed by March 1965. A stable tuning fork oscillator is used to control the timing and programming functions independently of the local mains supply, and programming is completely automatic over periods of one week. Failure of two commercial units delayed final installation of this equipment until June, but records are now available from the following stations:

Rarotonga	Lat. 21.2°S	Long. 200.5°E	20, 40 Mc/s
Auckland	37.0	175.0	20, 40, 41
Wellington	41.2	174.5	20, 40
Invercargill	46.5	168.4	20, 40, 41
Campbell Island	52.5	169.1	20, 40
Scott Base	77.9	166.8	20, 40, 41

The relative phase of the Faraday fading on 40 and 41 Mc/s is used to calculate the total electron content of the ionosphere up to the height of the satellite (about 1,000 km). At Rarotonga this information can be obtained using the 40 Mc/s frequency only, since the magnetically transverse condition is observed during each transit. At Campbell Island the 41 Mc/s signal is necessary for accurate calculations of total content, but it cannot be recorded directly since only two recorder channels are available. To overcome this difficulty a device was developed which operates a relay at the minima of the 41 Mc/s fading pattern, but is not affected by noise. This was found to provide a reliable means of recording the exact positions of the fading minima on a marker pen, and was shipped to Campbell Island in February.

The faster fading of the 20 Mc/s signal is used to study spacial variations in the total electron content of the ionosphere. A plot of the intervals between successive fading minima provides a sensitive means of displaying fluctuations in electron content caused by large ionospheric irregularities. The size and density of the irregularities can be calculated quite simply, and from measurements at different latitudes and under different conditions the occurrence and characteristics of the irregularities are being studied. The chart readers constructed at Auckland have been further improved by the installation of high precision Helipots, and provide a rapid and accurate means of producing the irregularity plots. When the data processing equipment being obtained under the current grant arrives, the readers will be coupled to a card punch so that the entire analysis can be carried on by computer.

(2) STUDIES OF THE ANTARCTIC IONOSPHERE.

The 20, 40 and 41 Mc/s signals from the Polar Ionosphere Beacon Satellite have been recorded at Scott Base for 14 transits each day since October 20, 1964. Some minor troubles have been experienced in the severe conditions, which require the equipment to operate unattended for seven days at a time, but about 94% of all possible transits have been recorded. Results up to the end of February have been received at Auckland, giving four months records for study before the main supply becomes available next summer.

The Faraday fading can be clearly identified on over half the 40 and 41 Mc/s records. This fading is caused primarily by horizontal gradients of ionisation, since the magnetic field is near vertical. The magnetic field factor M has been calculated for all the summer transits, and was found to pass through a minimum value at some time in each transit. At this time the Faraday fading rate depends only on the horizontal gradient in the total electron content. Measurements at these times are therefore being used to determine the size of these gradients. The sign of the gradient is obtained from the relative phase of the fading on the two 40 Mc/s channels, which use perpendicular aerials. The gradients will then be used to study variations in the total electron content over the polar cap, and the effects of solar and magnetic disturbances.

The total electron content of the ionosphere is being determined from the relative phase of the fading on 40 and 41 Mc/s. Because of the irregular fading rate this measurement is less precise than the gradient determination outlined above. Reasonably accurate measurements can, however, be obtained several times each day, so that the mean seasonal and diurnal variations will eventually be revealed.

The Faraday fading rate cannot normally be determined on the 20 Mc/s channel, because of strong scintillations. This prevents a detailed study of large ionospheric irregularities. The records are being used to classify the different types of amplitude fluctuations which are observed, and to try and relate these to specific regions or conditions over the polar cap.

To investigate the large irregularities a detailed record of the polarisation angle of the 40 Mc/s signal is required. The spinning aerial system described in section 3 would be ideal for this purpose; however unattended operation in the Antarctic would be difficult, and a high proportion of useful records could not be expected. An alternative system which obtains the same effect electronically has therefore been developed. The signals are received on a fixed turnstile aerial which separates the ordinary and extraordinary components. These are passed through phase locked receivers which produce final intermediate frequencies differing by 200 c/s. Mixing these signals and passing them through a narrow band 200 c/s filter then produces a clean, noise free output whose phase is governed by the difference in phase of the two input signals. A record of the phase of this output therefore provides a continuous record of the polarisation angle of the incoming wave. A prototype of this system, working on 20 Mc/s, has been tested and found to operate satisfactorily. Two 40 Mc/s versions will now be built for testing under conditions of scintillation at Invercargill, before one of them is shipped to Scott Base next summer.

(3) DETAILED RECORDS OF THE POLARISATION ANGLE OF SATELLITE SIGNALS.

The spinning aerial system was completed early this year, and has been operating continuously since February. It uses a curved 40 Mc/s dipole aerial rotating at 300 rpm, so that the aerial becomes perpendicular to the plane of polarisation of an incoming wave ten times per second. A receiver connected to the aerial therefore produces a 10 c/s output, which is passed through a filter with a bandwidth of 1.5 c/s. The resulting signal is compared with a 10 c/s reference dervied from the rotating aerial, and the phase difference is recorded. A circuit switching between two fixed levels has been developed to give an accurate and stable phase measurement. Independent measurements on the positive and negative going portions of the signal remove any errors from unbalance in the squaring circuits, and give 20 measurements per second. The output is filtered to remove fluctuations faster than 2 c/s and gives a continuous, detailed record of the polarisation angle of the received signal.

The records have a sawtooth appearance, each diagonal line covering a 180 degree rotation in the polarisation angle. The satellite Beacon-C is particularly valuable for these measurements. It provides east-west transits at Auckland in which the magnetic field factor changes very slowly, so that 180 degrees of polarisation rotation takes several minutes. Each sawtooth then displays the variations in total content over a length of up to 1,000 km in the ionosphere. The records are often very smooth, showing no fluctuations greater than one degree in polarisation angle. This indicates the absence of small-scale variations of more than .02% in total content. More generally, irregularities with sizes from 3 km to 1,000 km are observed. The larger irregularities show variations of up to 10% in the total electron content of the ionosphere. The smaller irregularities commonly occur in groups of about three, with a separation of 10 to 20 km and total content changes of 0.1%.

Isolated irregularities generally appear as increases in electron density. They have a defocussing effect which causes the amplitude of the received signal to decrease under the irregularity, and increase either side. A single dense irregularity, or several weaker ones, causes interference effects on the ground giving rapid variations in signal strength. Thus a 30 second burst of typical, strong scintillations may be produced by two or three isolated irregularities. A computer program has been written for calculating the amplitude and polarisation changes which would be caused by irregularities of different sizes, and it has proved possible to reproduce the experimentally observed effects. It therefore seems that the accepted explanation of scintillations, as being due to a large number of small irregularities with a scale equal to that of the signal strength fluctuations, is incorrect in many instances.

To enable a detailed correlation analysis of small fluctuations in the polarisation angle, a high speed tape punch has been obtained. This will be used to record the position of each of the 10 nulls obtained each second, for subsequent analysis on the University's computer.

(4) DETAILED RECORDS OF THE DIFFERENTIAL DOPPLER SHIFT.

Equipment has been constructed for obtaining a continuous record of the difference in phase of the 20 and 40 Mc/s satellite signals. A two channel receiving system is used to reduce the 20 and 40 Mc/s signals to 5 and 10 kc/s respectively. These signals are filtered and converted to trains of pulses. The 5 kc/s pulses are used to trigger the time base of an oscilloscope tube, which displays the 10 kc/s pulses as bright dots which move slowly across the screen. The display is photographed on moving film, giving a record consisting of a large number of diagonal lines. Each line shows how the differential phase varies over one cycle, so that very small fluctuations in phase can be observed. A second tube with a time base triggered on every fourth pulse is used to provide a series of lines covering four cycles of doppler shift, so that larger irregularities can be displayed. A third tube photographed on the same film shows the amplitude of the 20 and 40 Mc/s signals. All the equipment used in these measurements, including the receivers and oscilloscope units, was designed and constructed at the University of Auckland and was brought into operation in June.

The film records provide a sensitive and reliable means of studying small ionospheric irregularities. They have the great advantage that a clearly defined trace can be produced only by a steady signal, so that spurious irregularities do not appear if the signal drops below the noise level. The records therefore provide a good check on the polarisation angle measurements outlined above. For routine observations, however, a pen record is desirable. This has been produced by passing the 5 and 10 kc/s signals through binary counters dividing by 16 and 32 respectively. The resulting pulses are fed to a switching system which produces a voltage increasing linearly with the delay between the two trains of pulses. This voltage is smoothed and provides a continuous pen record of one sixteenth of the differential phase shift. This will be used for calculations of the total electron content of the ionosphere (for comparison with the results of other methods) and to study the effects of ionospheric irregularities on the phase of the 20 and 40 Mc/s signals. The division by 16 makes the phase fluctuations of about the same magnitude as the 40 Mc/s polarisation angle variations, so that the results of the two techniques can be compared easily.

(5) ELEVATION ANGLE MEASUREMENTS

Work carried out in 1961, using the rotating interferometer, showed that measurements of the angle of arrival of satellite signals do provide a practicable method of investigating the ionosphere. Such measurements have the advantage over Doppler and Faraday observations that the refraction no longer appears as an error in the analysis. Useful results can therefore be obtained under conditions of large refraction, giving information on the thickness (i.e. the temperature) of the peak of the ionosphere. The accuracy obtainable with the 60 ft rotating interferometer was, however, barely adequate for this purpose. Now that strong signals are available from the S-66 satellite, in a north-south orbit, a fixed interferometer has been constructed. This uses a north-south baseline with, initially, a length of 300 ft. This will enable the elevation angle of the signal to be measured to within a fraction of a degree at the ends of a close transit. The same instrument will also be used to study fluctuations in bearing, caused by large horizontal gradients of ionization, at the ends of the east-west transits of the satellite BE-C.

Construction of the equipment for these measurements has been completed. Turnstile aerials are used to separate the ordinary and extraordinary components, the individual elements being curved through 90 degrees to give improved performance at low elevation angles. Narrow band signals are required for accurate phase comparison, so the overall Doppler shift of the 20 Mc/s signals must be removed. This is done by introducing a relative frequency shift of 200 c/s in the signals from the two aerials before they are added. The combined signals then pass through a receiver. The 200 c/s output is filtered and its phase, which depends on the relative phase of the original 20 Mc/s signals, is recorded. The complete system has been tested on close spaced aerials, and produces good records down to low elevation angles. Routine operation using the 300 ft baseline will commence shortly.

(6) CONTINUOUS RECORDS OF THE TOTAL ELECTRON CONTENT OF THE IONOSPHERE.

Observations on the Beacon satellites give a value for the total electron content of the ionosphere up to a height of 1,000 km. Results are obtained at about four times each day, so that the mean diurnal variation can only be determined by averaging measurements taken over several months. This is rather inaccurate and unsatisfactory, and makes it impossible to study in detail the changes associated with solar and magnetic activity. Equipment has therefore been developed to use the telemetry transmission from the geostationary satellite Syncom 3. This satellite remains at a fixed elevation of 45.6 degrees north of Auckland. The 136 Mc/s signal is picked up on a four element yagi antenna which rotates continuously with a period of one second. The receiver output therefore has a 2 c/s component, and this is extracted by passing the signal through a 2 c/s amplifier with a bandwidth of only 0.03 c/s. The phase of the resulting clean signal is compared with that of a 2 c/s reference derived directly from the rotating aerial. The phase comparison circuitry is similar to that used in the spinning aerial system (section 3) and provides an accurate, linear record of the plane of polar-

isation of the incoming signal. Because of the narrow bandwidth which can be used with a stationary satellite the system is very sensitive, and will produce useable records from one short burst of faint signal every 20 seconds.

The equipment has been operating satisfactorily since early May. With the steady signals from Syncom 3 continuous records of good quality are obtained, giving the plane of polarisation of the satellite signal to within one degree. Total content changes of only a few parts in 10^3 can therefore be followed. This makes the records ideal for studying the movement of ionospheric irregularities, and the changes in production or loss rates associated with ionospheric disturbances. Because of the fixed geometry, with a constant magnetic field factor M, the records can be scaled to read directly in terms of total electron content. The absolute accuracy is limited by the accuracy with which a mean value of M, and the polarisation angle of the transmitted signal, can be specified. It seems likely that the overall absolute error will be less than 5% during the day and 10% at night. This is less than the errors normally obtained using Beacon satellites, and, because of the higher frequency, corrections for second order effects are negligible.

Records are produced on a Rustrak recorder using a chart speed of one inch per hour. The temperature of the 136 Mc/s converter must be stabilised to prevent drift, and with this precaution the only maintenance required is to change the charts every month. The records therefore provide a very efficient and economical method of obtaining continuous, detailed information on the electron content of the ionosphere. They are particularly suitable for studying the movements of large irregularities, or travelling ionospheric disturbances. A second recording system has been constructed at Invercargill for this purpose, and it is hoped to install two further systems in other parts of New Zealand. The results should throw valuable new light on the formation and movement of the large ionospheric irregularities observed during transits of the Beacon satellites.

(7) PUBLICATIONS.

With the increase in the number of useable satellite signals, many projects which have been planned for several years are becoming productive. Results are also appearing from some long-term observations, so that the amount of material suitable for publication is increasing rapidly. Papers accepted for publication, or under preparation at the present time, are listed below.

Papers Accepted for Publication.

Titheridge J.E. "Direct manual calculations of ionospheric parameters using a single-polynomial analysis," Radio Science.

Titheridge J.E. "The polynomial analysis of ionospheric h'(f) records," Radio Science.

Titheridge J.E. "The calculation of the heights of the peaks of the ionospheric layers," J. Atmosph. Terr. Physics.

Papers in Preparation

"The height of large ionospheric irregularities;" results from spaced receiver observations of Transit 44.

"Investigations of the polar ionosphere using satellite signals;" a general description for Polar Record of the S-66 observations at Scott Base.

"Continuous records of the electron content of the ionosphere;" describing the Syncom 3 measurements.

"The characteristics of large ionospheric irregularities;" containing results from the Cosmos 5 and Nora-Alice series of observations (recalculated after some results were lost in the fire of October 1964).

"The distribution of large ionospheric irregularities;" containing results from two years' records of Transit 4A at Auckland and at Invercargill (recalculated after all results were lost in the fire).