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RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

Research conducted in whole or in part under NASA Grant no. 377 includes theoretical and experimental radio and radar studies of lunar and planetary ionospheres, atmospheres, and surfaces, and radar studies of the sun and interplanetary medium.

PLANETARY RESEARCH

Studies of the correlation characteristics of radio noise storms from Jupiter and from the sun have begun. The noise, recorded at two closely-spaced frequencies around 25 Mc, was digitally sampled and cross-correlated. The degree of correlation should yield information on the noise generation mechanisms and/or scintillation effects along the path. When detectable correlation exists, the time shift at which the maximum correlation occurs can give information on the integrated electron density between source and receiver. (At the source, correlation would exist at zero time shift. However in passing through the intervening medium, the lower frequency signal would have a slower group velocity. On reaching the receiver then, there would be a time shift proportional to the frequency spacing of the two signals and to the integrated electron density.) All necessary computer programs have been developed and several Jupiter storms and solar noise recordings have been reduced. Results to date, although preliminary, are quite promising and more noise recordings and data reduction will be carried out.

PROPAGATION CHARACTERISTICS THROUGH THE SOLAR CORONA

A radio wave sent from earth to a solar probe will suffer a doppler shift arising primarily from the motion of the solar probe. Assuming a circular orbit of the probe about the sun, a static, spherically symmetric corona with appropriate electron density distribution, and using the high frequency approximation for the refractive index of the medium, the doppler shift of a signal received at the probe was calculated. Two cases were considered: (1) the doppler shift of a wave propagating along a direct path to the probe, and (2) the change in doppler between two rays, one of which travels directly to the probe while the other suffers severe refraction and travels along a carom path.

Case 1: The doppler shift can be expressed as the sum of the free space doppler and doppler excess. Expressions for the free space doppler and doppler excess were obtained, and curves were drawn of these two quantities normalized with respect to the probe speed. The curves were obtained for a 50 Mc wave and drawn as a function of probe position relative to the sun with the orbit radius as parameter.

Case 2: Additional approximations were made to obtain the change in doppler between the direct and carom ray paths. A piecewise linear description for the carom ray path was made, and reflection off a spherical shell about the sun was assumed. These approximations produced a relatively simple, closed expression relating the impact parameters of the two rays converging at the solar probe. Only the free space doppler was considered in arriving at the doppler change. Results were presented in the form of curves of the ratio of the doppler change to the probe speed plotted as a function of the spacecraft position at the two frequencies, 50 and 100 Mc.

MAGNETOHYDRODYNAMIC WAVES IN INTERPLANETARY SPACE

Investigation has begun on the use of radar astronomy techniques for detecting the presence of MHD waves in the interplanetary medium. This investigation was motivated by results of magnetometer measurements made by the first Pioneer flights which produced evidence of MHD waves in the interplanetary medium. Evidence also pointed to the existence of shock waves which if substantiated would serve as an important confirmation of the idea that MHD shocks can be formed in collisionless, gyrotropic plasmas.

The part of the investigation conducted to date has consisted of becoming familiar with the literature on MHD waves in collisionless plasmas. It is anticipated that the presence of an MHD disturbance can be readily detected using bistatic radar techniques. Exactly how the hydromagnetic disturbance affects the propagation characteristics of the transmitted radio wave, and what measurements on the received signal should be made, remains to be determined.

SOLAR RADAR PROGRAM

Work on the 1963 solar data has been completed with the conclusion that no solar echoes were present, even in the addition of nearly 20 runs. Computation based on the Lincoln Laboratory results suggests that the solar cross section is smaller than required for detection by the Stanford radar and is decreasing as the sunspot minimum approaches.

Since the potential contribution to knowledge about the solar corona through the use of 25 Mc radar echoes is great, preparations are now underway for as many runs as possible during the summer of this year. Data reduction techniques have been modified to include the use of an IBM 1620 for digitizing the two received channels. This will double the number of data points available, since individual integrations will be one second long instead of two seconds. A small additional improvement is also expected from slightly increased transmitter power output, though a major increase can only be accomplished by amassing many, many individual runs.

CISLUNAR GAS STUDIES

The two frequency experiment, described in the last progress report, has been run at least five days per week during most of the reporting period. Automatic data processing techniques have been developed and used regularly to edit and store the lunar radar data. To date about four months of data have been stored in easily accessible form on digital tape. In addition to the Faraday and doppler data, detailed amplitude and polarization data are available on these tapes. It is now possible to conduct many different studies on this large quantity of data with minimum expenditure of time and money. Present plans call for studies of the scintillation, libration, and polarization characteristics of the signals, and of cross correlations between fading on the two frequencies, between fadings on one frequency received at two different locations, and between fading and density changes determined by the Faraday and doppler measurements. Detailed analysis of events observed during times of solar and lunar eclipses have been planned. Several of these studies have been started, clearly illustrating the ease with which the desired information can be extracted from the digital computer.

Several methods of measuring cislunar gas density (originally proposed by Eshleman, Barthle, and Gallagher in the October 1960 issue of the Journal of Geophysical Research)have been further studied in the light of the experimental results. The main limitation of the pulse delay difference and the modulated CW phase difference techniques for measuring group path is lunar roughness coupled with libration. It was felt originally that this effect would limit the work to frequencies below 30 Mc where the effect of the medium is large. It now appears that the limitation is even more severe, for the interplanetary densities measured with satellites and space probes to date are at least an order of magnitude less than the generally accepted values of a few years ago. The net result is that the spread in delay, or noise on the difference signal, is many times greater than the desired measurement.

Investigation of pseudo-random coding techniques for group path measurement has progressed nearly to the hardware stage. The principal aim is to measure the difference in radar range to the moon on two widely separated frequencies by the use of coding techniques similar to those employed in the solar radar program. Based on the currently predicted cislunar gas densities, a 10 to 100 μsec difference in time of flight for radar frequencies of 25 and 50 Mc is expected. Present plans call for coding the 300 kw and 50 kw transmissions with a 180° phase reversal modulator driven from a 2^7-1 random sequence generator. By using a clock frequency of 100 kc it should be possible to obtain 10-μsec range resolution while still taking advantage of the large average powers of the transmitters.

The total sequence length would then be 1.27 msec. Since the moon is 11.3 msec deep, this would mean that the total energy reflected would be folded over onto itself about nine times. Stanford Research Institute and Lincoln Laboratory studies have indicated that the leading edge of the moon has a very strong return with half the total power contained in a range depth of 10 μsec or less. Thus it should be possible to range on this sharp return while disregarding the random noise contribution from the rest of the moon.

In addition to the usual doppler and Faraday measurements, a double sideband signal is transmitted on 50 Mc at the beginning and end of each run. By measuring the difference in polarization of the two signals separated by 100 or 400 kc, it is possible to "unwind" the Faraday and determine the total number of rotations since leaving the transmitting antenna. Thus, it is now possible each day to measure total electron content in the ionosphere as a function of time and rate of change of electron content over the entire earth-moon path. Preliminary results of the total content to date agree well with satellite measurements and exhibit the predicted diurnal behavior.

PAPERS PRESENTED

At the Spring 1964 meeting of the International Scientific Radio Union held in Washington, D. C. from April 15-18, the following papers were presented describing research supported wholly or in part by this contract: "Limb diffraction and atmospheric refraction of radio waves by Mars," (G. Fjeldbo and V. R. Eshleman); "Backscatter from partially ionized regions," (O. Buneman); "Jupiter decametric polarization viewed through the solar wind," (B. B. Lusignan); and, "The exploration of planetary ionospheres," (V. R. Eshleman, G. Fjeldbo, O. K. Garriott and F. L. Smith).

At the Symposium on Solar-Terrestrial Relationships held April 20-21 in Washington, D. C., Mr. H. T. Howard gave a paper entitled, "Radar studies of the cislunar gas density."

On April 28, Prof. V. R. Eshleman addressed the Space Science Symposium at NASA Ames Research Center on the subject, "Bistatic radar astronomy."

PUBLICATIONS

During this reporting period the following technical reports and journal articles were published:

"Bistatic-radar methods for studying planetary ionospheres and surfaces," by Gunnar Fjeldbo, Scientific Report no. 2, NsG-377, Radioscience Laboratory, Stanford University, California.

"Radar doppler measurements of the cislunar medium," by H. T. Howard, P. Yoh, and V. R. Eshleman, J. Geophys. Res., 69, 535-539, February 1, 1964.

"Radar doppler and Faraday polarization measurements of the cislunar medium during the July 20, 1963, solar eclipse," by H. T. Howard, B. B. Lusignan, P. Yoh, and V. R. Eshleman, J. Geophys. Res., 69, 540-544, February 1, 1964.

"On the determination of temperature and ionic composition by electron backscattering from the ionosphere and magnetosphere," by D. R. Moorcroft, J. Geophys. Res., 69, 955-970, March 1, 1964.