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INTRODUCTION -- H. T. HOWARD

Research at the Stanford Center for Radar Astronomy strongly emphasizes both theoretical and experimental radio and radar studies of the lunar and planetary atmospheres and surfaces, the sun and the interplanetary medium. This work is conducted with support from NASA and other federal agencies. The work is carried out by faculty, senior researchers, and graduate student research assistants working toward advanced degrees. Studies involving the propagation of radio waves between ground terminals and a probe in space have received special emphasis. This technique has been successfully applied to studies of the earth's ionosphere, the cislunar medium, the interplanetary medium, the solar corona, the atmospheres of Mars and Venus, and the surface of the moon. Members of the staff of the Center have been or are involved in radio science experiments on Pioneer, Explorer, Lunar Orbiter, Apollo, and Viking spacecraft, and on Mariner missions to Mars, Venus, Mercury-Venus, and Jupiter-Saturn.

NASA sustaining grant NGL 05-020-014 is central to the support and growing analytical capability of the Stanford group. It amounts to approximately 20% of the overall funding but, unlike more specific contracts and grants, provides a focal point for the Center and direct or indirect support for nearly all of the faculty, staff, and graduate students. The result is that we have been able to maintain strong theoretical and technological transfer between some widely diverse research areas. This was particularly evident in our early flight program participation and is now most visible in our membership on the various interplanetary probe mission radio teams.

There are several areas in which this interaction has given the Center unique capabilities. One of the early areas was the study of planetary atmospheres and ionospheres through dual-frequency propagation experiments and the radio occultation method. That the techniques are well developed, but still evolving, is evidenced both in the scientific literature and in individual work on the teams influencing spacecraft radio design. Similarly, the theory and experiments required to understand the characteristics of radio waves scattered from rough surfaces has been developed along unique lines. Third, software and hardware conceived while doing research and study under the grant has been carried to completion on specific contracts and is running on the Stanford Radioscience Laboratory XDS Sigma 5 computer. This is a versatile, locally controlled computing facility which has analog tape handling capability, analog to digital conversion interfaces and a considerable, but growing, library of scientific data analysis and reduction programs. These are now used in nearly all of the Center's research work. Finally, the ATS Faraday rotation polarimeters developed jointly with other research groups have been operational for some time. A refined version of this equipment is due for installation at DSN Station 13 to replace an earlier model and to provide accurate ionospheric information during the Mariner Venus-Mercury flight.

In the following pages, individual staff and student contributions in Section A outline current research activities at the Center. Particular attention is called to the report of T. A. Croft regarding probe and radio occultation measurements of planetary atmospheres. Section B lists Recent Publications, Technical and Scientific Reports, and Symposia Attended and Papers Presented.

SECTION A

FACULTY STAFF AND STUDENT CONTRIBUTIONS

Horen Chang

Interplanetary Scintillations

The study of radio wave scintillations caused by plasma density fluctuations in the solar wind furnishes a powerful method for investigating its turbulent properties. The modern theory of scintillation is based on ideas developed in V. I. Tatarski's book, "The Effects of the Turbulent Atmosphere on Wave Propagation" (Tatarski, 1967). The general formulae of weak amplitude and phase fluctuations of a plane monochromatic wave in an extended, smoothly varying random medium are derived from the wave equations by using the method of smooth perturbations. Given the three-dimensional spatial power spectrum of the refractive-index fluctuation, in, along the line of sight. One can find the variance and the spatial covariance function of $\ell n\ \rho$, where ρ is the power received at the plane of the observer.

Recent papers by Cronyn (1970), Lovelace et al, and Jokipii and Hollweg (1970) support that Φn is a power-law spectrum. Definitely, a power-law is more realistic than the Gaussian spectrum often assumed in early studies of interplanetary scintillations. Suppose the power-law Φn can be expressed as

$$\Phi n(\lambda,k,r) \alpha \lambda^4 k^\rho r^q$$

where λ = radio wavelength, λ^4 arises from the fact that the radio refractivity is proportial to λ^2

k = spatial wave number

r = radial distance from the Sun

p,q ? exponents to be found

then by substituting this Φn into Tartarski's weak scintillation formulae, Young (1971) has shown that the variance of $\ell n\ \rho$, $\delta^2 \ell n\ \rho$, is asymptotically proportional to $\frac{2-\rho}{\lambda^{2}\,\theta^{q+1}}$ for small θ, where θ is the solar elongation angle. The calculations of $\delta^2 \ell n \rho$ from a representative set of our scintillation data appear to indicate that saturation occurs at $\theta \approx 40^\circ$ for 50 MHz and $\theta \approx 9^\circ$ for 423 MHz. During unsaturated (or weak scintillation) region, $q = -3$ seems to fit the data fairly well for both frequencies.

Further work with our man-made point source data, including investigations of the power spectra and the temporal covariance, will hopefully shed light on building up a better model of solar wind turbulence. This is important to the designer of an interplanetary communication system.

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Lovelace, R.V.E., Salpter, E.E., L.E., and Harris, D.E., 1970, Ap.J., 159, 1047.

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T. A. Croft

Underlying Pheonomena Permitting Remote Observation

In studying the atmospheres by radio occultation or by entry probes, one makes use of measurements of a few observable qualities of radio (or light) signals:

1. Refraction, in the ray sense; that is, refraction of the body of the energy on a scale large compared with λ. This produces two observable effects:
   a. Signal strength variation due to focusing (or the inverse), and
   b. Signal strength variation due to the dependence of antenna gain upon angle.
2. Absorption along the refracted ray. Usually, analysis of this phenomenon involves an integration of a scalar along the ray.
3. Refraction, in the diffraction sense; that is, change in the RF phase angle due to small scale variation in the index of refraction. Although this effect should be evaluated along a refracted ray, it is a nearly-universal practice to assume that the bulk energy flow is along straight paths and to treat the scintillation as an added perturbation. In most cases, the measured parameter is a signal strength which varies because the induced phase differences lead to signal enhancement and/or cancellation in the far zone where the resulting amplitude variation can be observed and analyzed to determine the statistics of the turbulence in the medium. The phase variations are also observable.
4. Polarization angle is observed as a means for determining the Faraday rotation along the refracted path, although in many instances a straight-path approximation is used for analysis. In addition, analysis almost invariably involves application of the quasi-longitudinal approximation for the ray equations in magnetoionic media, and it frequently takes the form of an integration carried out along a refracted ray.
5. Signal delay along a path, from which one can calculate the average value of the refractive index on that path.

6. Signal frequency shift along the path, from which the time derivative of the average refractive index can be obtained, is closely related to 5. above. This is also an oft-used parameter for the study of precise orbits, primarily by virtue or the comparative precision with which frequency can be measured.

Tools Being Developed at SCRA for such Studies

Analysis falls into two clear categories:

1. Working from an assumed medium, calculate the observables mentioned above, or
2. Working from measured or assumed observable, calculate the characteristics of the medium.

The first of these is typically a direct calculation involving few approximations and can be carried out with a degree of precision and realism which is limited primarily by the time and effort which one is willing to devote to the task. Such analysis is often termed "direct;" in contrast, the second category is called "inversion" because of the comparatively cumbersome methods which must be used and the relatively crude assumptions which must be made.

Direct analyses are useful in mission design and in evaluation of inversion methods. Perhaps most importantly, the direct methods permit inclusion of physical features that cannot be included in any known inversion methods, so that it may be desirable to perform an inversion by indirection; that is, by performing a large number of direct calculations followed by comparison to the observables, with iterative solution toward a single goal. The inversion methods are well suited for the interpretation of actual existing measurements.

With this introduction to analytic approaches, we provide a framework for relating the following achievements, projects (completed or under way) and plans for the future of our development of analytic capabilities by direct and inversion methods.

DIRECT - For most solutions, the direct method involves setting up a model of the planet or satellite with its atmosphere or ionosphere and then computing rays through the medium from earth to the distant spacecraft in some hypothetical location. All of the observables (except scintillation) can be approached as an adjunct to such a calculation. For example, the absorption involves the continued sum of a computed loss per km along a path, while the Faraday rotation is a sum of a computed angle per km along the path. It would be possible to approach scintillation in this manner also, with a good physical basis.

About two years ago, while seeking a possible relationship between the ashen light of Venus and refraction toward the dark side, we developed a versatile computer program which synthesized a model of the atmosphere with several optional degrees of freedom. This was done using Basic, a computer language which allowed time sharing so that the operator could build the model anew with each execution in only a matter of minutes. This program then computed rays from a hypothetical transmitter located either on the surface of the planet or at some fixed elevation above the planet. The pressure-induced absorption was determined and the program also included a provision for an absorbing layer of unexplained origin which had an optional top and bottom altitude and an optional loss rate. This has been used to perform design studies in conjunction with the Pioneer-Venus probe under contract to NASA/Ames; the existence of the program and our capability in this respect is a direct by-product of the sustaining grant.

This same approach to calculation can be used for occultation studies by a modification wherein the transmitter height is raised in successive steps while, at each step, one horizontal ray is launched. This provides the occultation rays by virtue of the fact that each such ray has line symmetry about a planetary radial drawn through periapsis. In this manner, the program computes one-half of the ray and the other half is obtained from symmetry considerations.

The main limitation upon this general purpose program has been its lack of accuracy, one part per million on the time-sharing compiler at the Stanford computer. Its compensating virtue is its convenience and ready availability, coupled with ease of modification which follows from the fact that each line of the program is compiled as an entity. Furthermore, during the execution, one may interrupt the middle of the cycle and change the program, thus correcting logic errors without having to re-execute the beginning portion.

We have also developed a completely separate program which performs a similar calculation in Fortran in such a way that it complements the Basic version. A much higher degree of accuracy is obtained and, furthermore, the results are plotted and stored in various digital forms for use in further calculations. As a practical matter, the atmosphere model generation algorithms are separated in a program which is independently executed, storing the model in a digital matrix. Further, the ray calculation is broken into two programs, one of which is used for planetary probes and the other is used for occultation simulation. It turns out that logic controls and the relationships among the subroutines are sufficiently complex to justify the existence of two separate programs to perform these two kinds of analyses, even though the underlying equations are identical.

The planetary probe part of this program has been used in the aforementioned Pioneer probe study, and the occultation portion of the program is in the final stages of debugging at the time of this writing. It will be used in Venus occultation studies and in support of the MJS mission.

Finally, we are in the process of preparing a powerful computer program which performs ray calculations in a medium which has a three-dimensional variation of the electron density and neutral density and which incorporates a provision for magnetoionic effects. This will permit us to study the Faraday rotation in the ionospheres of planets or the separate propagation of the two magnetoionic components. This program is expected to have application in the study of Jupiter and Saturn; it will also be useful in all radar astronomy as an aid in understanding the deleterious effects of the earth's ionosphere through which we must look. Furthermore, the three-dimensional aspect of the program will permit us to study the neutral atmospheric variations on planets when there is a horizontal gradient of the refractivity. This is known to occur in association with weather fronts, dawn-dusk lines and other sources of inhomogeneity. It is significant that no inversion methods can incorporate such lateral gradients; rather, they make an assumption that refractivity varies only with the distance from the center of the planet.

INVERSION Method - So long as one is willing to accept the approximation of radial symmetry, it is possible to perform an inversion starting with the measured data and working (in a sense, backwards) to derive the atmospheric characteristics. The methods for doing this are simple in their basis, depending upon the tractable form of the ray equations for propagation in a thin, spherical homogeneous shell. The atmosphere is considered to consist of a large number of concentric shells like the layers of an onion, and the equations associated with each such shell are handled as an element in a matrix. By this means it is possible to formulate an approach to the relationship between the observable parameters and the atmospheric model which is similar in principle to the two axes of a matrix. We are planning an inversion routine for use in conjunction with the ray tracing programs described above. This Center has an extensive association with such inversion programs which are invaluable for the processing of data; however, for pre-launch analysis and for hardware design studies, like those in which we are now involved, the direct approach is more practical as a means for the solution of problems which relate the atmospheric models to the observable parameters.

SCINTILLATION analysis does not fall into the direct and inversion category, but rather it is performed by the more traditional methods of statistical and probabilistic studies, using the computer primarily as an aid in assembling the statistics. The mathematical basis of the scintillation is similar in all applications, although the superficialities may be differently treated by people who study the solar wind, the ionosphere, the troposphere, etc., in each of which the phenomenon Φ is evident. Our expertise in this subject is a byproduct of a current project now under way to determine the nature of the solar coronal turbulence through study of scintillations on radio signals at 50 and 423 MHz which we transmitted from Stanford to Pioneer 9 during its occultation by the sun. The capability thus developed is applicable to planetary atmosphere scintillation studies in considering the entry or occultation of space probes.

Michael S. Frankel

Low Frequency Gyro-Synchrotron Radio Noise from the Earth's Outer Radiation Belt

Electrons spiraling along magnetic field lines emit electromagnetic radiation at radio wavelengths via the cyclotron and synchrotron emission processes. Consequently, with the discovery of the Van Allen radiation belts, the possibillty of detecting synchrotron radiation from superthermal electrons trapped in these regions has become an important topic of research. Studies, which to the present have been limited to frequencies above 2 MHz, show that the radio noise from these electrons is not easily detected as it is less than noise generated by galactic and extragalactic sources.

In this project, the problem of detecting cyclotron and synchrotron noise from these superthermal electrons is analyzed for the frequency range 30 kHz to 300 kHz. Due to the earth's ionosphere, ground based observation of this noise is improbable. Therefore, the calculations are made for an observer in the interplanetary medium. In particular, the location is chosen in the geomagnetic equatorial plane at a geocentric distance of 32 earth radii. This position of the observer allows the theoretical results to be compared directly with data obtained from the Goddard Space Flight Center (GSFC) radio astronomy experiment aboard the IMP-6 spacecraft.

The energy, radiated by the trapped electrons and propagated to 32 earth radii, is calculated using the equation of radiative transfer. To solve this equation, models for the thermal and superthermal electron densities, throughout the earth's magnetosphere, are derived from in situ and indirect measurements made of these particle populations.

The analysis shows that appreciable radio noise in the LF range is emitted by electrons in the earth's outer radiation belt. The inner belt does not contribute power at these frequencies since it is located in the plasmasphere, a region of high thermal electron density, which inhibits radiation at these low frequencies. The intensity of the radio noise from the outer radiation belt is positively correlated with K_p (the planetary three-hour-range index). This correlation is due to the enhancement of the stably trapped electrons during periods of sustained geomagnetic activity.

For a frequency f in Hz (30 kHz $\le f \le$ 150 kHz), the average calculated brightness, I(f), is given by a constant, M, times the frequency raised to the (-a) power, where both M and (a) vary with K_p as follows: $1^- \le K_p \le 2$, log (M) = -12.82, a = 1.66; $3 \le K_p \le 4$, log (M) = -11.50, a = 1.71; $5 \le K_p \le 6^+$, log (M) = -10.13, a = 1.82. The units of I(f) are watts m^{-2} Hz^{-1} steradian $^{-1}$.

These theoretical results were compared with data from the GSFC experiment aboard the IMP-6, which detected radio noise in the LF range emanating from the earth. The predicted increases in M and (a) with K_p were found in the experimental data. Furthermore, the calculated increases in these quantities are within 10% of those seen in the IMP-6 data, and the experimental and theoretical values of (a) are within 9% for each K_p range.

The theoretical model, however, underestimates the noise intensity observed on the IMP-6 by a consistent factor of 5. This factor is felt to be within modeling and experimental errors. Consequently, it is concluded that detectable cyclotron-synchrotron noise in the LF range is generated by electrons trapped in the earth's outer radiation belt, and the intensity of this noise increases with increasing geomagnetic activity.

Based on this conclusion, three applications of the results of this study are suggested. First, the radio noise can be used to determine the spatially integrated flux spectrum for the electrons trapped in the earth's outer radiation belt. Second, the noise can be used to obtain an estimate of the maximum interplanetary electron density between the observer and the earth. (An example of this application is given in the study.) Finally, the ray path calculations in the analysis show that a radio occultation experiment between two satellites can be used to determine the location of the plasmapause as a function of K_p and/or time.

Don Johnstone

EM Scattering from Ocean Surfaces

The previously reported rough surface scattering cross section model based on Rice's (1951) perturbation approach has been expanded to include time varying surfaces.

The first order terms in the resulting expression are clearly due to first order Bragg scatter in agreement with radar scattering measurements of ocean surfaces. Second order terms can be explained as multiple Bragg scatter where EM waves are scattered successively from two different ocean wave trains with the intermediate EM wave being either propagating or evanescent. It is these second order terms which are expected to explain in part the radar results not attributable to simple first order Bragg scattering.

The general expression for radar cross-section obtained here reduces to the special case reported by Barrick (1971) for backscatter at grazing incidence when second order hydrodynamic effects and finite surface impedance are neglected in the Barrick formulation. This reduced expression is presently being evaluated numerically in order to develop the numerical techniques to be used eventually in evaluating the general expressions.

Future work includes incorporating second order hydrodynamic effects and finite surface impedances in the general theory, comparing numerical results based on this theory to radar measurements and finally developing a technique for deriving directional ocean spectra from radar cross-section measurements.

Rice, S.O., "Reflection of Electromagnetic Waves from Slightly Rough Surfaces," The Theory of Electromagnetic Waves, edited by Morris Kline, Dover Publications, Publications, Inc., New York, 1951, p. 351.

Barrick, Donald E., "Dependence of Second-Order Doppler Sidebands in HF Sea Echo Upon Sea State," 1971 G-AP International Symposium Digest.

Essam A. Marouf

Bistatic Radar Study of the Rings of Saturn

The system of rings surrounding the planet Saturn is a unique feature in our planetary system. More than 350 years have passed since Galileo identified them in his telescope and they are still as puzzling as they are beautiful. The brightness of the rings excludes the possibility of their being gaseous. Also, they cannot be liquid since only He and H_2 stay liquid at the rings' extremely cold temperature ($\sim 65^{\circ}K$) and neither has been spectroscopically identified. The rings exhibit differential rotation which excludes the possibility of a rigid flat disc. For stability reasons, therefore, the rings are most probably solid chunks of material, of unknown shape, size, size dispersion, and radial distribution; orbiting Saturn in its equatorial plane in nearly circular paths, each with its own Keplerian velocity. Although water frost was identified to exist, the exact composition of the rings' particles is by no means known yet. The composition is of extreme importance, however, for if these particles were the remanents of a satellite that failed to form, the rings would be the only place in our solar system with the original planetary material still available for study.

Optical, radio, and spectroscopic studies over the past years have helped us to learn a good deal about the general structure of the rings. Variation of the brightness distribution as a function of the radial distance as well as estimates of the optical thickness of different regions were reported. Observations made with the rings in the Earth-Saturn plane revealed a thickness that cannot exceed 10 Km and can be much smaller than that. Reflectivity spectra were used to give estimates of the particle size distribution. Theoretical studies of the mechanical stability of collision-free models led to some bounds on the total mass of the rings' material.

Optical and radio observations are usually limited by the fact that an observer has no control over the source causing the phenomena observed. Received signals are incoherent in nature. Bistatic radar, therefore, emerges as a new, powerful technique for the study of the rings. This research is primarily concerned with such study.

A coherent signal transmitted from a spacecraft, occulted by the rings' plane, and received on Earth will scatter on the rings' particles before reception. Because the rings' particles are randomly distributed in space and moving with time, the received signal will be stochastic in nature. The mean field, usually called coherent signal, would have a nagnitude that is reduced because of the total power scattered in all directions as well as the real absorption in the material of the particle. The phase, on the other hand, would vary from its free space value. The rate of such variation shows as a doppler shift of the carrier frequency. The integrated doppler is related to the amount of material that has been encountered by the wave, as well as the individual particle scattering properties in the forward direction. On the other hand, the mean square field fluctuations about the mean field, usually called incoherent signal, would show as a power spectrum, that is, spread in frequency. This is naturally expected because of the time varying nature of the system through which the signal has propagated. The shape, area, and bandwidth of such spectrum is related to the collective scattering properties of the scattering random slab (that is, rings), as well as to the craft antenna beamwidth.

Explicit expressions relating all the previous measurable quantities to the actual physical parameters describing the rings, namely, shape of the particles, orientation, size distribution, packing fraction, thickness of slab, as well as material, is extremely difficult in its full generality. Even for the case of spheres having same size, the exact solution is very difficult if one has to include all effects of multiple scattering between the particles. However, explicit solutions were obtained when specializing to the special case of large spheres (compared to wavelength) with small packing fraction. Both coherent and incoherent received signals were expressed explicitly in terms of particle density distribution, particle size and slab thickness. Approximate analytical doppler loci were derived for the case of narrow spacecraft antenna beam (3 m dish for λ = 3 and 13 cm). These loci were used to derive the incoherent signal parameters. For this special model, it was shown that observed data can be inverted. Other models are still being studied. Optimization of the spacecraft trajectory for best conditions of inverting the data, for a general model, is now being examined. Under study also is the problem of resolution.

Theoretical power spectral densities for the monostatic radar case (that is, both transmitter and receiver on Earth) have been worked out for the cases of uniform, power law (or combination of both) radial particle density distribution. The two-spike behavior of the derived spectrum agrees in its general form with recently measured spectra at JPL. The backscattering results are used as bounds on modeling the rings for the study of the forward scattering case.

This research is being done with an eye on an actual occultation experiment of the rings to be performed by the Mariner-Jupiter-Saturn mission.

Carl Mitchell

Communications Satellite System Computer Model

A computer model of a telephony-only satellite communications system has been developed and computer coding is under way. It is to be used to determine the particular set of output parameter values that yield the least-cost system for a given set of input parameter values.

The input parameters include the following:

1. A description of the demand for service in terms of the number of erlangs of traffic between any two locations (cities, towns, isolated farms or industrial plants, etc.) as a function of time.
2. The required quality of service, given in picowatts of noise power in a telephone channel baseband width.
3. The location of and the boundaries of the area to be served. This defines the dimensions, and gain, of the satellite antenna.
4. The frequency of the up-link and of the down-link.
5. Equipment cost data.

The output parameters include:

1. The diameter of the Earth-station antenna.
2. The effective input noise temperature of the Earth-station receiver.
3. The sequence of output powers of the power amplifiers for each Earth station.
4. The least-cost type of satellite for the given situation.
5. The launch schedule for the satellites.
6. The ratio of space-segment costs to ground-segment costs.
7. The present worth of the costs of the total system.

The model is quite comprehensive. Nevertheless, as implied by item number 1 in the list of output parameters, it is not yet sufficiently general to handle a situation requiring more than one value of G/T--i.e., more than one "size" of Earth station--or more than one telephone channel quality specification. My goal is to achieve such generality, with up to three "sizes" of Earth station permitted and determined, and up to nine different qualities specified.

When completed, this model may be used in conjunction with the terrestrial facilities cost model reported on in the previous semiannual report as an overall telecommunications system planning aid to identify the least-cost system configuration.

One outcome of my effort to this point is in the derivation of an expression, in closed form, that closely approximates the solution of the Erlang B equation for the number of trunks, t. In the program, there is a need to convert the number of erlangs offered a fully available trunk group to the number of trunks required to serve at a specified grade of service. The Erlang B formula (eq. 1) is used as the basis of these computations.

$$P(B) = \frac{a^t/t!}{\sum_{k=1}^{t} a^k/k!} \tag{1}$$

where a is the number of erlangs offered to a trunk group of

t trunks.

P(B) is the probability of blocking (i.e., the probability that any person whose conversations are part of the a offered erlangs of traffic, wishing to use the trunk group will find all trunks already occupied).

It may be seen that for heavy traffic requiring a large number of trunks, the use of this formula is very awkward. Moreover, the problem in the program (and in almost all other applications) is that P(B) and a are given and the corresponding t is required. If eq. 1 were used, a time-consuming iterative procedure would have to be generated.

I found that for various values of P(B), the function

$$t = a/r, \quad \text{where} \quad r = 1 - \exp(-k_1 a^k)$$

was accurate to within plus or minus one trunk for all tabulated combinations of a and t. For example, with P(B) = 0.001, use k = 0.302 and k = 0.35 for a greater than 160.

Computation time is shortened considerably.

Max North

Radio Acoustic Sounding System

Experiments with a Radio Acoustic Sounding System for measurement of atmospheric parameters in the lower atmosphere have continued. The basic system remains unchanged, with a low power 36.8 MHz CW radar and short, high power acoustic pulses at about 85 Hz. A simple digital frequency counter measures the period of each cycle of the radar doppler shift signal, allowing calculation of the speed of sound and, therefore, the temperature at each altitude.

The experimental system under study is designed primarily to measure temperature profiles. Normal operation provides temperature readings at 50 M intervals with 0.2°C resolution. Accuracy is influenced by many factors, including signal-to-noise radio, data processing method, and atmospheric conditions. In the present configuration root-mean-square errors due to noise are less than 0.5°C when SNR is only 10 db. However, since the speed of sound varies slightly with humidity, temperature measurements can be in error by up to 1.1°C if humidity is unknown. Large errors also result from vertical winds, but these can normally be reduced considerably by averaging measurements for a few minutes. Thus, if humidity can be estimated with reasonable accuracy, the total RMS error should be about 1°C or less.

Range of the system is limited mainly by wind which, by displacing the sound pulse, moves the focal point of the echo away from the receiver antenna. During periods of very light winds temperature profiles have been obtained to heights greater than 2.5 Km, but normally the maximum range is only about 1000 to 1500 M. Comparisons with profiles provided by radiosandes and a captive balloon sounder have generally shown agreement within the predicted error bounds. Recent comparisons have been used to calibrate the system below 300 M so now useful measurements are obtained down to about 150 M.

During one series of measurements a sudden variation in readings was observed in a region near 400 M altitude. The changes were so rapid (a total time of about 15 minutes) that the apparent temperature fluctuation probably could not have occurred. It is more likely that the actual cause was the passage of a thermal through the region probed by the sounder. Thus, although vertical winds make temperature measurement more difficult, in certain cases the winds can be detected and probably even measured.

Future work will involve improving the system to simplify data processing so that it will be practical to run for longer periods of time. Experiments are also planned for measurement of horizontal winds.

Mike Parker

Radio Wave Scattering from Rough Surfaces

Research activity during this period has centered around comparing bistatic-radar estimates of lunar slope distributions with similar estimates of slope distribution derived from stero-pair photography. Both the bistatic-radar and the photographic data were obtained during flights of Apollo spacecraft. A computer program was written to convert from all directional slope distributions obtained from bistatic-radar data to the unidirectional distributions which result from photographic measurements. This allowed photographic and bistatic-radar data to be compared directly. Preliminary comparisons of the two types of measurement show excellent agreement between bistatic-radar and photographic data at selected scale lengths. However, no comprehensive theory exists to predict the observed sensitivity of the bistatic-radar data to transmitted frequency.

Steve Russell

Digital Teleconferencing Study

A comparison of digital and analog techniques for satellite communications is presently under way. Most of the information being gathered concerns digital techniques. Information is being gathered in five areas:

1. Modulation techniques and signal design.
2. Interference properties of digital modulation.
3. Multiple access techniques, with emphasis on their route TDMA methods.
4. Channel and source coding.
5. Demand for information transfer.

All of these impact on the policy questions of the restrictions that should be placed on digital modulation, such as allowed frequency bands, allowance for special service categories, and permissible EIRP.

A fairly thorough literature search has been completed on the first three areas above. Using this data, some performance measures are being formulated. Modulation and multiple access methods will be compared for several parameters using the developed performance measures. It is expected that the results can be used to modify a computer program that optimizes hardware configurations for satellite teleconferencing services.

Work on the second two areas will start in earnest in about one month. Channel and source coding methods are expected to provide a great advantage for digital transmission. The demand data will be useful in comparing the ability of analog and digital techniques to service real needs.

The work is focused primarily on those techniques useful in providing educational services as defined in an Ames-sponsored follow-on to a teleconferencing study of two years ago.

R. A. Simpson

Monostatic Lunar Radar Studies

Experimental data from a 1290 MHz lunar echo study has been reduced and interpreted. Major conclusions are based on the fact that subradar points for each of the three observation days were widely separated. These conclusions are:

1. Shape of the power versus time curve can vary markedly depending on terrain at the subradar point.
2. Gaussian rms unidirectional slopes are 4-5° in the Sinus Medii and Schröter regions, but may be as much as twice this in the highlands around Hipparchus.

As anomaly in data taken with the Subradar point in Hipparchus was interpreted in terms of increased scattering area in the first observed range bin due to Hipparchus' 1 km depression below the mean level of surrounding terrain. An interpretation based on different slope distributions inside and outside the crater is also tenable.

The new slope distributions are consistent with recent bistatic analyses. It is urged that the heterogeneous nature of the lunar surface be recognized.

Cal Teague

Bragg Scatter Probing of Sea State

The Wake Island synthetic aperture data have been analyzed in considerable detail and appear to represent 7-second ocean wave directional spectrum measurements of very high quality. Directional resolution on the order of 10° has been achieved, and to that from waves traveling upwind is at least 25dB. This value is near the resolution limit of the experiment, so the actual value may be higher.

The synthetic aperture data from each run were transformed separately for each antenna direction. The antenna pattern measurements, made one or two times each day, were used to generate a model for the antenna pattern. A function of the form $A + B \cos \theta$, where A and B take slightly different values each day (due to mechanical vibration and salt spray) was found to be an adequate model. The vehicle velocity was measured by stopwatch between the end points of each path; the fractional rms variation in the run times was 0.008. Hence a constant velocity of 7.20 m/s was assumed for all runs.

For each run, a directional ocean-wave spectrum was computed from the Fourier transforms, the antenna pattern model, the measured vehicle velocity, and an assumed r^3 propagation path loss (for a homogeneous extended target). Echoes within 15° of the velocity vector were discarded. Finally, one or two average spectra were produced for each day from 10 runs in different directions and 10 range bins per run. These spectra are continuous over 360° (except for one day when only data from taxi runs were used), and have a dynamic range of 25 dB and a resolution of approximately 10°. They cover a time period of one-third hours each, and correspond to echoes from an annulus from 30 to 67 Km from the island.

The spectra for all days are quite broad--nearly 180° at the half-power points--and centered on the mean wind direction for the 24 hours preceding the measurement. (Hourly wind observations from the airport were available for the entire duration of the experiment.) The total energy increases with wind velocity, although data for 2 of the 8 days fail to fit a straight-line relation. Moments of the form $\int f(\theta)\cos^{p}\theta \sin^{8}\theta \, d\theta$ were computed for the radar data for p,q = 0,1,2. These were compared with corresponding moments calculated from the Scripps buoy data for the two days that the buoy was used, and the agreement is quite good. Finally, various spectral models of the form $h[\alpha + (1-\alpha)\cos^{n}(\frac{\theta-\theta_o}{\Delta})]$ were fit to the radar data. A four-parameter fit was tried first: Δ was fixed at 2, and h, α, n, and θ_o were varied for minimum squared error. Then three-parameter fits were tried with θ_o at the value from the four-parameter fit, n fixed at 2 or 4, and h, α, and Δ varied for minimum squared error. All gave results which were almost equally good.

It is believed that because of the dynamic range and directional resolution of these measurements, and the ideal (and locally instrumented) wind conditions under which they were made, they represent a unique set of oceanographic data for 7-second waves.

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Robert T. P. Wang

Video Data Compression

Television Video (Pictorial) Data Compression will become a topic of great value when digital data transmission starts to receive the hardware attention it deserves. Presently, no system exists where a data compression algorithm is hardware implemented for use in a real-time television system. The research conducted jointly with Dr. Dale Lumb, Captain Steve Noble, and Mr. Scott Knauer of the NASA Ames Research Center is directed toward designing, building, and testing a real-time data compression system using 3-dimensional block encoding in the Hadamard Transform Domain. This system is designed specifically for use in satellite relayed television used for educational and teleconferencing purposes.

While the system is being designed and built at Ames Research Center, the work at Stanford University has been in studying and understanding the problem of visual perception as reported by psychophysicists and psychophysiologists. This study is important to the understanding of compression strategies designed to optimize the algorithms in accordance to the visual perception properties of the human observers--the ultimate receivers of the data.

A report is under preparation concurrently with a paper designed to disseminate this information to the data compression community at large.

John F. Vesecky and Michael S. Frankel

Observations of a Low Frequency Cutoff in Magnetospheric Radio Noise Received on IMP-6

Observations of magnetospheric radio noise by the Goddard Space Flight Center radio experiment on the IMP-6 spacecraft have revealed a quasi continuous component at frequencies between 30 and 110 kHz. When the spacecraft is in the interplanetary medium or the magnetosheath, a low frequency cutoff often characterizes an otherwise power law spectrum. A positive correlation is observed between this cutoff frequency (f_{co}) and the solar wind plasma frequency (f_{sw}) as deduced from the Los Alamos plasma experiment on the same spacecraft--on average $f_{co} \approx 1.3\ f_{sw}$. If one pictures the magnetosheath simply as a homogeneous layer of plasma lying between the radio noise source at $L \sim 4$ to 7 and the spacecraft in the interplanetary medium and having an electron density 2 to 3 times that of the solar wind, then one would expect $f_{co} \gtrsim 1.4$ to $1.7\ f_{sw}$. Within the limits of experimental error this simple model correctly accounts for the observations. However, the data tend toward values of f_{co} lower than those predicted by the aforementioned simple model suggesting that significant amounts of radiation may propagate through the highly turbulent and inhomogeneous magnetosheath plasma at frequencies below the maximum plasma frequency in the magnetosheath.

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