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PROPOSED RFI AND MULTIPATH SURVEILLANCE EXPERIMENT

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ABSTRACT

An experiment for the measurement of the radio frequency inter-ference (RFI) and the multipath environments between 136 MHz and 154 MHz is proposed. This experiment is designed to be flown with a Delta or Scout Packaged Attitude Control (PAC) spacecraft. The purpose of the experiment is to obtain as much measured RFI and multipath data as pos-sible in order to permit the optimum design of a Tracking and Data Relay Satellite System (TDRS). A preliminary investigation has uncovered many potential RFI sources in the continental United States. Clearly it is not possible to pinpoint all sources of RFI using frequency assignment data alone. The only practical method of determining the RFI environ-ment is to perform a series of measurements of the received power and spectral content in the bands of interest. Once these measurements have been interpreted in light of a particular proposed system, one can make intelligent decisions toward circumventing these effects. The proposed experiment will determine the available channels for most reliable trans-mission of information both in the 136-154 MHz TDRS to user frequency band, and whenever circumstances allow, multipath effects, using the ATS-III spacecraft as a source, will be observed and analyzed.

SUMMARY

The planned use of NASA satellites in synchronous earth orbit to track and relay data from near earth orbiting spacecraft at VHF* requires the solution of two major problems—namely radio frequency interference (RFI) and multipath.

1. RFI, in this case, is primarily the result of numerous earth based radiating sources within or adjacent to the NASA frequency allocations.
2. Multipath is a problem in that the unstabilized spacecraft use omnidirectional receiving antennas at VHF. Thus they receive both a direct and indirect signal from the synchronous relay. The multipath effect is of course also evident in the communication link from the near earth orbiting user spacecraft to the synchronous relay.

Thus an experiment for measurement of the RFI and the multipath effects in the frequency bands of 136-138 MHz and 148-154 MHz is proposed. The purpose of this experiment is to obtain as much RFI and multipath data as possible to permit the optimum design of the forthcoming tracking and Data Relay Satellite (TDRS) Systems.

A preliminary file search of cataloged transmitters has uncovered many potential RFI sources within the continental United States.** Clearly, the only practical and reliable method for determining RFI environment is to monitor the NASA frequency allocated bands from an orbiting spacecraft. Once the output of this monitor has been analyzed one can make intelligent design decisions toward operating within this RFI environment.

The effect of multipath upon signals transmitted from the TDRS to user and vice versa is being studied.*** However, much needed experimental verifications are still lacking. To date there have been no experimental data obtained for this type link. The reasons for measuring such multipath effects are to validate theoretical considerations which will lead to optimum systems designs.

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*"GSFC Mark I Tracking and Data-Relay Satellite (TDRS) System Concept" GSFC Nov. 1969.

**"RFI Characteristics of a Data Relay Satellite System," J. W. Bryan, Proceedings International Telemetry Conference Sept. 1969.

***"Multipath Signal Model Development," ADCOM Inc., Contract NAS 5-10797.

PROPOSED RFI AND MULTIPATH SURVEILLANCE EXPERIMENT

1.0 INTRODUCTION

An experiment for the measurement of the Radio Frequency Interference (RFI) and the multipath environments between 136 MHz and 154 MHz is proposed. This experiment is designed to be flown with a Delta or Scout Packaged Attitude Control (PAC) spacecraft. The purpose of the experiment is to obtain as much measured RFI and multipath data as possible in order to permit the optimum design of a Tracking and Data Relay Satellite System (TDRS). The TDRS (Figure 1) is conceived as a repeater satellite capable of relaying telemetry and ranging signals from one or more near earth orbiting user satellites to an earth station while at the same time relaying command and ranging signals from the earth station to the user satellite(s). This TDRS system is envisioned as an augmentation to the present ground networks and eventual replacement of a substantial number of tracking and telemetry sites.

Shown in Figure 2 is a synchronous TDRS and a low orbiting user. Also shown are the direct paths between the user and the synchronous satellite, the multipath created by the user, and the potential interference sources which reside on the earth and interfere with the TDRS and the user spacecraft.

A preliminary investigation has uncovered many potential RFI sources in the continental United States alone. Clearly it is not possible to pinpoint all sources of RFI using frequency assignment data alone. The only practical method of determining the RFI environment is to perform a series of measurements of the received power and spectral content in the bands of interest. Once these measurements have been interpreted in light of a particular proposed system, one can make intelligent decisions toward circumventing these effects. The proposed experiment will determine the available channels for most reliable transmission of information both in the 136-154 MHz TDRS to user frequency band, and whenever circumstances allow, multipath information.

Experimental data will be collected at 136-138 MHz and 148-154 MHz by a near earth orbiting satellite. This only requires a single VHF receiving antenna and a single tunable receiver swept for RFI measurements in frequency over any selected 2 MHz band with the output translated to an intermediate frequency and detected. The output will be recorded when out of ground site view and played back when in radio sight of a STADAN site. The recorder output will be transmitted to the ground site in the S-band. The monitoring receiver will be operated on a non-interfering basis with the command receiver such that the spacecraft
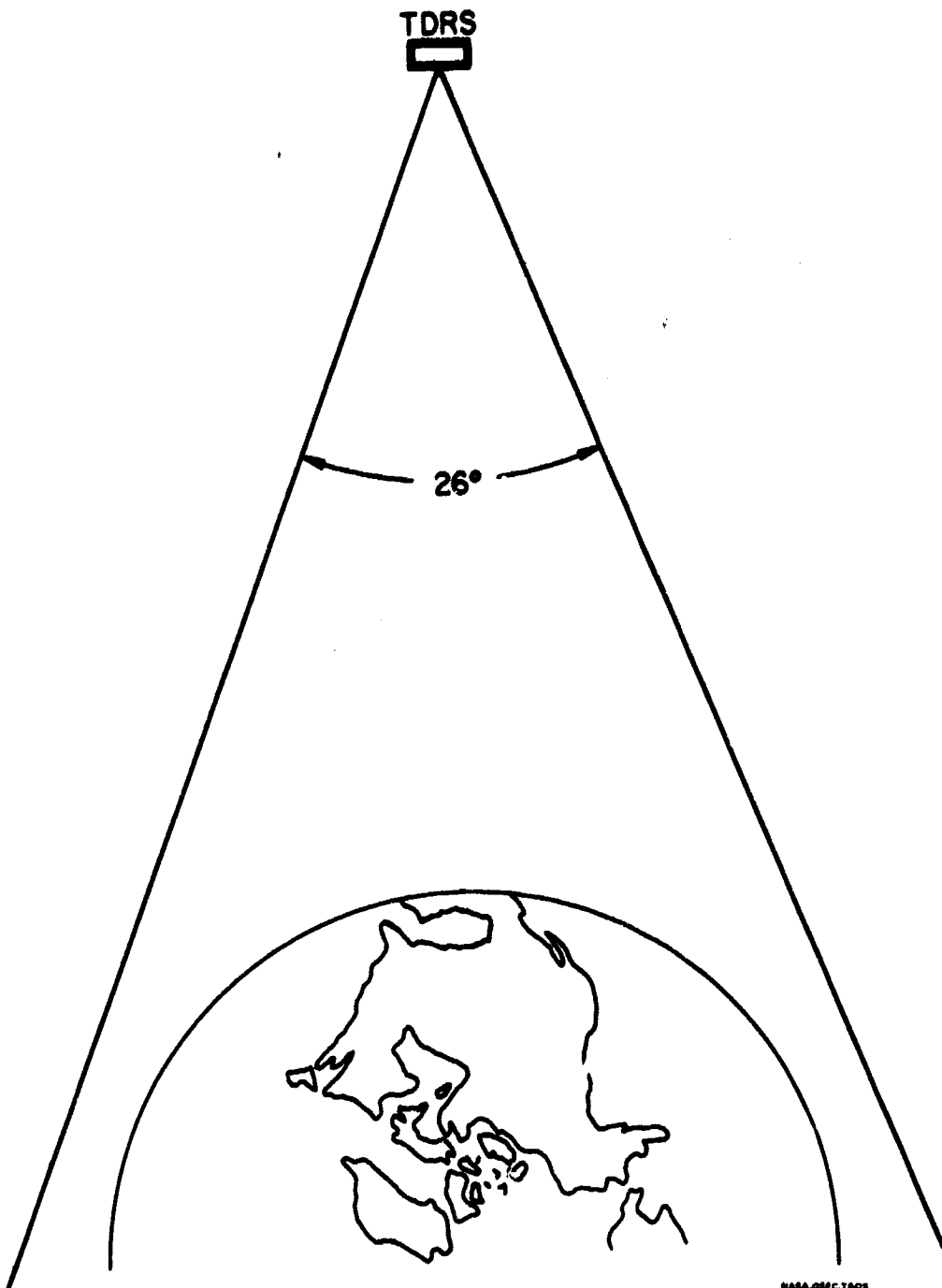
Figure 1—VHF Antenna Coverage

Figure 2–DRS/USER Link
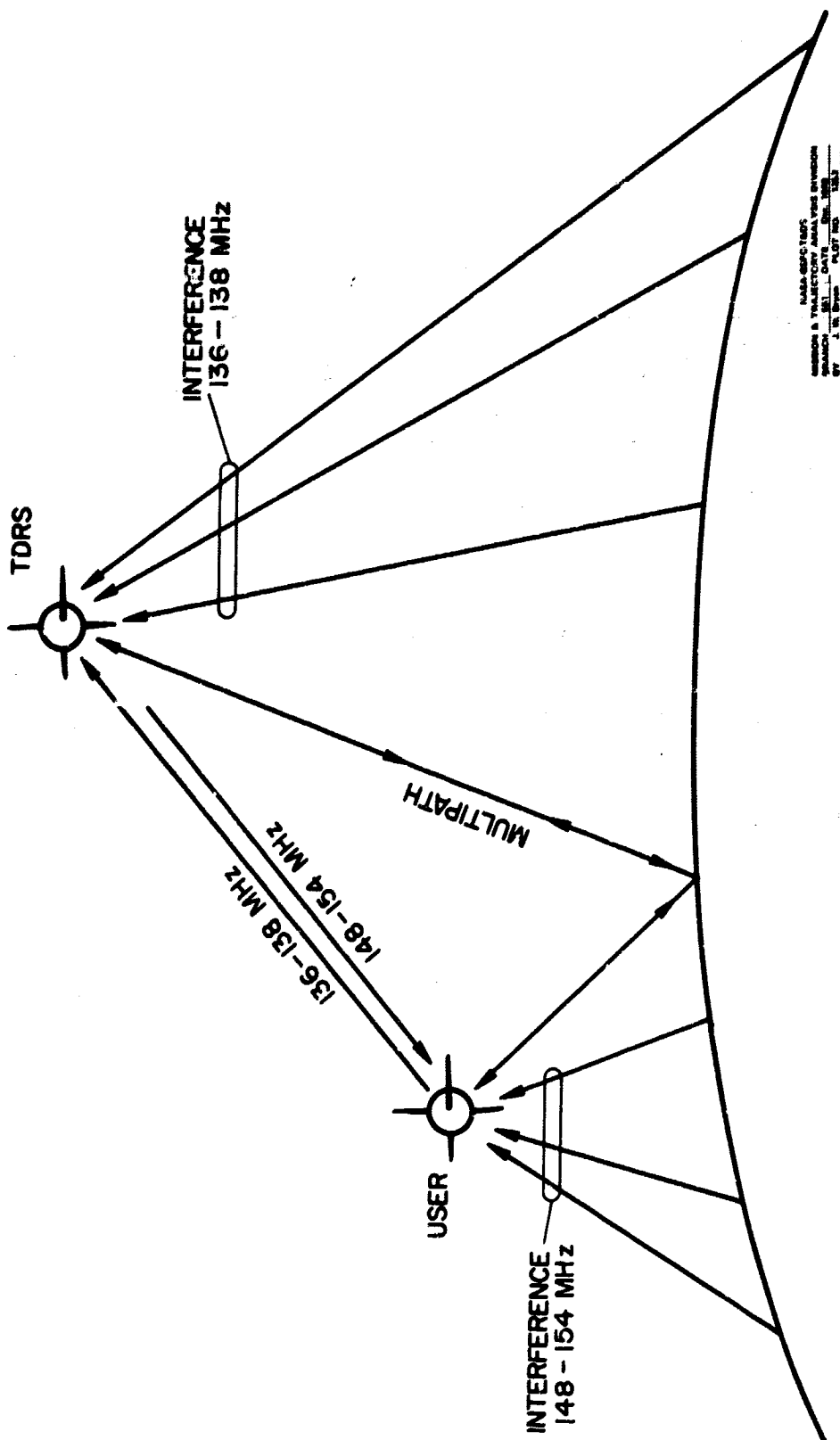
may be commanded in the present assigned frequency bands. Commands will be infrequent and self-interference caused by NASA command transmitters would present only a minor perturbation in the measurement data. Calibration of the experiment receiver will be accomplished using a ground generated signal of known signal strength.

Data reduction costs will be minimuzed by utilizing existing equipments in the RF System Branch of the Advanced Development Division with support from the Information Processing Division at GSFC.

The effect of multipath upon the signals transmitted from the TDRS to user and vice versa is being studied and analyzed. However, necessary experimental verifications are still lacking. Under certain conditions multipath effects can also be observed by way of this experiment.

There are a number of reasons why multipath measurements between a synchronous and non-synchronous satellite would be beneficial. To date there have been no such measurements made, only theory exists which does indicate that multipath, under certain reflection conditions, can be quite significant when a low orbiting user spacecraft is equipped with omni-directional antennas and is attempting to receive information from the TDRS. The multipath is also expected to affect the user to TDRS link. Therefore, one of the reasons for measuring multipath between a low orbiting user and the TDRS, or an equivalent synchronous satellite would be to establish the validity of the theory and to allow the theoreticians to refine their treatment in light of hard experimental data. In addition to the support of theory, these multipath measurements would collect realistic experimental data which could be used with less expensive electronic simulators to exercise various modulation and coding techniques designed to combat the effects of multipath. Knowing the statistical nature of the multipath, advanced systems concepts could be tried using valid simulations prior to actual launch. Furthermore, a better understanding of multipath would allow signal designers to arrive at more optimum designs for operations in this time varying channel.

2.0 DATA RELAY CONCEPT

In the space program the fact that small earth orbiting spacecraft are unstabilized precludes the use of directional antennas for data transmission. The presently assigned VHF (136-138 MHz) band is particularly attractive for this class of spacecraft utilizing low gain or so called "omnidirectional" antennas. TDRS optimization studies have indicated that an earth coverage antenna (i. e., 26° solid angle) on the TDRS for multiple low data rate (10 Kb/s or less) user will result in no appreciable degradation in the user data signal

to thermal noise ratio. These studies are predicated on the simultaneous relaying of data to as many as forty low data rate earth orbiting users. The use of an earth coverage receiving antenna on the TDRS has led to two major problems—namely, RFI and multipath.

2.1 RADIO FREQUENCY INTERFERENCE

At frequencies above about 30 MHz earth based receivers are shielded from most earth based RFI sources by terrain and antenna directivity. On the other hand, the TDRS continuously views approximately an entire earth hemisphere. Earth sources radiating powers several orders of magnitude greater than the small, low bit rate user would often fall directly in the TDRS antenna beam. A preliminary analysis of the known earth based RFI sources has indicated that the mean square value of these sources at the TDRS receiver will be -92 dbm with peaks as great as -80 dbm.[1] Assuming a receiving system 2 MHz wide with a 1000°K system noise temperature and a 16 db antenna gain, the anticipated noise level will be -105 dbm while a one watt user will have an effective signal of -123 dbm at the receiver input. Under these circumstances the TDRS receiver system will be interference limited rather than noise limited. Consequently, the data relay system must be carefully channelized and some specialized signal processing must be incorporated if the user-TDRS-earth data link is not to be seriously degraded. The interference problem clearly impacts TDRS receiver design which necessarily requires statistical data on anticipated interference flux levels. This experiment is designed to obtain such statistical data at a minimum cost.

A second, though perhaps more severe, RFI incident is associated with the TDRS to user link, where the user once again has an "omnidirectional" antenna. Here the problem results from relatively low TDRS command effective radiated power (erp) relative to earth based emitters in the same frequency band. Also, because of the geometry, earth based emissions reach the user with approximately 20 db less propagation loss. Here once again an investigation has been made of the known emitters within continental U. S. (Table I). Several instances of command blockage and false commands have been reported by the OSO[2] and OAO programs. This experiment can provide the necessary data to select a proper command frequency and coding scheme which will minimize such RFI problems.

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[1] "RFI Characteristics of a Data Relay Satellite System," J. W. Bryan, Proceedings International Telemetry Conference, September 1969.

[2] Foxe, Morton, GSFC Report X514-68-413 "Command Channel RFI and Its Effect on OSO IV," April 1969.

Table I
Effective Radiated Power Per Emitter In Watts

Frequency MHz	Total Emitters	Watts								Greater than 100 watts
		1-9	10-19	20-29	30-39	40-49	50-59	60-69	80	
148.20	6		5				1			
148.21	47		7	32		1	1	6		
148.215	4		3		1					
148.22	37	11		6	16	2	2			
148.23	28	1				12	13	2		
148.24	17				16			1		
148.25	56	4	8	29	11	1	1	1	1	
148.26	3									3
148.29	176	31	18	61	22	4	34	1	4	1
148.51	53	11		35				7		
148.515	18				17		1			
148.52	149	17	53	40	22	3	5	4	5	
148.54	88	21	59	1		1	2	1	3	
148.545	12		11					1		
148.55	316	50	222	8	15	5	11	4	1	1
148.56	1									1
148.575	1									1
148.59	16	1				11	4			
148.93	1						1			
148.95	32	17		9			4	2		
148.988	1							1		
149.00	33		1	31				1		
149.01	285	13	32	159	52	3	22	2	1	1
149.47	40	18		22				1		
149.48	229	64	37	14	110	1	1	2		
149.49	15			9			5	1		
149.50	150	60	44	1	34	4	5	1	1	
149.51	347	83	8	77	183	2	1	3		
149.53	40	25	7			4	4			
149.54	39	28	6			3	2			
149.55	13						1	12		
149.56	70	40	5	11	3	3	4	8	1	
149.565	47			47						
149.57	100	23	35	7	9	3	7	8	9	1
154.19	3				1	1	1			

1) An equivalent mean square sum of these emitters is not meaningful since a user will not be exposed to all of them at one time.

2) The NASA command transmitters have been excluded from this listing.

2.2 MULTIPATH EFFECTS

There are direct and indirect paths between the user and the data relay satellite. The direct path may be considered to be a non-fading signal path. Variations in signal strength along the direct path will depend primarily on variations in distance between the user and the data relay satellite system and imperfections in the user omnidirectional antenna pattern.

The indirect or multipath signal channel may be described in terms of a multiplicity of parameters. These parameters will be discussed in the following paragraphs.

The signal reflected off the earth is characterized by a time varying process which is statistically nonstationary because of the changing velocities and geometry between a user and the TDRS. The short-term statistics of this link can be considered stationary. If a CW signal is transmitted from a user craft this signal will be reflected off the earth and will appear at the TDRS. The reflected signal can consist of a specular component and a diffuse component. The degree of specularity and diffuseness associated with the reflected signal will in turn depend upon a multiplicity of parameters, e. g., the grazing angle, the roughness of the earth near the point of reflection, and the correlation length across the surface of the earth. Roughness factor (σ) is a measure of the rms "bump" height variations along the surface of the earth and the correlation length (L) is a measure of the degree of correlation between two points along the surface of the earth. In general the amount of reflected specular power can be expressed by the following equation.

$$P_{specular} = \langle p_s^2 \rangle \, D^2 \, |R_0|^2 \, P_d$$

$$\langle p_s^2 \rangle = \exp - \left(\frac{4\pi\sigma}{\lambda} \sin \psi \right)^2$$

P_d is the direct power

λ is the wavelength

σ = rms height of the reflecting surface

D is the average divergence factor associated with the spherical earth,

$|R_0|^2$ is the mean squared reflection coefficient and

ψ is the grazing angle (angle between the incident electromagnetic beam and the reflecting surface).

The amount of diffuse power can be expressed by the equation derived by Duranni and Sarras[3] and has the following form.

$$P_{diffuse} = D^2 \, |R_0|^2 F\,(\psi, \, h)\, P_d$$

h is the user height above the earth

$$F\,(\psi, \, h) \leq 1$$

The divergence factor is shown in Figure 3 as a function of the grazing angle for a 160 kilometer, 650 kilometer, and a 1600 kilometer orbit. For reasonable roughness factors and correlation lengths, the primary source of reflected power will be diffuse for grazing angles in excess of 20°. This angle will be exceeded during most of a single TDRS/user contact period.
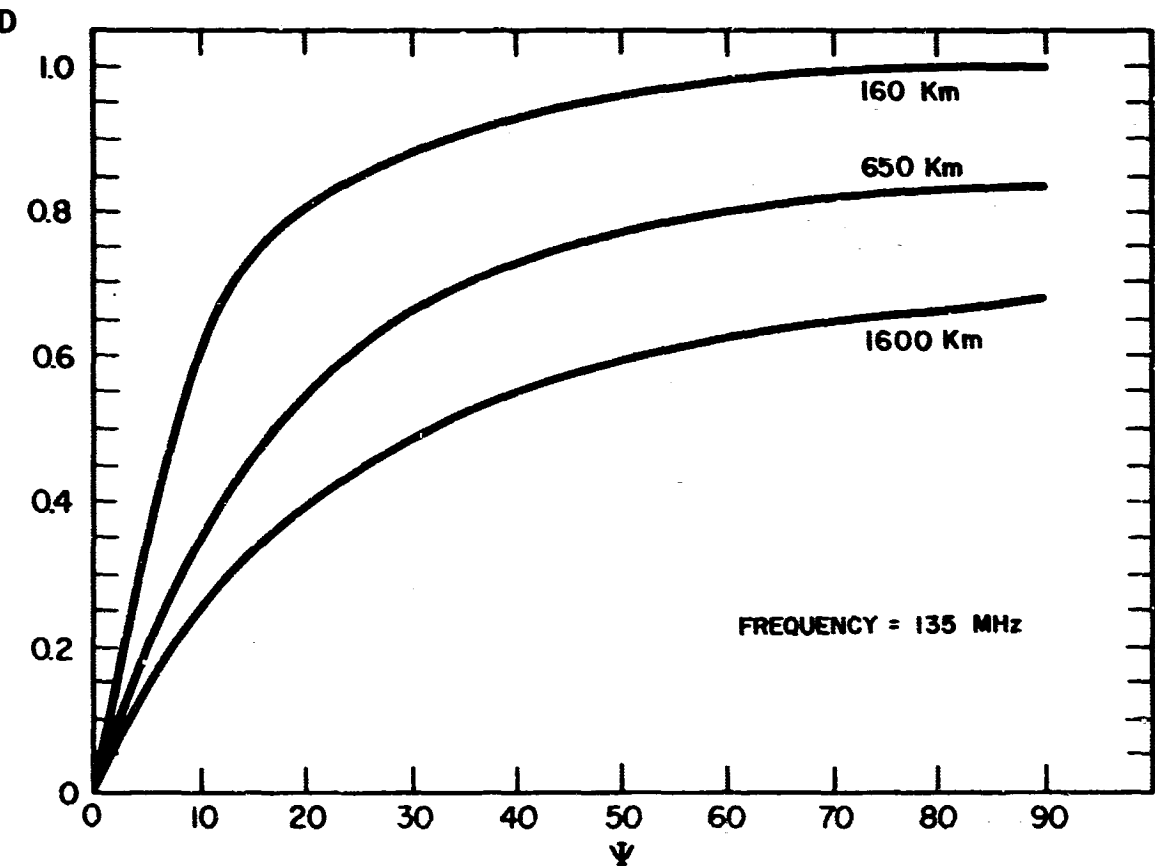

Figure 3—Divergence Factor

[3] RCA Review — March 1968 pp. 77-105

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The composite multipath or indirect signal power will normally be equal to or less than the direct path signal when reflection coefficients of the earth are essentially unity and the grazing angles are in excess of 20°.

If it were possible to separate the direct and the indirect signal paths at a TDRS when a CW signal is transmitted from a user, it would be observed that the envelope statistics associated with the indirect or reflected path would be Rician. This is true since the specular and diffuse components associated with the reflected path constitute a fading signal consisting of a CW component and a diffuse component, thus the probability density governing the envelope is Rician and is given by the following equation.

$$p\left(a_{indirect}\right) = \left[\frac{a}{P_{diffuse}} \exp - \left(\frac{a^2 + 2S_{specular}}{2S_{diffuse}}\right)\right] \left[I_0\left(\frac{a\sqrt{2S_{specular}}}{S_{diffuse}}\right)\right]$$

where

$p\left(a_{indirect}\right)$ is the probability density of (a)

a is the indirect signal amplitude

$S_{diffuse}$ is the diffuse component of the indirect signal

$S_{specular}$ is the specular component of the indirect signal

$S_{indirect} = S_{diffuse} + S_{specular}$ and

I_0 is the zero-order Bessel function of imaginary argument.

As the grazing angle increases beyond 20° theory states that the specular component diminishes rapidly and that the probability density associated with the envelope of the received signal from the indirect path is essentially Rayleigh.[4] Indirect path is also characterized by a differential Doppler relative to the direct path Doppler.[5]

In addition to differential Doppler the indirect signal, when reflected from the earth's surface, will fade. The fading bandwidth, B_F, is a function of the velocity of the user spacecraft relative to the earth, the ratio σ/L, and the grazing angle. This relationship is given in the following equation

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[4] This result has been observed experimentally by K. L. Jordan, "Measurement of Multipath Effects in a Satellite Aircraft UHF Link"– Proc IEEE June 67.

[5] Golden, Tom "Range and Velocity Component. of TDRS Multipath Signals," GSFC X-520-69-38, Feb., 1969.

$$B_F = \frac{|v|}{\lambda} \sqrt{2} \frac{\sigma}{L} \sin \psi$$

v is the velocity of the user spacecraft

L is the correlation length as defined on page 7.

The fading bandwidth is maximized when the grazing angle is 90° or the user is directly below the data relay satellite. At this point the reflected energy is completely diffuse and the fading bandwidth is maximum.[6]

Another parameter which is of importance in the evaluation of antimultipath systems is the coherent bandwidth of the user to data relay satellite link. The coherent bandwidth can be defined in a number of ways, but two preferred methods are illustrated in Figures 4 and 5.
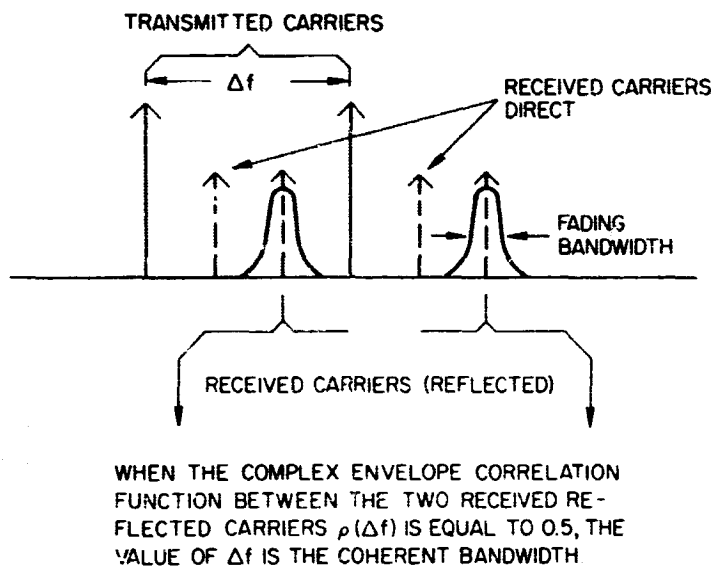
TRANSMITTED CARRIERS

RECEIVED CARRIERS
DIRECT

FADING
BANDWIDTH

RECEIVED CARRIERS (REFLECTED)

WHEN THE COMPLEX ENVELOPE CORRELATION
FUNCTION BETWEEN THE TWO RECEIVED RE-
FLECTED CARRIERS $\rho(\Delta f)$ IS EQUAL TO 0.5, THE
VALUE OF Δf IS THE COHERENT BANDWIDTH

Figure 4–Coherent Bandwidth (Frequency Definition)

In Figure 4 we indicate that two transmitted carriers separated in frequency by ΔF are received at the DRSS from a user craft via the direct and the indirect paths. If the normalized correlation coefficient between the two received carriers arriving via the reflected path is computed then the value of ΔF which is needed to produce a correlation coefficient of 1/2, is defined as the coherent bandwidth B_c. This definition is independent of the direct path received signals.
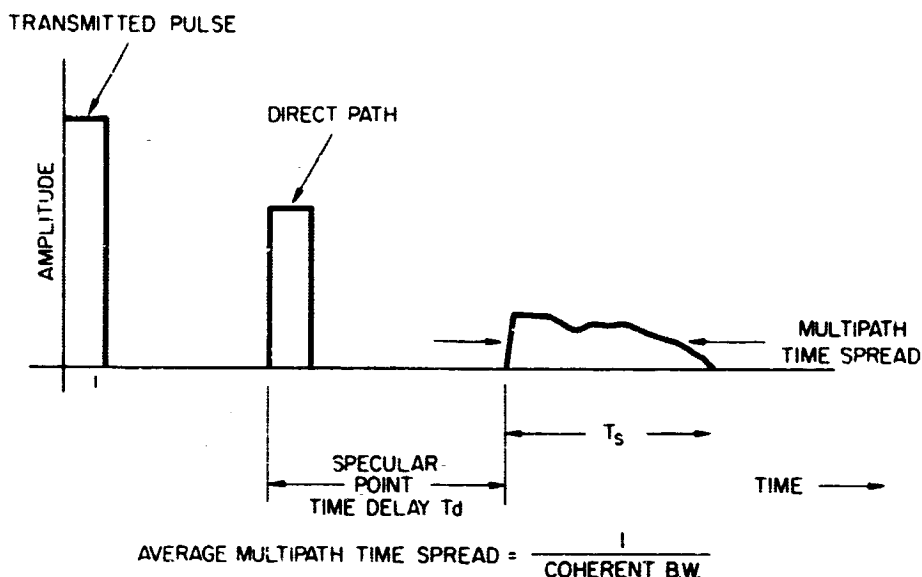
[6]ibid RCA Review

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Figure 5—Coherent Bandwidth (Time Definition)

Definition of coherent bandwidths based on the transmission of two CW signals separated in frequency is an accepted definition in the literature and is a <u>measure</u> of the coherent bandwidth of a fading channel.

In Figure 5 a pulse is transmitted by a user and after a time will be received by the TDRS via the direct path. At some later time (T_d) the indirect path signal will arrive. The pulse received via the indirect path will be spread in time. The coherent bandwidth is now the reciprocal of the time spread of the indirect signal as shown in the figure.

3.0 IMPLEMENTATION

3.1 RECEIVING ANTENNA

As stated earlier the TDRS is envisioned as having an earth coverage receiving antenna (solid angle of 26°). This corresponds to a gain of approximately 16 db not including cable losses. It is not feasible to implement such an antenna on the proposed PAC spacecraft nor is such a gain and beamwidth required for this experiment. The receiving antenna for this experiment will consist of the present four VHF whip antennas. The signals received on this antenna will be diplexed to the PAC command receiver and the experiment receiver. This allows reception of commands during the monitoring action of the experiment.

3.2 RECEIVER

The receiver (Figure 6) to be used in this experiment will be swept in four selected frequency bands, namely, 136-138 MHz; 148-150 MHz; 150-152 MHz; 152-154 MHz. The nominal bandwidth will be 2 MHz in the first IF. The system noise temperature, including earth and sky is expected to be 1000°K.

The receiver will be a multiple conversion superhetrodyne. Frequency band selection will be accomplished using a discrete stepped frequency first converter. One of four crystal local oscillators will be selected in sequence or by command for the first converter. The band selected will be recorded on the tape at the beginning of each sweep. These local oscillators are selected for a 30 MHz first IF. This 30 MHz IF will be 2 MHz wide at the 1 db points. A second converter will convert the received signal to 10.0 MHz. This 10 MHz IF band pass will be 100 KHz at the 1.0 db points. The sweeping action of the monitoring system will be accomplished in this converter, IF stage. The local oscillator for the second converter will be swept ±1.05 MHz. This essentially sweeps the 100 KHz filter of the second IF across the 2 MHz received spectrum. The output of the swept filter will be converted to 1.0 MHz and filtered to 3.0 KHz bandpass in the third IF. The resulting signal is now the output of a 3.0 KHz filter swept across the 2.0 MHz received spectrum. The output of the third IF will be envelope detected to realize a voltage proportioned to the amplitude of the flux density in the 3.0 KHz bandwidth. The voltage from the envelope detector will be converted to a logarithmic scale in a lin-log amplifier resulting in a voltage that is the flux density expressed as a logarithm. This voltage is sampled at the rate of 35 samples per second. Each sample is digitized in a 5 bit word and recorded on the tape recorder at 185 bits/sec.

3.3 CALIBRATION

In order for the output of the monitoring system to have meaning, the system must be calibrated. This calibration level will be established while the spacecraft is in view of a ground site. This will consist of transmitting a CW carrier from the ground and recording the level received. The level of transmission will be varied in 10 db steps to record a calibration curve on the tape. Considering a nominal 600 mile circular orbit for the PAC, ground based emitters having a power of 5 milliwatts will result in a signal to thermal noise ratio of +6 db in a 1.0 KHz bandwidth. This assumes that the emitter power is constrained to a one kilohertz bandwidth. This corresponds to a 5 watt transmitter radiating a flat spectrum over the kilohertz bandwidth. Since this is the type of RFI source that is expected, the system should respond to such inputs.
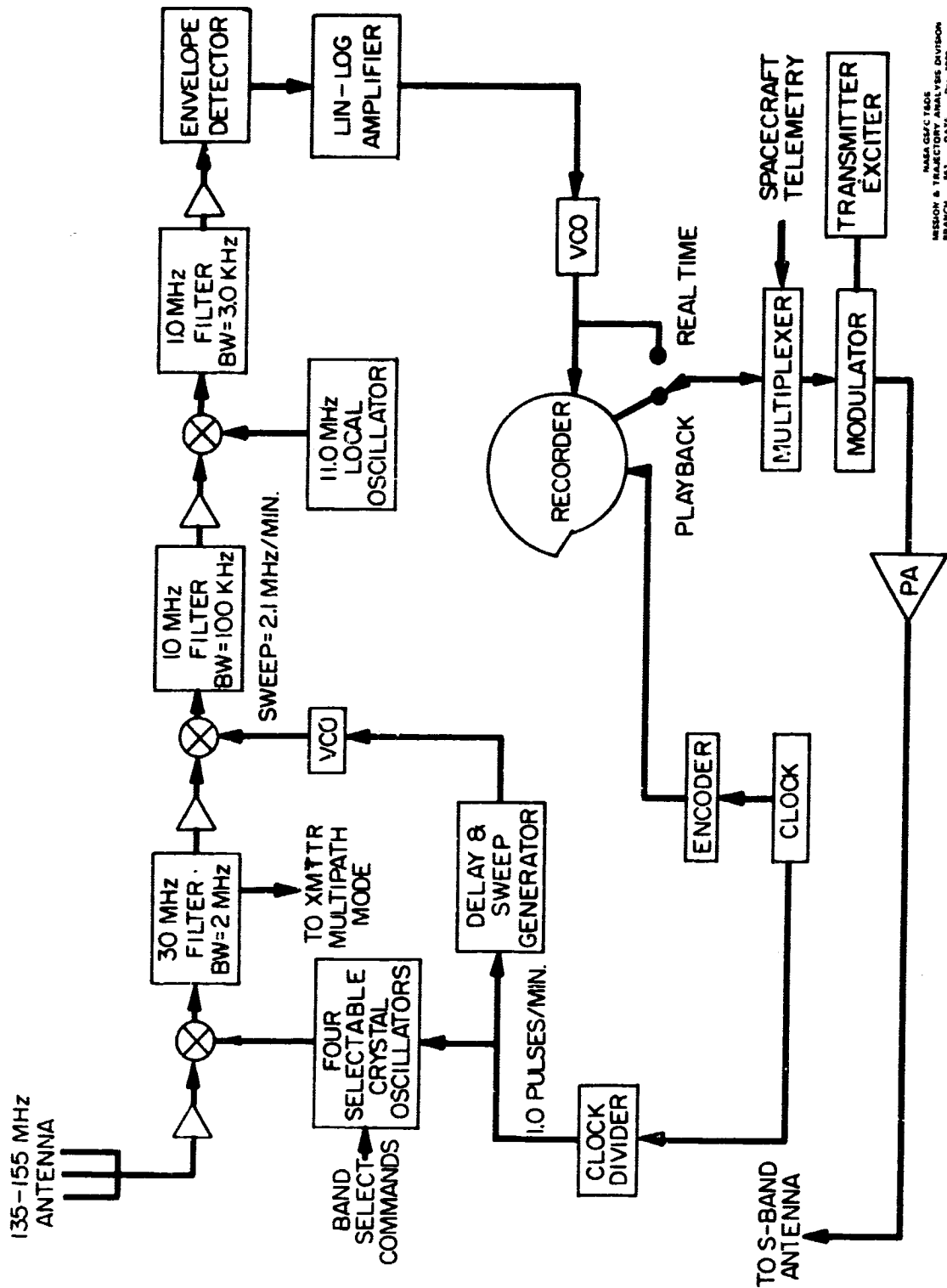
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Figure 6–Experiment Block Diagram

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3.4 RECORDING

The input to track #1 of the on-board tape recorder is the output of the VCO in the flux level detector. This VCO has a nominal frequency of 1.0 KHz. The second track will record the time of the sweep start to the nearest quarter minute for geographical reference. The timing system will encode the time from the last tape dump for up to two orbits. Tape dump to a STADAN site will be at a 30 to 1 speed up allowing entire tape dump in approximately three minutes. The signal from the receiver output will consist of a unipolar voltage varying as the logarithm of the input signal level. This voltage will drive the VCO over a range of 1000 $^{+150}_{-0}$ hertz. This gives a playback range of 30 $^{+4.5}_{-0}$ KHz to modulate the downlink system.

During the receiver flyback and recycle time the input to the VCO will be grounded. This will calibrate the zero noise, zero signal frequency of the VCO.

3.5 REAL TIME MODE

During that portion of the orbit when the PAC is within range of a STADAN site, real time monitoring of the RFI environment will be available. The output of the lin-log amplifier will be commanded to a 30 KHz VCO. This VCO will then serve as the input for the appropriate modulator in the downlink system. At the same time the sweep applied to the second local oscillator (sweep source) will increase in speed by a factor of 60. This will then sweep the 2 MHz band in one second and relay the spectrum with three kilohertz resolution to ground. The first local oscillator stepping will be synchronized to this new sweep speed. The same processes are now followed but at the increased rate. This is a commanded "ON" function. If a command to continue real time operation is not received the system will revert to the once per minute mode in five minutes.

3.6 TRANSMITTER

The transmitter for linking the above obtained information to the ground will operate in the S-band frequency band. This will be a 2.0 watt solid state transmitter. The tape output will provide a 30 KHz subcarrier and this subcarrier phase modulate the carrier while spacecraft housekeeping data is being modulated on a 10 KHz subcarrier and multiplexed with the RFI data for linkage to the ground. Radio Frequency Link parameters are summarized in the Appendix.

3.7 GROUND LINK ANTENNA

The S-band antenna for data transmission to the ground will consist of four linearly polarized yagi arrays mounted 90° apart around the circumference and about 10 inches above the bottom of the main body of the PAC. These antennas will be folded flat against the side of the PAC and deploy out to an angle of approximately 30° after the shroud is ejected. The gain of this four yagi array will be approximately 10 db.

The antenna will be fed by a hybrid and appropriate phasing network. The individual yagis will be phased such that the polarization would appear to be circular in the far field along the vehicle axis. This antenna will be used only after the spacecraft orbit has been determined, the condition of the spacecraft verified, and the normal 136.32 transmitter has been turned off.

4.0 EXPERIMENTAL CONFIGURATION

4.1 RFI MEASUREMENT MODE

The relative simplicity of this experiment, the reasonable cost when compared with the wealth of data to be collected, and the importance of the data to be collected and analyzed to the TDRS program make this experiment both very desirable and feasible. The experiment will monitor the 136-138 MHz and the 148-154 MHz bands to determine relative flux densities from nearly all points of the earth. Earth generated signals in these frequency bands will be converted to 1.0 MHz in a multiple conversion super heterodyne receiver, amplified and detected in narrow band detector. The first local oscillator (LO) will be stepped in discrete steps to allow the selection of a desired 2 MHz band. A sweeping action on the second LO allows the entire 2 MHz band to be strobed in a 100 KHz band within one minute. This action will essentially sweep a 100 KHz band across the 2 MHz selected. This signal will be down converted, filtered to a bandwidth of 3.0 KHz and detected. The resultant is a scan of the 2 MHz band with a 3.0 KHz resolution. Upon completion of a sweep the first local oscillator will be stepped to a new frequency so that the sweeping action may cause to be recorded the flux level received within the second 2 MHz band. This process will be continued until the flux levels in the following bands have been recorded, 136-138; 148-150; 150-152; 152-154 MHz. The first LO will then return to the first step and the sweep cycle repeated.

4.2 MULTIPATH RELAY MODE

This experiment will also be used to provide a means of measuring the TDRS multipath parameters. Of particular interest are (1) path length time

difference, (2) time spread of the path length time difference, (3) amplitude of the multipath returns, and (4) the frequency spread of the multipath return. Considering the importance of true measurements of these parameters to the TDRS multipath modulation problem, the following program is included.
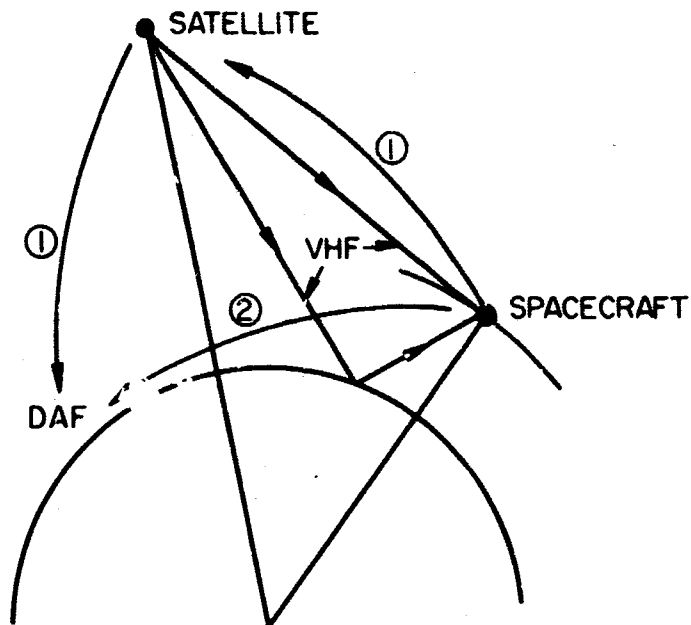
Referring to Figure 7 "Possible Configurations for Multipath Measurements," considerations of available RF sources for the PAC and for the stationary satellite (ATS-3) as well as considerations of antennas dictate the choice of mode (a). Mode b would require the ATS to relay the direct plus indirect signals received from the spacecraft. Of the two optional ways of returning the spacecraft data to ground, the spacecraft-to-earth (mode a) direct path is preferable. With this configuration, 135.6 MHz can be transmitted from ATS-3 directly under ground control by strapping the VHF transmitter modulation input to the receiver output. This modulation can easily be varied from the ATS ground transmitter. Reception of the VHF by the experiment receiver will consist of direct and multipath energy. The receiver will be commanded to a fixed-frequency (non-swept) mode. Either the wideband (2 MHz at 30 MHz) or narrowband (0.1 MHz at 1.0 MHz) will be relayed to the earth station in real time via the S-band link. The wideband relay is simpler but the narrowband permits the best dynamic range for observing the multipath returns. Which bandwidth is used will be determined during the experiment real time operations.

On the ground the S-band signal from the spacecraft will be received and processed as follows. Amplitude information will be obtained by envelope detection and doppler and doppler spread information will be obtained by (simultaneous) FM reception of the relayed VHF signals. The expected received signals are depicted in Figure 8.

From the data obtained as above the multipath returns can be characterized in sufficiently many ways to satisfy any foreseeable requirements. Reduction of the data will yield dependence of multipath spread and doppler parameters as a function of the differential path length for a typical altitude and for a wide variety of surface conditions. Estimates of the statistical spread of the data can also be derived as well as estimates of the day-to-day stability of the parameters.

The plan outlined above will provide results that are directly usable in determining the effects of multipath interference for pulse modulations of all types. No intermediate mathematical operations are required, although it is possible to (1) determine the medium's impulse response, (2) the medium's frequency response, and (3) evaluate models of the medium.

Another approach to the measurement of various parameters associated with the user/TDRS link is based upon the transmission of one or more CW

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(a)

①: S/C—TO—SATELLITE MICROWAVE

②: S/C—TO—EARTH MICROWAVE
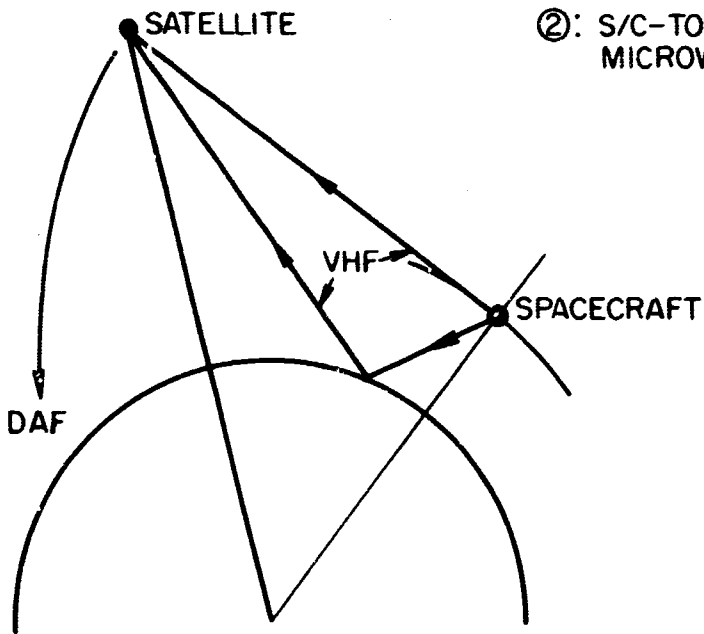
(b)

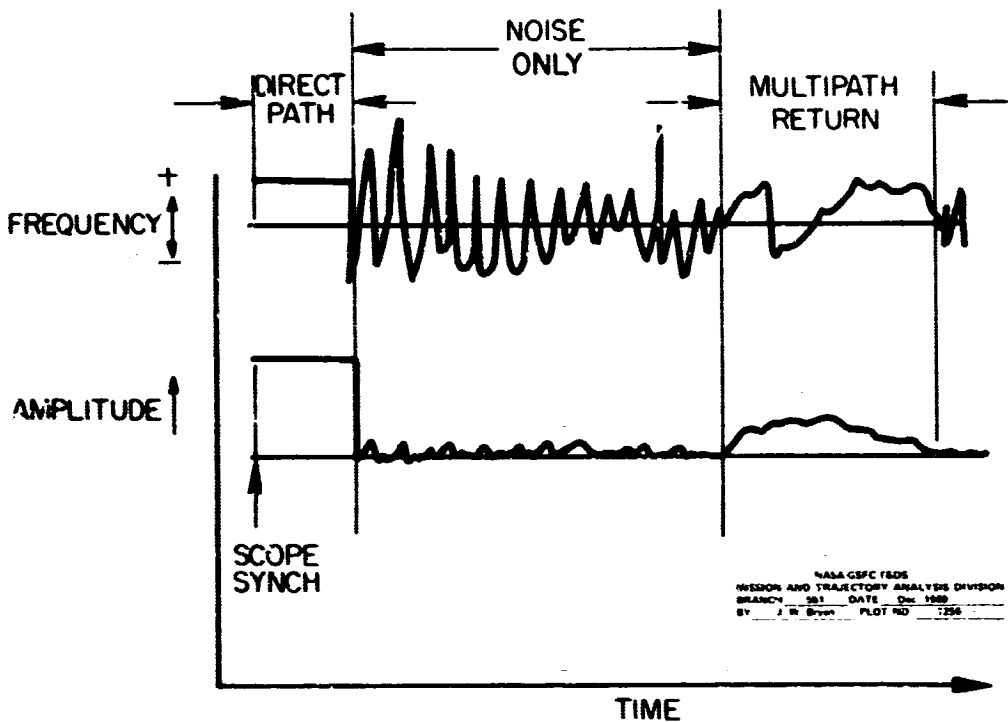Figure 7—Possible Configurations for Multipath Measurements

Figure 8—Anticipated Form of Oscilloscope Display

tones. Under this approach, to measure direct signal strength and indirect signal strength a CW tone would be transmitted and a phase-lock loop would be used to track the direct signal component. Phase-lock loop bandwidth is assumed to be narrow enough to remain in lock. Signal strength should be, in most instances, greater than the indirect signal path and, because of the fading nature of the indirect signal path, the indirect signal should be dispersed in frequency thus contributing only a small amount of interference in the bandwidth of the direct carrier phase-lock loop. Since the fading bandwidth is a maximum and the differential doppler zero when the spacecraft is directly underneath the TDRS, under these conditions the phase-lock loop bandwidth would discriminate against the indirect signal since the indirect signal would probably be diffuse and have a maximum fading bandwidth. Under other circumstances such as low grazing angles the divergence factor assists in diminishing the reflected signal strength. Coupled with the differential doppler, these two factors assist in maintaining the phase-lock loop tracking capabilities on the direct signal. Under these circumstances the fading bandwidth can be measured at the ground station with a frequency analyzer using the direct signal as a frequency calibration. Furthermore, differential doppler could be readily measured at the ground station using the same frequency analysis techniques.

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In order to measure coherent bandwidth two CW carriers spaced in frequency by ΔF (which will be varied continuously or stepped in frequency separation) will be transmitted via ATS and observed through this experiment at the ground station. Coherent bandwidth is defined by the separation in frequency between two carriers required to produce independent fading of these carriers. Thus phase-lock loop receivers could be used to form a two-channel tracking filter followed by a correlation coefficient computer to arrive at the coherent bandwidth at the ground station. Shown in Figure 9 is the implementation required to measure these various statistical parameters.
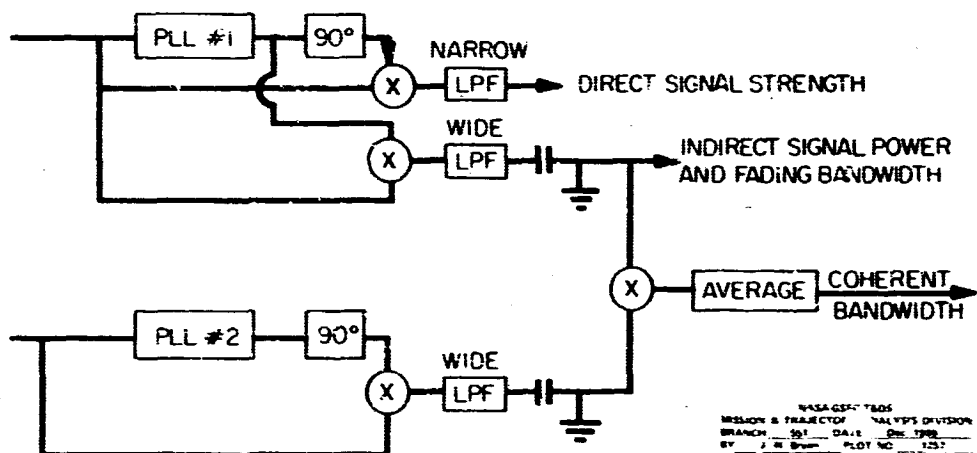

Figure 9—Correlation System

5.0 WEIGHT AND POWER ESTIMATES

The required weight and power estimates are listed in Table II. These are compatible with the Delta "piggy back" capability and the PAC power capability.

Table II

Item	Weight	Power
Receiver	2.5 lb	3.0 watts
S-band Transmitter	5.0 lb	6.0 watts
S-band Antenna	1.5 lb	N/A
Switching Circuitry	0.5 lb	0.05 watts
Total Weight: 16.5 lb		
Nominal d.c. Power: 3.00 watts record mode 10.00 watts real time (recorder off)		

6.0 TELEMETRY REQUIREMENTS

The data storage and play-back system for this experiment is as follows.

The output of the lin-log amplifier will be sampled at the rate of 35 samples per second. These samples will be converted to 5 bit per word serial bit stream netting 175 bits of data. The first ten bits stored will consist of the time from last tape dump. The next 5 bits will indicate the band being searched, and the next 175 bits will be the 35 samples as previously described. This sequence of 190 bits/sec will be stored for each 2.0 MHz sweep.

Upon command from a ground station, the tape will be dumped at a 30 to 1 speed up ratio. This dump will generate a bit stream of approximately 6 kilobits per second for transmission to the ground via the S-band link.

7.0 COMMAND REQUIREMENTS

This experiment requires a minimal of commands. The command required to turn off the 136.32 MHz transmitter (Command No. 48) can be used to simultaneously energize the experiment. The command to turn on the 136.32 MHz transmitter (Command No. 49) can be used to simultaneously de-energize the experiment. The required command to send the housekeeping and other data via the S-band transmitter instead of the VHF transmitter could also be the same command numbers.

The commands required to start the tape dump and/or tune the receiver to the fixed frequency mode, required for multipath measurement, should be available from the list of unused commands.

8.0 ACKNOWLEDGEMENTS

APPENDIX

A1 Link Characteristics for RFI

Ground Based Emitters to Experiment Link (VHF)

KTB of experiment receiver (record mode)	− 133.8 dbm
Desired SNR (+ 6 db)	+6 db
Minimum Detectable Signal (MDS)	− 127.8 dbm
Experiment antenna gain	−3 db
Space spreading loss (Ground to Experiment $\approx$ 400 nm)	− 134.5 db
RFI source erp (1 KHz band)	+6.7 dbm
	$\approx$ 4.5 mw

The unmodulated interfering carrier would have a peak power of 5 watts if the modulation resulted in a flat spectrum.

Experiment to Ground Link (S-band)

Spacecraft transmitter	+33 dbm
Antenna gain	10 db
Space spreading loss	− 163 db
Ground antenna gain	40 db
Ground receiver KTB	− 120 dbm
Carrier to noise ratio	40 db
Signal to noise ratio degradation	0.3 db
RFI to noise ratio (minimum)	5.7 db

A2 Link Characteristics for Multipath

ATS to experiment

P_t = 30 watts =	+45 dbm
Antenna gain $\approx$ 6 db	+6 db
Space spreading loss	− 166.3 db
Experiment antenna gain	−3 db
P_r = Received Power	− 118.3 dbm
N = KTB = −168 + 50 (100 KHz band)	− 118.6 dbm
SNR	−0.3

Thus the signal transmitted to the ground will have essentially 0 db signal to noise ratio.

Experiment to ground link

P_t =	+33	dbm
Antenna gain (experiment)	+10	dbm
Space spreading loss	− 158.0	db
Antenna gain (85' dish)	+48	db
P_r	-67	dbm
N = KTB (ground receiver)	− 122	dbm
Carrier to noise	+55	dbm

If the multipath signal is now detected in a 20 KHz bandwidth the

SNR =	+ 7	db

Another +10 db in the SNR can be realized if the received signals are correlated or viewed on an oscilloscope where repeated sweeps may be viewed.

Thus a net SNR of approximately 17 db is realizable. This SNR is sufficient to obtain the desired information.