ASA CR-132844

(NASA-CR-132844) ADVANCED TRACKING AND DATA RELAY EXPERIMENT STUDY: MULTIMODE TRANSPONDER EXPERIMENT Final Report, Sep. 1972 - Sep. 1973 (Magnavox Research Labs.) ~~49~~ 54 p HC $4.50 CSCL 17B
N74-10154
Unclas
G3/07 21806

ADVANCED TRACKING AND DATA RELAY EXPERIMENTS STUDY - Multimode Transponder Experiment

Magnavox Research Laboratories
2829 Maricopa Street
Torrance, California 90503

15 September 1973

Final Report for Period Sept. 1972 - Sept. 1973

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

RECEIVED
NASA STI FACILITY
INPUT BRANCH
NOV 1973

MRL TECHNICAL INFORMATION NOTICE

All entries must be completed prior to printing. If a particular block is not applicable, place N/A (not applicable) in the appropriate block.

DISTRIBUTION DATE 21 Sept. 1973

AUTHOR R. S. Cnossen	CONTRIBUTORS M. Bittner, MRL and Dr. N. Birch, A. S. A. O	MRL REFERENCE NO. R-4740 DOCUMENT DATE 15 September 1973
TITLE ADVANCED TRACKING AND DATA RELAY EXPERIMENT STUDY - Multimode Transponder Experiment		
SUBJECT/ KEY WORDS Experiments, Satellite Transponder, Modulation Evaluation		
GOVERNMENT CLASS, AND MRL CONTROL NO. Unclassified MAGNAVOX CLASS Customer Only	TYPE OF INFORMATION Interim Report	NO. OF PAGES 48 NO. OF ILLUST. 16

ABSTRACT/ CONCLUSIONS

This report sets forth the plans and implementation concepts for a series of experiments utilizing a multimode transponder mounted in an aircraft working either through a spacecraft or directly with a ground station which would simulate a TDRSS user working through the TDRSS. The purpose of the experiments would be to determine the best modulation and encoding techniques for combating RFI and multipath propagation and to determine the characteristics of VHF and UHF RFI in discreet bands. The experiments would also determine the feasibility and accuracy of range and range rate measurements with the various modulation and encoding techniques.

BY CUTTING OUT THIS RECTANGLE AND FOLDING ON THE CENTER LINE, THE ABOVE INFORMATION CAN BE FITTED INTO A STANDARD CARD FILE.

INFORMATION PREPARED FOR: National Aeronautics and Space Administration

APPROVED BY: PROGRAM MANAGER R. S. Cnossen DATE: 21 Sept. 1973

DEPARTMENT MANAGER B. G. Glazer DATE: 21 Sept. 1973

L 70-1002 A (See Reverse Side For Instructions)

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
ADVANCED TRACKING AND DATA RELAY EXPERIMENT STUDY - Multimode Transponder Experiment

5. Report Date
15 September 1973

6. Performing Organization Code

7. Author(s)
R. S. Cnossen

8. Performing Organization Report No.
R-4740

9. Performing Organization Name and Address
The Magnavox Company
Magnavox Research Laboratories
2829 Maricopa Street
Torrance, CA 90503

10. Work Unit No.
5

11. Contract or Grant No.
NAS5-21824

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

13. Type of Report and Period Covered
Type III
9-72 to 9-73

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report sets forth the plans and implementation concepts for a series of experiements utilizing a multimode transponder mounted in an aircraft working either through a spacecraft or directly with a ground station which would simulate a TDRSS user working through the TDRSS. The purpose of the experiments would be to determine the best modulation and encoding techniques for combating RFI and multipath propagation and to determine the characteristics of VHF and UHF RFI in discreet bands. The experiments would also determine the feasibility and accuracy of range and range rate measurements with the various modulation and encoding techniques.

17. Key Words (Selected by Author(s))
Experiments, Satellite Transponder, Modulation Evaluation

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
48

22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

This report, dated 15 September 1973, is entitled "Multimode Transponder Experiments." It is the first of three reports which contain the findings of a program titled "Advanced Tracking and Data Relay Experiments Study." The work was accomplished by the Magnavox Research Laboratories of Torrance, California and complies with the requirements of Contract Number NAS5-21824, Contract Data Item 2.

This report provides NASA with plans and implementation concepts for a series of experiments utilizing a Multimode Transponder mounted in an aircraft working either through a spacecraft or directly with a ground station which would simulate a TDRSS user working through the TDRSS. The purpose of the experiments would be to determine the best modulation and encoding techniques for combating RFI and multipath propagation and to determine the characteristics of VHF and UHF RFI in discreet bands. The experiments would also determine the feasibility and accuracy of range and range rate measurements with the various modulation and encoding techniques.

Magnavox wishes to acknowledge the assistance of Pat Mitchell, ATDRE technical officer and Keith Fellerman of the TDRSS program office, G. S. F. C.

This report was prepared by Messrs. R. Cnossen, M. Bittner, and J. Mackey of MRL, Dr. N. Birch of ASAO, Magnavox, and D. White of McDonnell Douglas.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION II

ADVANCED TRACKING AND DATA RELAY EXPERIMENTS

This section develops the plans and implementation concepts for a series of experiments utilizing the Multimode Transponder and its associated ground equipment. The purpose of these experiments is to determine the best modulation and encoding techniques for combating the problems known to exist for the forward and return links of the proposed TDRS system. These experiments would be used to determine the feasibility and accuracy of range and range rate measurement with the various modulation and encoding techniques.

In this section a series of candidate experiments is presented. Secondly, a recommended test plan is presented containing the most important tests from the candidate experiments in light of schedule and cost considerations.

The experiments described in this section have been grouped into three categories of experiments:

- Laboratory Experiments
- TDRSS Link Simulation, Experiments
- Flight Experiments

A number of air-to-ground and air-to-air tests have been outlined to allow evaluation of various modulation techniques under actual RFI and multipath conditions. These tests have been designed to provide a wide range of environmental conditions and would be valid and extremely useful at <u>any</u> RF frequency.

Finally, a series of experiments has been planned which would allow the evaluation of equipment performance under carefully simulated TDRS conditions. These tests would provide the dynamic conditions of air-to-air tests with the precision and control of laboratory experiments and would, therefore, closely approximate the anticipated TDRSS environment.

2.1 CANDIDATE EXPERIMENTS

2.1.1 LABORATORY EXPERIMENTS

The basic laboratory test setup is illustrated in figure 2-1. In this test configuration, the signal and noise sources can be controlled independently for both the forward and return links.

2.1.1.1 Data Performance Tests

A pseudo random data generator would be used to supply data at the following data rates:

Forward Link

- 100 BPS
- 300 BPS
- 1000 BPS

Return Link

- 300 BPS
- 1000 BPS
- 3000 BPS
- 10000 BPS

These data rates would be used in both the conventional PSK mode of operation and the PN mode of operation with the following chip rates:

Forward Link

- 34.133 kc/S
- 102.4 kc/S

Return Link

- 34.133 kc/S
- 102.4 kc/S
- 102.4 kc/S

Subsequently, during a track mode the forward/return link would be jammed with a noise source and the resulting data error rates would be recorded for all combinations of data rates and modes of operation.

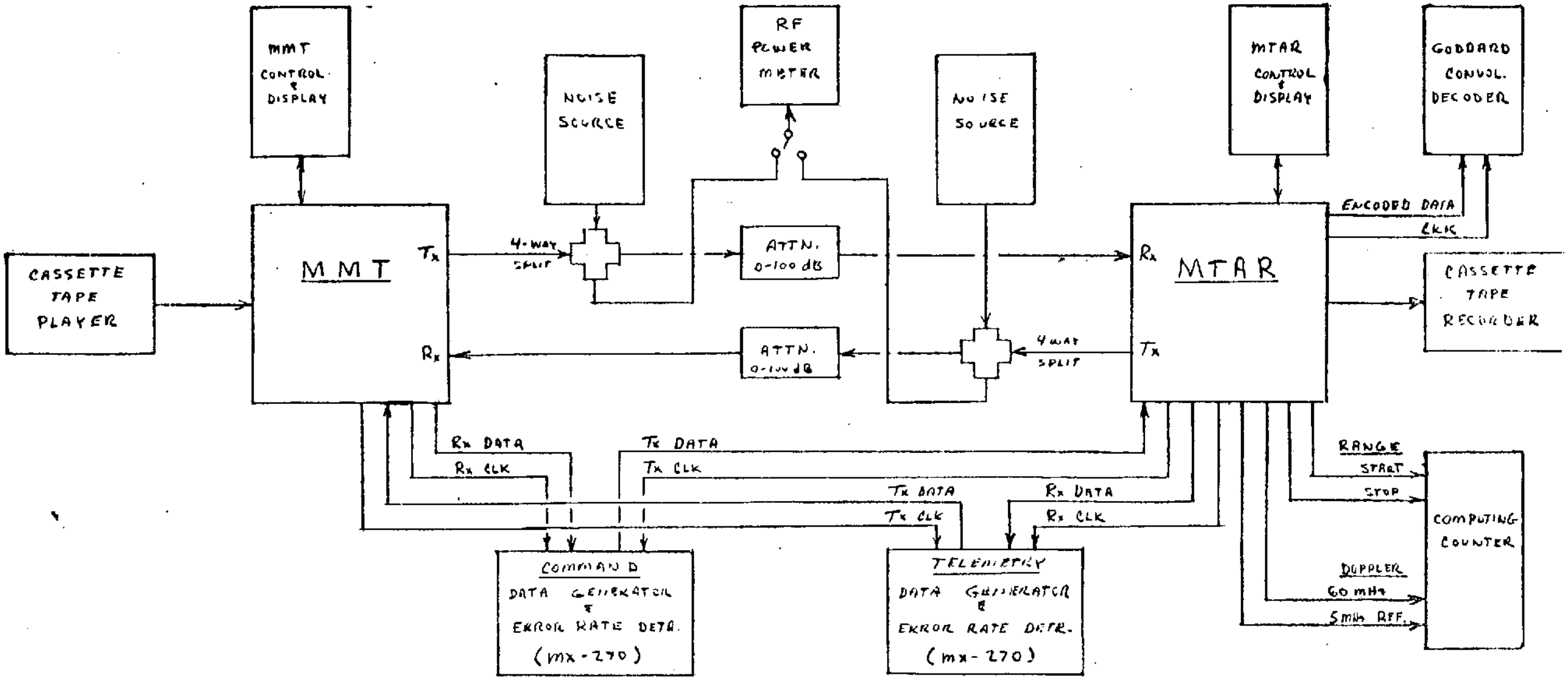


Figure 2-1. TDRS Multimode Transponder Lab Test Configuration

The resulting performance would be presented in graphs depicting S/N versus error rate. For each type of noise source, a family of curves would be plotted for the various data rates and modes of operation. For example, each graph would cover the range from threshold to clear channel for a given set of test parameters. A typical family of curves is illustrated in figure 2-2.

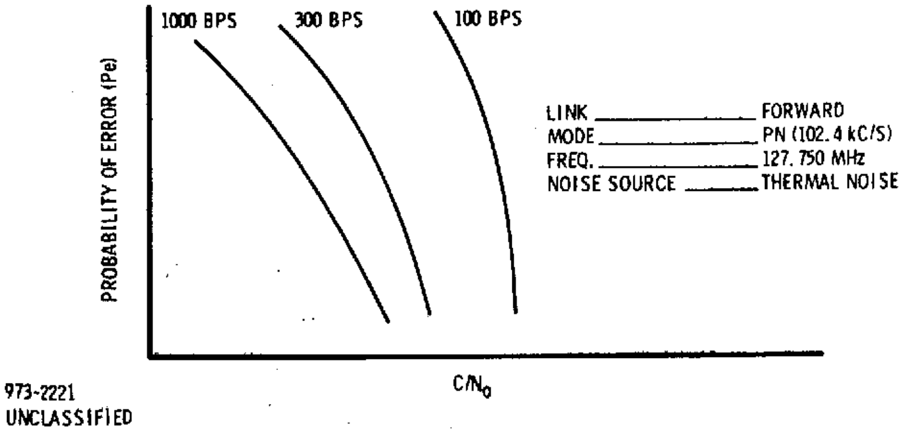


Figure 2-2. Typical Data Error Rate Curves

There are numerous RFI sources which should be used to evaluate performance including:

- Continuous wave (CW)
- FM modulated carrier
- AM modulated carrier
- Gaussian noise
- Orthogonal PN code
- Thermal noise (threshold conditions)
- Pulse Jamming

CW signals along with AM and FM modulated carrier signals should be used to jam the forward link since they approximate the type of man-made noise which will be seen by user satellites. The return link should be evaluated using a gaussian noise source or an orthogonal PN code source since they represent the type of RFI which will be seen by the return link. Both links should be evaluated at minimum signal conditions to establish threshold performance for various modes of operation.

2.1.1.1.1 Convolutional Code Tests

The improved performance offered by convolutional coding in a simulated RFI environment should be evaluated. Since the encoder located in the MMT unit has been designed to operate in conjunction with the convolutional decoder at G.S.F.C., it is suggested that the Multimode Transponder be shipped to Goddard for on-site testing. A CW jammer could be used to provide a range of S/N conditions needed to evaluate the performance improvements. Again graphs would be constructed to depict data error rates versus S/N.

2.1.1.1.2 Data Error Rate Tests

Digital data error rate measurements for transmissions between the MMT and MTAR would be performed with two MX-270 bit error rate analyzers manufactured by Magnavox Research Laboratories. An MX-270 would be used at each end of the communication link. One MX-270 would be clocked by the MMT/MTAR to generate a pseudorandom stream of digital data to be transmitted. The other MX-270 would generate an identical pseudorandom data stream and would compare it to the received data. This unit automatically searches and resolves the time difference between the two data streams. When the two data streams are synchronized, errors are counted and the error rate is displayed.

A preliminary analysis of the time required to perform a digital error rate measurement at each data bit rate was made. Near threshold the time required to obtain a data sample is relatively small, However, at low bit rates the time to obtain a sample of 10^6 or 10^7 bits is significant. Data sample time is an important consideration in choosing the number of data points to be obtained for each performance plot. Examples of the measurement times are shown in table 2-2 for a 100 BPS data rate.

2.1.1.2 Voice Intelligibility Tests

As shown in figure 2-1, voice channel quality would be evaluated by transmitting a pre-recorded phonetically balanced test message through a simulated link environment. The received message would be recorded and analyzed to obtain a percent intelligibility figure. The pre-recorded tape and the analysis of the recorded message would be purchased from Tracor, Inc., currently offering this service at nominal prices. The resulting voice intelligibility tests would be plotted versus the S/N ratios at which the tests conducted. A family of curves would be plotted for equipment parameter variations.

Table 2-1. Data Error Rate Measurement Time

ERROR RATE	MEASUREMENT TIME
1×10^{-3}	1 Second
1.0×10^{-3}	10
1.00×10^{-3}	100
1×10^{-4}	10
1.0×10^{-4}	100
1.00×10^{-4}	1000
1×10^{-5}	100
1.0×10^{-5}	1000
1.00×10^{-5}	10,000

2.1.1.3 Ranging Tests

Range measurement would require the use of both the forward and return links with the MMT unit functioning as a coherent transponder. To simulate a realistic environment, separate noise sources would be used for the forward and return links and voice or data transmissions would occur simultaneously with range measurement. As shown in figure 2-1, range data would be taken from the MTAR unit while the MMT would function as a transponder.

Range measurement would be accomplished by using an external counter to measure the elapsed time between start and stop pulses respectively derived from the "all ones" vector of the transmit and receive coders. Various delays would be simulated with different lengths of coaxial cable. Range accuracy under noise conditions would be measured by computing the standard deviation using the following equation:

$$\sigma(\Delta R) = \sqrt{\sum_{i=1}^{N} \frac{X_i^2}{N} - \left[\sum_{i=1}^{N} \frac{X_i}{N}\right]^2}$$

where:

X_i = range

This measurement would be accomplished using a Hewlett Packard 5360A Computing Counter with a 5379A Time Interval Plug in and the 5375A Keyboard. Graphs would be plotted to relate performance with parameter variations.

2.1.1.4 Range Rate Tests

Range rate measurement would also require transpond mode of operation. To simulate a realistic environment, separate noise sources would be used for the forward and return links, as shown in Figure 2-1.

Doppler measurements would be taken from the tracking VCO of the MTAR unit by counting the offset of a 60 MHz local reference signal. The 5 MHz signal used to generate all L.O. signals in the MTAR transmits is available as a reference for the counter. Doppler would be simulated by offsetting the transmitted RF signal. Doppler accuracy under noise conditions would be made by computing the standard deviation from the following equation:

$$\sigma \Delta V = \sqrt{\sum_{i=1}^{N} \frac{V_i^{2}}{N} - \left[\sum_{i=1}^{N} \frac{V_i}{N}\right]^{2}}$$

where:

V_i = doppler in Hz

This measurement would be accomplished using a H. P. 5360A Computing Counter. Frequency offsets would be simulated by replacing the 10 MHz and 10.24 MHz carrier and code reference clocks with external 10 and 10.24 MHz oscillators and offsetting their center frequencies. Graphs would be plotted to relate performance with parameter variations.

2.1.1.5 Static Multipath Tests

Under a controlled laboratory environment, multipath effects on the Multimode Transponder would be evaluated. The test setup for this experiment is shown in figure 2-3. With this test setup the coder of the MTAR transmitter would be advanced or retarded with respect to the receiver coder. The center frequency of the CW signal source could be varied by several kHz to simulate offset frequencies due to multipath. The resultant performance variations could then be measured for spectral multipath while varying one parameter at a time.

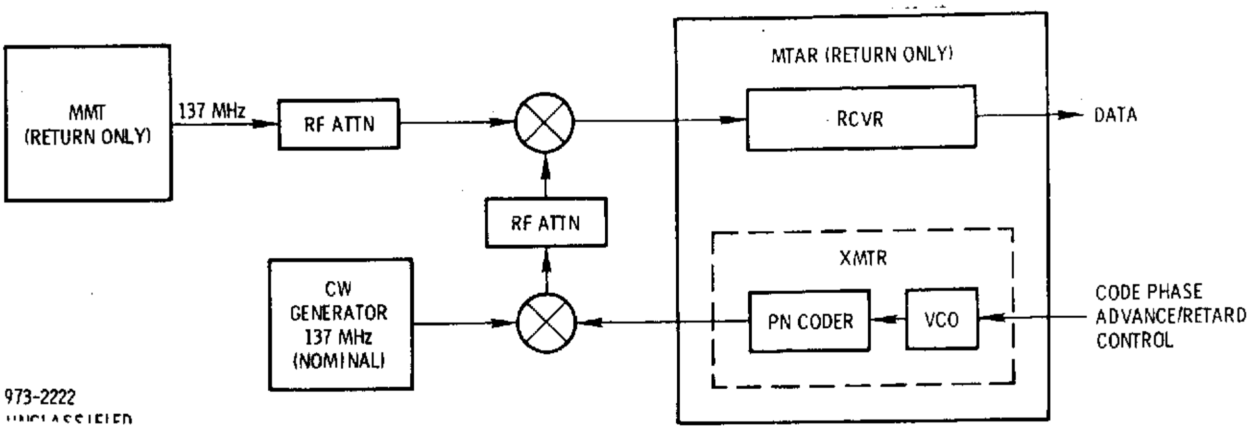


Figure 2-3. Test Setup For Static Multipath Experiments

The worse case tracking error for the Multimode Transponder, due to static multipath, is 0.5 bit. This worse case occurs when the multipath signal amplitude is equal to the direct signal amplitude, and the two signals separated in time by less than 1 bit. A time spread greater than 1.5 bits causes no mean tracking error in a delay lock clock tracking loop, however, this can cause a decrease in loop S/N of at most 3 dB. In the dynamic case no mean tracking error occurs for differential doppler greater than three times the loop bandwidth due to the filtering action of the narrow loops involved. The application of the results of this analysis with laboratory tests should yield new insight into the effects of multipath on PN delay lock tracking receivers.

2.1.1.6 Acquisition Tests

Acquisition and reacquisition capability of the eventual TDRS transponder is an important feature; therefore, the acquisition performance of the Multimode Transponder should be carefully evaluated in the presence of multipath and RFI. The test setup for this experiment is shown in figure 2-1.

Acquisition performance at each data threshold would be evaluated in both the PN and PSK modes of operation. A number of different noise sources would be evaluated and the results would be presented as a family of curves showing the probability of acquisition versus E_b/N_o for various parameter variations.

The doppler frequency shift encountered in the aircraft to ground tests will be much smaller than the TDRSS must be capable of handling. A laboratory experiment would evaluate duplex link acquisition of signal under simulated doppler frequency offsets.

Acquisition performance would also be evaluated in the presence of multipath. The test setup for the experiment is shown in Figure 2-3. The Multimode Transponder has the capability of discriminating against up to 2mS of multipath. This capability could be verified by advancing and retarding the reference PN coder by ±2mS.

2.1.1.7 Polarization Diversity Tests

The added performance capability offered by polarization diversity would be evaluated in a controlled environment. The MTAR antenna would be rotated on all three axis with respect to an isotropic antenna fed by the MMT equipment. Both tracking and acquisition tests would be conducted. Deep fades would be simulated at various rates. Also, the results of the sudden appearance of RFI noise on one of the antenna ports would be evaluated.

It is suggested that this test be conducted at Chu Associates, Inc., where a mechanical rig is available for this type of testing. The Multimode Transponder equipment could be transported and relocated at this site which is about a one hour drive from the Magnavox Research Laboratories.

2.1.1.7.1 Chu Associates Antenna Measurement Facility

The antenna test range, used for simulating and testing antennas, consists of a large level highly conducting ground plane and a central 22 foot diameter turntable.

When pattern measurements are taken, the ground antenna receives signals from transmitting antennas located at the edge of the ground plane or from antennas on a 40 foot radius A-frame which provides rigid support and accurate radius for overhead pattern coverage measurements up to 90° elevation angle.

The receiving equipment would be located under the turntable in an underground pit. A polar plotter connected to the receiving equipment could be synchronized with either the turntable rotation or with the vertical travel of the A-frame arc to automatically record azimuth or zenith plane antenna patterns.

2.1.2 TDRSS LINK SIMULATION EXPERIMENTS

One problem with real environment testing of modulation techniques is the difficulty in controlling the parameters that are effecting a given test series. An alternative, or perhaps companion and predecessor, testing technique would be to use a channel simulator for testing alternative modulation techniques. In this way, it could be assured that each modulation technique would be tested through an identical and statistically stationary channel.

Considerable effort was expended during the ATDRE study to develop an experiment which would subject the Multimode Transponder equipment to a realistic TDRSS environment. First, a program was written to define the behavior of a diffuse Multipath signal in terms of TDRSS orbital parameters. Second, the Magnavox simulator, designed by the Advanced System Analysis Office under NASA contract NAS5-20110 specifically for TDRSS link parameters, was re-evaluated for its capability and practicality. Third, a statement of work was written specifically for McDonnell Douglas to investigate the impact of modifying their On-Line Subsystem Facility (OLSF) to function as a TDRSS simulator.

2.1.2.1 TDRS Link Characteristics

In order to select a channel simulator to describe the link between the TDRS in geostationary orbit and a user satellite in low altitude orbit, it is necessary to define the parameters in the communication channel between the two spacecraft.

The channel parameters of interest can be grouped into six categories, namely:

- Attenuation Effects
- Atmospheric Refraction
- Signal Phase Delay
- Polarization Rotation
- Frequency Effects
- Noise and Radio Frequency Interference

The relative magnitude of the propagation channel characteristics for the TDRS/User link for both VHF and S-band are shown in table 2-2.

2.1.2.2 Multipath Characteristics

Multipath propagation conditions anticipated in the TDRSS are a function of the relative positions of the user and relay spacecrafts with respect to the earth. TDRSS geometry was studied to relate user satellite position to multipath signal delay times. Figure 2-4 shows the multipath signal for a TDRSS configuration.

Table 2-2. Comparison of the Relative Magnitude of the Propagation Channel Parameters for the TDRS/User Link

Description	VHF	S-band
Attenuation Effects:		
Free Space Attenuation		
Direct Path Loss	165-169 dB	189-192 dB
Indirect Path Loss	167-170 dB	191-193 dB
Ionospheric Absorption	<.1 dB	<.001 dB
Tropospheric Absorption	<.05 dB	<.3 dB
Losses due to Aurora	<1 dB	<.1 dB
Refraction:		
Ionospheric Refraction	$< 10^{-3}$ radians	$< 10^{-5}$ radians
Tropospheric Refraction	negligible	negligible
Signal Phase Delay:		
Ionospheric Effects	$= 10^{-8}$ sec	$= 10^{-8}$ sec
Tropospheric Effects	$= 10^{-6}$ sec	$= 10^{-8}$ sec
Birefringence	$< 10^{-9}$ sec	$< 10^{-9}$ sec
Multipath Time Delay	.2-30 msec	.2-30 msec
Polarization Rotation:		
Chromatic Aberation	$< 2^{o}$/MHz	$< 2^{o}$/MHz
Faraday Rotation*	= 200 degrees	- 1 degree
Frequency Effects:		
Direct Path Doppler	0-4 KHz	0-68 KHz
Differential Doppler	0-2 KHz	0-34 KHz
Fading Bandwidth	0-2 KHz	0-34 KHz
Coherent Bandwidth	5-30 KHz	5-30 KHz
Carrier-to-Noise Power Density:		
At TDRS	44.6 dB-Hz	33.8 dB-Hz
At User	54.6 dB-Hz	44.9 dB-Hz
Radio Frequency Interference		

*For systems employing circularly polarized antennas such as the TDRS, Faraday rotation effects are not encountered.

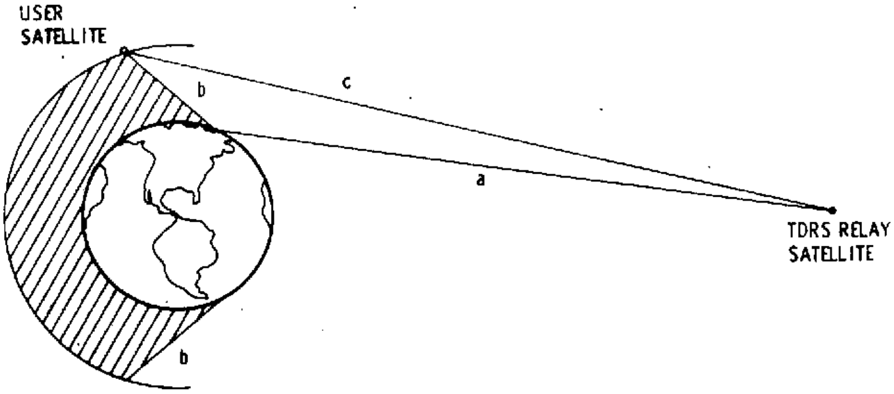


Figure 2-4. TDRS Multipath

The multipath signal is referred to as the indirect path or indirect signal. Because of the motion of the satellite relative to the surface of the earth, which has some rms height variation σ and a correlation distance along the surface L, the indirect signal will fade according to some statistical probability density. In this case, we are referring to the envelope statistics of the indirect signal. Researchers indicate that a combination of specular energy reflected from the earth's surface along with diffuse energy can be expected at VHF and UHF frequencies. Thus, the indirect signal or reflected signal can have two components, a specular component which is a replica of the transmitted signal and a diffuse component similar to random noise.

In general, the amount of reflected specular energy is expressed by the following equation.

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

The amount of diffuse power is expressed by the following equation.

$$P_{diffuse} = g D^2 | R_o |^2 P_d (1 - \langle P_s \rangle^2)$$

where

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

and

ψ	grazing angle
g	is a factor which is dependent on the satellite antenna pattern and controls the amount of power directed toward the surface.
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
$\|R_o\|^2$	is the mean squared reflection coefficient.

For low grazing angles the divergence factor serves to diminish the multipath or reflected signal. For VHF and UHF frequencies, the reflected signal should be primarily diffuse for $\psi > 20^\circ$ and normal surface conditions.

Scattering models of the earth's surface have been partially confirmed by measurement. These models usually rely upon a gaussianly distributed height variation and some correlation distance L which, in this case, indicates the degree of correlation between one point on the earth and another. The reflected signal, consisting of specular and diffuse conponents is illustrated in figure 2-5 along with the signal that is received via the direct path. In addition to the indirect signal, the receiver signal will be offset from the true transmitted frequency by the direct path doppler, and the indirect signal will be further offset by the differential doppler associated with the indirect path relative to the direct path.

The diffuse energy associated with the indirect path will have some bandwidth referred to as the fading bandwidth, as illustrated in figure 2-5. It can be shown that the fading bandwidth is related to the velocity of the aircraft, the RMS height variation of the surface σ, the correlation distance L along the surface of the ocean, and the grazing angle through the following equation.

$$B_F = \frac{\sqrt{2}\nu\sigma}{L\lambda} \sin\psi, \quad \nu = \text{user satellite velocity}$$

λ = wavelength

ψ = grazing angle

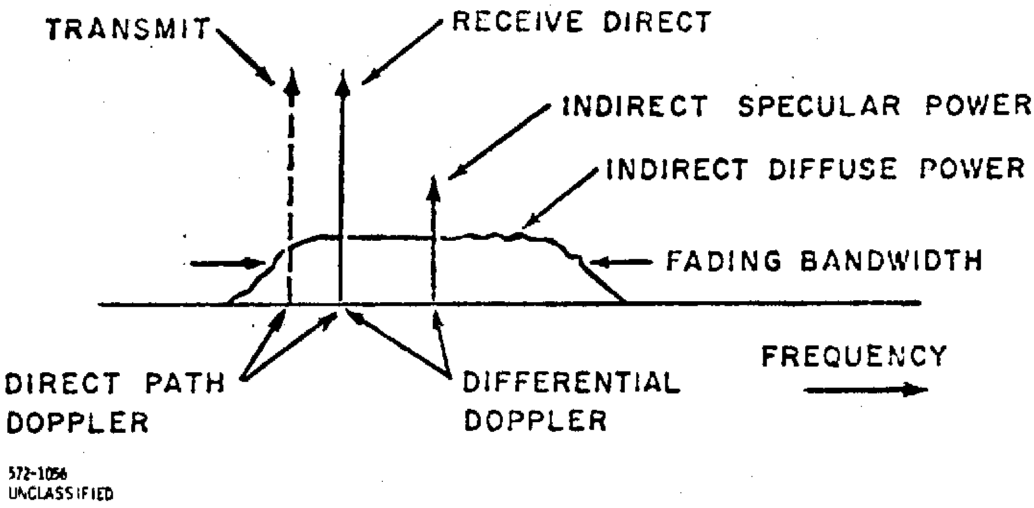
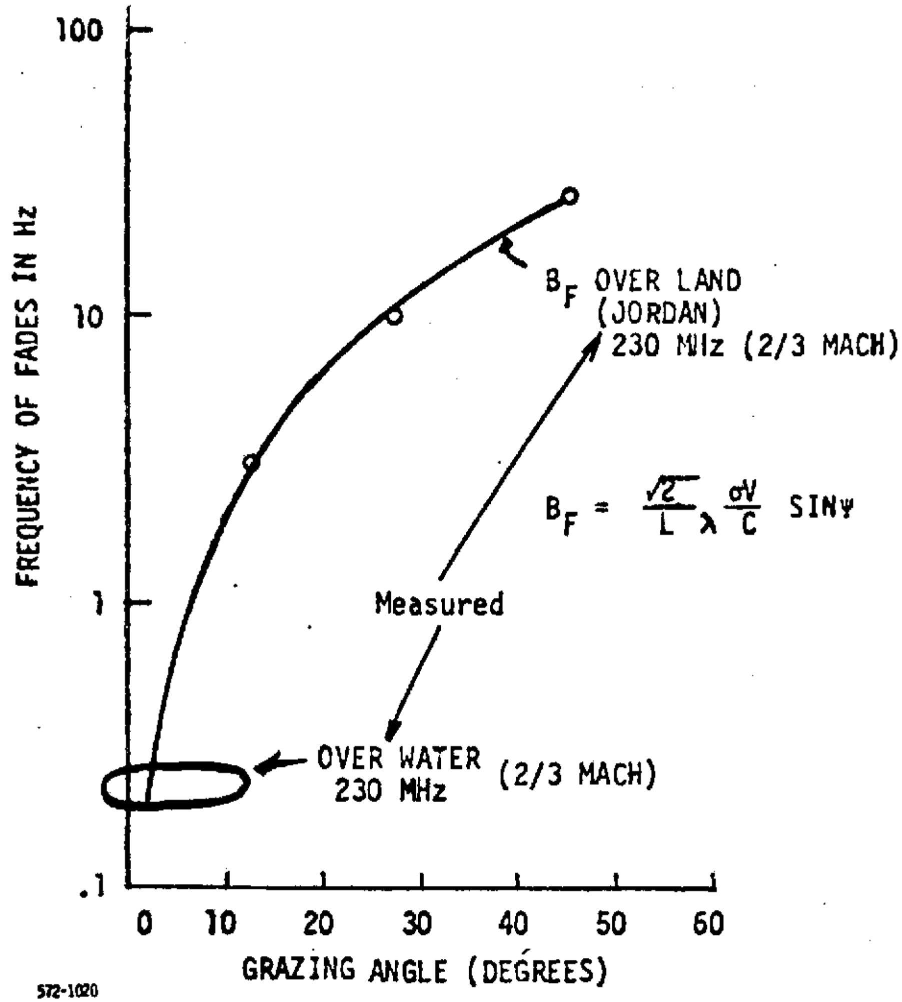


Figure 2-5. Channel Doppler and Fading Bandwidth Characteristics

So far we have established that the signal received at the TDRSS user satellite can be described by several parameters. First, there is the power associated with the direct path P_d, the total power associated with the indirect signal P_{ind}, the amount of power that is specular $P_{specular}$ as opposed to diffuse $P_{diffuse}$, the direct path doppler, the indirect path differential doppler, and the fading bandwidth associated with the diffuse components, and the coherent bandwidth.

If one isolates the indirect signal, one observes, in general, that the envelope will follow a Rician probability density, since this path consists of both a specular component and a diffuse component. If the reflected signal is completely diffuse, then we can expect the envelope of the reflected signal to have a Rayleigh envelope p.d.f. This has been observed by Jordan, who used a pseudonoise signal between a satellite and an aircraft at 235 MHz to investigate the fading bandwidth. Thus, both diffuse and specular components can exist depending upon surface roughness and the correlation distance along the surface. Under most general cases, the reflected signal envelope will follow a Rician probability density, when a constant envelope signal is transmitted.

When the direct signal is combined with the indirect signal at the spacecraft, the composite envelope of this complex signal (again assuming that constant envelope signals have been transmitted from the aircraft) will follow a generalized Rician density. Measured fading bandwidth data taken by Lincoln Labs is shown in figure 2-6.



572-1020
UNCLASSIFIED

Figure 2-6. Fading Bandwidth Versus Grazing Angle at 230 MHz

Table 2-3 summarizes the multipath parameters for a user satellite to synchronous satellite link suitable for the Multimode Transponder tests at VHF.

2.1.2.3 Multipath Components Calculations

To calculate the parameters for multipath geometry, the notation shown in figure 2-7 was used. The earth's center is the origin of coordinates. For the link between the synchronous satellite, S, and the near-earth vehicle, M, there are two possible paths -- a direct path, R, and a reflected path, $s = S_1 + S_2$. The following values were assumed:

$\overline{OS} = D = 4.2242166 \times 10^7$ meters

$\overline{DE} = A = 6.378166 \times 10^6$ meters

$\overline{OM} = \ell =$ Variable Parameter

$V = \sqrt{GM/\ell}$

$\sqrt{GM} = 1.9965069 \times 10^7$ meters^2 per second

$f = 136.0$ MHz, $\lambda - 2.0588235$ meters

$\angle SOE = \theta =$ Angle between radial to satellite and radial to reflection point on earth's surface

$\angle SOM = \phi =$ angle between radial to satellite and radial to near-earth vehicle

For computer analysis θ will be varied in two degree steps from zero degrees to that angle for which the incidence angle, β, is zero. By inspection of trigonometric relationships in figure 2-7 it can be seen that

$\overline{OC} = A \cos \theta$

$\overline{CE} = A \sin \theta$

$\overline{SC} = D - \overline{OC} = D - A \cos \theta$

$$\epsilon = \tan^{-1} \frac{\overline{CE}}{\overline{SC}} = \tan^{-1} \frac{A \sin \theta}{D - A \cos}$$

$\beta = 90 - \theta - \epsilon$

$$S_2 = \frac{A \sin \theta}{\sin \epsilon}$$

From the law of cosines

$$\ell^2 = A^2 + S_1^2 - 2\,AS_1 \cos (90 + \beta)$$

$$S_1^2 - [2A \cos (90 + \beta)]\, S_1 + [A^2 - \ell^2] = 0$$

and from the quadratic equation

$$S_1 = \frac{(2A \cos (90 + \beta)) \pm \sqrt{(2A \cos (90 + \beta))^2 - 4 (A^2 - \ell^2)}}{2}$$

This reduces to

$$S_1 = - A \sin \beta \pm \sqrt{\ell^2 - A^2 \cos^2}$$

which is calculable from the known relationships or the assigned quantities for the problem.

Table 2-3. Multipath Parameter Summary

Parameter	Equation	Magnitude at VHF
$P_{specular}$	$g\lvert R_o\rvert^2 D^2 e^{-\left[\frac{4\pi\sigma}{\lambda}\mathrm{Sin}\psi\right]^2}$	decreases rapidly $\psi > 15^o$
$P_{diffuse}$	$g\lvert R_o\rvert^2 D^2 \; 1\text{-}e^{-\left[\frac{4\pi\sigma}{\lambda}\mathrm{Sin}\psi\right]^2}$	referred to direct power at $\psi > 15^o$
Direct Doppler	$f_o \frac{\nu}{c} \cos \psi$	
Differential Doppler	$^* \frac{2vh}{R_e \lambda} \mathrm{Sin}\ 2\psi$	
Coherent Bandwidth	$= \frac{c\ \mathrm{Sin}\psi}{h} (L/\ )^2$	dependent on σ/ν values
Fading Bandwidth	$\frac{\sqrt{2}}{\lambda} \frac{\sigma}{L} \frac{\nu}{c} \mathrm{Sin}\psi$	
Differential Time Delay	$= \frac{2h}{c} \mathrm{Sin}\psi$	
Polarization of Reflected Signal	sense of reflection can reverse	horizontal predominates over vertical

* R_e is the equivalent earth radius.

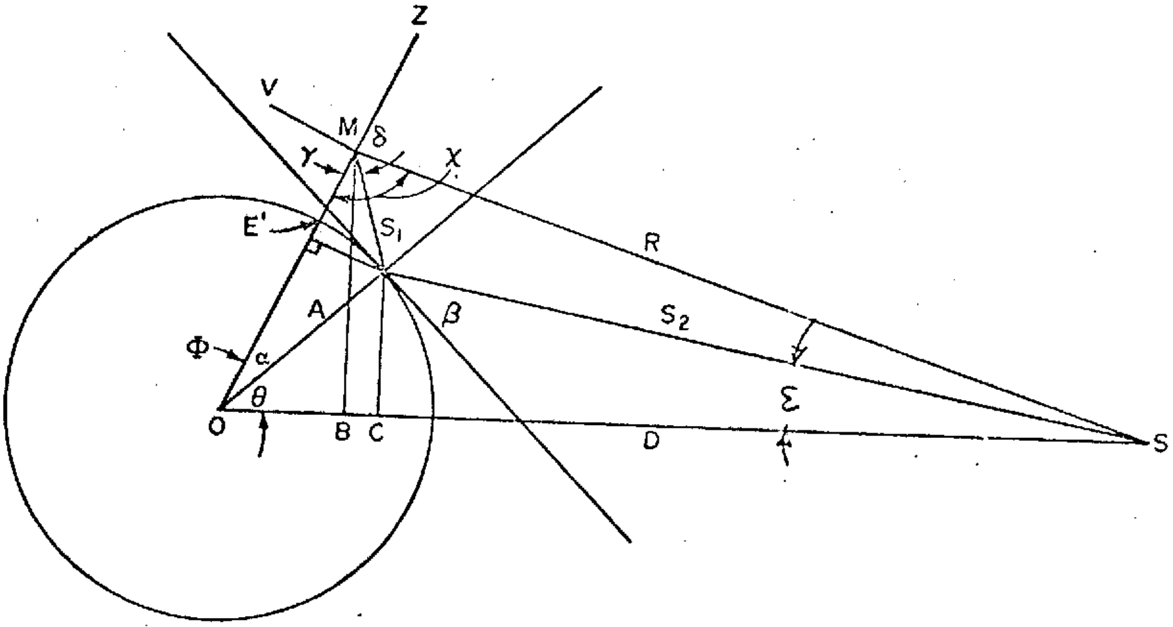


Figure 2-7. Geometry for Calculating Multipath Components

Again by the law of cosines it may be shown that $\angle$OME = γ is

$$\gamma = \cos^{-1}\left(\frac{S_1^2 - A^2 + \ell^2}{2\,S_1\,\ell}\right)$$

and $\overline{EE'}$, perpendicular to $\overline{OM}$ is

$$\overline{EE'} = \frac{S_1}{(\sin\gamma)^{-1}}\,.$$

The angle EOM = $\Phi - \theta = \alpha$

$$\alpha = \sin^{-1}\frac{\overline{EE'}}{A}$$

and

$$\overline{OB} = \ell\cos\phi$$

$$\overline{BS} = D - \ell\cos\phi\,.$$

Since ∠SBM is a right angle

$$R = \sqrt{\ell^2 + D^2 - 2D\ell\cos\phi}$$

$$\sigma = S_1 + S_2 .$$

The path length difference is simply

$$\Delta R = R - \sigma$$

2.1.2.4 Multipath Propagation Computer Program

```
 100 C      MULTIPATH PROPAGATION PROGRAM
 300 C      COMPUTATION OF DIRECT AND REFLECTED PATHS BETWEEN SYNCHRONOUS
 400 C      SATELLITE AND A NEAR-EARTH ORBITING SPACECRAFT
 410 C      ALTITUDE=200 TO 2000 KM.
 500        IMPLICIT REAL * 8 (A-H,O-Z)
 600        R = 6378166.0
 700        D = 42242166.0
 710        Q=57.29577866662
 730        PI = 3.14159265
 740        WAV =2.058823529
 750        VEL = 299.79250
 800        DO 10 I=2,92,2
 900        THETA=(I-2)/Q
1000        RSIN=R*DSIN(THETA)
1100        RCOS=R*DCOS (THETA)
1200        DENO=D-RCOS
1300        ETA=DATAN2 ( RSIN,DENO)
1400        BATA= 90-(THETA+ETA)*Q
1500        BETA=BATA/Q
1502        ANCID = BATA - 90
1510        IF (BATA . LE. 0.0 .OR. ETA .EQ. 0.0) GO TO 10
1600        R2=RSIN/DSIN(ETA)
1700        THATA=THETA*Q
1800        ATA=ETA*Q
1900        DO 9 J=1,20
2000        H=R+(200000.00*J)
2002        SK= J * 200.00000
2050        GNU= 19965069.5/DSQRT (H)
2100        S1=-R*DSIN(BETA)+DSQRT(R**2*(DSIN(BETA))**2-R**2+H**2)
2300        G=DARCOS((S1**2-R**2+H**2)/(2*S1*H))
2302        GEE =G*Q
2400        A=S1*DSIN(G)
2410        IF (A/R .GT. 1.0) GO TO 9
2420        IF ( A/R  . LT.  -1.0)  GO TO 9
2450        ALFA=DARSIN(A/R)
2452        AHLFA  = ALFA * Q
2500        HSIN=H*DSIN(THETA + ALFA)
2600        DEN1=D-H*DCOS(THETA+ALFA)
2700        R3=DSQRT(HSIN**2+DEN1**2)
2800        S3=S1+R2
2900        DELTA=S3-R3
```

```
 2910        DELR = R3/VEL
 2920        DELS = S3/VEL
 2930        DELDEL = DELTA / VEL
 3000        GNUMO1= R3**2+H**2-D**2
 3100        DENO1 = 2*R3*H
 3200        QUOT1 = GNUMO1/DENO1
 3300        IF (QUOT1 .GT. 1.0) GO TO 9
 3400        IF (QUOT1  .LT.  -1.0) GO TO 9
10100        Z=DARCOS(GNUMO1/DENO1)
10310        ZETA=PI-Z
10312        ZATA  = ZETA * Q
10400        DRDT=GNU * DSIN(ZETA)
10450        SINTH=DCOS(BETA)
10500        DFIDT=GNU/H
10600        DF1DH=1-((R/H)*(DSIN(BETA)/DCOS(G)))
10610        TERM1=DSIN(ALFA)*( DTAN(BETA))
10620        DR1TH=(H/SINTH)*((DCOS(ALFA)*DF1DH)-TERM1)
10630        DF2DH=1-((R/D)*(DSIN(BETA)/DCOS(ETA)))
10640        TERM2=DSIN(THETA)*( DTAN(BETA))
10650        DR2TH=(D/SINTH)*((DCOS(THETA)*DF2DH)-TERM2)
10660        DHDFI=1/(DF1DH+DF2DH)
10670        XI = 180-ZEE-THATA-AHLFA
10680        DRRDT=(DR1TH+DR2TH)*DHDFI*DFIDT
10690        ANGLE=(THETA +ALFA)*Q
10691        GNAD = 180 - GEE
10692        SEP = GNAD - ZATA
10700        DIF=DRDT-DRRDT
10701        WAVDF = DIF /WAV
10702        WVDDF = DRDT / WAV
10703        WVRDF = DRRDT / WAV
  100%       WRITE (6,6)THATA,ANGLE,SK,SEP,ANCID,ZATA,GEE,GNAD
  200 6      FORMAT (1X,8F14.2)
  100%       WRITE (6,8)SK,THATA,DELR,DELS,DELDEL
  200 8      FORMAT (1X,2F8.1,3E20.8)
  100%       WRITE (6,7)SK,THATA,GNU,DRDT,DRRDT,DIF,WAVDF,WVDDF,WVRDF
  200 7       FORMAT (1X,F5.0,F8.1,F10.1,F9.1,3F18.1,F9.1,F18.1)
  100%       WRITE (6,5) SK,THATA,ANGLE,BATA,R3,DRDT,S3,DRRDT,DELTA,DIF
  200 5      FORMAT (1X,4F7.1,F13.1,F9.1,2(F13.1,F18.1))
10820        IF  (J .EQ.  5  )  GO TO 500
10870        GO TO 91
10920    500 WRITE (6,50)
11020     50 FORMAT (/)
11030    91  IF (J .EQ. 10) GO TO 501
11040        GO TO 92
11050    501 WRITE (6,51)
11060     51 FORMAT (//)
11070    92  IF (J.EQ.15) GO TO 502
11072        GO TO 9
11080    502 WRITE (6,52)
11090     52 FORMAT (/)
11120      9 CONTINUE
11220        WRITE (6,600)
11320    600 FORMAT (///)
11420     10 CONTINUE
11520        STOP
11620        END
```

% One of the write statements 5, 6, 7 or 8 should be selected

2.1.2.5 Magnavox RFI/Multipath Simulator

The general model of the channel simulator has been configured to allow an apparent correspondence between the major components of the simulator and the propagation parameters of the TDRS/user channel (See Figure 2-8.)

The simulator is a hybrid system in that it is comprised of a mixture of both analog and digital circuitry. Control of the simulator is digital and is provided through one of two modes of operation. The first is the AUTO MODE in which the control of the simulation is maintained by an on-line computer or computer-generated magnetic tapes. This "dynamic" controlled operation provides for:

- Complete orbit dynamics
- Preemptive resume control
- Preemptive repeat control
- On-line user interaction
- Programmable tests
- Real and virtual time

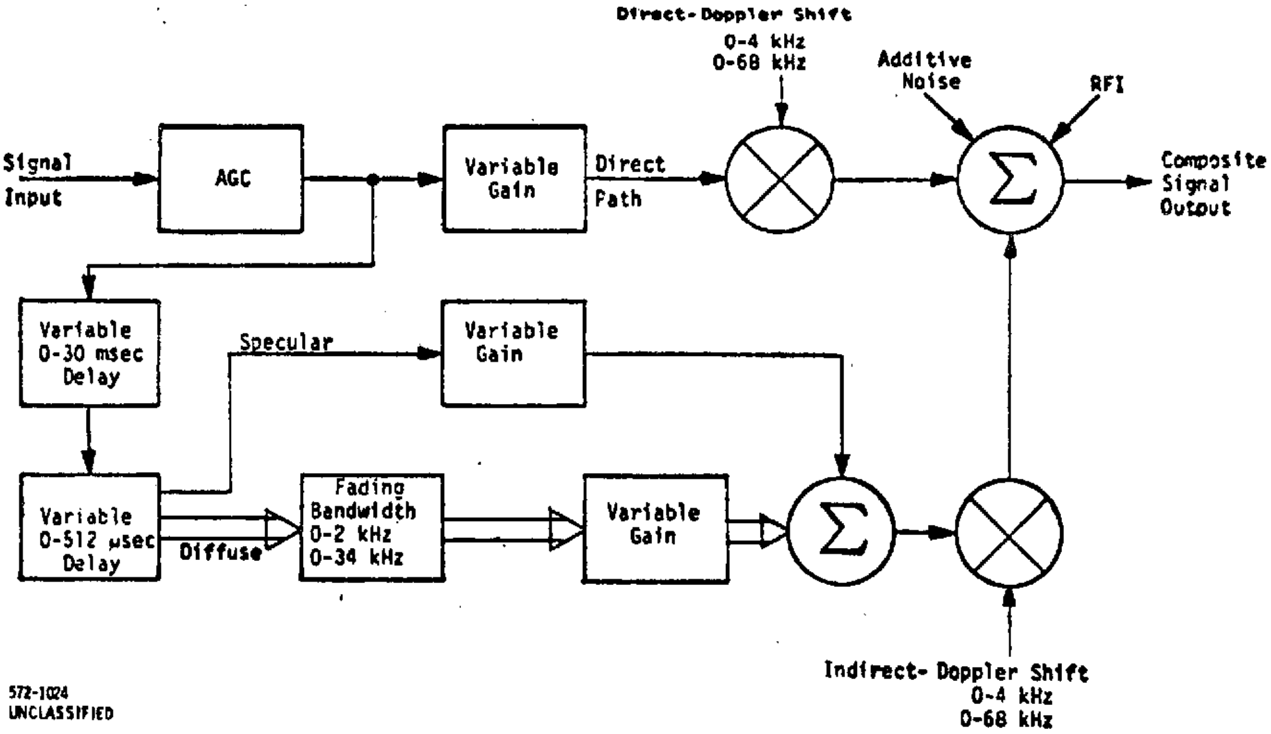


Figure 2-8. Functional Block Diagram of the TDRS Channel Simulator

The second mode of operation, the MANUAL MODE, is referred to as the "static" operation and provides for:

- Independent operation
- Manual setting of controls
- Frozen orbit statistics
- Independent calibration

In general, the simulator operates with any class of input signal regardless of the modulation format, providing the signal bandwidth is confined to 2 MHz. The simulator subsystem components require, at most, present state-of-the-art hardware, and thus are essentially "off-the-shelf" items.

The basic design requirements of the TDRS channel simulator are presented for the implementation which will approximately realize the channel parameters selected. A summary of those parameter values is presented in Table 2-4. The values specified in the table cover a range which is actually in excess of what would typically be encountered over the TDRS/user link, thereby permitting modems to be tested under more severe conditions. In arriving at the selected design approach, the following points were considered:

- The ease and flexibility with which the simulator parameters could be changed by an external control unit.
- The cost of implementation traded off against the accuracy to which parameters could be adjusted.

It can be shown that the channel parameters having the most profound effect on the performance of the link are:

- Free Space Attenuation
- Multipath Time Delay
- Direct Path Doppler
- Differential Doppler
- Fading Bandwidth
- System Noise Power Density
- Radio Frequency Interference

The primary factors considered in arriving at the selected simulator are twofold. First, the ease and flexibility with which the simulator parameters could be changed by an external control unit. Second, the cost of implementation traded off against the accuracy to which parameters could be adjusted. The range of variation of the simulator parameters is shown in Table 2-4. In addition to those parameters in the table are the introduction of noise and RFI which are controlled externally.

Table 2-4. Summary of Simulator Parameters

Parameter	VHF (136-139 MHz)	S-Band (2.3 GHz)
Differential time delay between Direct and Reflected Signals	0-30 ms	0-30 ms
Signalling Bandwidth	2 MHz	4 MHz
Maximum Differential Time Delay of Reflected Signal	255 μsec	256 μsec
Fading Bandwidth of Reflected Signal	~0-2 kHz	~0-34 kHz
Direct Path Doppler	~0-4 kHz	~0-68 kHz
Reflected Path Doppler	~0-4 kHz	~0-68 kHz

2.1.2.6 McDonnell Douglas TDRSS Channel Simulator

As part of the ATDRE study MRL investigated the possibility of using the McDonnell Douglas On-Line Subsystem Facility (OLSF) to simulate a TDRSS channel. The reasons and expected results of such a simulation were:

- Determination of the severity of the RFI and multipath problem on proposed modulation techniques (i.e., BER versus processing gain for different interference flux densities, etc.).
- Evaluation of candidate interference reduction techniques and their effect on system parameters.
- A determination of operational considerations for candidate interference reduction techniques.

Unfortunately, prior to tasking McDonnell Douglas with this assignment, the TDRSS program began to change direction and the investigation was not pursued. However, since the eventual TDRS System will most likely operate at S-band frequencies instead of VHF, the use of OLSF equipment for TDRSS channel simulation still has merit because it was designed to operate in this frequency region. Therefore, a brief summary of the S.O.W. to McDonnell Douglas and a description of the OLSF equipment are included in this report.

2.1.2.6.1 Summary of McDonnell Statement of Work

- Purpose Of Work

Define, in sufficient detail for technical evaluation, a series of laboratory simulations. These laboratory simulations would be part of a series of experiments aimed at optimizing system parameters in the Advanced Tracking and Data Relay Satellite System (ATDRSS) for the National Aeronautics Space Administration. The contractor shall:

- Develop plans and implementation concepts for a series of simulations that exercise actual ATDRSS transmitters, receivers and transponders in the McDonnell Douglas On-Line Subsystem Facility (OLSF).
- Describe the above plans and concepts in a final report.
- Analyze and predict the costs and schedules of the simulations.
- Submit the final report, costs and schedules as part of a proposal to perform the simulation series.

- Problem Areas

Since the TDRS System involves spacecraft-to-spacecraft communication over a constantly changing link distance through omnidirectional antennas, the following probelm areas arise and must be accounted for in the simulations.

- A multipath signal due to reflection from the earth contaminates the direct signal. The multipath signal undergoes different path attenuation, phase shift, doppler shift, and signal delay than the direct signal. Also, it suffers a reflection attenuation, delay spreading and is the composite of a variable ratio of specular and diffuse reflection.

- Man-made radio frequency interference (RFI) from earth-based sources will contaminate each link channel.

It is well known that many natural physical phenomena influence the character of radio signals and the performance of equipment in a TDRS System. These factors include birefringence, Faraday rotation and earth warm body radiation among others. Preliminary analysis has shown that many of these factors have negligible effect. For example, birefringence results in only a few nanoseconds of signal delay, Faraday rotation is of no consequence in a system employing circular polarization, and the warm body radiation level is well below the anticipated level of RFI and internal noise.

The conclusion of the preliminary analysis is that for the purpose of the simulation series, the catalog of natural phenomena that may influence the TDRSS performance should be reduced to only those few significant factors whose specification will enable precise mathematical definition of the effects referred to above (multipath and RFI), plus normal propagation path loss and equipment internal noise.

The mathematical definitions required to model multipath and RFI effects used as inputs to the simulations will be supplied to McDonnell Douglas.

- Presentation Of Simulation Results

The simulation results should be presented in a succinct fashion for easy interpretation. A graphical presentation is one way of achieving this. It is suggested that the results be presented in the form of plots of the angle ϕ (plotted on the abscissa) versus errors in data, range, and range rate for selected combinations of controlled parameters. This would enable rapid visualization of the effects of the controlled parameters on the link performance, where performance is defined as being data bit probability error, range error and range rate error where each is a function of the user orbital position (orbital position defined by the angle ϕ and the distance H) for various combinations of controlled parameters. The controlled parameters are:

- Link Mode	Forward or Return
- Modulation Mode	PN or PSK
- Carrier Frequency	127.750, 137, 149.0, or 401 MHz
- Data Rate	100, 300, 1000, 3000, or 10,000 bps
- PN Chip Rate	34.133, 102.4, or 1024 KHz

-	RFI	CW or Gaussian noise
-	Multipath	Land or Sea

2.1.2.6.2 Description of OLSF

The On-Line Subsystem Facility (OLSF) which is a MDAC-owned facility complex dedicated to dynamic, real-time performance evaluation of critical subsystem hardware operating in a controlled "ground flight test" mission type environment. It consists of a Central Data Processor (hybrid computer) tied to a multiplicity of subsystem hardware test apparatuses as depicted in figure 2-9. It provides the unique capability of switching from a pure hybrid computer simulation of a system to a closed-loop, real-time, hardware simulation of the same system using available candidate subsystem hardware. This allows early evaluation of the impact of a particular subsystem hardware design on the total system's performance for any desired mission. OLSF is continually in a state of evolution to provide the generalized, mission oriented, hardware testing capability required for new system analysis, design, development and evaluation activities.

The current OLSF configuration is summarized as follows:

- The Central Data Processor (CDP) is a hybrid computer that is the central integrating facility for the overall OLSF complex.
- The OLSF Hybrid Computer consists of a medium size digital computer, a modern analog computer with two consoles, and a large interface which provides a high-speed data transmission between the analog and digital computers. In addition to the CDP, there are two small portable analog computers that can be used independently or connected to appropriate OLSF test apparatus.
- The Electro-Magnetic Generator (EMG) is a radio frequency (RF) channel simulator whose primary function is generating the complex microwave signal spectrum that would be incident upon a radar or communications receiving antenna. Up to four propagation paths are simulated. Elements that contribute to receiver hardware inaccuracies such as transmitter waveform, doppler shift, space attenuation, multipath, radar cross-section and antenna pattern

effects are generated in the EMG under computer control. The EMG is, therefore, a mission simulator test bed for evaluating radar or communication receiver hardware.

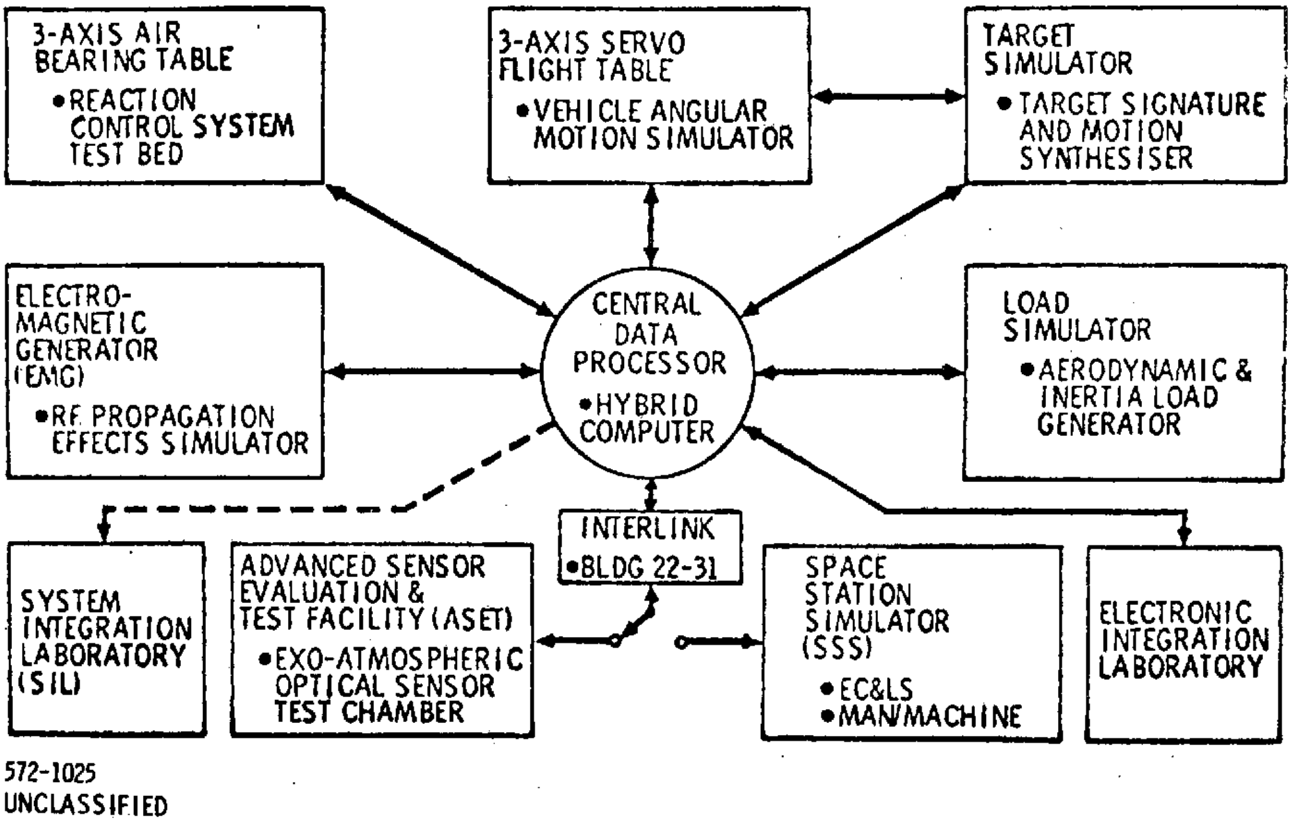


Figure 2-9. On-Line Subsystem Facility - 1972

Experiments conducted in the laboratory at MDAC using this simulation capability would provide:

- Real time readout of test results.
- Test flexibility to allow time for resolving unexpected problems.
- Control of the RFI and multipath intensities to obtain practical limits and threshold of the interference reduction technique under test.
- Control of propagation parameters for realistic RF path simulation.

The simulation would be conducted at RF using real VHF operational frequencies. RF space link parameters such as thermal noise, time delay, doppler shift, antenna gains, RFI interference, and multipath signals would be simulated. The main reason for conducting a simulation at real RF frequencies is that there are no analytical means of evaluating multiple mixed RF signals and under analytical evaluation, too many assumptions as to the operation of communication equipment must be made.

2.1.3 FLIGHT EXPERIMENTS

A group of flight tests have been proposed in this section which would measure the MMT/MTAR performance under actual multipath and RFI conditions.

This study describes tests with signal transmission between the MMT (in an aircraft) and the MTAR (in a ground installation). It includes flight tests with the MMT (in a high altitude aircraft) transmitting to the MTAR (in a low altitude aircraft). It also outlines a test using a balloon as an airborne vehicle.

2.1.3.1 Aircraft to Ground Tests

As a background for establishing a baseline for TDRSS performance characteristics, a series of operational tests could be conducted from a mobile NASA van to an aircraft as illustrated in figure 2-10. These tests will encompass a variety of operational environments and procedures. In order to ensure reliable data, a sequential integration procedure will be used for the test series. This test sequence is recommended to verify proper TDRSS operation during the final stages of TDRSS operability testing.

I. Back-to-Back testing in the Mobile Van
II. Operation from the MRL Lab to the Mobile Van
III. Operation from the Mobile Van to an aircraft (hardware)
IV. Flight Tests (RF-Normal Link)
    A. Heavy RFI Environment (Metropolitan)
    B. Light RFI Environment (Desert and Ocean)

2.1.3.1.1 Back-to-Back Testing

Prior to actual installation of the TDRS System in the test aircraft, MRL would complete a series of tests in the back-to-back configuration. The TDRSS would be installed in the NASA mobile van and a series of baseline performance figures would be verified. The following data would be extracted as a baseline:

- Error rates at various C/KT's
- Voice clarity at various TT/N's
- Operation in both PSK and wideband PN modes
- Performance at various frequencies

2.1.3.1.2 Operation from the MRL Lab to the Mobile Van

After establishing the baseline for operation in the back-to-back mode, tests would be conducted from the mobile van to the MRL lab. These tests would simulate actual operational environments but with the controls that could be imposed in a strict laboratory atmosphere. The data obtained during this testing would be recorded and compared to the baseline data gathered in the back-to-back mode.

2.1.3.1.3 Preflight Testing

Tests would be conducted after the installation of the TDRSS in the aircraft to verify proper operation of the system prior to flight testing. These tests would be the same tests used to establish the system baseline and the data recovered would be compared to the original data obtained during back-to-back testing. Tests during this phase would be conducted with both a hardwire and atmospheric conductor between the van and the aircraft.

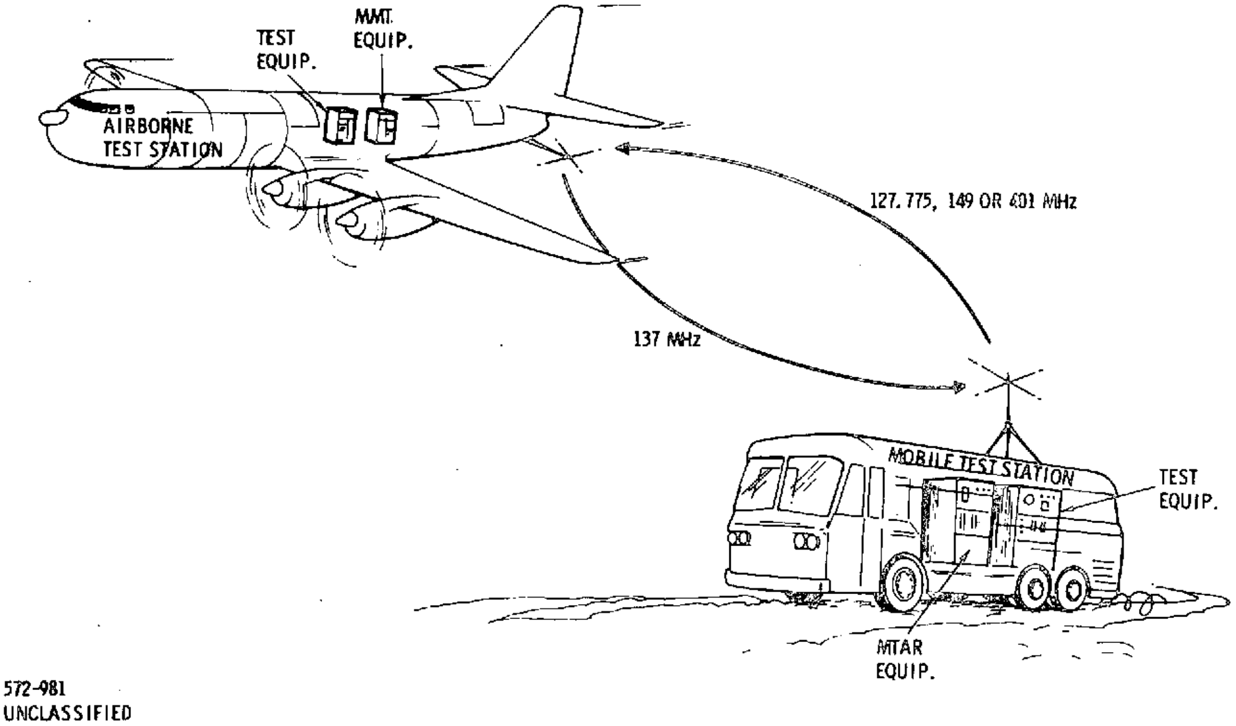


Figure 2-10. Multimode Transponder Test Configuration

2.1.3.1.4 Van to Aircraft Operation

After completion of aircraft and van integration tests, a series of flight tests would be conducted to evaluate system performance in a variety of operational environments. These tests would be conducted in both heavy and light RFI atmosphere and in the various modes and data rates available. All data gathered during flight testing would be recorded and compared to original baseline information. One of the main considerations of the flight testing would be the evaluation of the system under RFI conditions. By conducting the flight tests under a variety of atmospheres in terms of RFI and multipath, an excellent evaluation of performance could be accomplished.

Test Procedures - For evaluating the performance of the TDRS System during the flight, a complete testing program would be generated to ensure proper and thorough exercising of the system. A baseline for system performance would be established from the lab tests.

In order to evaluate system performance prior to actual aircraft tests, a review of reproducible test conditions must be established. The following tests would allow reproducibility of results.

Digital Data - In order to evaluate system performance in the digital mode, a method of determining error rate versus C/KT or J/S must be devised. Use of an MX-270 data analyzer would meet this requirements. The MX-270 generates a data stream which is then recovered from the receiver and compared to the transmitted data.

The MX-270 would enable error rates at various data rates and C/KT's to be determined in order to establish baseline system performance in both the wideband and PSK modes. This baseline would then be compared to system performance during actual operational conditions.

Voice - Since the main criteria in voice communication is clarity or intelligibility of voice, system performance in the voice mode would be determined in the following manner. A commercially available prerecorded tape would be used to transmit voice and then the response would be recorded on the receive side of the tape. The receive tape would then be compared with the transmitted tape for clarity and intelligibility.

The other method for determining voice quality is to measure test tone to noise ratio during operation. By establishing test tone to noise versus C KT figures during back-to-back testing, a baseline for voice quality could be established for use during flight testing.

2.1.3.1.5 Flight Testing

During flight testing of the TDRSS multimode transponder, the following information would be recovered:

- Polarization Diversity Performance
- Digital Data Performance
- Voice Performance
- PSK versus Wideband Performance
- Range Rate
- Range

Flight tests would be conducted in a variety of operational environments. The MTAR would be installed in the NASA mobile van and the MMT installed in the test aircraft. Along with the test equipment installed in the mobile van, an MX-270 and data recorder would be installed.

During the flight testing, one of two aircraft could be utilized. The first aircraft is the NASA C-121. The MMT would be installed in the craft and tests conducted under a variety of conditions. This aircraft would be outfitted with equipment to determine the nature of the RFI in the different test areas during flight. This would provide a method to correlate RFI with the multimode transponder performance.

During flight testing of the TDRSS, digital data error rates would be taken at all rates and in both the PSK and Wideband modes. These errors would then be correlated to C/KT as determined in lab tests.

Voice tests would be conducted during flight testing to determine clarity and intelligibility of voice. By utilizing both measurement methods described earlier in the test plan, an effective evaluation of voice performance could be made.

Two other criteria must be met during flight testing. These would be the determination of range and range rate (doppler) of the aircraft. Range could be accurately determined in the wideband mode. A line from the transmit coder representing the all ones vector is brought out to a timing device. A second line from the receive coder representing the all ones vector is also sent to the counter. By measuring the time interval between vectors, using an internal counter, an accurate range measurement could be made.

To determine range rate, one would measure the offset in 60 MHz IF frequency with respect to the 5 MHz system reference clock over an interval of time. This would then be directly converted to range rate.

2.1.3.2 Air-to-Air Tests

This experiment would consist of actual flight tests involving two aircraft plus ground support equipment and would be conducted in two parts designated A and B.

The purpose of Part A of this experiment would be to determine the effects of multipath on user/TDRSS links as isolated from RFI effects. The experiment would utilize two aircraft operating over the ocean and over a sparsely populated land area thus enabling operation of an air to air link in the presence of multipath reflected from actual representative earth surfaces. The relatively low altitude of the aircraft (compared to satellites) combined with their ability to cruise to low population density areas would enable quantitative evaluation of multipath effects without the contaminating effects of RFI.

Part B of this experiment would utilize the identical procedures and equipment as Part A except that the experiment would be conducted over a high population density area to determine the combined effects of both RFI and multipath on the link performance.

2.1.3.2.1 Test Sites and Vehicles

Primary consideration in selection of the test site base is the available base locations of NASA U-2 aircraft. These aircraft are based at Wallops Island, Virginia (Washington, D. C. area), and Moffett Field, California (San Francisco area). The next consideration is the distances from test base to test areas (ocean, low population land, and high RFI area). Both U-2 bases are adjacent to ocean areas, large cities (RFI generators), and within reasonable flying distance (400 miles) of low population and land areas. It would not be necessary to use two U-2 aircraft for the tests. Only one would be used to carry the MTAR equipment in a "normal" altitude flight profile cruising at 65,000 feet. A second aircraft cruising at a lower altitude would carry the MMT. For testing on the West Coast, test aircraft are available from firms in Oakland, California, and Long Beach, California. In addition, Rockwell has available a Sabreliner specially equipped for avionics tests and this would be considered as an alternate. Commercially available test aircraft on the East coast are not known at this time, however, there are several NASA, DC-6 aircraft at Wallops Island that are outfitted for avionics tests and one of these might possibly be utilized.

2.1.3.2.2 Aircraft Modifications

U-2 - The MTAR equipment, data recording and interface equipment would be mounted in a common fixture for subsequent installation, as a single unit in the U-2's lower equipment bay. The control panel for the equipment would fit in a MIL-STD panel console already available in the U-2 cockpit. A suitable cable harness should be fabricated to connect the control panel to the equipment. The antenna would be mounted on the surface of the lower equipment bay door. Cables should be fabricated to connect this antenna and the aircraft 28 VDC power to the equipment.

Low Altitude Aircraft - The MMT equipment as well as data recording and interface equipment and the control panel would be rack mounted in existing equipment racks in the aircraft passenger compartment and interconnected by the same cable harness assemblies used in the initial bench tests. Antennas would be mounted in the nose and the tail of the aircraft and connected to the equipment via a specially fabricated coaxial switch and cable assembly. This would enable selection of either antenna as required to prevent the airframe from shadowing the direct and reflected propagation paths. The specific antenna configuration would require further study due to the non-adaptability of the present ground antenna to an airframe flying in excess of 200 mph. At present, electrically shortened turnstile antennas appear to be reasonable choices. Propagation path calculations show that as much as 10 dB loss could be taken in the antennas without compromising test validity. Therefore, electrically short antennas could be used provided they would be fed through proper matching networks for minimum VSWR. The smaller physical size of such antennas would enable one to be mounted in the nose radome and the other on a tail sting. The tail antenna would require streamline cross-section, rather than round, elements as it would project in the air stream. Proper phasing of the antennas and placement with regard to their distances respectively ahead of the forward bulkhead and behind the empennage should provide each with a circularly polarized, hemispherical radiation pattern.

2.1.3.2.3 Propagation Path Geometry

The most valuable data obtainable from tests in which aircraft simulate the TDRSS and user would be on system performance at low multipath grazing angles. This is a very critical situation for the real TDRSS when users in low orbits are near the horizon. The geometry is such that the actual situation in which the multipath length is nearly equal to the TDRSS-to-user, direct path length could be achieved very accurately with aircraft. At high grazing angles, in which the aircraft would be close and the direct path is more vertical than horizontal, the geometry would become unrealistic in terms of the actual TDRSS although it could very realistically provide data on satellite to aircraft systems such as AEROSAT. Figure 2-11 shows the propagation situation for Part B of the airborne experiments in which ocean reflected multipath and RFI would contaminate the direct signals and the resultant effects would be evaluated.

2.1.3.3 Balloon Platform Tests

A very convenient multipath and RFI measurement configuration consists of a high altitude balloon and a low altitude aircraft such as the C-121. The high altitude balloon would be launched from the ground to an altitude of approximately 120,000 feet. The balloon could carry a linear translating repeater which would accept signals transmitted to it from the aircraft. These signals would then be retransmitted at an appropriate frequency to the ground station for further processing. This concept is illustrated in figure 2-12. In addition to providing a high altitude relay to simulate a stationary satellite, the balloon could be outfitted with an RFI receiver

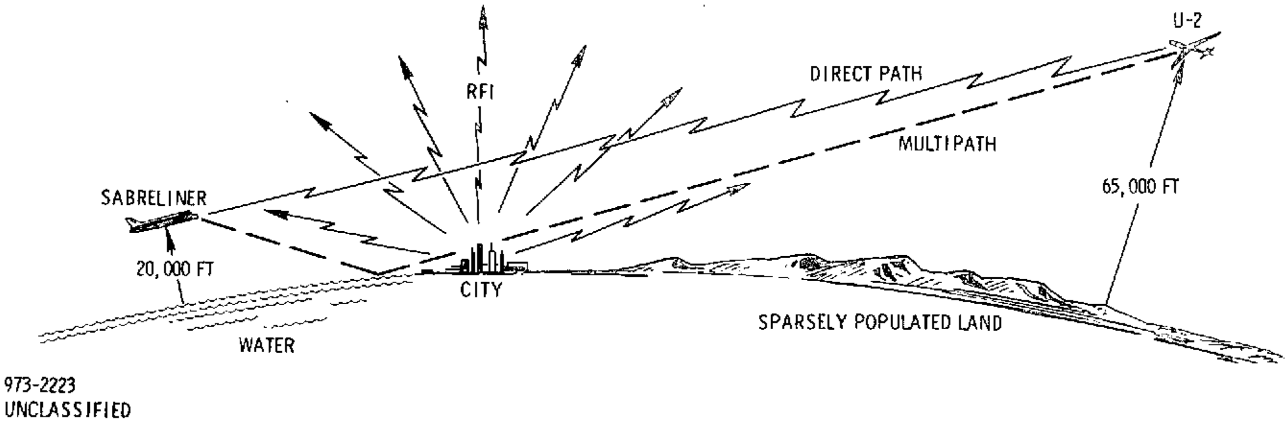


Figure 2-11. Typical Test Propagation Path Geometry

and telemetry and command signals could be transmitted to the balloon's transponder to change its mode from a linear translating repeater to an RFI measurement device. In this configuration most of the complex instrumentation would be placed at the ground station and the aircraft would need only transmit multimode signals to the high altitude balloon for processing at the ground station. By placing an antenna on top of the aircraft so as to avoid multipath and RFI, a link could be established between the ground station and the aircraft independent of the multimode transmission RF signal. The second transmission could be used for command and control and voice messages to the aircraft as long as it would be in field-of-view of the high altitude balloon.

This configuration would be attractive for several reasons. With a relatively stationary balloon, the aircraft could be flown over land masses so that various multipath situations could be measured. This configuration could also minimize the problem of tracking since the ground station would need only track a slowly moving high altitude object as opposed to tracking a low altitude, relatively high velocity aircraft. Furthermore, the high altitude balloon could be outfitted with either an expendable or retrievable electronic package. By properly choosing the frequency for transmission from the high altitude balloon to the ground station, a relatively narrow beam antenna at the ground station could be used so as to minimize potential multipath in the balloon to ground station link.

The aircraft/balloon configuration has been used with great success by the European Satellite Research Organization, NASA Goddard, and the Transportation System Center of the Department of Transportation. Specifically, the aircraft/balloon configuration has been used at L-Band to successfully simulate a synchronous satellite operating with a high velocity aircraft.

It is obvious that the link between the aircraft and ground station could be reversed so that the aircraft would receive signals from the ground station through the high altitude balloon. In this situation the aircraft would be given the latitude to maneuver over land, water and urban territory, thus creating a purely multipath channel or combination of multipath and RFI channel.

2.1.3.3.1 Balloon Statistics

The feasibility of conducting tests using a balloon as a test platform was explored. GSFC presented some data on balloons available for tests. It would be possible to attain altitudes of 120,000 feet with a total payload of up to 500 pounds for up to 8 hours. Preliminary information indicates that balloon launches would probably be confined to the North or South Dakota area during the month of August. The cost for a single balloon launch, track and retrieval would be in the ballpark of $10k. Some of the problem areas include reliability, retrieval and the fact that no launch can be made over metropolitan areas.

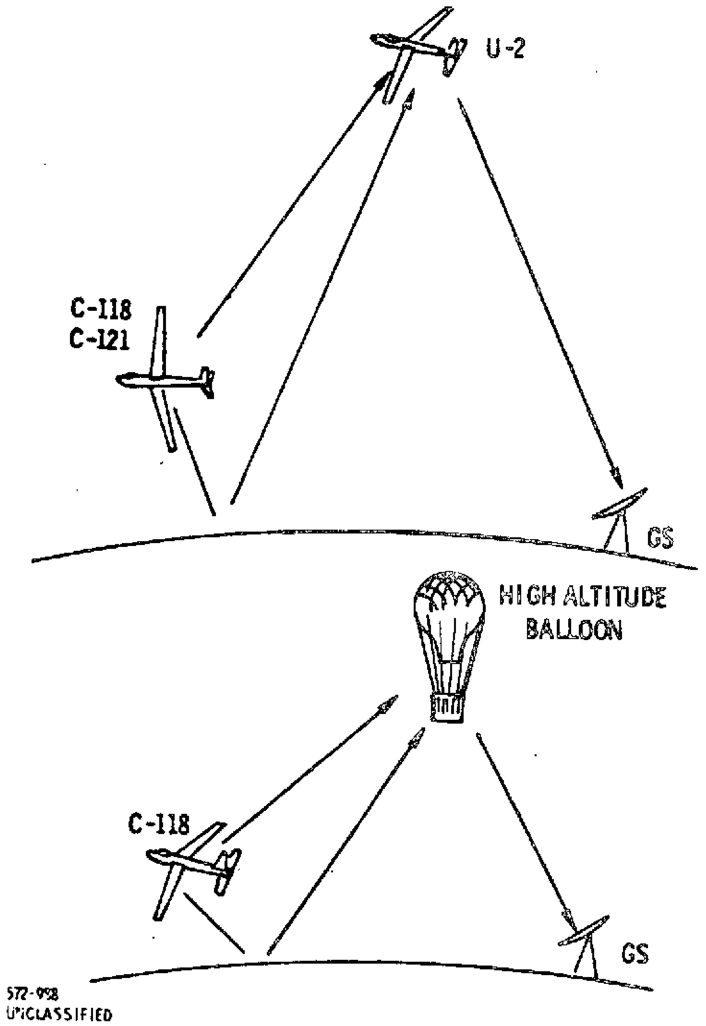


Figure 2-12. Aircraft-Relay-Ground Test Configurations

2.2 RECOMMENDED TEST PLAN

This section contains a set of detailed tests which have been selected from the candidate experiments presented in section 2.1. These tests were selected from a practical standpoint and will provide a great deal of information about modulation techniques for the proposed TDRSS system at a minimum cost. Each set of tests has been designed to help meet the test objective of determining the best equipment configuration for TDRSS.

Each experiment will specify test conditions progressively approaching the TDRSS communications environment. The laboratory experiments will define the expected performance for each of the modes in a controlled environment. Although the TDRSS link simulator experiments have not been included because of their high cost, a flight test has been selected to provide an environment near that anticipated for the TDRSS configuration.

2.2.1 LABORATORY TEST PLAN

The modes of operation which should be evaluated during laboratory testing are summarized in Table 2-5.

The recommended test setup for the laboratory tests is shown in figure 2-13 for the Forward or Return modes of operation.

The signal and noise levels will be measured at the output of the RF amplifiers of the MMT and MTAR R/T. At this point the channel bandwidths are fully characterized.

The performance of each mode of operation would be evaluated with respect to E_b/N_o. This ratio should be measured in the MMT and MTAR equipments using the following relationships:

For PSK: $$(E/N_o)_{baseband} = 2 \times \frac{S}{N} \times \frac{B_N}{B_D})$$

For PN: $$(E/N_o)_{baseband} = (2 \times \frac{S}{N} \times \frac{B_N}{B_D} \times \frac{B_N}{B_{PN}})$$

where:

E/No = baseband signal-to-noise ratio in the data bandwidth.

S/N = RF signal-to-noise ratio measured at the input to the first IF.

B_N = Equivalent noise bandwidth at input to first IF.

B_D = Data bandwidth at baseband.

B_{PN} = Equivalent signal bandwidth at input to first IF (B_{PN} = PN code rate).

Table 2-5. MMT/MTAR Modes Of Operation

Forward Only	
Mode	PN, PSK
RF Frequency	127.750, 149, 401 MHz
Diversity	Rcvr #1, Rcvr #2, Both Rcvrs.
PN Chip Rate	34.133, 102.4 kcs
Data Rate	100,300,1000 bps and Voice
Data Encoding	On/Off
Doppler Offset	0-4 kHz
Signal Level	-100 to -140 dBm
Return Only	
Mode	PN, PSK
RF Frequency	137 MHz
Diversity	Rcvr #1, Rcvr #2, Both Rcvrs
PN Chip Rate	34.133, 102.4, 1024 kcs
Data Rate	300,1000,3000,10,000 bps and Voice
Data Encoding	On, Off
Doppler Offset	0-16 kHz
Signal Level	-100 to -140 dBm
Transpond	
All of the above combinations of Forward and Return Only shown above.	

2.2.1.1 Signal Acquisition Tests

Acquisition performance would be evaluated by determining the probability of acquisition (P_A) for a given E / N_o. For each mode, the number of successes in ten trials would be used to determine P_A. Each mode should be evaluated for PA = 0.5 to 1.0. For PN operation, the acquisition time for each trial should be recorded.

Configure the Multimode Transponder equipment per the forward or return link setup as shown in figure 2-13. Each of the modes of operation shown in table 2-5 should be evaluated for the following types of noise.

- Thermal Noise (threshold performance)
- CW Jammer
- Pulse Jammer

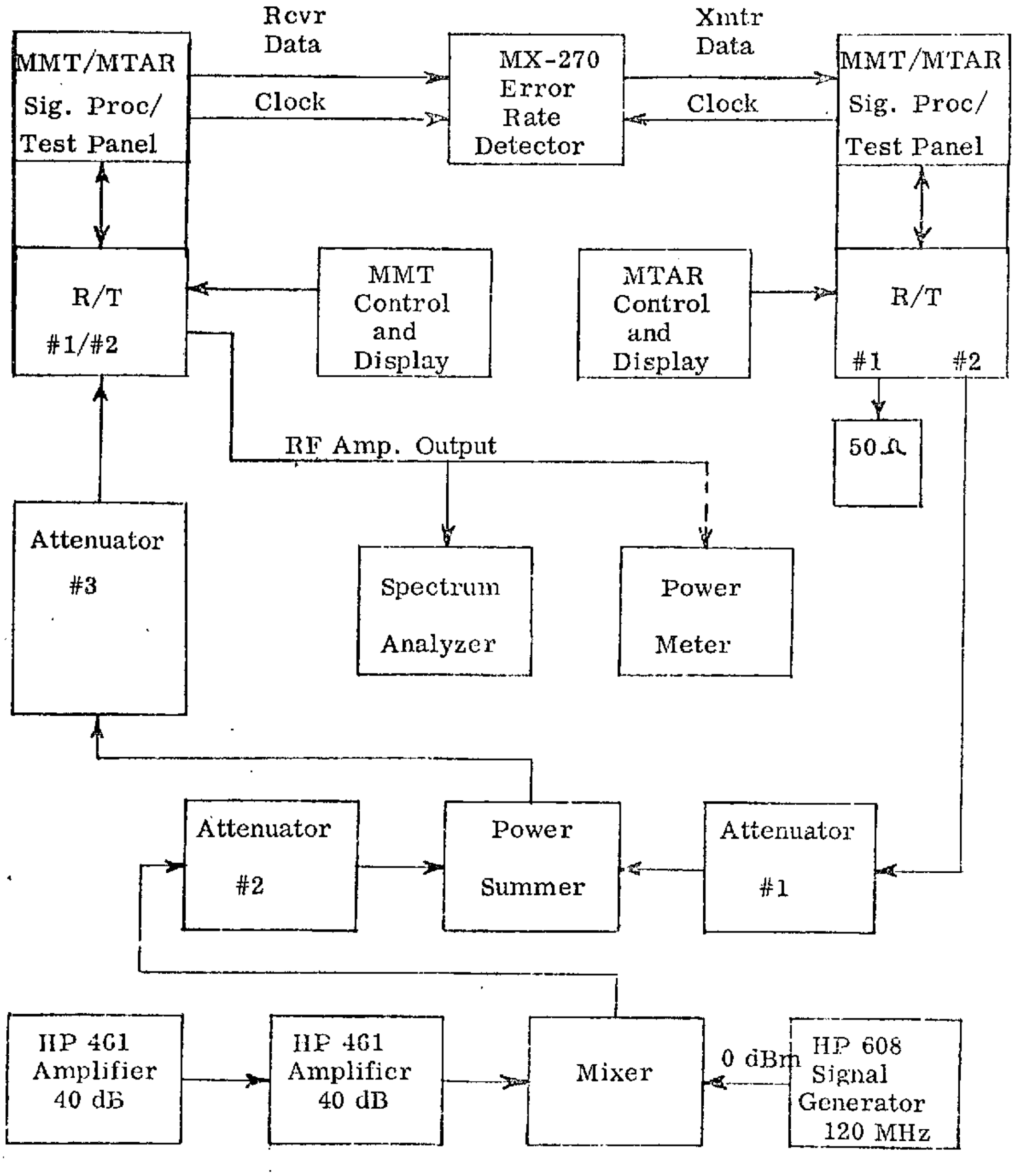


Figure 2-13. Forward or Return Link Test Setup

Performance should be evaluated over an RF input signal range of -100 to -135 dBm.

2.2.1.2 Data Demodulation Tests

Data demodulation performance would be evaluated by measuring the E/N_o ratio for a given data error rate. For each mode, the E_b/N_o for a data error rate of 10^{-3} to 10^{-5} should be measured. As shown in table 2-1, the time required to obtain a sufficient sample size for good confidence in the error rate results becomes appreciable at low data error rates. Care should be taken to perform only those tests which would provide the most information in the least time.

Configure the Multimode Transponder equipment per the forward or return link setup as shown in figure 2-13. Each of the modes shown in table 2-5 should be evaluated for thermal noise, CW and Pulse Jamming noise sources.

2.2.1.3 Voice Mode Tests

Testing of the voice mode would be accomplished using a CW or gaussian noise source in both the PN and PSK modes of operation. The transmitting equipment would be modulated at the audio interface with a pre-recorded tape of word lists from Tracor, Inc., and the receiving equipment would output the demodulated voice signal at the audio interface into a blank Tracor tape. This test would be repeated for the selected noise sources at various E_b/N_o ratios. The tape recording would be returned to Tracor for intelligibility scoring and the results would be presented on graphs.

For voice mode testing, interconnect the Multimode Transponder equipment as shown in figure 2-14. Before each recording, speak through a mike to record the test conditions which will subsequently be recorded and listen through the headsets to ensure that the equipment is functioning.

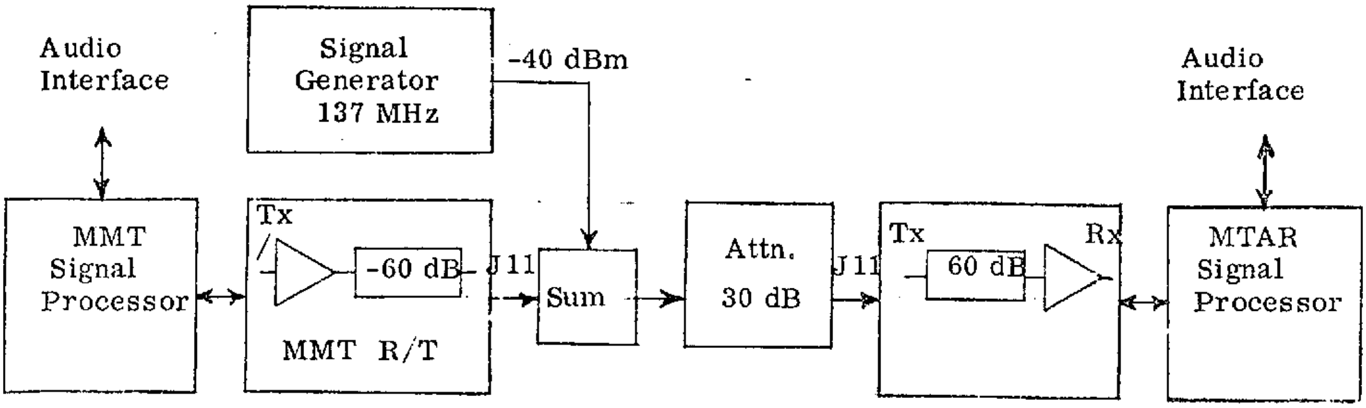


Figure 2-14. Test Setup for Voice with CW Interference

2.2.1.4 Range Measurement Performance Tests

Range measurement performance would be conducted in a full duplex configuration, as shown in figure 2-15. A Hewlett Packard Computing Counter (model 5379A and its associated 5379A Time Interval Plug-in) would be used to measure

- RMS jitter performance
- Mean range error performance

Noise sources should be inserted into the forward and return links to simulate realistic conditions.

2.2.1.4.1 RMS Jitter Performance

1. Select the desired mode of operation
2. Select the desired noise source
3. Setup the desired signal and noise levels.
4. Set the H.P. computing counter for a "time interval rms jitter" program. Refer to the H.P. instruction sheet No. 13.
5. Initialize and acquire the system
6. Compute and record the rms jitter
7. Repeat for each desired mode of operation

2.2.1.4.2 Mean Error Performance

Set up the H.P. counter for a time interval measurement. Repeat step 2.2.1.4.1 above and collect 10 samples for each mode.

2.2.1.5 Range Rate Measurement Performance Tests

Range rate measurement would be performed in a full duplex mode of operation as shown in figure 2-15. A H.P. counter would be used to measure

- RMS jitter performance using the MTAR 10 MHz oscillator as a reference
- Mean range rate performance.

Separate noise sources would be inserted into the forward and return links to simulate realistic TDRSS link conditions.

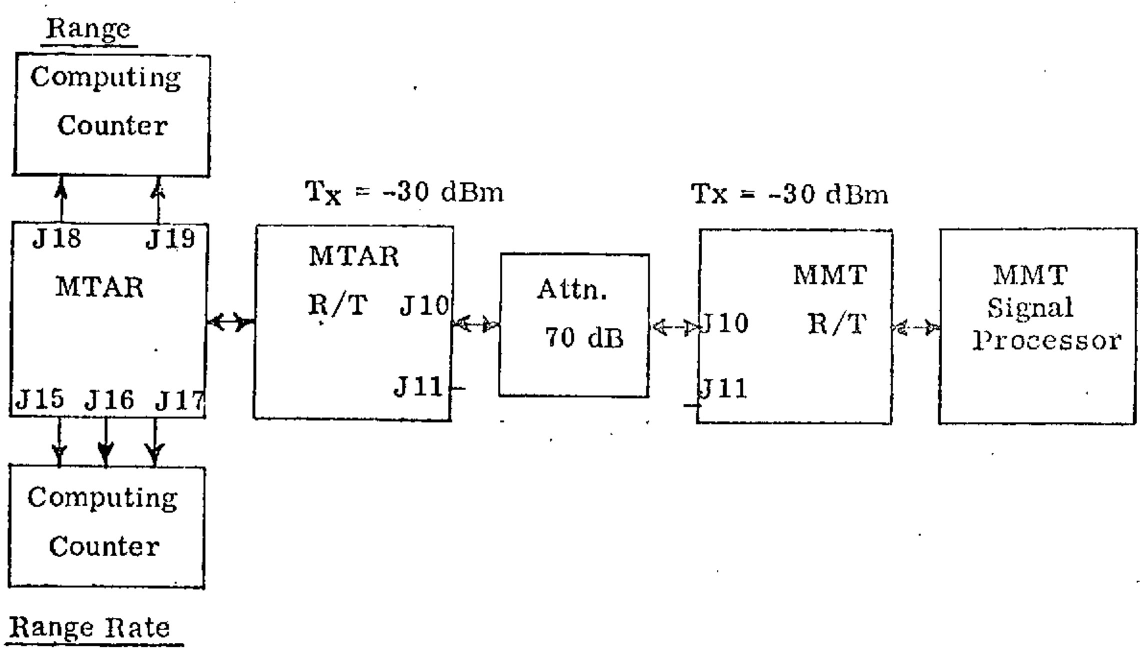


Figure 2-15. Test Setup for Range and Range Rate Tests

2.2.1.5.1 RMS Jitter Performance

Setup the H. P. computing counter for a "fractional frequency deviation" program. Refer to the H. P. instruction sheet No. 7. Repeat the steps in section 2.2.1.4.1 and collect 10 samples from each test.

2.2.1.5.2 Mean Error Performance

Setup the H. P. computing counter for a "mean frequency" measurement. Program for a 10 second average. Repeat step 2.2.1.4.1 above and collect 10 samples for each mode of operation.

2.2.1.6 Cost

It is estimated that the effort required to support the laboratory tests and provide a report summarizing all results is on the order of six man-months and could be accomplished at a cost of approximately $30k.

2.2.2 FLIGHT TEST PLAN

The purpose of flight tests would be to simulate, as closely as possible at a minimum expense, the conditions that a TDRSS user satellite transponder would encounter in space and measure its performance under these conditions. The conditions that flight tests specifically address are:

- Near-zero grazing angle propagation path
- Acutal RFI over urban areas
- Land and sea multipath return
- Combinations of the above

2.2.2.1 Test Location

The tests would be performed on the U. S. West Coast with test aircraft based at Mojave, California. Two test aircraft would be employed; a Lockheed T-33 provided, on subcontract, by Flight Systems, Inc., of Newport Beach, California, and a NASA DC-6. These aircraft plus a NASA instrumented mobile van would be the only vehicles involved in the tests. Tests would be conducted over a period of eight working days with one flight per day. Actual flight time for the jet aircraft would be between 3-1/2 and 4 hours per day.

2.2.2.2 Scope of Tests

Due to the expenditures required to support the operation of actual aircraft, the number of flights would be limited to eight. Consequently, all the possible combinations of conditions the MMT may encounter could not be simulated and careful planning is necessary to ensure useful results from tests.

The various parameters that may be altered and their possible values are as follows:

- Polarization: Vertical, horizontal, right circular, left circular
- RF Frequency: 127.75 MHz, 149 MHz, 401 MHz, 137 MHz
- Modulation: PN, PSK
- Baseband: Voice, Data
- Data Rate: 100, 300, 1000, 3000, 10,000 bps
- PN Chip Rate: 34.133 kHz, 102.4 kHz, 1024 kHz
- Multipath Reflection Point: Land, Sea
- RFI Environment: RFI, No RFI

This list has been analyzed to determine which parameter combinations would provide the most useful test data. It was decided that certain parameters could be held constant or deleted in the test series without too much loss of information. Thus:

Polarization:	Circular only, right or left TBD
Frequency:	1 VHF and 1 UHF
Baseband:	Data only
Chip Rate:	102.4 kHz and 1.024 MHz
Multipath:	Sea return only

Operation with and without natural RFI remains as well as evaluation of PN against PSK modulation.

2.2.2.3 Flight Planning

A reasonable evaluation of operation with this abbreviated parameter list could be performed in seven flight tests with an eighth flight test scheduled for contingencies such as failures or unexpected performance encountered on any previous test. The first six flights would evaluate only the one-way Forward Link in which the MTAR in a high alitutde aircraft (T-33 at 40,000 feet) transmits to the MMT in a low altitude aircraft (NASA DC-6 at 8,000 feet). In the seventh flight, the MMT and MTAR equipments would be exchanged between aircraft, and the one-way Return Link would be tested. All data recording equipment could be kept in the DC-6 and the T-33 installation would be simplified through this procedure. The first four flights would exercise the UHF frequency. Between the fourth and fifth flights, the UHF antenna would be replaced by a VHF antenna on the T-33. Remaining flights would exercise the frequency of 149 MHz except for the seventh flight in which the Return Link, 137 MHz frequency would be tested.

The general plan for all flights would be to have the DC-6 take off at the start of the work day and fly to a position over the Pacific Ocean northwest of Los Angeles. A short time later, the T-33 would depart either from Chino Airport or Mojave Airport and climb to a high altitude position over the Pacific, south of Los Angeles. Then, at a predetermined time, the aircraft would assume courses such that they would fly directly toward each other while maintaining their altitude separation. At this time they must be at least 354 nm apart to simulate the situation of a satellite that is just coming over the horizon. The test would begin at this point and end when the T-33 would cross over the DC-6. The exact position to be taken at the start of each test and the courses to be flown by the aircraft must be determined by the pilot on the day of the test as it would be dependent upon wind, weather and test schedules of the Pacific Missile Range. However, certain overall rules would prevail. These are that:

1. Tests one, two and six would be conducted at least 200 miles further west than the remaining tests to shield the DC-6 from the RFI generated by the generalized metropolitan area from Ventura, California (north of Los Angeles) to San Diego.

2. The fourth through seventh tests would be conducted such that the generalized area of the multipath reflection point would remain more-or-less constant in the vicinity of Los Angeles to obtain worst case RFI. Note: This would be possible due to the higher speed of the high alitutde aircraft and the geometry of the situation (see figure 2-16).

A summary of the parameter set-ups for each flight test is shown in table 2-6. Test data would consist of aircraft position, velocity, altitude, and course; time of signal acquisition, bit error rate, doppler, range, AGC level, time, status bits and logging of unusual events, occurrences and failures.

Table 2-6. Flight Test Parameter Set-up

Flight No.	1	2	3	4	5	6	7	8
Frequency	401	401	401	149	149	149	137	As Required
Polarization	Circ	Circ	Circ	Circ	Circ	Circ	Circ	
Data Rate	1KC	1KC	1KC	1KC	1KC	1KC	1KC	
PN Chip Rate	102	-	102	102	-	102	1 M	
Baseband	Data	Data	Data	Data	Data	Data	Data	
Multipath Reflector	Sea	Sea	Sea	Sea	Sea	Sea	Sea	
RFI	No	No	Yes	Yes	Yes	No	Yes	
Modulation	PN	PSK	PN	PN	PSK	PN	PN	

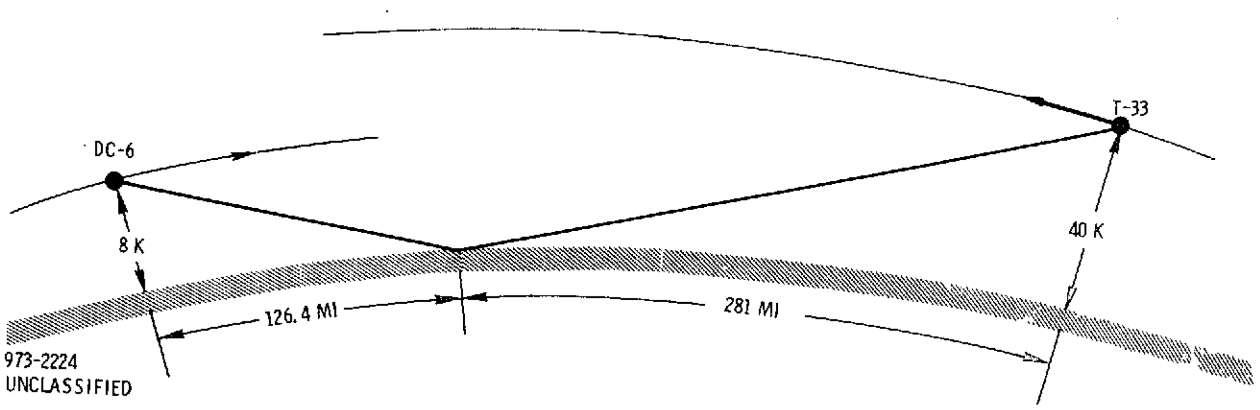


Figure 2-16. Propagation Geometry

2.2.2.4 Test Subcontractor

The test subcontractor tentatively selected for operation of the high altitude aircraft is Flight Systems Test, Inc., of 3723 Birch Street, Newport Beach, California 92660. This corporation was formed in 1968 in the belief that a group of individuals combining high levels of professional accomplishment in aeronautical engineering and engineering flight testing could provide valuable services to a wide cross-section of government and private industry.

This unique concept has been maintained and developed to the point that Flight Systems now offers a wide variety of inter-related services ranging from the performance of advanced systems studies through technology development to flight operations and specialized consulting.

Concentration has been placed on building a staff which combines outstanding capabilities in professional aerospace engineering, engineering flight testing, civil and military aviation, and advanced systems management. The result is an integrated organization skilled not only in its ability to pursue advanced research, but also particularly well qualified to undertake solutions of those technical and management problems which invariably occur during the development of any new airborne or related ground system.

Flight Systems is dedicated to the principle that, in the performance of any technical or systems study, high quality is only achieved when the analysis fully accounts for the viewpoint of the system evaluator or operator. This can only be accomplished when operational experience exists within the investigating organization itself. Accordingly, Flight Systems is engaged in a variety of flight operations which involve the testing, evaluation, or operation of advanced airborne hardware. These flight operations are totally integrated into the Flight Systems organization in order that they may receive the full benefit of the Corporation's technical skills, and so that they may, in turn, enhance the base of practical operational experience upon which the analytical efforts of the Company are founded.

In summary, Flight Systems has brought together a staff whose collective skills in aerospace engineering, flight operations, and system management have been acquired during the last two decades of intensive development and operational activity in air weapon systems, commercial air transport, and space exploration. This depth and breadth of experience has been forged into a unique Corporation which stands ready to apply its talents to the problems of the future.

The specific services they would provide for the ATDRE flight tests are:

1. Flight Test Planning
2. Equipment Installation Engineering
3. Aircraft Selection and Modification
4. FAA/DOD Coordination
5. Flight Operations and Test Crews

They would provide for all aspects of the flight test program including initial test planning, selection of test aircraft, aircraft modification, equipment installation, actual flight operation, and final reporting. This complete "package" capability ensures successful interface between the customer's technical requirements and the engineering and operational considerations associated with in-flight testing.

Aircraft would be selected and tailored to the needs of the test program and may range from small light twin piston engine types to high performance jet aircraft of either the executive transport or military fighter type.

Test activities would be broadly divided into three categories with aircraft types chosen accordingly. For avionics or airborne equipment evaluation a "test bed" aircraft with adequate volume and aerodynamic performance would be selected and for avionics development the aircraft requirements more frequently dictate a high performance military type.

2.2.2.5 Data Recording Format

Data recording formats were studied with consideration given to the recorder equipment that may be available for the experiments. Some tradeoffs are possible between the ideal of having all equipment mode variables and performance data recorded together and the minimum of manually reporting test variables with the performance data.

A NASA furnished Franklin printer would be used to record the data for the proposed flight tests. The printout would be in the following format:

Time	6 places
Range	6 places
Data Error Rate	2 places
Range Rate	6 places