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Utilizing a TDRS Satellite for Direct Broadcast Satellite-Radio Propagation Experiments and Demonstrations

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ABSTRACT

The NASA/VOA Direct Broadcast Satellite - Radio (DBS-R) Program will be using a NASA Tracking Data Relay Satellite (TDRS) satellite at 62° West longitude to conduct live satellite S-band propagation experiments and demonstrations of satellite sound broadcasting over the next two years (1993-1994) (See Figure 1). The NASA/VOA DBS-R program has applied intensive effort to garner domestic and international support for the DBS-R concept. An S-band DBS-R allocation was achieved for Region 2 at WARC-92 held in Spain. With this allocation, the DBS-R program now needs to conduct S-band propagation experiments and systems demonstrations that will assist in the development of planning approaches for the use of Broadcast Satellite Service (Sound) frequency bands prior to the planning conference called for by WARC-92. These activities will also support receiver concept development applied to qualities ranging from AM to Monophonic FM, Stereophonic FM, Monophonic CD, and Stereophonic CD quality.

INTRODUCTION

The Direct Broadcast Satellite - Radio (DBS-R) Program is a joint effort between The National Aeronautics and Space Administration (NASA) and the United States Information Agency/Voice of America (USIA/VOA). In May, 1990, an interagency agreement established a detailed, multi-year technical effort with joint management and funding by both agencies. The agreement established a program designed to provide service and technology definition and development contributing to commercial implementation of a direct-to-listener satellite sound broadcasting service, thereby benefiting the U.S. satellite communications industry. NASA's Lewis Research Center (LeRC) was assigned program management responsibilities within NASA for the effort, while specific task areas were carried out by LeRC and the Jet Propulsion Laboratory (JPL). LeRC and JPL efforts for the DBS-R Program are conducted under the auspices of NASA's Office of Advanced Concepts and Technology [1].

A DBS-R service has been under discussion domestically since at least 1967, and internationally since at least 1971. Evolution of digital and mobile satellite communications technologies has enhanced the potential quality and availability of a DBS-R service well beyond original expectations. By its nature, a DBS-R satellite system can be very flexible in its antenna coverage area-from approximately 100,000 square mile coverage area using a 1° spot beam to 1,000,000 square mile coverage area using a 3° spot beam-depending upon the desired broadcast area to be reached with the necessary power flux density [2].

DBS-R will also be able to offer audio signals with various levels of sound quality-ranging from robust AM quality, through monophonic FM quality, stereophonic FM quality, monophonic CD quality and stereophonic CD quality. DBS-R digital audio signals will be able to reach a variety of radio receiver types (fixed, portable, and mobile) in various environments (indoor/outdoor, rural, urban, and suburban). Studies have shown that DBS-R systems can provide an economical cost per broadcast-channel-hour for wide-area coverage [2]. As the potential quality and availability of a direct-to-listener satellite radio service have evolved, so has recognition of the desirability of such a service. As a consequence, the 1992 World Administrative Radio Conference (WARC) established new frequency allocations for the Broadcast Satellite Service (BSS) (Sound).

DBS-R offers listeners and service originators many benefits not previously available in the audio broadcast medium. Satellites can broadcast on a single channel to a national, regional, or continental audience. Wider coverage presents new opportunities for audience access to a variety of types of programming. Such programming might include educational, cultural, national, or target audience-oriented broadcasts which may not be economically attractive to offer in any other way. Commercial radio broadcasting has not seen a more dramatic possibility for change since the introduction of FM stereo broadcasting.

THE DBS-R PROGRAM

The DBS-R Program is managed within the Communications Systems Branch of the Space Electronics Division at NASA's Lewis Research Center (LeRC), and the Voice of America's Office of Engineering. Two specific areas of the DBS-R program that need significant effort and study are propagation at S-band and targeted demonstrations.

1992 WORLD ADMINISTRATIVE RADIO CONFERENCE ACTIVITIES

The International Telecommunications Union, an organization within the United Nations, convenes periodic Administrative Radio Conferences to construct agreements among member nations on the use of radio frequency spectrum. The World Administrative Radio Conference for dealing with Frequency Allocations in certain parts of the Spectrum, was held February 3 - March 2, 1992, to consider frequency allocations for the Broadcast Satellite Service (Sound) in the 500-3000 MHz portion of the spectrum [3 and 4].

NASA and VOA made extensive contributions to the U.S. Conference preparations conducted by the Department of State, the Federal Communications Commissions (FCC) and the National Telecommunications and Information Administration (NTIA), particularly by providing numerous U.S. inputs on the subject of the BSS (Sound) to the International Radio Consultative Committee (CCIR).

WARC-92 established multiple frequency allocations for the BSS (Sound), within which DBS-R systems may be implemented. These allocations vary by nation (See Exhibit 1). The U.S. will use the 2310-2360 MHz band. The band 1452-1492 MHz was allocated to this service for a majority of nations throughout the world. However, in some nations, this allocation is secondary to other existing allocations until the year 2007. The band 2535-2655 MHz was allocated to BSS (Sound) for a number of nations in Eastern Europe, Commonwealth of Independent States, and Asia. The WARC also recommended that a future WARC be held prior to 1998, in order to plan the use of frequency bands allocated to the BSS (Sound) service (Ref. 3&4).

PROPAGATION STUDIES AND MEASUREMENTS

NASA conducts propagation research through JPL with investigative support currently performed by the University of Texas-Austin. Prior to WARC-92, the University of Texas-Austin conducted extensive propagation studies relevant to DBS-R in the frequency range 800 MHz to 1800 MHz.

The goal of these studies was to provide propagation data models to the United States WARC-92 Delegation and disburse the data to other countries that were interested in DBS-R. Additionally, the data was made available to satellite system engineers to assist in the design of DBS-R systems.

The research has shown that attenuation varies depending on the environment the receiver is in.

Indoors

During this phase of the propagation studies representative types of buildings were studied to determine what effect they had on the simulated satellite signal(s). These studies indicated that receivers located indoors in a building could experience impaired reception depending upon location. By moving the receiver or antenna only tens of centimeters the reception quality would improve from impaired to acceptable or better. More importantly, this research demonstrated that direct indoor reception of a digital audio signal transmitted by satellite is feasible with receiver antenna gain.

Outdoors/Mobile

During this phase of the propagation study representative measurements were made under varying environmental conditions from a sunny clear day to cloudy, rainy, and foggy days. Locations varied from the desert environment of Texas, to the mountains and seacoast of the pacific northwest to the middle west (St Louis, MO) and east coast (Connecticut and Washington, D.C.). The research indicated that outdoor mobile reception of a DBS-R satellite service was feasible.

Results of these studies contributed significantly to characterizing the indoor/outdoor/ mobile DBS-R reception environment and have formed the basis for several U.S. contributions to the CCIR, CITEL and other such organizations.

Our link budget calculation and experiments indicate that a relatively high powered satellite would be required. Ideally, the satellite should have at least an EIRP of 50 to 60 dBW which will allow sufficient link margins.

Propagation Studies Post WARC-92.

WARC-92 concluded with the United States Allocation for DBS-R at S-band (2310-2360 MHz). The allocation is in the process of being approved by the Federal Communications Commission. It is necessary that new propagation studies be conducted at

S-band. The specific purpose of studies would be to develop the propagation characteristics for S-band.

NASA currently has available, on a scheduled basis a TDRS satellite located at 62° West longitude (see Figure 1). Currently, the satellite in this "spare" position is the latest TDRS launched by NASA in mid January 1993. From this location elevation angles range from 10° for the extreme northwest corner of CONUS to better than 40° for southeast CONUS (See Figure 2). The TDRS satellite provides single-access service to low-earth orbiting spacecraft at both S-band and Ku-band via two steerable 4.9 meter antennas. (It also provides S-band multiple access service via an S-band helical phased array.) The two S-band single access (SSA) forward links (one per 4.9 m antenna) are normally used to transmit command data from the ground to LEO spacecraft at rates up to 300 kbps. The plan is that one of these forward links be used to serve as a satellite downlink to a DBS-R receiver in the 2020.435-2123.315 MHz frequency band which is near the 2310-2360 MHz DAB allocation. (These are the 3-dB band edges. In this range, the TDRS SSA forward link carrier frequency is user selectable over the 2030.435-2113.315 MHz region with a 20 MHz maximum allowable channel bandwidth which is limited by the forward processor hardware onboard the TDRS). Utilizing the TDRS in this fashion will provide a peak transmit EIRP of 46.5 dBW (26W S-band TWT transmitting through a 4.9 meter, 42% efficiency antenna with 4.4 dB line loss). This is nearly 63 times the EIRP of the INMARSAT's MARECS-B satellite used in the initial L-band experiments with an EIRP of 28.6 dBw. With TDRS, link margins for indoor portable reception of DBS-R are estimated to range from 10.77 dB (for reception of 192 kbps CD-quality audio at 20° elevation) to 18.95 dB (for reception of 32 kbps AM quality audio at 40° elevation) (See Tables 2-4). This assumes an indoor receiver with a G/T of -14.7 dB/K and 10^{-4} BER performance using QPSK modulation with rate 1/2, K=7 convolutional coding. For mobile reception using an omni-directional antenna with a receiver G/T of -19 dB/K, link margins range from 4.47 dB (reception of 192 kbps at 20° elevation) to 12.65 dB (reception of 32 kbps at 40° elevation) (See Tables 5-7). These margins are substantially larger than those of the earlier experiments.

It is NASA's intention to utilize the TDRS capabilities, in conjunction with the ongoing propagation studies at JPL and the University of Texas, to better understand the S-band propagation characteristics. While the results will not be at the authorized DBS-R allocation frequencies extrapolation of the data can be made to accurately reflect the signal characteristics at the U.S. authorization and the upper S-band (2535-2655 MHz) allocation. Recognizing these facts we are currently in the process of developing a very extensive S-band propagation study.

Lewis Research Center in coordination with JPL has developed an initial TDRS S-Band propagation measurement plan that will address the following: (1) all or most of the issues that were addressed in the initial propagation plan and discussed earlier in this paper; (2) using as much of the existing equipment from the previous L-band experiments but shifting to the new S-band capability will allow us to accomplish most of the items in 1 plus the following: (a) mobile measurements of amplitude and phase in urban, suburban, and rural environments, and (b) probe spatial signal structure in buildings, in vehicles, behind trees, with linear positioner; and (3) using an airplane-campaign tested delay-spread receiver and new S-band front-end.

FUTURE DEMONSTRATIONS

It is the intention of NASA and the VOA to conduct various demonstrations during the period 1993 through 1994. The purpose of these demonstrations would be to demonstrate DBS-R receiver technology, to evaluate propagation and multipath effects and to educate observers regarding the capabilities of a DBS-R service. Satellite demonstrations of a DBS-R type service will help significantly in the development of planning approaches for the use of BSS (Sound) frequency bands prior to the future planning conference.

The first of these demonstrations is in conjunction with the Electronic Industries Association (EIA), Consumer Electronics Group, Digital Audio Radio Subcommittee which "will organize and initiate a fair and impartial analysis, testing and standards - setting program to determine which DAR technical system will best serve the consumer electronics industry and consumers." The EIA is planning to have demonstrations and testing of proponent systems in the July through December 1993 timeframe. This time schedule is paced by the fact that the CCIR plans to make its recommendations in 1994.

Additional demonstrations will be planned around significant events which will have positive influence for DBS-R. At this point details concerning where and when such demonstrations should be conducted are still being evaluated.

CONCLUSIONS

The relatively high downlink EIRP of TDRS's Single Access S-band beam (46.3 dBW) is quite sufficient for our proposed propagation experiments and demonstrations for most if not all of our DBS-R concepts and innovations that have been or will be identified by the NASA/VOA DBS-R program team as critical for viable commercialization of this new and dynamic service.

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Table 1. DBS-R Broadcast of 192 kbps Stereo CD Quality Digital Audio Channel using TDRS 4.9-meter SSA Antenna (Ku-band feederlink is via 18.3-meter (60') terminal at White Sands,NM; portable receiver with 13 dBi gain)

GENERAL SYSTEM PARAMETERS		
Satellite Altitude (km)	35784.00	(GEO S/C Altitude)
Uplink Frequency (GHz)	14.70	(K-band Uplink to TDRS SGL Antenna)
Downlink Frequency (GHz)	2.05	(S-band Forward Link from TDRS SSA Antenna)
Required Value of Eb/No (dB)	3.30	(10-4 BER using QPSK and R=1/2,K=7 Conv. Coding)
Information Bit Rate (bps) per Channel	192000	(Stereo CD Quality Digital Audio)

TRANSMIT TERMINAL PARAMETERS		
Antenna Diameter (m)	18.30	(60 foot White Sands Ground Terminal)
Transmit Antenna Efficiency	0.50	
HPA Xmit Power/Channel (after backoff	5.00	
Xmit Feed Loss (dB)	-2.00	
Elevation Angle to Satellite (deg)	40.00	(TDRS Satellite located at 62 deg W)
Antenna Gain (dBi)	65.99	
Antenna HPBW (deg)	0.08	
Transmit Terminal Peak EIRP (dBW)	70.98	

SATELLITE PARAMETERS		
Uplink Antenna Diameter (m)	2.00	(TDRS 2-meter SGL Antenna)
Uplink Antenna Efficiency	0.42	
Uplink System Noise Temp (K)	4000.00	
Uplink Antenna HPBW (deg)	0.72	
Uplink Antenna Gain (dBi)	46.01	
Satellite Receive G/T (dB/K)	9.99	
Downlink Antenna Diameter (m)	4.90	(TDRS 4.9-meter S-band Single Access Antenna)
Downlink Antenna Efficiency	0.42	
Xponder Power/Channel (after backoff) (	26.00	(26 W S-band TWT)
Downlink Antenna Feed Loss (dB)	-4.40	
Downlink Antenna HPBW (deg)	2.12	
Downlink Antenna Gain (dBi)	36.68	
Satellite Transmit Peak EIRP (dBW)	46.43	

RECEIVE TERMINAL PARAMETERS		
Antenna Diameter (m)	0.30	(S-band indoor table-top portable receiver)
Receive Antenna Efficiency	0.50	
System Noise Temp (K)	625.00	
Elevation Angle to Satellite (deg)	40.00	
Antenna Gain (dBi)	13.31	
Antenna HPBW (deg)	28.04	
Receive Terminal G/T (dB/K)	-14.65	

LINK PARAMETER	UPLINK numeric	UPLINK dB	UPLINK dB	DOWNLINK numeric	DOWNLINK dB	DOWNLINK dB
Transmit Power/Channel (W)	5.00	6.99		26.0000	14.15	
Xmit Line Loss (dB)		-2.00			-4.40	
Xmit Ant Diameter (m)	18.30			4.90		
Xmit Ant Efficiency	0.50			0.42		
Xmit Ant Gain		65.99			36.68	
Peak Xmit EIRP (dBW)			70.98			46.43
Slant Range (km)	37778.30			37778.30		
Free-Space Path Loss (dB)			-207.34			-190.23
Atmospheric Loss (dB)			-0.50			-0.25
Rain Loss (dB) (99.9% availability)			-1.40			-0.05
Xmit Ant Pointing Loss (dB)			-0.10			-0.50
Recv Ant Pointing Loss (dB)			-0.50			-0.05
Other Losses (EOC,Pol,Interfer) (dB)			0.00			-3.00
Power Flux-Density (dBW/m^2)		-93.46			-116.41	
Recv Ant Diameter (m)	2.00			0.30		
Recv Ant Efficiency	0.42			0.50		
Recv Ant Gain		46.01			13.31	
Total System Noise Temp (K)	4000.00	36.02		625.00	27.96	
Recv G/T (dB/K)			9.99			-14.65
Boltzmann Constant (dBW/K-Hz)			-228.60			-228.60
Information Data Rate/Channel (bps)	192000		52.83	192000		52.83
Up/Down Link Eb/N0 (dB)			46.89			13.47

Overall Eb/N0 (dB)	13.47
MODEM Implementation Loss (dB)	-2.00
Required Eb/N0 (dB)	3.30
Link Margin (dB)	8.17

TABLE 2. DBS-R LINK BUDGETS FOR INDOOR PORTABLE RECEPTION USING TDRS S-BAND DOWNLINK (SATELLITE ELEVATION ANGLE OF 40°, RECEIVER G/T OF -14.7 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	40.00	40.00	40.00	40.00	40.00	40.00
Slant Range (km)	37778.30	37778.30	37778.30	37778.30	37778.30	37778.30
Free-Space Path Loss (dB)	-190.23	-190.23	-190.23	-190.23	-190.23	-190.23
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Indoor Portable Recvr (dB/K)	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	69.30	69.30	69.30	69.30	69.30	69.30
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	24.25	22.49	19.48	18.23	17.26	16.47
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	5.30	5.30	5.30	5.30	5.30	5.30
Link Margin (dB) at beam center (dB)	18.95	17.19	14.18	12.93	11.96	11.17
Link Margin at 3-dB edge of coverage	15.95	14.19	11.18	9.93	8.96	8.17

COMMENTS:
INDOOR TABLE-TOP CD-QUALITY RECEPTION WILL BE FEASIBLE IN MOST SINGLE FAMILY HOUSES
INDOOR TABLE-TOP FM-QUALITY RECEPTION WILL BE FEASIBLE IN MOST BUILDINGS

TABLE 3. DBS-R LINK BUDGETS FOR INDOOR PORTABLE RECEPTION USING TDRS I S-BAND DOWNLINK
(SATELLITE ELEVATION ANGLE OF 30°, RECEIVER G/T OF -14.7 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	30.00	30.00	30.00	30.00	30.00	30.00
Slant Range (km)	38609.69	38609.69	38609.69	38609.69	38609.69	38609.69
Free-Space Path Loss (dB)	-190.42	-190.42	-190.42	-190.42	-190.42	-190.42
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Indoor Portable Recvr (dB/K)	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	69.11	69.11	69.11	69.11	69.11	69.11
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	24.06	22.30	19.29	18.04	17.07	16.28
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	5.30	5.30	5.30	5.30	5.30	5.30
Link Margin (dB) at beam center (dB)	18.76	17.00	13.99	12.74	11.77	10.98
Link Margin at 3-dB edge of coverage	15.76	14.00	10.99	9.74	8.77	7.98

COMMENTS:
INDOOR TABLE-TOP CD-QUALITY RECEPTION WILL BE FEASIBLE IN MOST SINGLE FAMILY HOUSES
INDOOR TABLE-TOP FM-QUALITY RECEPTION WILL BE FEASIBLE IN MOST BUILDINGS

TABLE 4. DBS-R LINK BUDGETS FOR INDOOR PORTABLE RECEPTION USING TDRS S-BAND DOWNLINK
(SATELLITE ELEVATION ANGLE OF 20°, RECEIVER G/T OF -14.7 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	20.00	20.00	20.00	20.00	20.00	20.00
Slant Range (km)	39552.52	39552.52	39552.52	39552.52	39552.52	39552.52
Free-Space Path Loss (dB)	-190.63	-190.63	-190.63	-190.63	-190.63	-190.63
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Indoor Portable Recvr (dB/K)	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	68.90	68.90	68.90	68.90	68.90	68.90
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	23.85	22.09	19.08	17.83	16.86	16.07
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	5.30	5.30	5.30	5.30	5.30	5.30
Link Margin (dB) at beam center (dB)	18.55	16.79	13.78	12.53	11.56	10.77
Link Margin at 3-dB edge of coverage	15.55	13.79	10.78	9.53	8.56	7.77

COMMENTS.
INDOOR TABLE-TOP CD-QUALITY RECEPTION WILL BE FEASIBLE IN MOST SINGLE FAMILY HOUSES
INDOOR TABLE-TOP FM-QUALITY RECEPTION WILL BE FEASIBLE IN MOST BUILDINGS

TABLE 5. DBS-R LINK BUDGETS FOR MOBILE RECEPTION USING TDRS S-BAND DOWNLINK
(SATELLITE ELEVATION ANGLE OF 40°, MOBILE RECEIVER G/T OF -19.0 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	40.00	40.00	40.00	40.00	40.00	40.00
Slant Range (km)	37778.30	37778.30	37778.30	37778.30	37778.30	37778.30
Free-Space Path Loss (dB)	-190.23	-190.23	-190.23	-190.23	-190.23	-190.23
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Mobile Recvr (dB/K)	-19.00	-19.00	-19.00	-19.00	-19.00	-19.00
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	65.00	65.00	65.00	65.00	65.00	65.00
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	19.95	18.19	15.18	13.93	12.96	12.17
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Mobile Channel Fade Loss (dB)	2.00	2.00	2.00	2.00	2.00	2.00
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	7.30	7.30	7.30	7.30	7.30	7.30
Link Margin (dB) at beam center (dB)	12.65	10.89	7.88	6.63	5.66	4.87
Link Margin at 3-dB edge of coverage	9.65	7.89	4.88	3.63	2.66	1.87

TABLE 6. DBS-R LINK BUDGETS FOR MOBILE RECEPTION USING TDRS S-BAND DOWNLINK
(SATELLITE ELEVATION ANGLE OF 30°, MOBILE RECEIVER G/T OF -19.0 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	30.00	30.00	30.00	30.00	30.00	30.00
Slant Range (km)	38609.60	38609.60	38609.60	38609.60	38609.60	38609.60
Free-Space Path Loss (dB)	-190.42	-190.42	-190.42	-190.42	-190.42	-190.42
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Mobile Rcvr (dB/K)	-19.00	-19.00	-19.00	-19.00	-19.00	-19.00
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	64.81	64.81	64.81	64.81	64.81	64.81
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	19.76	18.00	14.99	13.74	12.77	11.98
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Mobile Channel Fade Loss (dB)	2.00	2.00	2.00	2.00	2.00	2.00
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	7.30	7.30	7.30	7.30	7.30	7.30
Link Margin (dB) at beam center (dB)	12.46	10.70	7.69	6.44	5.47	4.68
Link Margin at 3-dB edge of coverage	9.46	7.70	4.69	3.44	2.47	1.68

TABLE 7. DBS-R LINK BUDGETS FOR MOBILE RECEPTION USING TDRS S-BAND DOWNLINK
(SATELLITE ELEVATION ANGLE OF 20°, MOBILE RECEIVER G/T OF -19.0 dB/K)

DIGITAL AUDIO QUALITY	AM	MONO-FM	STEREO FM	NEAR-CD	ALMOST CD	CD-QUALITY
DIGITAL AUDIO BIT RATE (kbps)	32.00	48.00	96.00	128.00	160.00	192.00
TDRS S-band SA Downlink Freq (GHz)	2.05	2.05	2.05	2.05	2.05	2.05
TDRS S-band SA Antenna Diameter (m)	4.90	4.90	4.90	4.90	4.90	4.90
TDRS S-band SA Antenna Efficiency	0.42	0.42	0.42	0.42	0.42	0.42
TDRS S-band SA Antenna HPBW (deg)	2.12	2.12	2.12	2.12	2.12	2.12
TDRS S-band SA Downlink Power (W)	26.00	26.00	26.00	26.00	26.00	26.00
TDRS S-band SA Downlink Power (dBW)	14.15	14.15	14.15	14.15	14.15	14.15
TDRS S-band SA Downlink Ant Gain (dBi)	36.68	36.68	36.68	36.68	36.68	36.68
TDRS S-band SA Downlink Feed Loss (dB)	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
TDRS S-band SA Downlink EIRP (dBW)	46.43	46.43	46.43	46.43	46.43	46.43
Satellite Elevation Angle (deg)	20.00	20.00	20.00	20.00	20.00	20.00
Slant Range (km)	39552.52	39552.52	39552.52	39552.52	39552.52	39552.52
Free-Space Path Loss (dB)	-190.63	-190.63	-190.63	-190.63	-190.63	-190.63
Atmospheric Losses (dB)	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Rain Attenuation (50 mm/hr rain rate)	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Pointing Loss (dB)	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
G/T of Mobile Rcvr (dB/K)	-19.00	-19.00	-19.00	-19.00	-19.00	-19.00
Boltzmann Constant (dBW/K-Hz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Received C/No (dB-Hz)	64.60	64.60	64.60	64.60	64.60	64.60
Data Rate (dB-bps)	45.05	46.81	49.82	51.07	52.04	52.83
Available Downlink Eb/No (dB)	19.55	17.79	14.78	13.53	12.56	11.77
Theoretical Eb/No for 10-4 BER (dB) (QPSK with R=1/2,K=7 Conv. Coding)	3.30	3.30	3.30	3.30	3.30	3.30
Mobile Channel Fade Loss (dB)	2.00	2.00	2.00	2.00	2.00	2.00
Receiver Implementation Loss (dB)	1.50	1.50	1.50	1.50	1.50	1.50
Interference Degradation (dB)	0.50	0.50	0.50	0.50	0.50	0.50
Total Receiver Eb/No Requirement (dB)	7.30	7.30	7.30	7.30	7.30	7.30
Link Margin (dB) at beam center (dB)	12.25	10.49	7.48	6.23	5.26	4.47
Link Margin at 3-dB edge of coverage	9.25	7.49	4.48	3.23	2.26	1.47

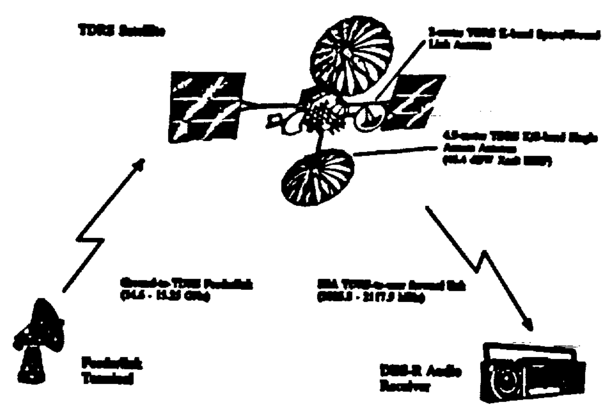

Figure 1. Schematic of DBS-R/TDRS Demonstration

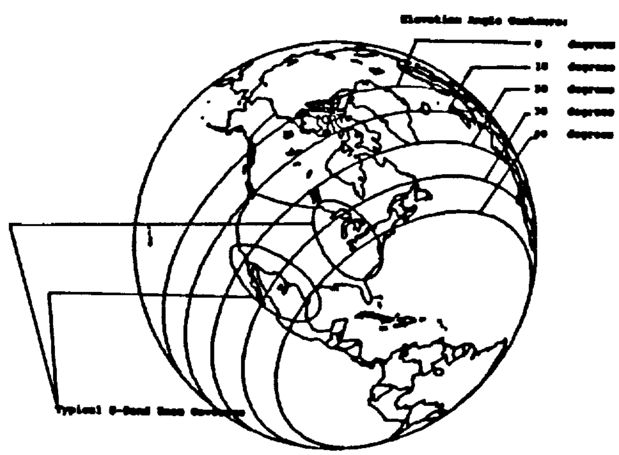

Figure 2. TDRS-1 Elevation Angle Contours From North America (Satellite at 62° West Longitude)

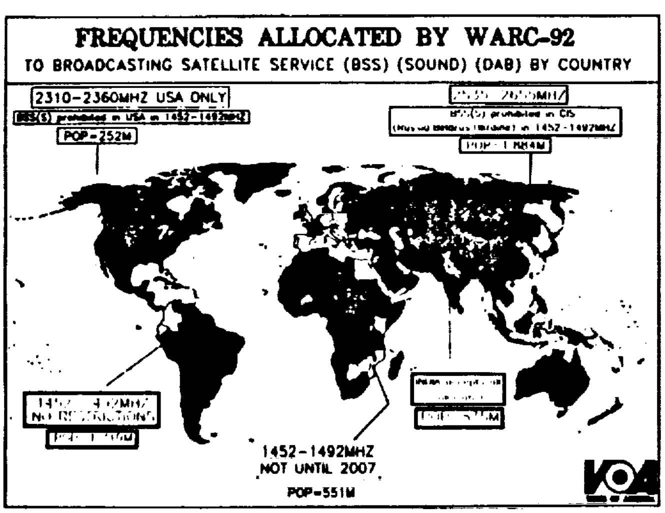

Exhibit 1