CGMS XXVII
USA-WP-19.1
Agenda Item I.3.2

DEVELOPMENTAL TESTING AND SUPPORT FOR SPREAD SPECTRUM DEMONSTRATION OVER UHF SATELLITE

Summary and Purpose of Document
To provide a report on a study for "Developmental Testing and Support for Spread Spectrum Demonstration over the GOES (UHF) Satellite."

Action Requested: None

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FINAL REPORT

DEVELOPMENTAL TESTING AND SUPPORT FOR

SPREAD SPECTRUM DEMONSTRATION OVER UHF SATELLITE

July 27, 1999

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1. INTRODUCTION

1.1 Purposes and Objectives

This report summarizes results of a study "Developmental Testing and Support for Spread Spectrum Demonstration over UHF Satellite," conducted by Comtech Mobile Datacom Corp. (CMDC) for the General Services Administration under the Project #9BN024S31. The objectives of the study are:

a) to demonstrate the feasibility of using CDMA carriers to overlay over the existing TDMA carriers in frequency over the existing GOES UHF-to L transponders;
b) to determine the potential for increased transponder usage by using CDMA carriers without degrading, to unusable levels, the current TDMA capacity; and
c) to identify possible CDMA architecture and preliminary specifications for a CDMA-based system to operate over the NOAA-GOES satellite.

1.2 Background

The NOAA-GOES system has two operational GEO satellites: GOES-East (GOES-10, located at 75^{o} W longitude) and GOES-West (GOES-8, located at 135^{o} W longitude). Each satellite has an identical bent-pipe UHF-to-L transponder. These two transponders are being used to support the GOES Data Collection System (DCS). The GOES DCS comprises of many remote Data Collection Platforms (DCPs) that are used to relay monitored environmental data (e.g., temperature, pressure, snow, ocean current) to the Wallops Command and Data Acquisition Stations (CDAS), located at Wallops Island, Virginia.

Under the current mode of operation to serve the DCS, the entire 400-kHz transponder bandwidth is divided into 266 1.5-kHz channels (frequency slots). The first 200 channels are dedicated to domestic DCS users with one 1.5-kHz channel corresponding to a domestic DCS channel; and last 66 channels are dedicated to international DCS users with two 1.5-kHz channels corresponding to a single international DCS channel. To reduce "adjacent channel interference," the odd domestic channels (i.e., Channels 1, 3, …, 199) are assigned to GOES-East and the even domestic channels (i.e., Channels 2, 4, …, 200) are assigned to GOES-West. The frequency plans for the GOES-East and GOES-West UHF-to-L transponders are depicted by Figure 1. Each DCS channel supports a usable data rate of 100 bps, using a binary phase shift

keying (BPSK) modulation. Time division multiple access (TDMA) is used by DCPs to gain access to the channels. Note that DCPs can be interrogated by the Wallops CDAS, using different transponders (L-to-UHF transponders) on board the GOES satellites.

Under the current operation, the UHF-to-L transponders are not utilized efficiently. Even under the best scenario, when all of the channels are fully utilized (duty cycles of 100%), the total aggregate supportable data rate is only 26.6 kbps (266 channels in 2 transponders with each channel supporting 100 bps.) This converts to a bandwidth utilization efficiency of 26.6/(2x400) = 0.03 bit/Hertz, an extremely low number.

The government has a desire to improve the utilization of these UHF-L transponders. One scenario of concern here is to achieve the improvement without replacing or modifying the existing DCS (e.g., the DCPs and the processing equipment at the Wallops CDAS). Because the bandwidth of the transponders is fully allocated for use by the DCS, one possible solution is to introduce direct sequence spread spectrum carriers that are spread in frequency over the TDMA carriers and over themselves through the use of Code Division Multiple Access (CDMA). Accordingly, the government has created a study called "Developmental Testing and Support for Spread Spectrum Demonstration over UHF Satellite" and selected CMDC to conduct the study. The objectives of the study are stated in the previous section.

1.3 Approach

CMDC carried out the study by using its own newly developed CDMA equipment. (These new CDMA equipment are being used to upgrade and enhance CMDC's satellite-based hub-spoke messaging services.) CMDC, in cooperation with the government, integrated the CDMA equipment with the UHF earth station and the L-Band CDAS located at the Wallops Island for proof-of-concept and demonstration testing. Tests were conducted on May 19 and June 22, 1999, using the GOES-East UHF-to-L transponder. Prior to the integration and testing, relevant data on the satellite and ground were collected; tradeoffs on the link performance were then conducted, to determine suitable parameters and equipment that can be used for the testing. After the testing, collected test data were analyzed, conclusions and recommendations were then made.

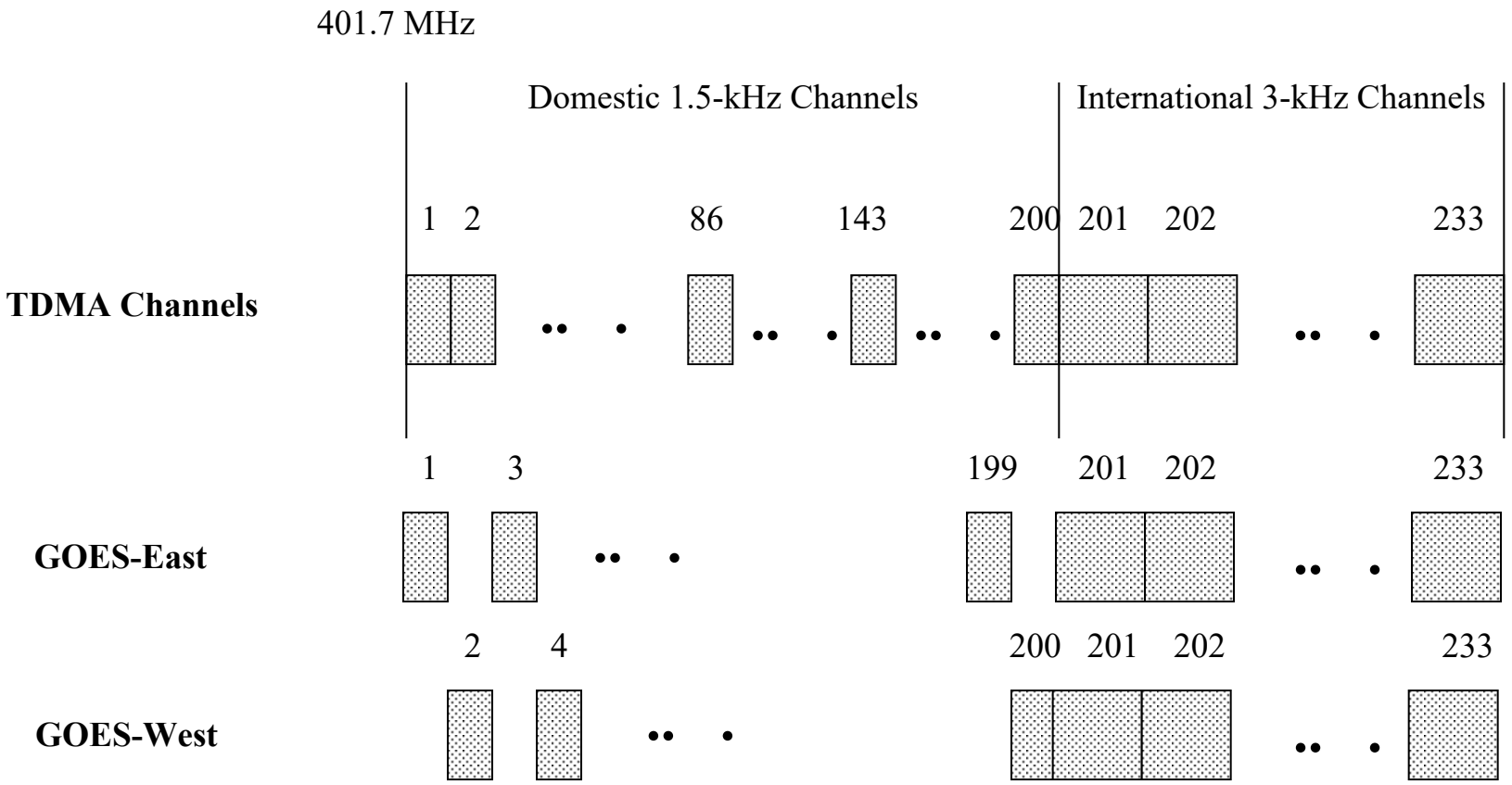

Figure 1. GOES UHF-L Transponder's DCS Frequency Plan

2. PERFORMANCE TRADEOFFS

Tradeoffs on the performances of the CDMA and TDMA links were conducted to determine suitable parameters and equipment that can be used for testing. Tradeoffs were based on the following relevant data collected:

(a) An uplink EIRP of 47 dBm from Wallops Island, after being passed through the GOES-East UHF-to-L transponder, will provide a C/No of 53.95 dBHz at the Wallops Island, using the existing giant receive earth station (G/T = 26.6 dB/K). A deviation of X dB from the EIRP above 47 dBm will result in a deviation of X dB from the C/No above 53.95 dBHz.

(b) DCP, described in Section 1.2 above, can transmit a TDMA carrier with an EIRP of up to 50 dBm. The nominal EIRP for a TDMA carrier is, however, 34 dBm. (This is equivalent to a C/No of 40.95 dBHz or an Eb/No of 20.95 dB).

(c) A CMDC CDMA carrier uses an unfiltered BPSK modulation and a 1/2-rate FEC convolutional coding. It has a chip rate of 84.375 kcps and a spreading factor of 32 (including a factor of 2 for FEC), to give a user data rate of around 2.6 kbps.

2.1 Interference From CDMA Carriers To TDMA Carriers

Although each CDMA carrier has a user data rate of about 2.6 kbps (which is 26 times higher than a TDMA user data rate of 100 bps), its interference effects to TDMA carriers should be low. A CDMA carrier uses a 1/2-rate forward error correction (FEC) coding which reduces the power density by a factor of about 8 and a direct sequence spread spectrum modulation which has a spreading factor of 32. From the collected information (2a) and (2c) above, the power densities of a CDMA carrier can easily be calculated for a given CDMA EIRP at a transmit earth station and are shown in Table 1.

Table 1. CDMA Carrier Power Density Relative To Noise Floor (dB) Versus Uplink CDMA Carrier EIRP (Reference: 40-dBm EIRP For 53.95-dBHz C/No)

EIRP	At Number of 1.5-kHz Channels Away From Carrier Center Frequency												
dBm	0	5	10	15	20	25	30	35	40	45	50	55	60
50	7.69	7.58	7.23	6.65	5.80	4.66	3.16	1.21	-1.36	-4.93	-10.55	-25.19	-16.46
49	6.69	6.58	6.23	5.65	4.80	3.66	2.16	0.21	-2.36	-5.93	-11.55	-26.19	-17.46
48	5.69	5.58	5.23	4.65	3.80	2.66	1.16	-0.79	-3.36	-6.93	-12.55	-27.19	-18.46
47	4.69	4.58	4.23	3.65	2.80	1.66	0.16	-1.79	-4.36	-7.93	-13.55	-28.19	-19.46
46	3.69	3.58	3.23	2.65	1.80	0.66	-0.84	-2.79	-5.36	-8.93	-14.55	-29.19	-20.46
45	2.69	2.58	2.23	1.65	0.80	-0.34	-1.84	-3.79	-6.36	-9.93	-15.55	-30.19	-21.46
44	1.69	1.58	1.23	0.65	-0.20	-1.34	-2.84	-4.79	-7.36	-10.93	-16.55	-31.19	-22.46
43	0.69	0.58	0.23	-0.35	-1.20	-2.34	-3.84	-5.79	-8.36	-11.93	-17.55	-32.19	-23.46
42	-0.31	-0.42	-0.77	-1.35	-2.20	-3.34	-4.84	-6.79	-9.36	-12.93	-18.55	-33.19	-24.46
41	-1.31	-1.42	-1.77	-2.35	-3.20	-4.34	-5.84	-7.79	-10.36	-13.93	-19.55	-34.19	-25.46
40	-2.31	-2.42	-2.77	-3.35	-4.20	-5.34	-6.84	-8.79	-11.36	-14.93	-20.55	-35.19	-26.46
39	-3.31	-3.42	-3.77	-4.35	-5.20	-6.34	-7.84	-9.79	-12.36	-15.93	-21.55	-36.19	-27.46
38	-4.31	-4.42	-4.77	-5.35	-6.20	-7.34	-8.84	-10.79	-13.36	-16.93	-22.55	-37.19	-28.46
37	-5.31	-5.42	-5.77	-6.35	-7.20	-8.34	-9.84	-11.79	-14.36	-17.93	-23.55	-38.19	-29.46
36	-6.31	-6.42	-6.77	-7.35	-8.20	-9.34	-10.84	-12.79	-15.36	-18.93	-24.55	-39.19	-30.46
35	-7.31	-7.42	-7.77	-8.35	-9.20	-10.34	-11.84	-13.79	-16.36	-19.93	-25.55	-40.19	-31.46
34	-8.31	-8.42	-8.77	-9.35	-10.20	-11.34	-12.84	-14.79	-17.36	-20.93	-26.55	-41.19	-32.46
33	-9.31	-9.42	-9.77	-10.35	-11.20	-12.34	-13.84	-15.79	-18.36	-21.93	-27.55	-42.19	-33.46
32	-10.31	-10.42	-10.77	-11.35	-12.20	-13.34	-14.84	-16.79	-19.36	-22.93	-28.55	-43.19	-34.46
31	-11.31	-11.42	-11.77	-12.35	-13.20	-14.34	-15.84	-17.79	-20.36	-23.93	-29.55	-44.19	-35.46
30	-12.31	-12.42	-12.77	-13.35	-14.20	-15.34	-16.84	-18.79	-21.36	-24.93	-30.55	-45.19	-36.46

Note that:

- The values of the calculated power densities are relative to the overall thermal noise floor (satellite (uplink) thermal noise density and receive earth station (downlink) thermal noise density combined);
- Due to the use of unfiltered BPSK modulation, the CDMA carrier power spectrum is not flat (as that of thermal noise) and follows a $[\sin(x)/x]^2$ curve with its first nulls being 84.375 kHz or 56.25 1.5-kHz DCS channels away from the CDMA carrier frequency center;
- At an EIRP of 42.6 dBm or less, a CDMA carrier is below the (thermal) noise floor (negative values in Table 1); at an EIRP higher than 42.6 dBm, part of the main lobe of the CDMA carrier is above the noise floor.

Because the CDMA and TDMA carriers are independent from each other, effectively the interference, more or less, can be treated as noise. That is, it can be said that the interference effectively causes the noise floor to raise (to degrade). The amount of effective noise degradation (due to interference) can be calculated in a straightforward manner. They are shown in Table 2 for different values of the CDMA carrier EIRPs and at different frequency locations specified in terms of 1.5-kHz DCS channels away from the CDMA carrier frequency center.

Note that although the above discussions involve only one CDMA carrier, they also apply to the general case where there are multiple active CDMA carriers accessing the transponder. For the multiple active CDMA carrier case, in Tables 1 and 2, the EIRP becomes the aggregated EIRP and the interference power densities become the aggregated power densities.

Table 2. Effective Noise Floor Change (dB) Caused By CDMA Carrier Versus Uplink CDMA Carrier EIRP (Reference: 40-dBm EIRP For 53.95-dBHz C/No)

EIRP	At Number of 1.5-kHz Channels Away From Carrier Center Frequency												
dBm	0	5	10	15	20	25	30	35	40	45	50	55	60
50	8.37	8.28	7.98	7.50	6.81	5.94	4.87	3.66	2.38	1.21	0.37	0.01	0.10
49	7.53	7.44	7.16	6.69	6.04	5.21	4.22	3.12	1.99	0.99	0.29	0.01	0.08
48	6.73	6.64	6.37	5.93	5.31	4.54	3.63	2.63	1.65	0.80	0.23	0.01	0.06
47	5.96	5.88	5.62	5.21	4.63	3.92	3.09	2.21	1.36	0.65	0.19	0.01	0.05
46	5.23	5.16	4.92	4.53	4.00	3.35	2.61	1.83	1.11	0.52	0.15	0.01	0.04
45	4.56	4.49	4.27	3.91	3.43	2.84	2.19	1.52	0.90	0.42	0.12	0.00	0.03
44	3.94	3.87	3.67	3.35	2.91	2.39	1.82	1.24	0.73	0.34	0.10	0.00	0.02
43	3.37	3.31	3.13	2.84	2.45	2.00	1.50	1.02	0.59	0.27	0.08	0.00	0.02
42	2.86	2.80	2.64	2.39	2.05	1.65	1.23	0.83	0.48	0.22	0.06	0.00	0.02
41	2.40	2.36	2.21	1.99	1.70	1.36	1.01	0.67	0.38	0.17	0.05	0.00	0.01
40	**2.01**	**1.97**	**1.84**	**1.65**	**1.40**	**1.11**	**0.82**	**0.54**	**0.31**	**0.14**	**0.04**	**0.00**	**0.01**
39	1.66	1.63	1.52	1.36	1.15	0.91	0.66	0.43	0.25	0.11	0.03	0.00	0.01
38	1.37	1.34	1.25	1.11	0.93	0.74	0.53	0.35	0.20	0.09	0.02	0.00	0.01
37	1.12	1.10	1.02	0.90	0.76	0.59	0.43	0.28	0.16	0.07	0.02	0.00	0.00
36	0.91	0.89	0.83	0.73	0.61	0.48	0.34	0.22	0.12	0.06	0.02	0.00	0.00
35	0.74	0.72	0.67	0.59	0.49	0.38	0.28	0.18	0.10	0.04	0.01	0.00	0.00
34	0.60	0.58	0.54	0.48	0.40	0.31	0.22	0.14	0.08	0.03	0.01	0.00	0.00
33	0.48	0.47	0.44	0.38	0.32	0.25	0.18	0.11	0.06	0.03	0.01	0.00	0.00
32	0.39	0.38	0.35	0.31	0.25	0.20	0.14	0.09	0.05	0.02	0.01	0.00	0.00
31	0.31	0.30	0.28	0.25	0.20	0.16	0.11	0.07	0.04	0.02	0.00	0.00	0.00
30	0.25	0.24	0.22	0.20	0.16	0.13	0.09	0.06	0.03	0.01	0.00	0.00	0.00

2.2 Interference From TDMA Carriers To CDMA Carriers

A CDMA carrier has a null-to-null bandwidth of 2x84.375 kHz. This bandwidth spans about 113 1.5-kHz DCS channels. Accordingly, many TDMA carriers will fall into the noise bandwidth of a CDMA carrier and causes interference to the CDMA carrier. The interference, however, is significantly reduced because the CDMA carrier uses a direct sequence spread spectrum modulation:. At the receive earth station (hub station), the despreader (that despreads the CDMA carrier) will spread the TDMA carriers. Effectively the TDMA carriers will become spread spectrum carriers. As far as interference effects are concerned, the TDMA carriers can be treated as if they were CDMA carriers and accordingly, values on Tables 1 and 2 also apply to estimate the effects of from TDMA carriers to CDMA carriers. In the tables, the EIRPs now refers to the TDMA carrier EIRPs and the interference now refers to interference due to the TDMA carriers.

2.3 Link Budget Analyses

Based on the collected information in Section 2a and 2b and values from Tables 1 and 2, power budgets for the CDMA and TDMA links were performed and summarized as Table 3 for different values of CDMA carrier EIRP. For the TDMA link budget, the TDMA carrier is assumed to have the same center frequency as the CDMA carrier (worst case). For the CDMA link budget, it was assumed that the DCS channels that spans the CDMA carrier are 10% loaded with the TDMA carriers (i.e., TDMA carriers have a duty cycle of 10%). From Table 3, a TDMA carrier operated at a nominal EIRP of 34 dBm, has a very large link margin and can use this margin to counter interference from a CDMA carrier whose EIRP or multiple CDMA carriers whose aggregated EIRP can be as high as 49.5 dBW, assuming the minimum acceptable Eb/No is 13 dB. On the other hand, if there is only one CDMA carrier, then it can operate as low as 37 dBm, assuming the minimum acceptable Eb/No is 5.5 dB.

Table 3. Power Budgets Of The CDMA And TDMA Links For Various Different CDMA Carrier EIRP Values

CDMA Link					TDMA Link (EIRP = 34 dBm, C/No = 40.95 dBHz)			
EIRP (dBm)	C/No (dBHz)	Eb/No (dB)	C/Io* (dBHz)	Eb/(No+Io) (dB)	C/Io (dBHz)	C/(No+Io) (dBHz)	Eb/(No+Io) (dB)	Δ(C/No)** (dB)
50	56.95	22.74	54.75	18.49	33.26	32.58	12.58	8.37
49	**55.95**	**21.74**	**53.75**	**17.49**	**34.26**	**33.42**	**13.42**	**7.53**
48	54.95	20.74	52.75	16.49	35.26	34.22	14.22	6.73
47	53.95	19.74	51.75	15.49	36.26	34.99	14.99	5.96
46	52.95	18.74	50.75	14.49	37.26	35.72	15.72	5.23
45	51.95	17.74	49.75	13.49	38.26	36.39	16.39	4.56
44	50.95	16.74	48.75	12.49	39.26	37.01	17.01	3.94
43	49.95	15.74	47.75	11.49	40.26	37.58	17.58	3.37
42	48.95	14.74	46.75	10.49	41.26	38.09	18.09	2.86
41	47.95	13.74	45.75	9.49	42.26	38.55	18.55	2.40
40	**46.95**	**12.74**	**44.75**	**8.49**	**43.26**	**38.94**	**18.94**	**2.01**
39	45.95	11.74	43.75	7.49	44.26	39.29	19.29	1.66
38	44.95	10.74	42.75	6.49	45.26	39.58	19.58	1.37
37	**43.95**	**9.74**	**41.75**	**5.49**	**46.26**	**39.83**	**19.83**	**1.12**
36	42.95	8.74	40.75	4.49	47.26	40.04	20.04	0.91
35	41.95	7.74	39.75	3.49	48.26	40.21	20.21	0.74
34	40.95	6.74	38.75	2.49	49.26	40.35	20.35	0.60
33	39.95	5.74	37.75	1.49	50.26	40.47	20.47	0.48
32	38.95	4.74	36.75	0.49	51.26	40.56	20.56	0.39
31	37.95	3.74	35.75	-0.51	52.26	40.64	20.64	0.31
30	36.95	2.74	34.75	-1.51	53.26	40.70	20.70	0.25

* Assuming 10% Duty Cycle For TDMA Carriers Falling Into CDMA Carrier

** For TDMA Carrier Located @ CDMA Carrier Center, Worst Case

2.4 Selection Of CDMA Carrier Parameters For On-Air Testing

CDMA Carrier Frequency

The UHF-to-L transponder has a bandwidth of 400 kHz (i.e., 266 1.5-kHz channels) and the CDMA carrier has a null-to-null bandwidth of 2x84.375 kHz (i.e., 112.5 1.5-kHz channels). Because there are more TDMA carriers assigned to the lower DCS channels, it was planned to disturb the international DCS channels (Channels #201 and higher) as little as possible, The government and CMDC staff have agreed to select the CDMA carrier center frequency to coincide with the DCS Channel #143 center.

Number Of CDMA Carriers

Due to limited resources and funding available, it was planned to test with just one CDMA carrier. As far as interference to TDMA carriers are concerned, it does not really matter whether the transponder is accessed by one or more CDMA carriers, as long as the total aggregated EIRP is the same. To CDMA carriers, interference is a concern (whether there are one or more CDMA carriers), because there is interference among the carriers. These CDMA self-interference effects can be calculated or measured off-air and accounted for. Testing with multiple CDMA carriers will be deferred for a later date when new funding is available and operation with a single CDMA carrier is determined to be successful.

CDMA Carrier EIRP

The CDMC staff has recommended the use of a CDMA carrier EIRP of 40 dBm for testing and it was agreed by the government. At the 40-dBm EIRP, the CDMA carrier would have a power spectrum, which is at least 2.3 dB below the thermal noise floor (see Table 1). At the 40-dBm EIRP, the CDMA carrier would be operated with an Eb/(No+Io) of 8.5 dB, which would leave about a 3-dB margin over the typical minimum acceptable Eb/No of about 5.5 dB for other transmission impairments and also for CDMA self-interference. At the 40-dBm EIRP, the worst TDMA carrier would be degraded by 2 dB from an Eb/No of 20.9 dB to an Eb/(No+Io) of 18.9 dB. This would still leave a margin of around 6 dB, over a typical minimum acceptable Eb/No of around 13 dB, for other transmission impairments and also for future operation with multiple CDMA carriers.

Table 3. Power Budgets Of The CDMA And TDMA Links For Various Different CDMA Carrier EIRP Values

CDMA Link					TDMA Link (EIRP = 34 dBm, C/No = 40.95 dBHz)			
EIRP (dBm)	C/No (dBHz)	Eb/No (dB)	C/Io* (dBHz)	Eb/(No+Io) (dB)	C/Io (dBHz)	C/(No+Io) (dBHz)	Eb/(No+Io) (dB)	Δ(C/No)** (dB)
50	56.95	22.74	54.75	18.49	33.26	32.58	12.58	8.37
49	55.95	21.74	53.75	17.49	34.26	33.42	13.42	7.53
48	54.95	20.74	52.75	16.49	35.26	34.22	14.22	6.73
47	53.95	19.74	51.75	15.49	36.26	34.99	14.99	5.96
46	52.95	18.74	50.75	14.49	37.26	35.72	15.72	5.23
45	51.95	17.74	49.75	13.49	38.26	36.39	16.39	4.56
44	50.95	16.74	48.75	12.49	39.26	37.01	17.01	3.94
43	**49.95**	**15.74**	**47.75**	**11.49**	**40.26**	**37.58**	**17.58**	**3.37**
42	48.95	14.74	46.75	10.49	41.26	38.09	18.09	2.86
41	47.95	13.74	45.75	9.49	42.26	38.55	18.55	2.40
40	**46.95**	**12.74**	**44.75**	**8.49**	**43.26**	**38.94**	**18.94**	**2.01**
39	45.95	11.74	43.75	7.49	44.26	39.29	19.29	1.66
38	44.95	10.74	42.75	6.49	45.26	39.58	19.58	1.37
37	43.95	9.74	41.75	5.49	46.26	39.83	19.83	1.12
36	42.95	8.74	40.75	4.49	47.26	40.04	20.04	0.91
35	41.95	7.74	39.75	3.49	48.26	40.21	20.21	0.74
34	40.95	6.74	38.75	2.49	49.26	40.35	20.35	0.60
33	39.95	5.74	37.75	1.49	50.26	40.47	20.47	0.48
32	38.95	4.74	36.75	0.49	51.26	40.56	20.56	0.39
31	37.95	3.74	35.75	-0.51	52.26	40.64	20.64	0.31
30	36.95	2.74	34.75	-1.51	53.26	40.70	20.70	0.25

* Assuming 10% Duty Cycle For TDMA Carriers Falling Into CDMA Carrier

** For TDMA Carrier Located @ CDMA Carrier Center, Worst Case

3. ON-AIR TESTING AND TEST DATA ANALYSES

3.1 Equipment Integration And Test Setup

CMDC CDMA equipment and test equipment were integrated to the existing UHF transmit earth station and the L-Band receive earth station located at Wallops Island for testing, see Figure 2. The government-furnished equipment (GFE) and which equipment were supplied by CMDC are easily identified. The test equipment indicated in the block diagram are the spectrum analyzer and BER-analyzer.

3.2 May 19, 1999 Tests

The first set of tests was conducted on May 19, 1999.

CDMA Link Performance Tests

Tests associated with the performance of the CDMA link could not be conducted, because it was discovered that the CMDC CDMA receiver (hub), was equipped with a wideband (1-MHz) IF filter. It picked up too much out-of-band interference, causing its AGC and A/D to operate outside their dynamic ranges.

Noise Floor Measurement Test (For Collected Information (a) Validation)

By using a DCP at Wallops Island, a CW carrier with an EIRP of 47 dBm was generated. By using a spectrum analyzer, Co/No was measured and C/No was calculated to be 51.1 dBHz which is 2.85 dB less than the collected value of 53.95 dBHz. From the test

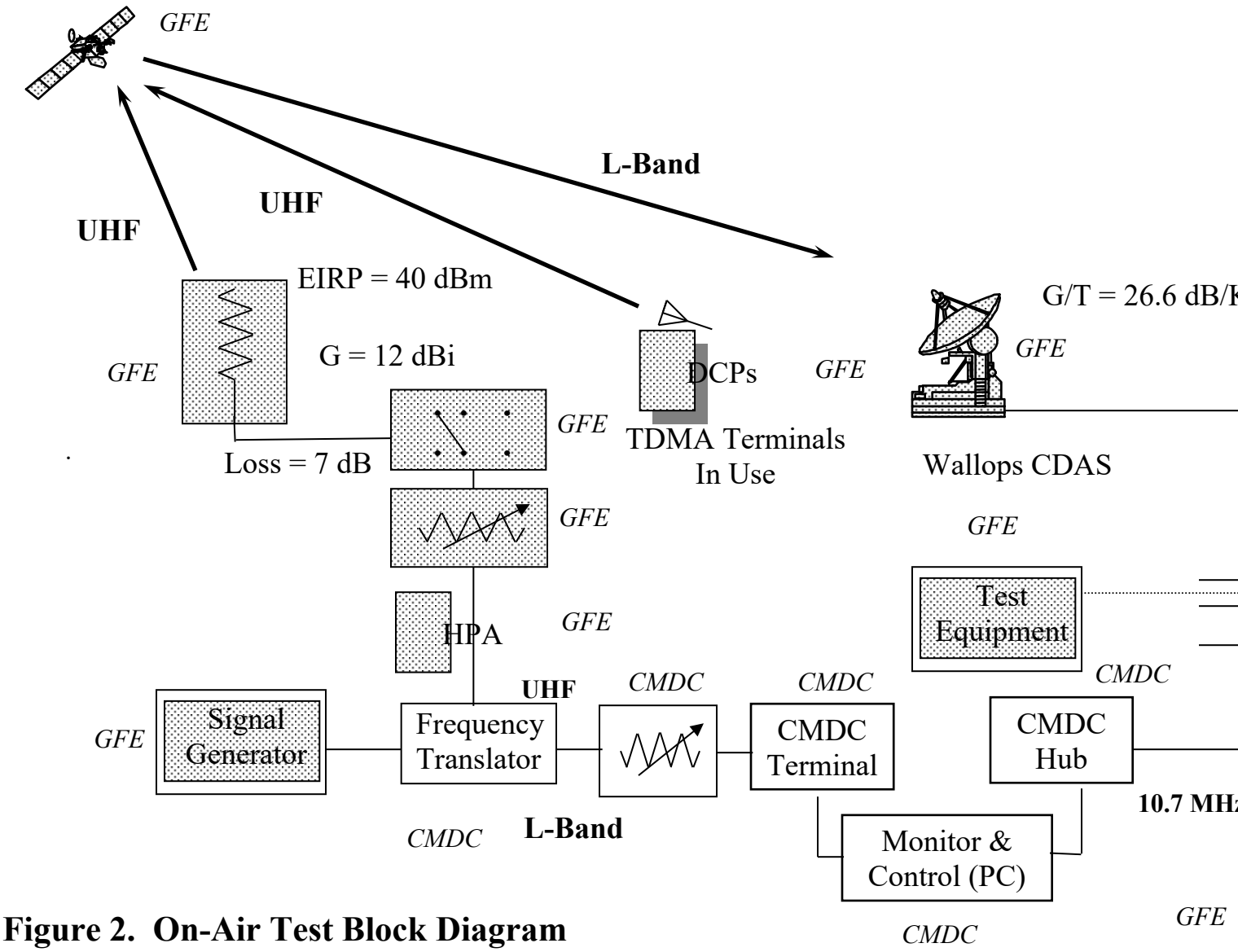

Figure 2. On-Air Test Block Diagram

below, measured noise spectral densities are not really flat across the 400 kHz band and there is a different of 2.2 dB in the noise floor levels due to filtering, power instability, spurious and out-of-band emission. If the 2.2-dB difference in noise level and measurement errors with a spectrum analyzer are taken into consideration, the difference of 2.85 dB is probably justified.

Conclusion: Measured noise floor is 2.85 dB higher than the collected value used in the tradeoffs. The difference, however, is within the uncertainty range

TDMA EIRP Measurement Test (For Collected Information Validation)

This test was used to validate the information collected in Section 2b. A TDMA carrier can be transmitted from a DCP with an EIRP of 50 dBm, but the nominal TDMA carrier EIRP is 34 dBm.

A spectrum analyzer was used to measure the power densities across the transponder bandwidth. The following values were recorded:

* Measured Carrier Power Densities:

Highest:	-35.5 dBm/Hz	(Corresponding Noise Floor: -74.5 dBm/Hz)
Lowest:	-50.5 dBm/Hz	(Corresponding Noise Floor: -72.3 dBm/Hz)
Average:	-41.0 dBm/Hz	

Accordingly, the highest value for C/No is (-35.5 + 20 + 74.5) or 59.0 dBHz and the lowest value for C/No is 41.8 dBHz. If the measured relationship of 47-dBm EIRP for 51.1-dBHz C/No is used, then the highest and lowest TDMA carrier EIRPs are 54.9 and 37.7 dBm. (Note: if the collected information in Section 2a is used (47 dBm EIRP for 54 dBHz), then the corresponding EIRPs will be 52.0 and 34.8 dBm.

Conclusion: The collected information from Section 2b is not valid. The TDMA carrier's EIRP was not controlled to a nominal value of 34 dBm, they varied by as much as 15 dB and are all higher than 34 dBm. The lowest EIRP was 2.7 dB higher than the nominal 34 dBm.

3.3 June 22, 1999 Tests

The out-of-band interference problem described in Section 3.2 was corrected by:

i) replacing the wideband IF filter(1-MHz) with a much narrower 100-kHz filter and

ii) replacing the AGC with a manually adjusted gain control.

Testing was resumed on June 22, 1999.

Noise Floor Change (Due To CDMA Carrier) Test

This test was conducted to determine how the noise floor would raise when a CDMA carrier with a 40-dBm EIRP is introduced. The noise floor, see Table 2, is supposed to increase by 2.0 dB. Nevertheless, if the May 19 results (47-dBm EIRP for 51.1-dBHz C/No) is used, then the noise floor is should raise by 1.2 dB.

By using a spectrum analyzer, the noise floor was measured before and during the introduction of a CDMA carrier (Channel #143). The change in noise floor was first recorded to be 1.6 dB. Some time later, the same test was conducted and the noise floor change was reduced to 1.3 dB.

Conclusion: When a CDMA carrier is introduced, the noise floor changes. Measured noise floor changes are consistent with calculated noise floor change, within the power instability range and the measurement uncertainty.

CDMA Link Performance Tests

These tests were conducted under the actual operation of the DCS. Other than the CDMA carrier, a test CDMA carrier was also introduced for the testing. The test TDMA carrier was manually set to operate at C/No of 33.5 dBHz (or equivalently, Eb/No of 13.5 dB) in the absence of the CDMA carrier. The CDMA carrier was set to a nominal EIRP of 40 dBm. The CDMA and test TDMA carriers were set to have the same center frequency. According to the test plan, the carriers were set to only the center frequency of Channel #143. Nevertheless, due to presence of a large number of TDMA carriers at lower channels, tests were also conducted at Channels #172 and at Channel #200. For tests at Channel #200, there was a large unknown (possibly TDMA) carrier located at Channel #200, and accordingly, the test CDMA carrier was moved to Channel #195 to avoid harmful interference caused by the carrier located at Channel #200.

Measured data for these CDMA link performance tests were collected and summarized in Appendix A. From the appendix, the percentages of a packet (whose length is 1024 bits or

1024x32+256 = 33024 chips) received without errors are 25%, 75% and 83% at Channels #143, 172 and 200, respectively.

Conclusion: Due to presence of a large number of TDMA carriers at lower channels, the packet error rate performance of the CDMA carrier gets better at higher carrier frequency. The performance was very poor at Channel #143, the original frequency plan.

TDMA Link Performance Tests

The conditions for these TDMA link performance tests were the same as those for the CDMA link performance tests. Measured data for the TDMA link performance tests were collected and summarized in Appendix A. From the appendix, the bit error ratio (BER) at Channel #143 was $6x10^{-5}$, which is an acceptable number, at Eb/No (without interference) of 13.5 dB. At Channel #172, however, the measured BER was $53x10^{-5}$,which is an unacceptable. Nevertheless, when the test TDMA carrier power was raised by 0.5 dB to set Eb/No of 14.0 dB, there were no corrupted bits detected over the BER test time interval of 17 minutes.

Note that logically the BER for the test TDMA carrier should be the same regardless of the channel where both carriers (the CDMA carrier and the test TDMA carrier) are located. The measured BER values are, however, very different at different channels. Possible explanations for the difference are:

i) the power stability of the HPA is poor:

ii) there are other sources of interference: and

iii) the test time intervals were not long enough to provide reliable BER readings (note that only 100000 bits or around 17 minutes of test data were generated for each BER measurement.)

Also, the test TDMA carrier was set to operate at Eb/No (without interference) of 13.5 dB. This Eb/No level is extremely low as compared to the Eb/No values associated with the actual TDMA carriers. From the May 19, 1999 tests (see above), the measured Eb/No associated with all of the TDMA carriers has a range from 21.8 dB (i.e., C/No of 41.8 dBHz) to 39.0 dB (i.e., C/No of 59.0 dBHz).

Conclusion: Interference from a 40-dBM EIRP CDMA carrier to a TDMA carrier is negligible.

4. OTHER ANALYSES

4.1 Retransmission Analysis

From Section 3.3, due to TDMA carrier interference, the measured packet error rates (PERs) of the CDMA carrier at the three locations (Channels #143, #172 and #200) are 75%, 25% and 17%, respectively. Regardless of the PER, retransmission of packets can always be used to guarantee that packets sent via the CDMA carriers are received at certain quality of services (QoSs), e.g., 99.5 % of the time that the packet will be received without errors. Poor PER will require more retransmissions and longer inter-transmission time. The optimal number of retransmissions and the inter-transmission time for the three cases tested can be calculated and the results are shown on Table 4 for the QoS of 99.5%.

A sample calculation is as follows. From the test data collected on Channel #172, PER is 25% and MNCMP (maximum number of consecutive missed packets) is 17 and packets (of length of 1024 bits or 33024 chips) are sent at every 1.7 seconds (duration of 4480 bits). If N packets are "time-independent", then the probability of receiving all N packets with errors is $(PER)^N$. Thus one has

$$QoS = 1 - (PER)^N$$

For PER = 0.25 and N = 4, one obtains QoS = 99.6% which is better than the required 99.5%. Because MNCMP is 17, for two packets to be "time-independent," they must be sent at least 17x1.70 = 28.9 sec apart from each other. Thus to have 4 "time independent' packets, the minimum elapsed time between the transmission of the first packet and the 4th packet is 3x28.9 = 86.7 sec. That is, if Channel #172 is used, it is necessary to transmit the same packet 4 times and the inter-retransmission time of at least 28.9 sec.

Table 4. Retransmission Parameters To Support QoS Of 99.5% For Three Different CDMA Carrier Center Frequencies

	Channel #147	Channel #172	Channel #200
Packet Error Rate (PER)	75	25	17
Maximum # Consecutive Missed Packets (MNCMP)	90	17	4
# Retransmissions	11	4	3
Minimum Time Between Retransmission	153.0 sec	28.9 sec	6.8 sec
Total Elapsed Time	1530 sec	86.7 sec	13.6 sec

4.2 Number of Active CDMA Carriers Supportable

The following provides a conservative estimate of the number of active CDMA carriers that the UHF-L transponder can support in addition to the existing TDMA carriers. The TDMA carriers are all operating at the nominal EIRP of 34 dBm to provide an Eb/No of 21.0 dB (see Table 3). If the minimum acceptable Eb/No (including interference) is 13 dB, then from Table 3, the TDMA carrier has enough margin to counter interference from CDMA carriers whose aggregated EIRP can be as high as 49.5 dBm. If the operating EIRP of a single CDMA carrier is 43.5 dBm (3.5 dB over 40 dBm to accommodate CDMA self-interference and to further improve packet error performance), then there can be four additional active CDMA carriers. That is, there is an additional capacity of 10.5 kbps (i.e., 4x84.375/32) out of the current maximum capacity of 26.6 kbps.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

SOW Compliance Conclusion

This study has conducted in full compliance with the Statement of Work of the Contract. Namely, it has

- Demonstrated the operation of the CDMA system (made by CMDC) at the designated ground station (the CDAS at Wallops Island, Virginia) via the GOES-East UHF-L transponder on June 19, 1999;
- Provided the link budget analyses for both the CDMA and TDMA links in this Final Report, Section 2.3, Table 3;
- Provided this Final Report to include test results (Section 3 and Appendix A), predicted number of CDMA carriers supportable (which is 4 as described in Section 4.2) and a recommended system architecture and specification for an operational system (which is described in Section 5.2 below).

Other Conclusions

Based on the tradeoff analyses and on-air measurements described above, the following conclusions can be made:

a) The DCS TDMA carrier EIRPs are not controlled to a nominal value of 34 dBm recommended. The TDMA carrier EIRPs vary by as much as 15 dB and are all higher than the nominal value of 34 dBm. The lowest EIRP was 2.7 dB higher than the 34-dBm nominal. This high EIRP variation severely limits improvement on the utilization of the UHF-L transponder resources due to interference caused to the CDMA carriers

b) The DCS TDMA links are operating with very high link margins. The operating carrier Eb/No ranges from 21.8 to 39 dB. These high link margins make interference from the typical CMDC CDMA carriers negligible. However, these high link margins also limit improvement on the utilization of the UHF-L transponder resources, due to interference caused to the CDMA carriers.

c) The transponder has many active TDMA carriers operating at lower DCS channels. This, coupled with a), causes severe interference to the CDMA carrier, if the CDMA carrier is centered at the Channel #143. By moving away from these active TDMA carriers, i.e., by setting the CDMA carrier center to a higher frequency, the performance of the CDMA carrier significantly improves.

5.2 Recommendations

Recommendations On The CDMA System Architecture And Specification

A recommended CDMA system for an operational system is the CDMA system developed by Comtech Mobile Datacom (CMDC) or alike with the following specifications:

- BPSK with 1/2-rate FEC convolutional coding;
- Spreading factor of 32;
- Chip rate of 84.375 kcps;
- Packet size of 1024 bits;
- Automatic packet retransmission capability
  (current CMDC system does not yet have this capability)

Other Recommendations

To improve the utilization of the transponder resources, the following recommendations are made:

a) To investigate means to control the EIRP variation among the DCP TDMA carriers, particularly among those that fall into the CDMA carrier main lobe. The investigation should make use of the fact that the DCPs can be interrogated remotely from the Wallops CDAS (via the L-UHF transponder);

b) To perform analyses to determine the optimum power levels to operate the TDMA and CDMA carriers. The transponder will fully be utilized, when the TDMA and the CDMA carrier levels are set to balance out the interference effects. Currently, the operating TDMA carrier power levels seem to be too high, to accommodate the CDMA carriers effectively. Also the CDMA carrier EIRP of 40 dBm seems to be low for operation with multiple CDMA carriers. These analyses should be the extension of the analyses performed in Section 2; and

c) To demonstrate (over satellite) with the recommended system that would operate with multiple CDMA carriers and with/without the use of the retransmission technique described in Section 4.1.

APPENDIX A:
TEST RESULTS FOR CDMA AND TDMA LINK PERFORMANCE TESTS

Test Results on NOAA testing using a CDMA system with a TDMA system (Channel 143)

This test was carried out on channel 143 (401.914 MHz) with both the NOAA DCP and the CDMA terminal transmitting. The first table shows the levels used in transmitting from both units, Table 2 shows the results from the BER results on NOAA's Test terminal. Table 3 shows CDMA packets received over NOAA's satellite into CDMC's Receive HUB. While conducting this test all other TDMA channels were busy transmitting data, these TDMA channels are spaced 1.5 kHz apart from each other. The C/No measured on the CDMA transmit terminal is approximated since this measurement was taken without the effect of multiple DCP's transmitting or without having a DCP transmitting on the same channel. Measured C/No on NOAA's test transmitter was taken before CMDC's terminal was turned on, therefore making this value approximated A changing noise floor affects both measurement recorded on table 1.

Table 1

setup	Channel	Eb/No	C/No
Assigned channel for CMDC's transmit terminal :	**143**	**12.8**	**47**
Assigned channel for NOAA's test data collection platform(DCP) :	**143**	**13.5**	**33.5**

Table 2

BER on NOAA's test Terminal	Channel	Eb/No	BER
Bit Error Rate monitor on channel :	**143**	**13.5**	**6 e-5**

Table 3

CDMA Received packet summary		
	Total	**percentage %**
Total no. of packets sent	**809**	**--**
Total no. of good packets	**204**	**25**
Total no. of packets received with errors	**318**	**39**
Total no. of packets missed	**287**	**35**
Total no. of received packets (good, w/errors)	**522**	**65**

Test Results on NOAA testing using a CDMA system with a TDMA system (Channel 172)

This test was carried out on channel 172 (401.9575 MHz) with both NOAA Test DCP and CDMA terminals transmitting. The first table shows the levels used in transmitting from both units, Table 2 shows the results from the BER results on NOAA's Test terminal. Table 3 shows CDMA packets received over NOAA's satellite into CDMC's Receive HUB. While conducting this test all other TDMA channels were not very busy transmitting data, the surrounding channels were less active when compared to channel 143. Channel 157 had some DCP transmitting at higher levels than others thus causing more interference on the receive hub. These TDMA channels have the same 1.5 kHz spacing from each other. The C/No measured on the CDMA transmit terminal is approximated since this measurement was taken
without the effect of multiple DCP's transmitting or without having a DCP transmitting on the same channel. The same measurement setup was taken in table 1, where NOAA's C/No measurement was taken without The CDMA terminal transmitting, therefore making this value approximated A changing noise floor affects both measurement recorded below.

Table 1

setup	Channel	Eb/No	C/No
Assigned channel for CMDC's transmit terminal :	**172**	**12.8**	**47**
Assigned channel for NOAA's test data collection platform(DCP) :	**172**	**13.5**	**33.5**

Table 2

BER on NOAA's test Terminal	Channel	Eb/No	BER
	172	**13.5 ***	**53 e-5 ***
Bit Error Rate monitor on channel :	**172**	**14**	**0 e-5**
*** needed to take CDMA data with a noted impact on the TDMA channel, thus using a lowered Eb/No to accomplish such results.**			

Table 3

CDMA Received packet summary		
	Total	**percentage %**
Total no. of packets sent	**573**	**--**
Total no. of good packets	**432**	**75**
Total no. of packets received with errors	**61**	**11**
Total no. of packets missed	**80**	**14**
Total no. of received packets (good, w/errors)	**493**	**86**

Test Results on NOAA testing using a CDMA system with a TDMA system (Channel 200)

This test was carried out on channel 200 (401.9995MHz) with both the NOAA and CDMA terminals transmitting. The first table shows the levels used in transmitting from both units, Table 2 shows the results from the BER results on NOAA's Test terminal. Table 3 shows packets received over NOAA's satellite into CDMC's Receive HUB. While conducting this test all other TDMA channels were not very busy transmitting data, the surrounding channels were less active when compared to channel 143 and 172. These TDMA channels have the same 3 kHz spacing from each other.
While testing was in progress, an unknown carrier remained centered at ch 200 having a C/No of 45.5. This unknown carrier was present for the entire duration of the testing.
The C/No measured on the CDMA transmit terminal is approximated since this measurement was taken
without the effect of multiple DCP's transmitting or without having a DCP transmitting on the same channel. The same applies to channel 200 as with channel 143 and 172 on the C/No measurement taken for NOAA.'s test transmitter

Table 1

setup	Channel	Eb/No	C/No
Assigned channel for CMDC's transmit terminal :	**200**	**12.8**	**47**
Assigned channel for NOAA's test data collection platform(DCP) :	**200**	**13.5**	**33.5**

Table 2

BER on NOAA's test Terminal	Channel	Eb/No	BER
Bit Error Rate monitor on channel :	**143**	**13.5**	**0 e-5**
	195	**13.7**	**1 e-5**
	233	**14.4**	**0 e-5**

Table 3

CDMA Received packet summary		
	Total	**percentage %**
Total no. of packets sent	**2076**	**--**
Total no. of good packets	**1720**	**83**
Total no. of packets received with errors	**305**	**15**
Total no. of packets missed	**51**	**2**
Total no. of received packets (good, w/errors)	**2025**	**97.5**

][