Evaluation Of The CDM-700 With 64-QAM Over Satellite

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1 Summary

Dual and single carrier testing of 155.52 Mbps carriers over a 72 MHz satellite transponder was conducted using CDM-700 modems operating with 64-QAM and 7/8 Turbo Coding. A 16.4 meter A-station antenna and 1000W SSPA provided the transmission. The main results were:

- The measured bit error rate (BER) between 10^{-5} and 10^{-7} was achieved with two 155.52 Mbps carriers in a 72 MHz transponder.
  - This is not sufficient for acceptable levels of operation.
  - The test included finding the optimal operating point, a tradeoff between Carrier to Noise (C/N) and Carrier to Intermodulation and Distortion (C/I).
  - An acceptable link should attain quasi-error-free operation at the operating threshold and have about 1 dB margin at the nominal operating point.

- No errors appear when a single 155.52 Mbps carrier is transferred over the same link.
  - This is obtained by simply turning OFF one of the carriers in the two-carrier test.
  - Ample margin is available for a useful link.

- Operation with one 155 Mbps carrier over a 36 MHz transponder will work.

1.1 Other Outcomes

Several other items are noteworthy:

- The (C+N)/N of each carrier received from the transponder is 21.3 dB and should correspond to an Eb/No = 14.2 dB. However, the Eb/No reported by the modem is 12.7 dB (corrected to include modem implementation loss) indicating other impairments are degrading the carrier.
  - Data was taken to verify the main contributor to impairment is the transponder. With greater backoff the link is C/N limited, and with less backoff the link becomes C/I limited.
  - This is not an indictment of the transponder, but emphasizes the need for high linearity for 64-QAM.
  - The 36 and 72 MHz transponders deliver the same EIRP. This puts the 72 MHz transponder at a 3 dB disadvantage on a Watts/Hz basis. With 3 dB additional EIRP the transponder would support two 155 Mbps carriers.

- Single carrier operation eliminates the intermodulation degradation due to two carriers
  - Nonlinear compensation in the modem improves performance by at least 0.8 dB

2 Test Configuration

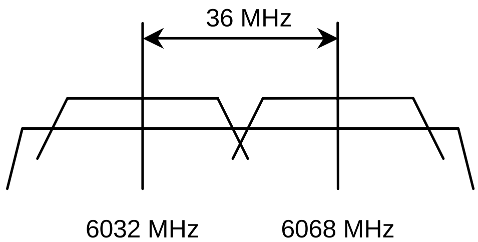
The uplink to the transponder was allocated the band from 6014 to 6086 MHz. Additional details of the transponder allocation are shown in **Figure 2-1**. The nominal uplink EIRP is 74.3 dBW for each carrier. One carrier operated at 6032 / 3807 MHz and the other at 6068 / 3843 MHz corresponding to one carrier at -18 MHz and the other at +18 MHz relative to the center of the transponder.

The modem parameters are:

> The CDM-700 data rate is 155.52 Mbps plus 2.5% modem overhead (OH) resulting in a composite symbol rate of 30.5532 Msps with 64-QAM and code rate of 7/8 (20/23 actual). The corresponding IF frequencies for the modem carriers are 122 and 158 MHz.
>
> The CDM-700 was equipped with special non-linear compensation test software to help offset the saturation effects in the link. The special non-linear software is not available in the CDM-700 product.

The CDM-700 includes a linear adaptive equalizer that corrects for the linear “filter-like” effects including amplitude variation, tilt, group delay or bandwidth limiting.

Carrier Centers (6032 RHCP / 3807 LHCP, 6068 RHCP / 3843 LHCP)



CDM-700 Satellite Modem at 155.52 Mbps
@ 64QAM 7/8 (20/23 actual), OH = 2.5%
Alpha (rolloff) = 25%
SR = 155.52*1.025*/(6*20/23) = 30.5532 MHz
Nominal Carrier Spacing = 1.3xSR = 39.72 MHz
Actual Carrier Spacing = 36 MHz
Relative Carrier Spacing = 36/30.5532 = 1.18xSR

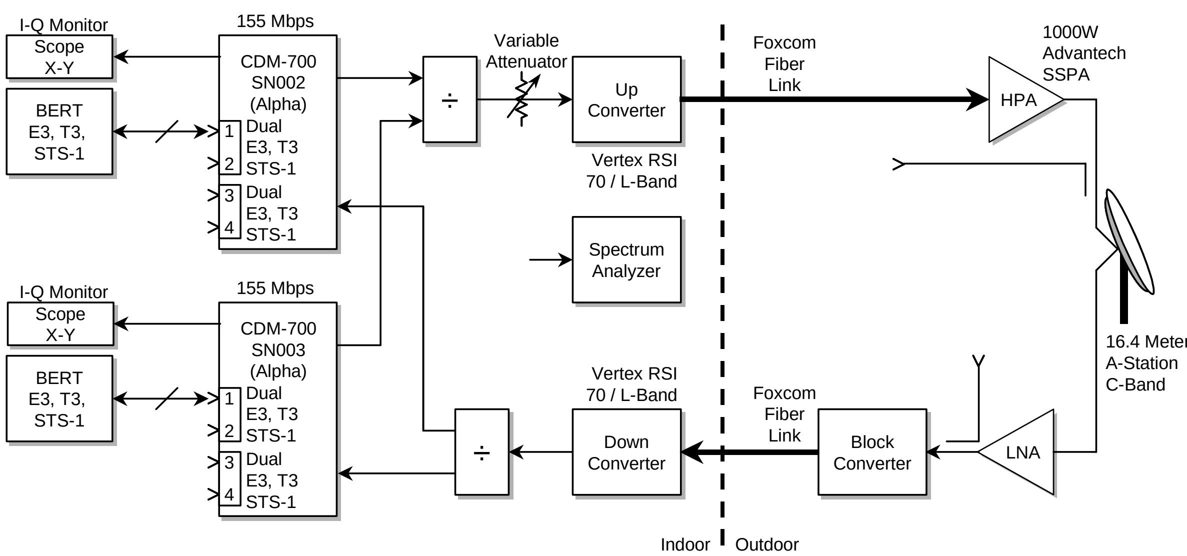
Transponder Resource
EIRP = 37 dBW Beam Edge (est 42.8 dBW Center)
SFD = -75.6 dBW/m^2 Edge (est -81.4 dBW/m^2 Center)

Transponder Allocated
6032 MHz
UL EIRP = 74.3 dBW
DL EIRP = 35.3 / 29.5 dBW (Center / Edge)

6068 MHz
UL EIRP = 74.3 dBW at 6068 MHz
DL EIRP = 35.3 / 29.5 dBW (Center / Edge)

Figure 2-1. Satellite Configuration

A simplified block diagram of the test setup is shown in **Figure** 2-2.



Notes:
1) The composite data rate is programmable after the data interface to set the overall symbol rate to OC-3 or any rate for test purposes while allowing the use of any data port for connection to a BERT.

Figure 2-2. Test Setup

Included in the block diagram are Bit Error Rate Test (BERT) equipment along with two sets of CDM-700 modems, up converters, down converters and HPAs (SSPAs in this case) plus the LNA.

Only one BERT is needed for the test. It is possible to move the BERT from port to port to verify the setup is functioning properly, but another method is discussed later that provides better flexibility for the test. The oscilloscopes are used to display the QAM constellation. This is a key test point for evaluating impairments.

2.1 Test Method With A Single BERT

Test equipment is at a premium so a method was devised to expand test capability while preserving the integrity of the test. The CDM-700 was configured with 2 each CDI-10 Dual G.703 ports for a total of up to 4 ports. Each port is configured to E3, T3 or STS-1 (34.368, 44.736 or 51.84 Mbps) allowing a convenient range of data rates including 155.52 Mbps. In addition, a special internal variable data rate port was available to allow programming the composite modem data rate to any data rate. Internally, the modem adds 2.5% overhead to the composite terrestrial data rate for multiplexing the data streams together. At the receive end the process is reversed and the recovered data is directed to the to an internal sink (thrown away) or sent to the data port for connection to a BERT.

During the test one BERT was operated at a T3 rate and the other at an E3 rate.

3 Tests

Following checkout of the modems and setup of the earth station interfaces and levels several tests were conducted to assess performance.

3.1 Converter Loopback Via Test Translator to Modem

3.1.1 Test with Carrier #1, Carrier #2 and Test with Carriers #1 & #2

A quick check of the modems looped through the converters ran error free.

3.2 Isolation of Compression to Satellite Transponder

Once the nominal operating point was reached, compression effects were evident. A test was conducted at the outdoor equipment room to isolate whether the compression was in the Tx chain between the modem and the output of the 1000-Watt SSPA or if it was in the satellite transponder.

Using a spectrum analyzer to observe the carriers, the lower carrier was turned OFF and the power out of the SSPA showed no change in the remaining carrier's power or spectral shape. Observing the spectrum at the output of the LNA sample port, the remaining carrier increased by 0.5 dB, and the spectral shape changed slightly when the lower carrier was turned OFF.

It was concluded that the transponder chain is slightly into peak limiting although no increase in the noise floor was visible.

Figure 3-1 is representative of this effect, but the plot was taken at the input to the demodulator rather than at the output of the LNA. The picture shows two stored traces. In the first one, the two carriers are operating together (light blue trace) to set a reference. The second trace (light green) plots the effect when one of the carriers is turned OFF and indicates an increase of about 0.6 dB.

3.3 Testing through the satellite

3.3.1 Single Carrier Tests

Each carrier was individually set to the proper level and tested through the link. A -4 dB setting on the variable attenuator corresponds to the nominal operating point. **Figure 3-2** shows a plot of the Eb/No reported by the modem versus the setting of the variable attenuator following the modems. The Eb/No is determined as follows:

The demodulator uses a Turbo Product Code IC that measures raw BER as part of the operation of the decoder. The raw BER is noted and the Eb/No is taken from a table of Eb/No versus raw BER. The raw BER represents the bit error rate at the output of the demodulator prior to the TPC decoder. (Note: the Eb/No is simply read from the unit in the CDM-700 modems available today.)

Raw BER is the method of choice because the slope of BER versus Eb/No is not very steep making it easier to extract data. A corrected BER versus Eb/No is so steep that measuring a wide range of operating conditions is not practical.

The measurements were taken with the nonlinear compensation engaged and with it turned OFF to measure the impact. The nonlinear compensation extended the single carrier operating point and increased the available Eb/No by 0.8 dB.

Previous experience with SSPA and TWTA type amplifiers indicates that the 0.8 dB is reasonable for the SSPA. Improvements of 2.5 dB were previously observed for a non-linearized TWTA.

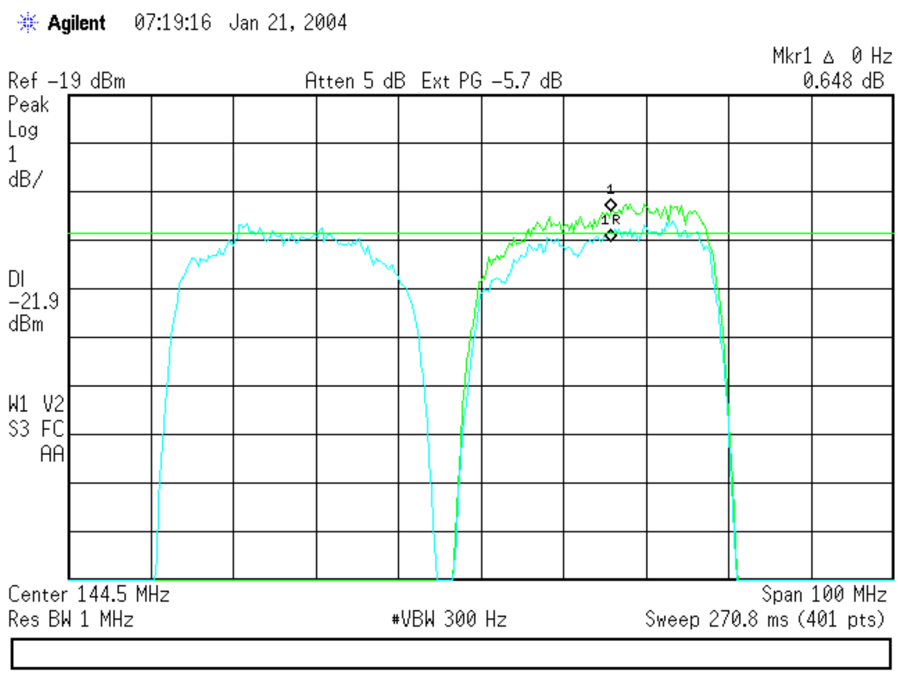


Figure 3-1. Level Change When One Carrier Is Removed

Figure 3-3 shows the impact of non-linear distortion on a single carrier with and without the non-linear compensation. The picture on the left illustrates the distortion caused by non-linearity while the one on the right shows how the dots are realigned to the correct position when compensation is engaged.

3.3.2 Two Carrier Tests

Data was taken with the transponder supporting two carriers. The results are shown in **Figure 3-4**. This shows the transition from noise-limited case starting at the left of the figure to the distortion-limited case as transponder power increases. The peak operating point (maximum Eb/No) is located at about the -3 dB setting of the attenuator. This is about 3 dB lower than when operating with a single carrier.

Another way of presenting the data is by plotting the corrected BER versus the attenuator setting as shown in **Figure 3-5**. This is the BER measured by the BERT equipment external to the modem. This dramatically illustrates the best spot for operating with two carriers. It also shows the performance is not adequate with two 64-QAM carriers. In an additive Gaussian white noise (AWGN) environment quasi error free operation is expected when the operating Eb/No is 12.7 dB. The nonlinear impairment is non-AWGN and further degrades the corrected BER.

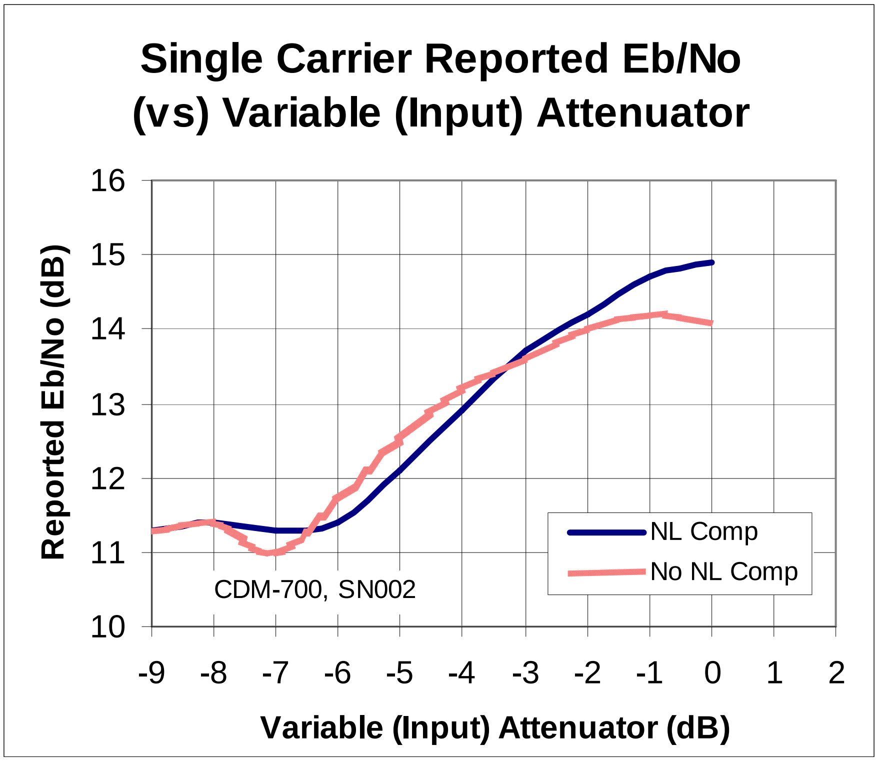


Figure 3-2. <u>Single Carrier</u> Reported Eb/No versus Variable Attenuator.

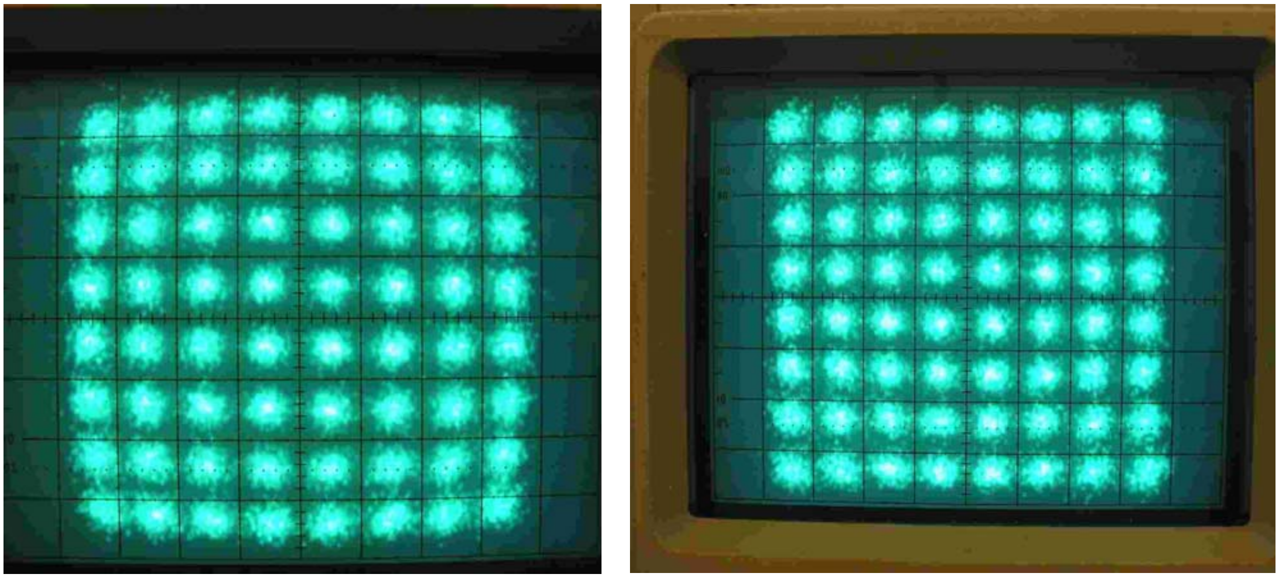


Figure 3-3. Single Carrier: Left No Non-Linear Compensation. Right, With Non-Linear Compensation.

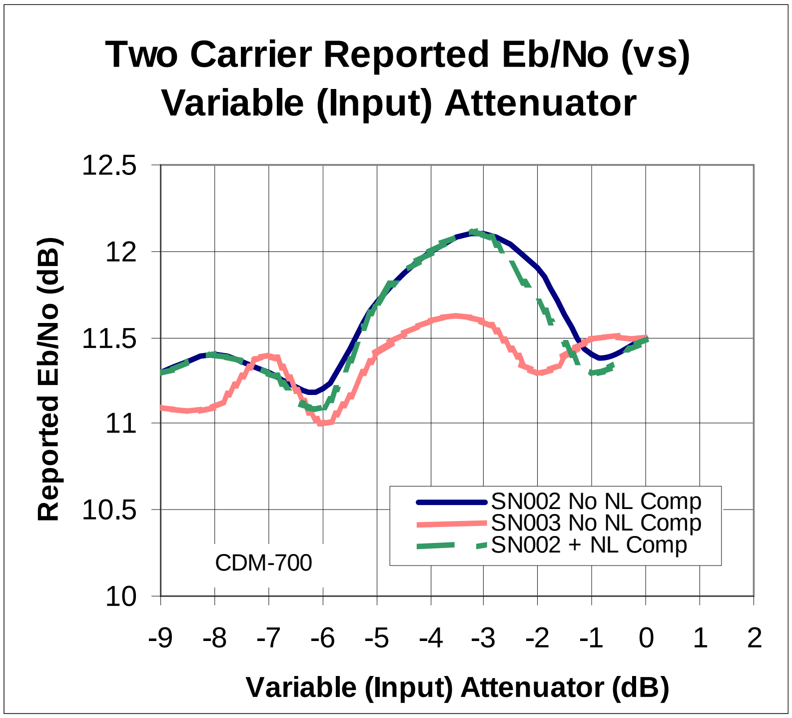


Figure 3-4. Two Carrier, Reported Eb/No versus Variable Attenuator

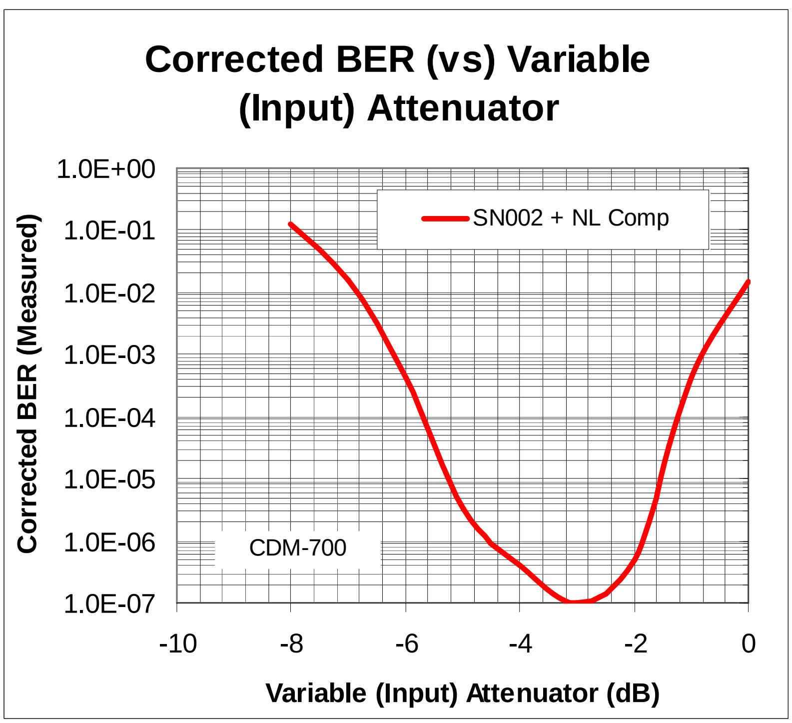


Figure 3-5. Two Carrier, Corrected BER versus Variable Attenuator

The impact of non-linear distortion with two 64-QAM carriers is displayed in **Figure 3-6**. The figure on the left shows the dots out of position with a bulging effect. The right hand picture shows the effects of correction with non-linear compensation applied. In both cases, the dots away from the center exhibit a higher degree of fuzziness indicating the greater degree of degradation due to non-linear distortion compared to the inner constellation dots. The dots not only move out of position they also become elliptical and exhibit different amounts of rotation or twist depending upon their position.

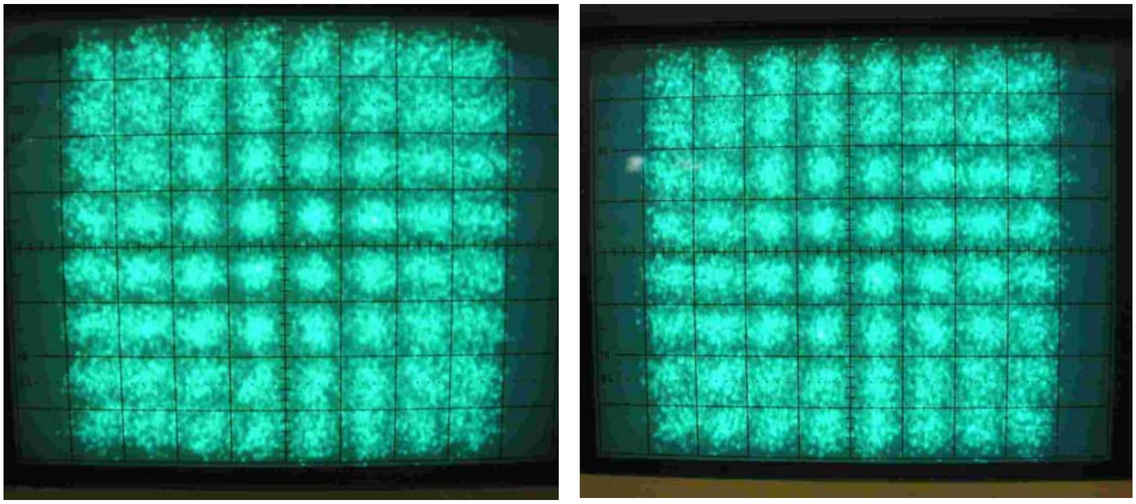


Figure 3-6. Two Carriers: Left, No Non-linear and Right With Non-Linear Compensation.

The non-linear correction is much less effective with two carriers because the instantaneous power and angle is inaccurately estimated. During single carrier operation there is only one carrier occupying the transponder and each constellation point is pre-distorted before passing through the non-linearity allowing the resultant point from the transponder to appear close to the desired position. With two carriers present, the estimate from each modulator is incorrect due to the presence of the other carrier at the transponder. The instantaneous magnitude and phase is now the sum of the two carriers and one modulator does not know which constellation point the other modulator is sending to the transponder. The result is that many of the constellation points transmitted with two carriers present are not ideal. The compensated two carrier constellations exhibit much poorer results compared to the single carrier plot in **Figure 3-3**.

4 Link Budget

Transmission of a 64-QAM over satellite requires a great deal of care. Generally, an A-Station is necessary to close the link along with very linear, high power transponders. Yet, these links are feasible, and the monthly cost savings are phenomenal when all the key pieces of the link are in place to support it. The test results support 155.52 Mbps operation over a single carrier in 36 MHz.

Two links budget examples are presented in the tables below. The first uses the Comtech EF Data's Bandwidth Optimization Tool, which is available for anyone to input their own link budgets and see if more efficient alternatives are possible. See **http://optimize.comtechefdata.com/**. For a 64-QAM link an 11-meter earth station is at both earth stations. The cost savings is based upon $3000 / MHz / Month.

The second table shows a typical link budget using the more cumbersome spreadsheet approach. This calculation illustrates two nearly identical links that differ only by the saturated flux density (SFD). In the right hand portion of the table the SFD differs by -2 dB for comparison. Both earth stations are located on a 1.5 dB contour below the transponder's peak EIRP and also 1.5 dB below the peak of the G/T footprint. These confirm that a 64-QAM link will close, when there is a combination of a high power and very linear transponder available.

Independent tests by customers indicate that operation between 9-meter antennas is possible when there is a high transponder EIRP available.

Using Comtech EF Data's Bandwidth Optimization Tool (**http://optimize.comtechefdata.com/**):

	Current Link		**New Link**		**Savings**
	A - > B	**Total**	**A - > B**	**Total**	
Data Rate	155,520.00 kbps		155,520.00 kbps		
Modulation, Coding	16QAM, TPC 7/8		64QAM, TPC 7/8 (20/23)		
Carrier-in-Carrier™	No		No		
Target Eb/No	7.90 dB		12.40 dB		
Carrier Spacing	1.20		1.20		
Occupied Bandwidth	53,321.14 kHz		36,679.25 kHz		
HPA (Excl. Backoff)	29.97 W		99.88 W		
Transponder BW	98.74%	98.74%	67.92%	67.92%	
Transponder Power	5.44%	5.44%	56.55%	56.55%	
Leased Bandwidth		**53,321.14 kHz**		**36,679.25 kHz**	**31.20 %**
Monthly Bandwidth Cost		**$159,963.43**		**$110,037.74**	**$49,925.69**

SATELLITE LINK ANALYSIS

09-Mar-07

155.52 Mbps Link
Tx Beam Peak EIRP-1.5 dB, Rx Peak G/T-1.5 dB
BER = 10-8

		11 M TO 11 M			11 M TO 11 M		
		CLEAR	UL FADE	DL FADE	CLEAR	UL FADE	DL FADE
DATA RATE	KBPS	155,520.00	155,520.00	155,520.00	155,520.00	155,520.00	155,520.00
COMPOSITE CODE RATE		20/23	20/23	20/23	20/23	20/23	20/23
MODULATION EFFICIENCY, THEORETICAL	Bits/Hz	6.00	6.00	6.00	6.00	6.00	6.00
UPLINK							
E/S EIRP TOWARD SATELLITE	dBW	76.52	76.52	76.52	78.20	78.20	78.20
UPLINK PATH LOSS	dB	-200.00	-200.00	-200.00	-200.00	-200.00	-200.00
UPLINK FADE & OTHER	dB	-0.20	-0.70	-0.20	-0.20	-0.70	-0.20
G/T SATELLITE TOWARD UPLINK	dB/K	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
BOLTZMAN'S CONSTANT (-K)	dBW/K-Hz	228.60	228.60	228.60	228.60	228.60	228.60
C/No UPLINK	dB-Hz	102.92	102.42	102.92	104.60	104.10	104.60
DOWNLINK							
SATELLITE EIRP TOWARD DOWNLINK E/S	WATTS	3135.94	2794.91	3135.94	2910.50	2593.98	2910.50
SATELLITE EIRP TOWARD DOWNLINK E/S	dBW	34.96	34.46	34.96	34.64	34.14	34.64
DOWNLINK PATH LOSS	dB	-196.20	-196.20	-196.20	-196.20	-196.20	-196.20
DOWNLINK FADE & OTHER	dB	-0.20	-0.20	-0.50	-0.20	-0.20	-0.70
G/T OF E/S	dB/K	32.70	32.70	32.70	32.70	32.70	32.70
BOLTZMAN'S CONSTANT (-K)	dBW/K-Hz	228.60	228.60	228.60	228.60	228.60	228.60
C/No DOWNLINK	dB-Hz	99.86	99.36	99.56	99.54	99.04	99.04
OTHER DEGRADATION							
C/IMo, SATELLITE INTERMODULATION	dBW-Hz	102.43	101.93	102.43	102.10	101.60	102.10
C/Io, XPOL, ADJ E/S & SATELLITE	dBW-Hz	102.96	102.46	102.96	102.64	102.14	102.64
C/(IMo+Io)	dBW-Hz	99.68	99.18	99.68	99.35	98.85	99.35
SUMMARY							
COMPOSITE C/No	dB-Hz	95.82	95.32	95.70	95.82	95.32	95.60
DATA RATE	dB	81.92	81.92	81.92	81.92	81.92	81.92
Eb/No (REQUIRED)	dB	12.90	12.90	12.90	12.90	12.90	12.90
MARGIN	dB	1.00	0.50	0.88	1.00	0.50	0.78
OTHER TRANSPONDER & CARRIER PARAMETERS							
EIRPsat TOWARD DOWNLINK E/S	dBW	39.10	39.10	39.10	39.10	39.10	39.10
SFD, SAT FLUX DENS TOWARD UPLINK E/S	dBW/M^2	-77.50	-77.50	-77.50	-75.50	-75.50	-75.50
BOo, OUTPUT BACKOFF FROM SATURATION	dB	4.00	4.00	4.00	4.00	4.00	4.00
BOi, INPUT BACKOFF FROM SATURATION	dB	9.00	9.00	9.00	9.00	9.00	9.00
SATELLITE GAIN INCLUDING ANTENNAS	dB	158.64	158.64	158.64	156.64	156.64	156.64
RADIATED BANDWIDTH AT -20 dB	KHz	35,769.60	35,769.60	35,769.60	35,769.60	35,769.60	35,769.60
CARRIER SPACING = 1.2 x Symbol Rate	KHz	35,769.60	35,769.60	35,769.60	35,769.60	35,769.60	35,769.60
TRANSPONDER BANDWIDTH	MHz	36.00	36.00	36.00	36.00	36.00	36.00
# CARR = (XPONDER BW)/(CARR SPACING)		1.01	1.01	1.01	1.01	1.01	1.01
# CARR = (EIRPsat-BOo)/(EIRP/CARR)		1.03	1.16	1.03	1.11	1.25	1.11
OTHER E/S DATA							
Tx FREQUENCY	GHz		6.00			6.00	
Rx FREQUENCY	GHz		3.78			3.78	
Rx ANTENNA GAIN	dB		51.50			51.50	
Tx ANTENNA GAIN	dB		55.50			55.50	
Tx LINE LOSS TO ANTENNA	dB		1.00			1.00	
POWER PER CARRIER INTO LINE	dBW		22.02			23.70	
SSPA / HPA OUTPUT BACKOFF	dB		3.00			3.00	
SSPA / HPA POWER PER CARRIER	dBW		25.02			26.70	
SSPA / HPA POWER PER CARRIER	WATTS		317.83			467.52	
# OF CARRIERS			1			1	
TOTAL SSPA / HPA POWER	WATTS		317.83			467.52	