TRANSPORTATION OF THE RF SPECTRA OVER FIBER: A WORKING SYSTEM

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ABSTRACT

This paper presents the results of installing a distributed feedback (DFB) laser transmitter and the appropriate optical receiver in an operational site. Frequencies from 1435 to 2400 megahertz are transported intact from a remote site to a local site. From the theoretical calculations, 10 dB of dynamic range may need to be recovered by the use of an automatic gain circuit. The actual device is a delight, needing no additional circuitry to meet specifications. Predictions of performance were made from calculations. The installed system was measured for 1 dB compression point and for figure of merit.

KEY WORDS

distributed feedback (DFB) laser, Figure of merit, 1 dB compression point

INTRODUCTION

The problem is to transport 1435 to 2400 megahertz (MHz) from a remote site to an area where the signal can be processed. This paper discusses one solution that uses a fiber optic transmitter/receiver set surrounded by amplifiers. The local site contains the people and the telemetry receivers. The remote site contains the antenna. Between these two sites are single mode fiber optic cables. This solution uses a fiber optic receiver-transmitter set to transport all antenna frequencies. The transmitter contains a distributed feedback (DFB) laser operating at a wavelength of 1310 nanometers with an advertised RF input noise of -160 dBW/Hz over the 1435 to 2400 MHz range. This is a desired solution as it removes all data equipment from the remote site. The remote portion of the tracking system and two fiber optic transmitter-receiver sets with their amplifiers would be all that is left at the remote site. The prototype has been operating for approximately a year. This paper presents some of the data gathered during this year and compares this against predicted results.

This project is the result of work started by Tony Matsuo and Gene Law of NAWCWPNS at Point Mugu about 1990. Another source of information is a handbook distributed by Ortel Corporation.

DEFINING THE SYSTEM

The original antenna system is as shown in Figure 1. This system was designed and tested to the following specifications:

Table 1. Original GKR-13 Ground Station Specifications

Frequency (MHz)	Figure of Merit G/T (Max, dB/K)	Noise Temperature (Max, ^{O}K)	Antenna Gain (Min, dB)	Overall Dynamic range* (dB)
1435-1535	10	320	35	noise to -10 dBm
1750-1850	11.5	320	36.5	noise to -10 dBm
2200-2300	13.5	320	38.5	noise to -10 dBm
* Note: This is the range presented to the receiver inputs at the remote site. Specified tracking dynamic range is -120 dBm (100 kHz bandwidth) to -40 dBm at the LNA inputs.				

Table 2 shows the results from the original acceptance tests:

Table 2. Contractor Acceptance Test Data

Frequency (MHz)	Polarity	Figure of Merit G/T (Max, dB/K)	Noise Temperature (Max, ^{O}K)	Antenna Gain (Min, dB)	Dynamic range (dB)
1485	RHCP	11.6	199.5	34.6	noise to -10dBm
1485	LHCP	11.9	199.5	34.9	noise to -10dBm
1800	RHCP	13	223.9	36.5	noise to -10dBm
1800	LHCP	12.5	281.8	37	noise to -10dBm
2250	RHCP	13.6	316.2	38.6	noise to -10dBm
2250	LHCP	14.4	281.8	38.9	noise to -10dBm

VERIFYING THE ORIGINAL SYSTEM

The system was checked and verified. The original system has not degraded significantly. Some degradation was found in the Hi-L band. The system was not originally specified to operate in Hi-S band. The original contractor put Hi-S band capability onto the feed. The original system was physically verified to be operational as specified. Taking comparison data was postponed until the fiber optic system is in place. The noise floor was measured as -88 dBm to -90 dBm in a 1 MHz bandwidth.

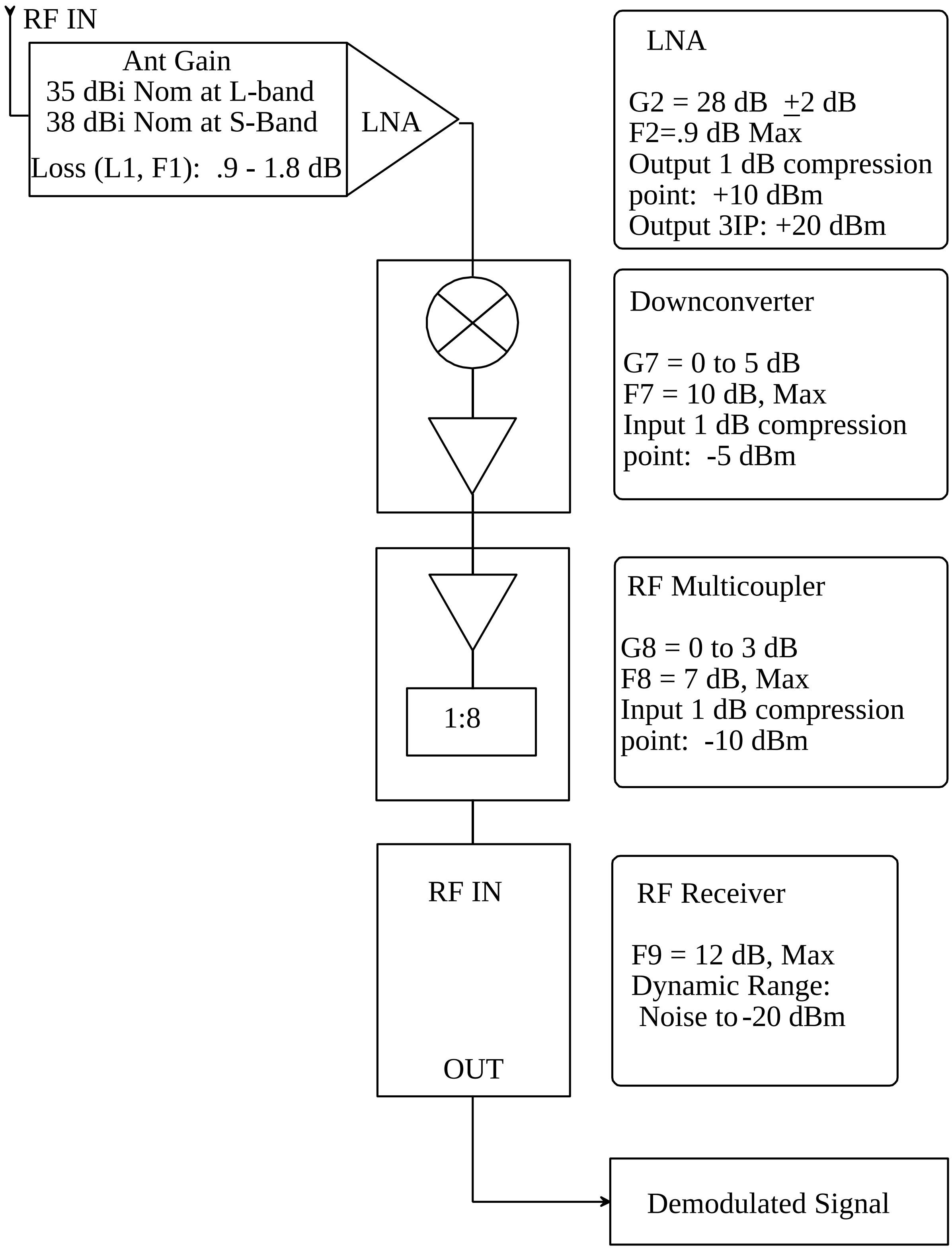

Figure 1. Original RF Signal Flow

ADDING THE FIBER OPTIC TRANSMITTER AND RECEIVER

Practical experience with RF noise levels shows that if a signal is passed from one stage with a noise floor at -85 dBm (1 MHz bandwidth) into the next stage with an input noise at -70 dBm (1 MHz bandwidth), an amplifier is needed before the noise source. Considering both noise and transfer loss, an amplifier will be required after the fiber optic pair.

The original system as shown in Figure 1 is replaced with the system as shown in Figure 2. Inserting anything with a significant loss is going to have impact on the system effective temperature and the related noise figure. This starting point was very simple. The original starting equations were simple and approximated:

Original approximated path to the downconverter:

$$F = F2 + \frac{F7 - 1}{G2} \quad \text{(Equation 1)}$$

New approximated path to the downconverter (most significant terms):

$$F = F2 + \frac{F5 - 1}{G2 * G4} + \frac{L5 * (F6 - 1)}{G2 * G4} + \frac{L5 * (F7 - 1)}{G2 * G4 * G6} \quad \text{(Equation 2)}$$

Where F is the system noise figure. For all other values, refer to Figures 1 and 2.

With the original RF path as shown in Figure 1, the noise figure determined by equation 1 was 1.81. The current noise figure and gain values are as shown in Figure 2. The first chosen gain of LNA1 was 36 dB. Using equation 2, the resulting noise figure of 1.84 would predict a signal to noise ratio at virtually the same place. There is another consideration, the third intercept point (3IP) and the resulting intermodulation distortion. The antenna could have signals as high as -8 dBm after the LNA. These signals would be subject to intermodulation distortion. By the specification, the maximum level before the LNA is -40 dBm, which results in an after LNA level of -10 to -14 dBm. A gain of 36 dB would send the signal into hard saturation. Therefore, the gain of LNA1 became 30 dB.

The antenna must feed both data and tracking systems. Since the impact of the added system should be minimal to the tracking system, a power divider was added to the system. This adds 3.5 dB of attenuation between the feed LNA and LNA1. Adding a 3 dB attenuator adds 6.5 dB of attenuation, effectively decreasing the 3IP distortion. There will be -11.5 dBm after LNA1 of Figure 2 if there is -40 dBm prior to the LNA in the feed. The power divider would also add 3.5 dB of loss to the tracking system.

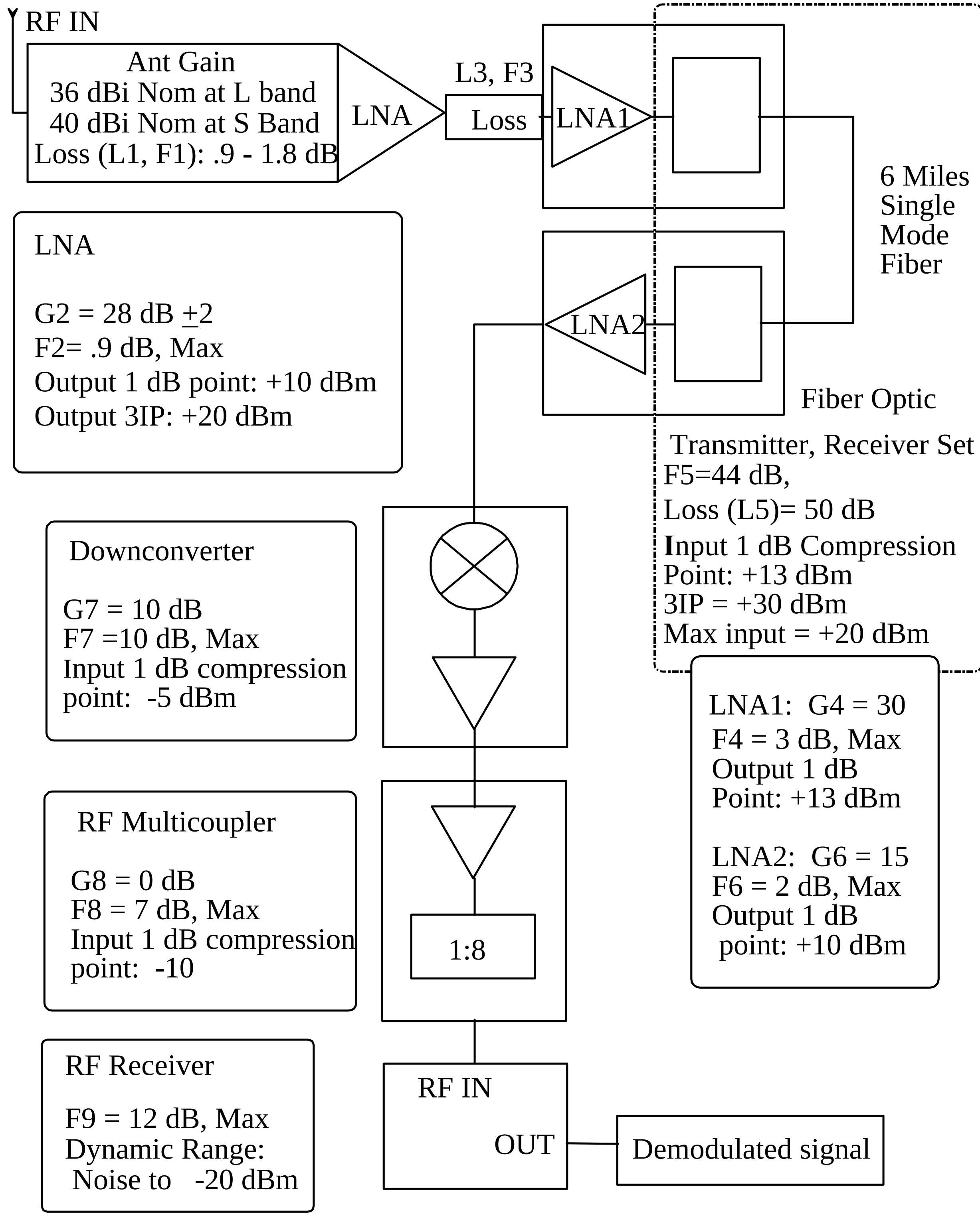

Figure 2. RF Signal Flow After Adding Fiber Optic Transmitter and Receiver

Note that the feed losses were not taken into account. The feed losses were determined from the original contractor equivalent system temperature data. A system equivalent temperature of 199.5 translates into a feed loss of about .9 dB. A system equivalent temperature of 316.2 translates into a feed loss of about 1.8 dB.

Another issue with the feed was the inequality of signal levels from S band to L band signals. From observing input from operations, the L band had much more gain than the other bands. After investigating this phenomena using the boresight, the L band path had about 7 dB more gain than the S band signal path through the feed. After examining the initial contractor data, the feed did have more L band LNA gain but the feed losses in L band are .9 dB while the feed losses in S band are 1.8 dB on the right hand side. Currently, not all the S band losses are known. After examining all data, 4 dB attenuation was inserted into the L band path after the LNA on both polarities.

The fiber optic devices were better on the bench than specified. The RF loss through the fiber optic device is 45 dB on the bench. The fiber optic devices also have a noise figure derived from the specified -160 dBW/Hz noise level. This translates to a noise figure of 44 dB. Since the loss and noise level of the fiber device depends on optical reflections and optical loss, the resulting noise level and loss of the fiber optic transmitter-receiver set is an unknown.

All of this now adds to the estimated system noise and decreases the G/T value. The estimated G/T values are shown in Table 3.

Table 3. Figure of Merit (G/T) Calculated Predicted Values

	G/T (dB/K) from Contractor original data		G/T (dB/K) at remote site - calculated values (Note 1)	G/T (dB/K) at local site with added L3 attenuation - calculated values (Note 2)		
Freq (MHz)	Spec	Meas		3.5 dB attenuation	6.5 dB attenuation	9.5 dB attenuation
1485	10	11.6	11	9.8	8.4	6.5
2250	13.5	13.6	13.2	10.5	8.6	6.2

Note 1: Added 4 dB attenuation after LNA at 1485 MHz, all bands have 3.5 dB of added attenuation due to RF power divider. RF path is similar to the path shown in Figure 1.
Note 2: At 1485 MHz, 4 dB is added to the value. RF path is as shown in Figure 2.

The other requirement was that -40 dBm into the LNA in the feed would not cause any part to go over the 1 dB compression point. Table 4 shows the RF path signal level when attenuator L3 is changed. The RF multicoupler was not included in this calculation because any input over -10 dBm may cause saturation. The multicouplers are old and untested, hence eliminated when determining 1 dB compression point of the system.

Table 4. Input Near 1 dB Compression and the Resulting Signal Level

Input LNA1 (dBm)	At the Receiver Inputs, Figure 1	L3 = 3.5 dB		L3 = 6.5 dB		L3 = 9.5 dB	
		After LNA1	At Local	After LNA1	At Local	After LNA1	At Local
-40	-12 dBm	14.5 dBm*	-5.5 dBm	11.5 dBm	-8.5 dBm	8.5 dBm	-11.5 dBm
-38	-10 dBm	16.5 dBm *	-3.5 dBm	13.5 dBm *	-6.5 dBm	10.5 dBm	-9.5 dBm
-41	-13	13.5 dBm *	-6.5 dBm	10.5 dBm	-9.5 dBm	7.5 dBm	-10.5 dBm
* NOTE: In compression "At Local" measurements are taken at downconverter output.							

With regards to the 1 dB compression point, LNA1 of Figure 2 appears to be the controlling agent. The amplifier was chosen to give maximum range to the signal without overloading the input to the fiber optic transmitter. The fiber optic transmitter has a maximum range of +20 dBm. Therefore, the fiber optic transmitter is the device that controls the dynamic range, since an amplifier is always required in this application.

At this point in the development, there was a possibility that an automatic gain control (AGC) circuit would be installed to make this work, where gain is increased for low level signals, hence lowering the noise figure where needed. The prototype was designed without the AGC circuit.

THE DATA

The data is much better than the predictions. One significant change is the performance of the fiber optic device. This will be shown as the data is revealed. With only the power divider in the path (L3 = 3.5 dB), there were no significant bit errors between the local site and the remote site. The test was performed by radiating a 2250.5 MHz carrier, frequency modulated with a 735 Megabits per second (Mbps) NRZ-L signal. The signal was generated by a link analyzer. The level was reduced until small errors resulted in the link analyzer. There was no significant difference between the local and the remote sites.

Table 4 already revealed a problem when L3 is only 3.5 dB. The system was tested with L3 equal to 6.5 dB and 9.5 in the RF data path. The antenna tracking path, which is similar to Figure 1, has only 3.5 dB attenuation inserted after the LNA. The L band has an added 4 dB attenuation after the feed LNA. To determine the height of the third intermodulation product, signals from two signal generators were mixed through a power combiner and sent up the antenna test line. The input levels were adjusted to -10 dBm at the power combiner inputs. This is close to -40 dBm before the LNA in the feed. Table 5 is the result of the test of the right hand polarization of the feed. As one can see, the L band signals are still higher than the S band levels. The other polarization had similar results.

Table 5. Signals Near 1 dB Compression Point and the Third Intermodulation Products

	Freq (MHz)	Level after feed LNA	L3 = 9.5 dB		L3 = 6.5 dB	
			After LNA1	At Local	After LNA1	At Local
f1	1490	-16.8 dBm	9.9 dBm	-7.2 dBm	12.7 dBm	-4.1 dBm
f2	1500	-17.6 dBm	8.8 dBm	-8.3 dBm	11.7 dBm	-5.1 dBm
2f1-f2	1480	-56 dBm	-11.7 dBm	-28.3 dBm	-2.5 dBm	-19.0 dBm
2f2-f1	1510	-58 dBm	-13 dBm	-29.4 dBm	-3.9 dBm	-20.0 dBm
f1	2250	-17.5 dBm	5.8 dBm	-14.8 dBm	8.7 dBm	-11.6 dBm
f2	2260	-15 dBm	6.9 dBm	-13.0 dBm	9.8 dBm	-10 dBm
2f1-f2	2240	-57.8 dBm	-21.5 dBm	-42 dBm	-12.7 dBm	-32.9 dBm
2f2-f1	2270	-53.8 dBm	-19.1 dBm	-40 dBm	-10.1 dBm	-30.8 dBm
Note: After LNA1 is measured at the remote site.						

There was a signal to noise test performed using the boresight and with L3 = 9.5 dBm. Table 6 displays the results.

Table 6. Signal to Noise with L3 = 9.5 dB

Receiver IF measured at site	Freq (MHz)	Polarity	Signal level at NOTE (dBm)	Receiver IF		S/N (1 MHz)
				Signal (dBm)	Noise (dBm, 100 kHz BW)	
remote	1490.5	LHCP	-56.7	-8.8	-48.4	29.6
	1490.5	RHCP	-56.7	-9.1	-49.5	30.4
local	1490.5	LHCP	-64	-8.9	-48.1	29.2
	1490.5	RHCP	-67.6	-9.1	-47.6	28.5
remote	2250.5	LHCP	-58.9	-9.5	-48.3	28.8
	2250.5	RHCP	-67.0	-8.3	-46.8	28.5
local	2250.5	LHCP	-60.2	-9.2	-46.5	27.3
	2250.5	RHCP	-71.4	-9.4	-44	24.6
NOTE: Signal is measured at the remote site after the feed LNA. Signal is measured at the local site after LNA2 at the local site.						

It is readily apparent that there are variations in the signal to noise ratio from the remote site to the local site. A figure of merit test, known as a gain divided by temperature (G/T) test, was performed at 2250 MHz. There was about 1.5 dB variation between the measurement taken at the local site versus the remote site. Even this variation was lower than predicted by Table 3. L3 was permanently changed to be 6.5 dB. The G/T results as shown in Table 7 are amazing and not true to the predictions. The G/T tests were performed on subsequent days when the sky was clear. The day's temperature was between 65 ^{O}F to 70^{O}F. Each test consisted of three runs. The tests were run at the remote site first, reading the power difference from the IF of a receiver. The G/T test was performed at the local site on the same day.

Table 7. Figure of Merit

Frequency /Polarity	Specified G/T (dB/K)	Record #	G/T, receiver at remote (dB/K)		G/T, receiver at local (dB/K)	
			day 1	Day2	day 1	day 2
1469.5 left	10	1	12.38	12.48	12.48	11.88
		2	12.08	12.48	11.98	12.08
		3	12.28	12.48	12.28	12.08
1469.5 right		1	10.98	11.18	11.38	12.78
		2	10.48	11.28	12.48	11.98
		3	10.88	11.18	11.98	11.88
1784.5 left	11.5	1	12.81	12.81	---	13.4
		2	11.92	12.92	---	13.9
		3	12.42	12.92	---	13.8
1784.5 right		1	12.61	13.01	13.1	14.6
		2	12.02	13.02	13.2	13.8
		3	12.53	13.03	14.4	13.7
2234.5 left	13.5	1	13.55	14.05	14.45	14.65
		2	12.95	13.95	13.95	14.25
		3	13.35	13.95	13.85	14.35
2234.5 right		1	13.75	14.15	14.25	13.95
		2	13.35	14.15	13.75	13.75
		3	13.85	14.15	14.65	14.35
2334.5 left	Not specified	1	15.57	15.27	14.37	12.47
		2	13.87	14.97	14.07	14.07
		3	14.97	15.07	14.17	11.57
2334.5 right		1	14.97	15.47	12.47	11.37
		2	13.97	14.97	12.87	10.77
		3	14.87	13.77	9.57	9.67
--- denotes no data possible. Loose cable found.						

It is recognized that G/T tests have about half a decibel of error. The G/T results clearly show that the fiber optic devices are performing much better than specified. Where signal flow has been measured, the fiber optic receiver-transmitter set does have 45 dB of loss. The improvement must be in the noise figure of the fiber optic receiver-transmitter set. However, the Hi-S band at 2334.5 has generally lower figures of merit as measured in the local site than as measured in the remote site. The figures of merit for day 2 seem a bit higher than day1. The day 1 solar flux values were used for day 2, as day 2 values were not available on the Internet for a few days. Although knowing the G/T value is good, consistency is more desired for comparison purposes.

CONCLUSION

The prototype system works. The figure of merit results were very pleasing, however, the discrepancy between the calculated G/T predictions and the actual working system will require further investigation. With this design, the amplifiers before the fiber optic transmitter-receiver set determine the 1 dB compression point. However, the fiber optic transmitters control how many RF signals can be applied to them, hence controlling the selection of the amplifier.

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