SIGNAL TRANSMISSION FROM REMOTE TELEMETRY ANTENNAS USING WIDEBAND ANALOG FIBER OPTIC LINKS

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ABSTRACT

This paper will present the results of an investigation of the feasibility of using broadband analog fiber optic technology to send telemetry antenna outputs from remote sites to a central site. The fiber optic hardware consisted of a prototype analog fiber optic transmitter and receiver plus 10 km of single-mode fiber. Laboratory tests were performed to simulate the performance in the real-world. The fiber optic system had a noise figure of 33.5 dB and a third order intercept point of 16.75 dBm. The use of this fiber optic system to transmit a 215-320 MHZ telemetry antenna downconverter output over a 10 km fiber would only degrade the quality of real-world telemetry signals by a few tenths of a decibel. Key words: analog fiber optic transmission, remote telemetry antennas.

INTRODUCTION

The Pacific Missile Test Center is installing new telemetry receiving antennas on Laguna Peak and San Nicolas Island. These antennas are located at unmanned remote sites at distances up to 10 km from the main telemetry receiving sites. Each antenna will be able to receive signals in four separate frequency bands (1435-1540, 1750-1850, 2200-2300, and 2310-2390 MHZ). The bands are separated in the antenna pedestal and each band is applied to a separate downconverter. The output frequencies of all downconverters are between 215 and 320 MHZ. Telemetry receivers can be used to convert the downconverter outputs to relatively narrow band predetection signals. The telemetry receivers can also demodulate these signals. The receiver predetection and demodulated outputs can be sent to the main sites using off-the-shelf baseband fiber optic systems. There are several advantages to sending the antenna outputs rather than the receiver outputs. These advantages include: less hardware at remote sites, antennas can be used to receive more signals because all of the receivers at the main site are available, and wide band telemetry signals can be processed by installing wide band receivers at the main site only. One disadvantage of sending the antenna outputs rather than the receiver outputs is the large dynamic range of the telemetry signals at the antenna output. This variation is illustrated in figure 1. The variation in received signal power can exceed 70 dB. Off-the-shelf fiber optic systems do not have the dynamic range to handle real-world telemetry signal level variations. The purpose of this task was to determine the ability of custom fiber optic systems to transmit real-world telemetry antenna outputs.

The advantages of optical fiber compared to coaxial cable include lower loss and smaller size. The optical loss of fiber optic cable at a wavelength of 1300 nm is only 0.5 dB/km (an optical loss of 0. 5 dB/km is equivalent to an electrical loss of 1 dB/km). The loss of 1. 625 inch diameter coaxial cable is 13.2 dB/km at a frequency of 300 MHZ and 33 dB/km at a frequency of 2000 MHZ.

Fiber optic technology is currently being used to distribute cable television and satellite earth station signals [1]-[5]. These applications have some similarity to aerospace telemetry. However, they are much easier applications because the signals have nearly constant amplitudes.

This task was divided into two phases. The first phase studied the feasibility of sending the antenna downconverter outputs (215-320 MHZ) over 10 km of nine micron diameter single-mode fiber optic cable. The second phase will investigate the feasibility of sending the 1435-2400 MHZ band over a single fiber. This paper presents the test results of the first phase.

One limiting factor on dynamic range is the very high noise figure of fiber optic links. Typical values are in excess of 40 dB. The main causes of noise in a fiber optic system are laser relative intensity noise (RIN) and detector noise. The degradations in receiving system noise temperature for several combinations of gain before the fiber optic transmitter and fiber optic noise figure are shown in figure 2. The excess noise generated by the fiber optic system (referenced to the preamplifier input) can be calculated by dividing the noise temperature of the fiber optic system by the net gain between the preamplifier input and the fiber optic input. The required difference (dB) between the net gain and the fiber optic noise figure can be calculated using

$$G_{AMP} - NF_{FO} = 10LOG_{10}\left(\frac{290}{T_S} \times \frac{1}{10^{\frac{D}{10}} - 1}\right)$$

where:

NF_{FO}	= noise figure (dB) of fiber optic system
G_{AMP}	= net gain (dB) between preamplifier input and fiber optic input
T_S	= receiving system noise temperature (K)
D	= allowable degradation (dB) in receiving system sensitivity.

If the receiving system noise temperature is 250 K and the maximum allowable degradation is 0.3 dB, the gain before the fiber optic transmitter must exceed the fiber optic system noise figure by 12.1 dB. A reasonable value for gain is 46 dB. Therefore, the maximum allowable noise figure is approximately 34 dB (noise power of -80 dBm/MHZ or -140 dBm/Hz).

Another factor which limits dynamic range is system linearity. The modulation and detection processes must be linear over a wide dynamic range. The modulation process is the main source of nonlinearity in current analog fiber optic systems. Extraneous signals will be generated if any nonlinearities are present. The linearity is typically specified in terms of the third order intercept point (the point at which the third order products would have the same amplitude as the input signal). The expected power in the intermodulation products is equal to three times the input power minus two times the third order intercept point. A third order intercept point of +18 dBm and two input signals with power equal to -15 dBm would result in intermodulation powers of -81 dBm (3(-15) - 2(18)). This is approximately equal to the noise power density per MHZ of a fiber optic system with a noise figure of 34 dB.

TEST RESULTS

A prototype wide band analog fiber optic transmitter, receiver, and 10 km of single-mode fiber were ordered in 1989. The critical specifications included:

frequency band:	215-320 MHZ
bandpass ripple:	±2 dB maximum
third order intercept:	≥18 dBm
1 dB compression:	≥dBm
spurious response:	≤-85 dBm (3 kHz bandwidth)
noise figure:	≤34 dB (-140 dBm/Hz)
link distance:	10 km

The initial hardware had a noise figure of approximately 49 dB and was somewhat unstable with small input signals and less than 60 dB of amplifier gain in front of the fiber optic transmitter. This instability is illustrated in figure 3. The hardware was returned to the contractor. The contractor determined that this problem was caused by reflected energy being fed back to the laser output. The contractor applied index matching fluid to the connectors and replaced the laser with a higher power laser (output power of new laser was 2 mW).

The modified hardware has a noise figure of 33.5 dB, is stable with 40 to 56 dB of amplifier gain before the transmitter, and has a third order intercept point of 16.75 dB. These values are similar to the values presented in reference [6] for direct modulation.

The fiber optics transmitter uses a 1300 nm distributed feedback (DFB) InGaAsP laser diode. The laser is kept at a constant temperature using a thermoelectric cooler. The data is applied to the optical signal using direct intensity modulation. The laser output is connected to an anti-reflection isolator. The 10 km spool of cable was connected to the receiver and transmitter using ST connectors. Fusion splicing would probably be used in the actual application. The optical detector is an InGaAs PIN diode.

The system does have some low frequency spurious components with no input signal and no microwave amplifier before the fiber optic transmitter. However, the system will never be used in this mode. No spurious signals were detected when the gain before the fiber optic transmitter was at least 40 dB. DFB laser diodes have narrow spectral occupancy when no modulation signal is applied. The modulation broadens the output spectrum. This spectral broadening reduces the coherence of the reflected signal which minimizes the spurious signal problem with the DFB laser diode [7]-[10]. This hardware meets our specifications in all areas except third order intercept point. The lower intercept point would only cause a 2.5 dB increase in intermodulation product levels when two or more very strong signals are present in any 100 MHZ wide telemetry band. Predicted intermodulation levels are shown in figure 4 for both the specified intercept point and the measured intercept point. This data shows that the degradation is small. The predicted intermodulation power is insignificant (below -80 dBm) for ranges in excess of 32 statute miles with a transmitter effective radiated power (ERP) of 34 dBm. The gain of the fiber optic system was flat within ±0.4 dB.

The setup for static bit error rate (BER) testing of the fiber optic system is shown in figure 5. This setup simulates the real-world receiving systems. The effect of the fiber optic system on bit error rate is shown in figure 6. The data in this chart shows that the fiber optic system degraded the overall performance by approximately 0. 15 dB with 46 dB of gain before the fiber optic transmitter. The degradation was approximately 0.5 dB with 40.5 dB of gain before the fiber optic transmitter. The calculated degradations are 0.14 dB and 0.48 dB respectively (the test system noise temperature was 500 K). BER tests were also performed with 25 dB fades. The degradation caused by the fiber optic system was approximately the same with fading as with static signal levels. The fiber optic system had no noticeable effect on noise power ratio values with a gain of 46 dB before the fiber optic transmitter.

CONCLUSIONS

Fiber optic technology is capable of transmitting antenna downconverter outputs for distances of 10 km with only a small degradation in data quality. The main problem is the wide dynamic range of the telemetry signals. The gain before the fiber optic system and the fiber optic system noise figure and third order intercept point must be optimized to minimize signal degradation. The dynamic range of state-of-the-art wideband fiber optic systems is not as large as the dynamic range of good telemetry equipment. Therefore, wideband fiber optic systems modulated by antenna outputs will be more susceptible to degradation from large undesired signals than will fiber optic systems modulated by receiver outputs. The best system for transmitting signals from remote antennas may include both receivers plus multiplexed baseband fiber optic systems and wideband fiber optic systems.

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ACRONYMS AND ABBREVIATIONS

The following acronyms and abbreviations were used in the figures contained in this paper.

AMP	Amplifier
BER	Bit Error Rate
ERP	Effective Radiated Power
FO	Fiber Optic
G	Gain
G/T	Gain/Temperature
NF	Noise Figure
NO FO	No Fiber Optic
RF	Radio Frequency

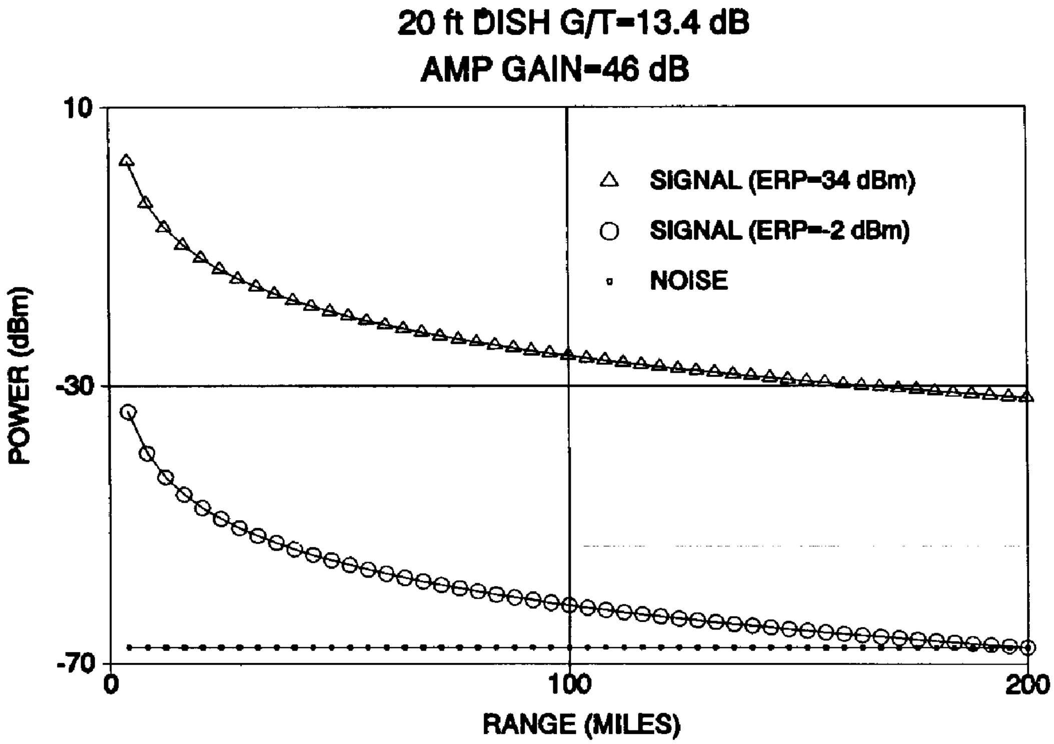

Figure 1. Received Signal and System Noise Power.

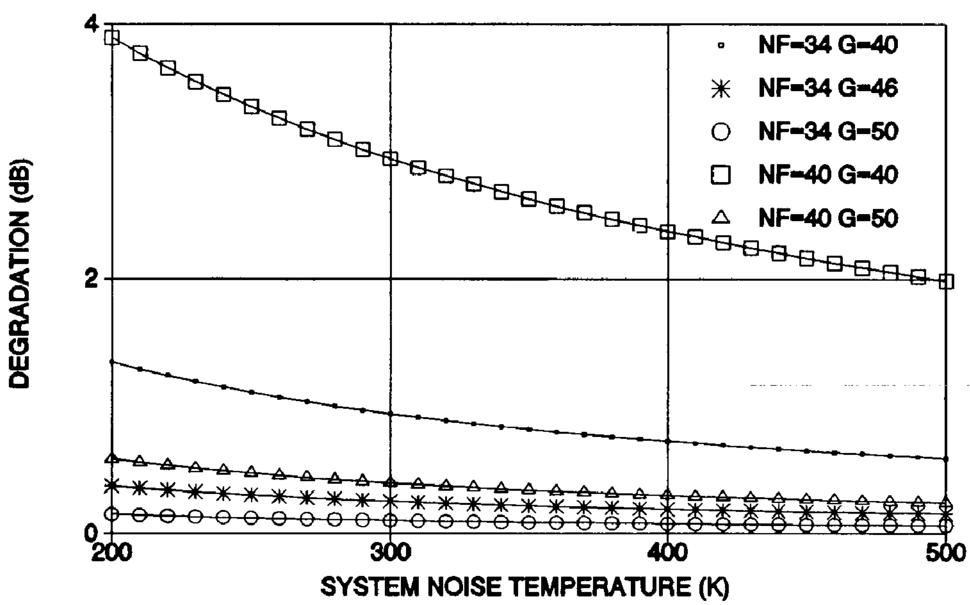

Figure 2. Calculated Degradation in System Sensitivity.

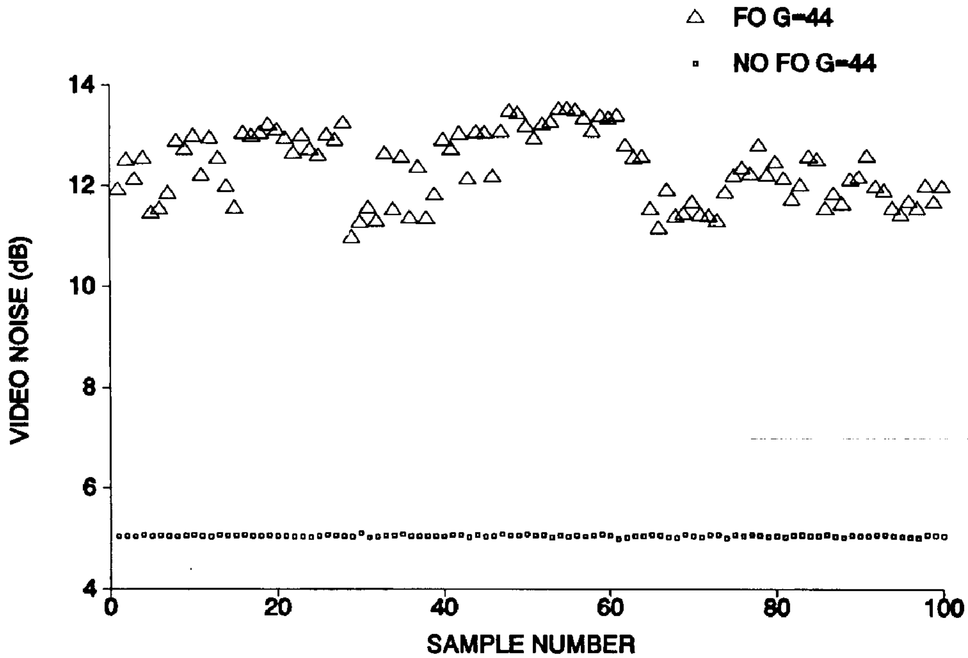

Figure 3. Receiver Video Noise Level Instability.

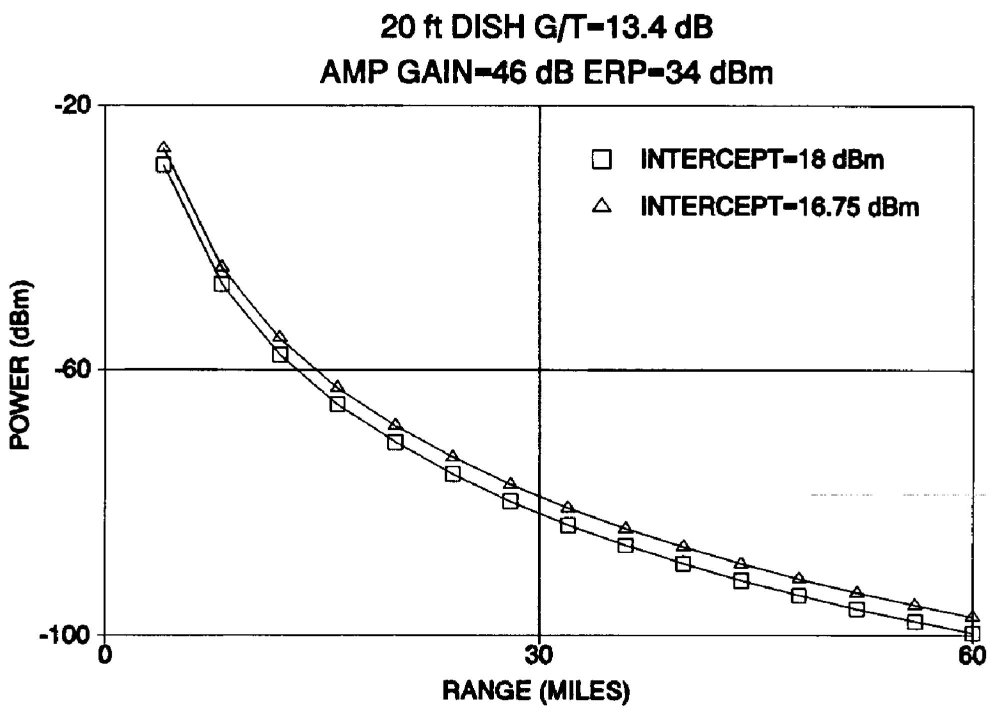

Figure 4. Predicted Intermodulation Power.

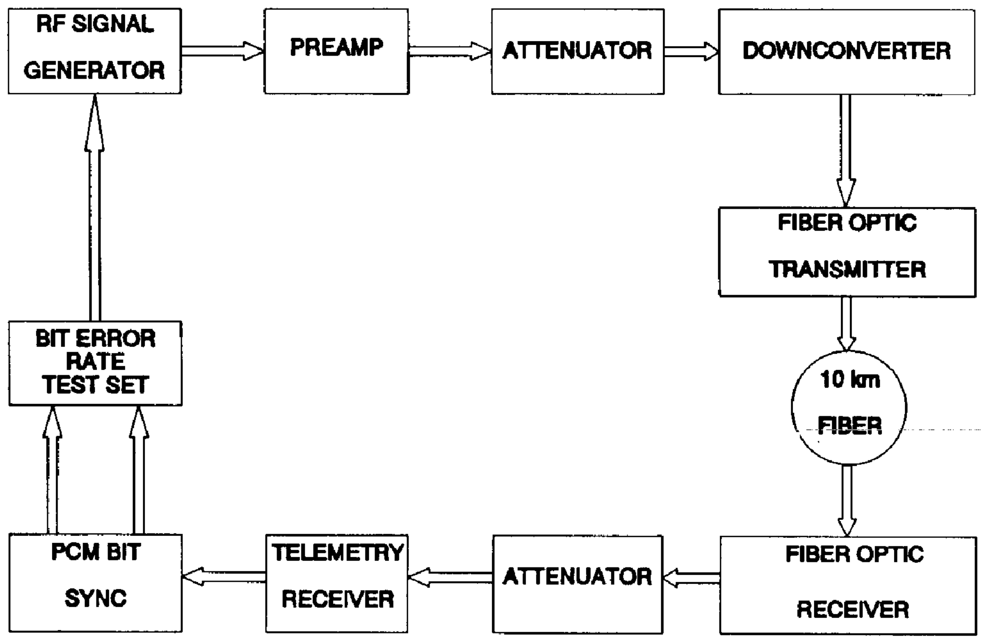

Figure 5. Test Setup for Bit Error Rate Test.

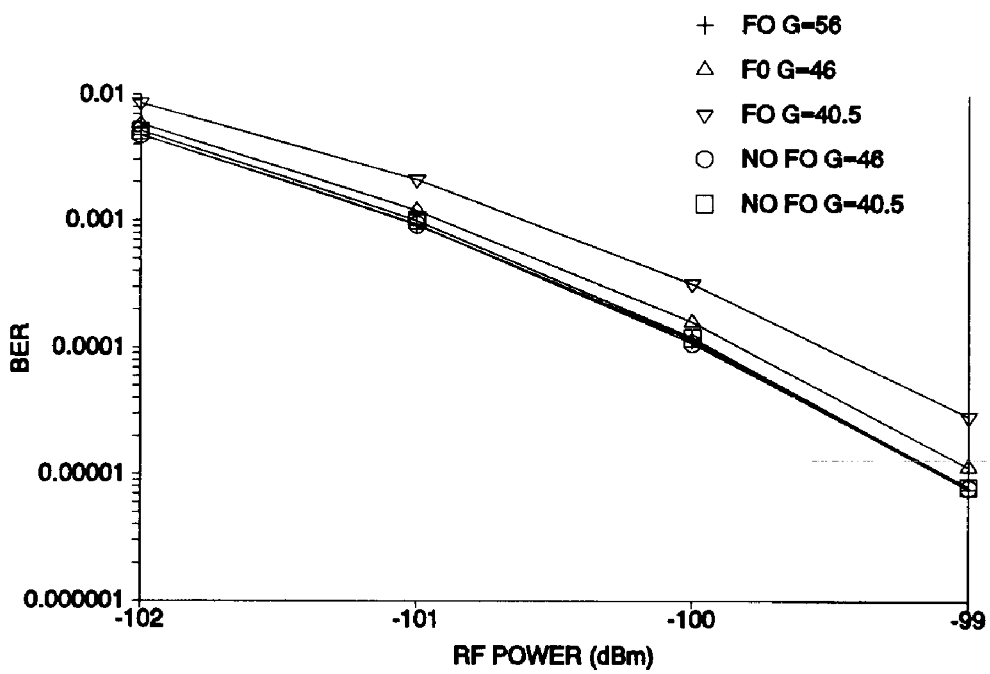

Figure 6. Bit Error Rate Data.