# Field Demonstration of Photonic Antenna Remoting at X-Band in the NASA Deep Space Network

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## ABSTRACT

We report on the successful demonstration of antenna remoting at X-band using a low
phase noise and high dynamic range fiber optic link in an operating antenna receiving
system, while tracking Magellan spacecraft. The insertion of the fiber link into the existing
system adds no observable degradat ion in noise temperature to the system. We compare
the experimental results with our theoretical predictions of degradat ions in noi se
temperature and d ynamic range of the system caused by the insertion of the fiber link.

## INTRODUCTION

1ligh speed and high dynamic range externally modulated fiber optic links for antenna
remoting applicat ions have been demonstrated in the laboratory environment.] We report
here on the successful field demonst ration of a fiber optic link that can directl y t ransmit X-
band (8.4(31 lz) microwave signals from an antenna site to a remote signal processing
facility, in a operating NASA deep space communication complex. This demonstration is
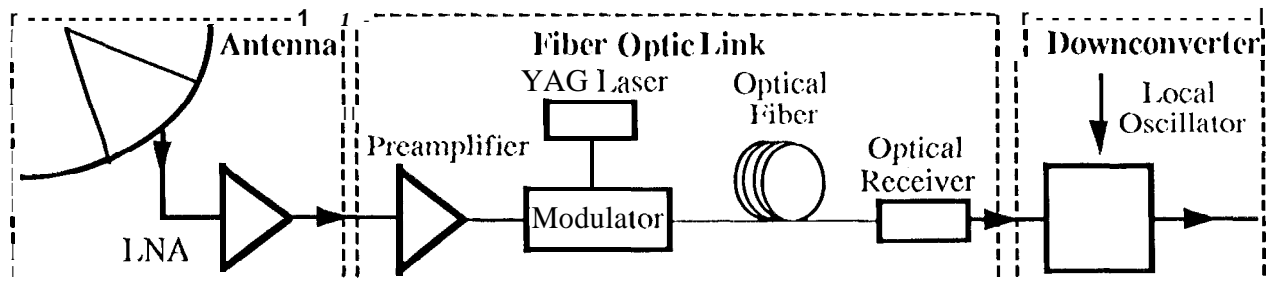critical for implementing photonic antenna remoting in the NASA I )ccp Space Network.



Fig . 1

The optical link consists of a diode-pumped YAG laser, an 18GIIz LiNbO3 modulator, an
RF preamplifier, and a 12 G] Iz opt ical receiver. It is designed to be inserted bet wccn the
low noise amplifier and the down-converter in a current NASA/JPL Deep Space Network
antenna receiving system, as shown in Fig. 1. This link will permit the down-converter and
related equipment to be moved out of the antenna to the signal processing center, and will
substantially reduce the amount of equipment located at the antenna area, in systems with
multiple, widely separated antennas, this new configuration will lower hardware and
operating cost, and increase performance, flexibility, and reliability.

The ultimate requirement of the optical link for antenna remoting is that the link is
"transparent" in the existing system. That is, the insertion of the optical link does not
change the system's noise temperature, dynamic range, and gain profile significantly.

## SYSTEM EVALUATION

We first evaluated the optical link in the laboratory. The phase noise of the optical link was
measured to be less than -110 dBc/Hz at 1 Hz from the carrier frequency of 8.4 GHz, and

the measurement was limited by the noise floor of the measurement system. This phase noise is 56 dB below the local oscillator phase noise specification of the Deep Space Net work and is adequate to coherently array multiple antennas. With 12 kilometers of single mode fiber between the modulator and receiver, the photocurrent in the load resistor of the optical receiver was $I_{ph} = 0.25$ mA. Higher photocurrent was necessary to maintain the dynamic range of the system, as shown later. Our YAG laser had an internal noise reduction circuit that reduced the relaxation oscillation noise peak by more than 35 dB and the final **RIN** noise peak was measured to be $RIN(f_{RLX}) = -135$ dB/Hz. Our analysis indicated that such a noise reduction was necessary for our system. Due to the high $V_\pi$ (about 30 volts) of the modulator used in our optical link, the RF insertion loss $G_{op}$ is high, about -60 dB. The frequency response of the link was very flat from 130 MHz to 10 GHz. The preamplifier with a gain of 60 dB and a noise factor of $F_{pr} = -2$ was used to compensate for the loss. The loss-compensated optical link had a gain of unity and its frequency response was determined by the preamplifier.

We next evaluated our optical link at S-band in a test facility which simulated the operation conditions of a real antenna receiving system in the Deep Space Network. The test showed that the insertion of the fiber optic link added no observable degradation to the receiving system.

Finally, we evaluated our optical link at an operating antenna receiving station (DSS-13) of NASA's Deep Space Network in Goldstone California, while Magellan spacecraft was tracked. As shown in Fig.1, the optical link was inserted between the low noise amplifier and X-band downconverter, both of which were located at the pedestal room of the antenna. A 12 km spool of single mode fiber was used to simulate the path between the antenna and the signal processing center. When the fiber optic link was inserted, there was no change of the received spacecraft signal level at 8.426 GHz. We also measured the noise temperature of the system before and after the insertion of the optical link and found no observable difference. The dynamic range degradation of the system was not measured due to the time and equipment constrains.

in these experiments, the gain of the low noise amplifier of the receiving antenna was $G_{LNA} = 36$ dB and the input noise temperature was $T_{LNA} = 36.8$ K. The temperature at the input of the optical link was $T_{op} = 290$ K. The input third order intercept point and 1 dB compression of the system before inserting the optical link were $IP_{sys} = -47$ dBm and $P_{sys}^{1dB} = -62$ dBm respectively. They were limited by the X-band downconverter of the system. The corresponding 1 dB compression dynamic range of the system was $D_{sys} = 121$ dB/Hz.

## SYSTEM ANALYSIS
### The Requirement of the Preamplifier
The RF insertion loss $G_{op}$ (or gain) of the optical link without preamplifier is:[2]

$$G_{op} = \pi^2 \frac{I_{ph}^2 R_L}{(V_\pi^2/R_m)} \tag{1}$$

where $R_m$ is the input impedance of the modulator and $R_L$ is the load impedance of the receiver. In Eq. (1), the numerator is the electrical power generated by the photocurrent in the receiver and denominator is the input electrical power to the modulator with a

modulation voltage of $V_\pi$. In order to have unity gain for the loss-compensated link, $G_{pr} = 1/G_{op}$ is required. On the other hand, to ensure that the preamplifier does not limit the dynamic range of the system,[3]

$$IP_{pr} \gg 4I_{ph}^2 R_L \qquad (2)$$

is required. For a of $V_\pi$ of 10 volts, $I_{ph}$ of 1 mA, and $R_L$ and $R_m$ of 50 Q, the gain of the preamplifier is required to be 36 dB and the input third order intercept to be much larger than -7 dBm. The corresponding output intercept point should be much larger than 29dBm. Output intercept point of 40 dBm is common for amplifiers with a gain of 36 dB. Therefore, commercial amplifiers can easily meet the requirements on the gain and intercept point.

Dynamic Range Degradation Caused by the Optical Link
From our analysis, the degradation $\Delta(SFD_{sys})$ of the spur-free ynamic range of the system caused by the insertion of the optical link can be expressed as:[3]

$$\Delta(SFD_{sys}) \approx 6.7 \log(1 + G_{LNA} IP_{sys}/4I_{ph}^2 R_L), \qquad (3)$$

Using our experimental parameters of $G_{LNA} = 36$ dB, $IP_{sys} = -47$dB, and $I_{ph} = 0.25$ mA, the dynamic range degradation $\Delta(SFD_{sys})$ is 5.8 dB. in order for $\Delta(SFD_{sys})$ to be less than 1 dB, the photocurrent must be:

$$I_{ph} \geq 0.8\sqrt{G_{LNA} IP_{sys}/R_L}. \qquad (4)$$

]n our antenna system, the minimum required photocurrent from Eq. (4) is 1 mA.

From Eqs. (3) one can see that the photoelectric power ($= I_{ph}^2 R_L$) is the only parameter of the optical link that affects the dynamic range of the system. This parameter also determines the gain of the optical link and restricts the third order intercept of the preamplifier, as shown by Eqs. (1) and (2). On the other hand, the choice of modulator does not affect the system's dynamic range if it is not drive level limited, It only affects the gain of the preamplifier.

Noise Factor Degradation Caused by the Optical Link
The noise factor increase. $\Delta F_{op}$ of the system caused by the optical link peaks at $f_m \pm f_{RLX}$ and can be written as:[3]

$$\Delta F_{op} \approx (T_{op} F_{pr} + 1160 I_{ph} + 116 I_{ph}^2)/T_{LNA} G_{LNA} + SNR_{sys} RIN(f - f_m)/4, \qquad (5)$$

where $SNR_{sys}$ is the signal to noise ratio at the input of the low noise amplifier, $f$ is the frequency of interest, $f_m$ and is the modulation frequency. in Eq. (5), the first term is the noise factor contribution from the preamplifier, the second term is from the shot noise of the optical link, the third term is from the base band RIN noise of the laser (assuming a RIN of -165dB/Hz), and the last term is from the RIN noise peak at low frequency. The RIN noise Peak of the YAG laser is caused by the relaxation oscillation and has a frequency, $f_{RLX}$,

around a few hundred kHz. When the laser light is modulated by the microwave signal, this noise peak is multiplied up around the modulation frequency $f_m$. The larger the modulation signal, the larger the multiplied RIN noise peaks.

At low modulation levels, such as in the case of the experiment, the contribution to the noise factor from the multiplied RIN noise is small. The noise factor (temperature) degradation of the system can be calculated using Eq. (5) to be 0.75% (or 0.032 dB), using the experimental parameters given previously. Such a degradation indeed is not measurable and is consistent with the experiment. At high modulation levels, the contribution from the multiplied RIN noise peaks become more important around $f = f_m \pm f_{RLX}$. Because the largest signal to noise ratio of the system is the dynamic range $D_{sys}$ of the system, the maximum $\Delta F_{op}$ is obtained by replacing $SNR_{sys}$ with $D_{sys}$ in Eq. (5). With experimental parameters $RIN(f_{RLX}) = -135 dB/Hz$ and $D_{sys} = 121 dB/Hz$, the noise factor contribution from the multiplied RIN noise peaks is 1% at $f = f_m \pm f_{RLX}$ and the total noise temperature degradation is 1.75% (or 0.075 dB). If we increase the photocurrent to 1mA, the noise factor degradation caused by the first three terms in Eq. (5) is 1.6% (or 0.07 dB) and the maximum $\Delta F_{op}$ at $f = f_m \pm f_{RLX}$ is thus 2.6% (or 0.1 dB). With this photocurrent, the dynamic range degradation is only 1 dB from Eq. (3).

## CONCLUSION

We successfully demonstrated fiber optic antenna remoting capability at X-band in an operating antenna receiving system in the NASA/JPL Deep Space Network and found no observable degradation in noise temperature caused by the inset-lion of the fiber link. We also presented analytical results to predict noise temperature and dynamic range degradation of the system caused by the insertion of the fiber link. We fount] that photoelectric power is the only parameter of the optical link that affects the dynamic range of the system, and that relaxation oscillation RIN noise. peak of the laser cent ributes significant y to the total noise factor degradation of the system.

## ACKNOWLEDGMENT

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