



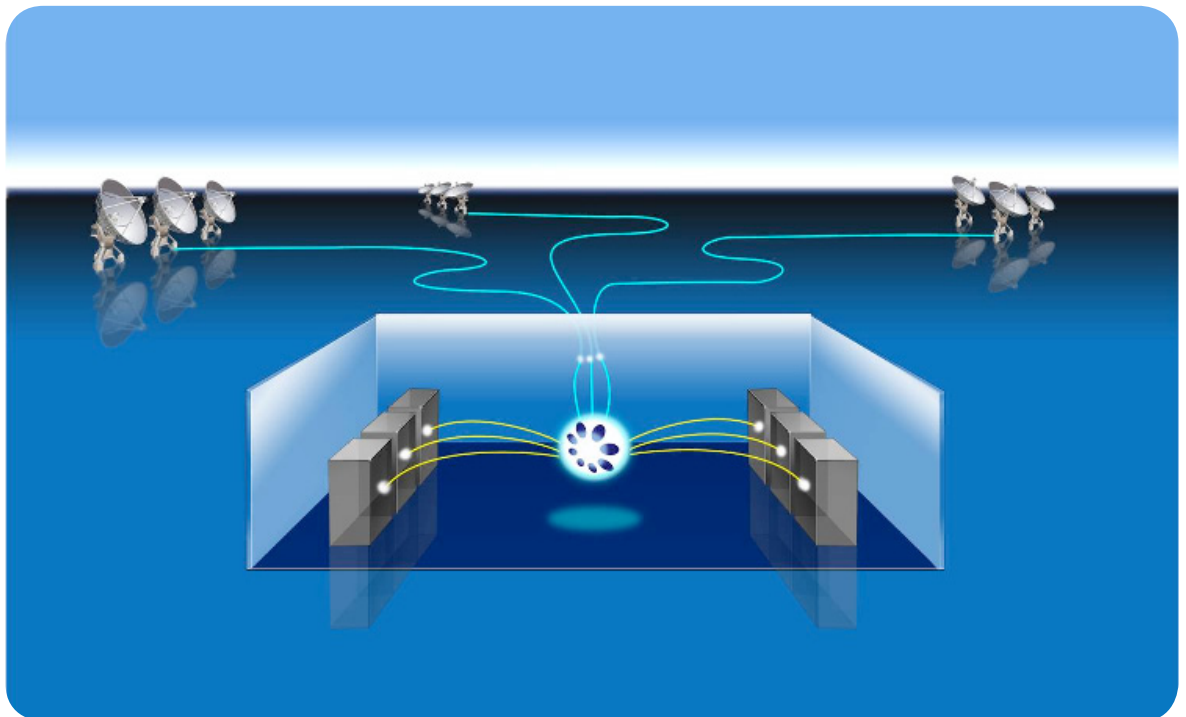
US Agency

Create

Monitor

Reconfigure

The benefits of using fiber for data transmissions are significant and undisputed. However, RF engineers have believed that fiber optics delivers lower dynamic ranges with higher cable costs compared with coax. This belief has limited fiber's deployment to RF applications where long distance transmissions were beyond coax's capabilities. Today, a new generation of coax-to-fiber converters combined with Glimmerglass Intelligent Optical Systems are producing extraordinary results, delivering better dynamic ranges with very low noise figure levels - at a lower overall system cost. This study looks at one example implementation.



The Problem

One large US federal systems integrator discovered the benefits of using this fiber-optic technology combination first hand in its design of a system to dynamically connect RF receivers to antenna arrays with each antenna array having multiple band outputs. The system, intended for use by a government customer, was facing budget constraints. The system had to receive signals from multiple band antenna feeds coming from multiple antennas for a broad spectrum of frequencies up to 18GHz. The system had to connect multiple receivers to any single octave band in the array at different times. The over \$100,000 cost of each broadband microwave receiver that could operate over a large range was a problem. Equipment costs alone could have made the project unaffordable within the available budget if done in the traditional manner where the microwave frequency receivers are colocated close to the antennas.

Solution Architecture

Senior Technical Manager Bruce Mead and his systems engineering team theorized that, by using fiber and sharing assets via an optical switch, they could use fewer total receivers in a pooled asset configuration. In the conventional solution, the receivers and an RF switch are placed close to the antennas and the IF routed over the long coax cable runs through an IF switch to the processing subsystem. Instead, in the approach for the system paths the design team settled on, the fiber transmitters would be located as close to the antenna feed LNAs (low noise amplifiers) as possible, right where the paths were divided into bands. The remainder of the equipment including the optical switch would be located in the relatively benign environment of the operations center. The longest distance between an antenna array and the operations center was 1000 feet. Other runs were shorter but also significant distances. Unlike coax, fiber can transmit RF cleanly over this distance without sustaining massive losses, allowing them to bring the RF signals all the way back to the receiver in the operations center. The expensive receivers did not need to be positioned out by the antenna arrays.

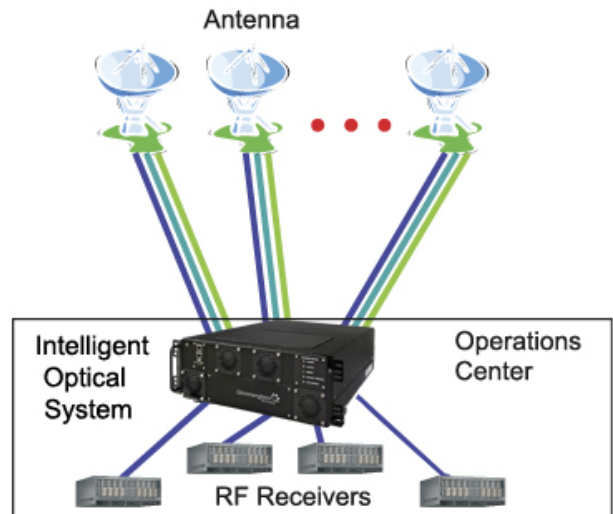


Figure 1. Solution architecture

This concept however, required some leaps of faith that flew in the face of traditional RF design thinking.

- First, conventional wisdom stated that you could only get 40 to 45dB of dynamic range out of singlemode fiber. Could fiber support the required two tone third order dynamic range of at least 50dB in a 1MHz band width?
- Second, transmissions from each of the antennas needed to be connected and distributed to up to four receivers simultaneously. Conventional RF switches that are non-blocking, full fan-out, are very expensive, especially to support high dynamic ranges and this frequency range. Could an optical switch with optical splitters do the job?
- Third, the need to multicast RF signals optically and connect them to multiple receivers simultaneously required amplification in the light path, adding additional cost and noise. Could an optical amplifier perform at an affordable price and not add too much noise to the paths?
- Fourth, could the solution exhibit the very low noise figure performance (< 5dB) needed for signals traversing the 1000' distance, passing through the RF-to-fiber converters, through the optical amplifiers, moving through the optical switch to the fiber receiver and then to each RF receiver?

RF-to-Fiber Converter Selection

The key question was: Could the required sensitivity and dynamic range goals of the program be met? A few years ago, singlemode fiber could not even be considered for links much above 3GHz. Today, however, fiber links are available up to 50GHz with outstanding performance. The conventional wisdom was that fiber is good but you cannot get more than about 45dB of two tone dynamic range out of it and the program required a minimum of 50dB two tone dynamic range in a 1MHz band width.

An investigation found that at least two of the RF over fiber equipment vendors had equipment that appeared to just make the 50dB minimum when the specification sheets values were put into a standard RF cascade analysis. So, risk reduction demonstrations were scheduled with both vendors. During these demonstrations both vendors' equipment exceeded the 50dB two tone dynamic range requirement.

Proof of Concept

A risk reduction test was assembled consisting of singlemode fiber, RF-to-fiber converters, an optical amplifier at 1550 nanometers and a Glimmerglass Intelligent Optical System. To assist in this first-of-a-kind test, Glimmerglass sent two engineers along with its system to the test site. In turn, Mead invited an ace field engineer, known for his skill and ability to fix difficult problems. He was ultimately the person who would have to install the solution at the customer's site and do the final system sign off. It was important that he truly believed that the approach was going to meet its goals. At the conclusion of the first test, the engineer said:

“This is the finest RF performance I’ve seen in 35 years. We don’t need to do any more testing. They’ll get even better performance in the field.”

He had just witnessed dynamic ranges of between 63 to 70dB at 20Mbps of receiver bandwidth, utilizing 1MHz resolution bandwidth on the spectrum analyzer, with no significant amplitude variation over the various fiber spans ranging from 650 to 1000 feet.

System Performance

The system delivers 62dB of dynamic range at 18GHz. This is more than 10dB better than anyone had ever seen using a conventional coax system with even half of these distances. The system's amplitude variability is also tiny compared with coax approaches, only 1dB in signal amplitude variation over the entire 12 to 18GHz band. Traditional systems would see a very significant gain slope over this band. With coax, a broadband IF requirement of 500MHz or more would force the use of amplitude equalizers to flatten the IF bandwidth.

System receiver sensitivities ranged from -110 to -104dBm, better than what Mead could get injecting from the signal generator directly into the back of the receiver. The low noise figure LNA and residual gain in the path resulted in a total noise figure through the receiver to its 160MHz IF output of 3.2dB. The RF paths met their goals and then some. Two tone dynamic ranges varied from 54dB to 73dB with the majority of the measurements falling in the mid 60dB range.

For example, in the 12 – 18GHz band of the LNA input to the 160 MHz IF output of the receiver, tests show a noise figure across the octave of 3.2dB over a 1000' fiber run from the antenna. A 3.2dB noise figure with tangential sensitivities around minus 109dBm and a total gain variation of ± 1 dB, that's a hard combination to beat. Figure 2 shows a sweep of the 12 – 18GHz path with a noise figure test set from the LNA input to the RF input connection at the back of the receiver. Note that the noise figure is ≈ 1.7 dB across the band and the gain is relatively flat at between +12 and +13dB.

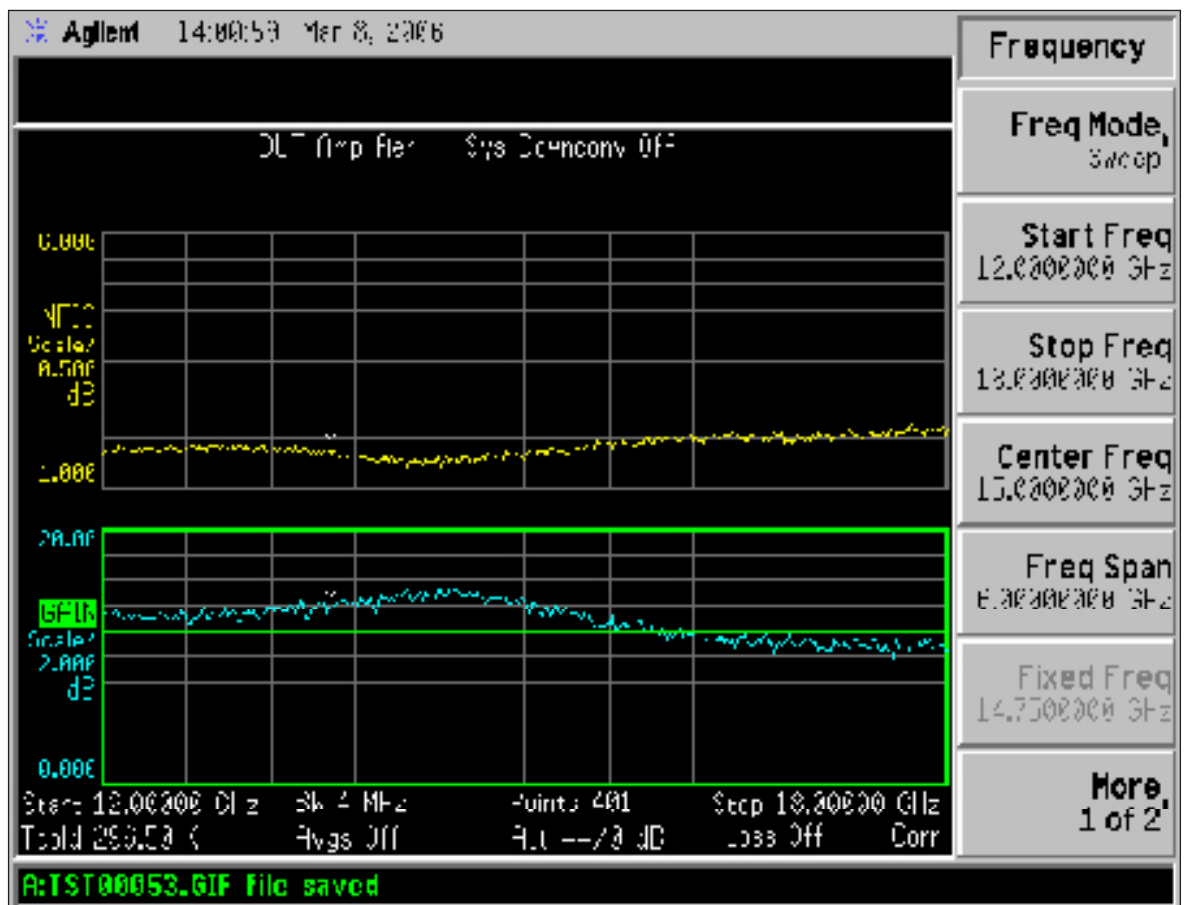


Figure 2. Noise Figure Measurement

Results Analysis

A cascade analysis of this path using the actual measured values for the components shows an overall noise figure through the receiver to the IF output of 3.2dB, as show in Figure 3 below, which matches what was measured through the receiver in the actual path.

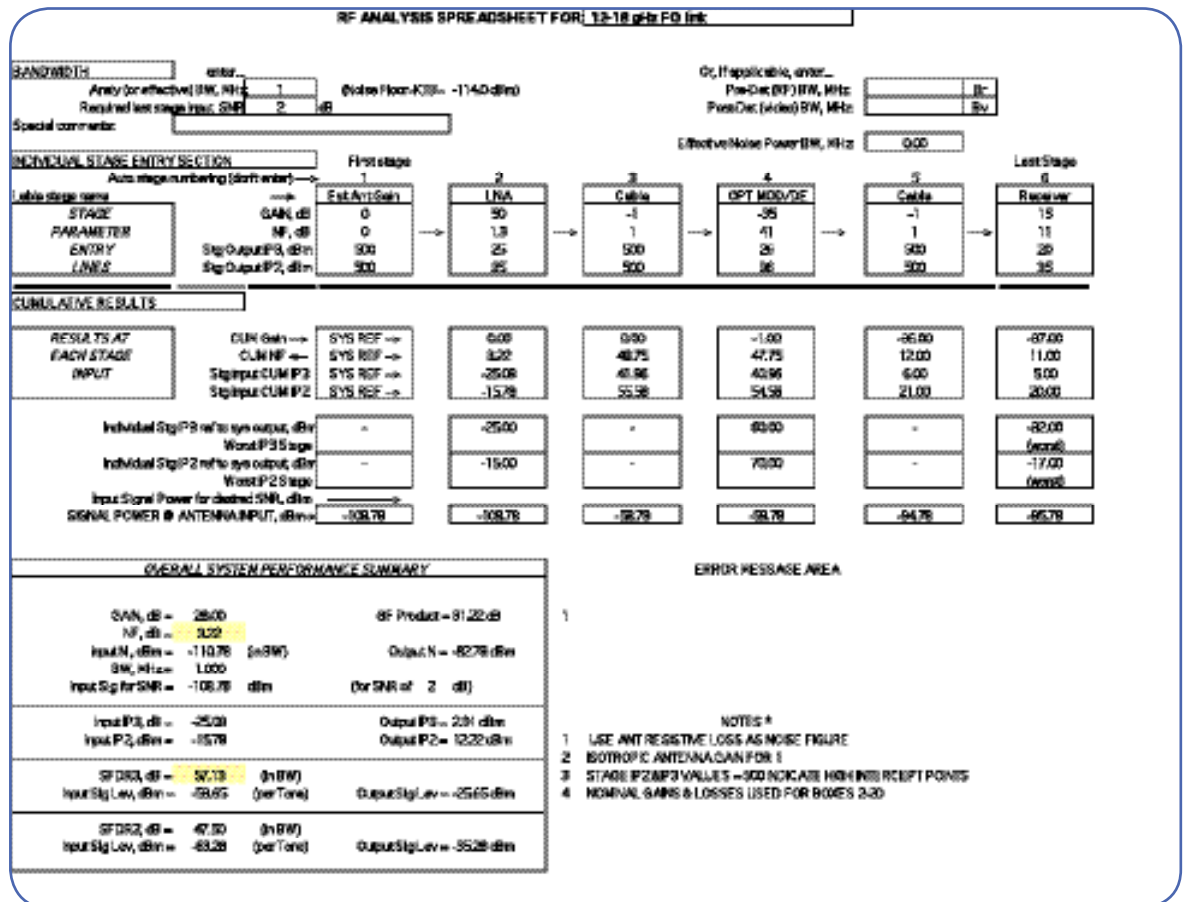


Figure 3. Cascade Analysis

In addition, considering the formula:

$$\text{Noise floor} = \text{noise figure of the path (LNA to receiver IF out)} + 10 \log \text{resolution bandwidth} - 174.$$

For this system:

$$\text{Noise floor} = 3.2 + 60 - 174 = -110.8 \text{ dB}$$

and the measured results show the signal at around -109dB emerging from the noise in a 1MHz resolution bandwidth on the spectrum analyzer. This is again about what the cascade analysis predicts.

In retrospect, hindsight is always 20/20. Doing the cascade analysis using the measured performance of all the components rather than the specification sheet values of the components results in values very close to the actual measured performance. This project was fortunate that all the components utilized exceeded their specification sheet values by significant margins.

Conclusions

The combination of singlemode fiber, RF-to-fiber converters and a Glimmerglass Intelligent Optical System costs significantly less than a system of this type with receivers dedicated to each antenna and colocated with the antennas out in the radomes. While fiber may cost more per foot than coax, from a systems perspective, looking at the total cost of implementation, fiber has become a much less expensive option. Furthermore, it's now proven to outperform conventional solutions where any significant distance is involved.

In this instance, using this combination, the systems team was able to successfully design a system using half the originally estimated quantity of RF receivers, a major savings. They were able to deploy the entire configuration for what a single non-blocking, full fan-out RF switch would have cost.

The system's RF performance opens up new options for systems designers that have operational centers removed a significant distance from their antennas. "This end-to-end system performance utilizing the optical transmission medium is so good that people will no longer use coax for applications where they have to move the RF any significant distance. We're changing the paradigm", said Mead.

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