DWDM Block Converted Return Transmission Performance

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ABSTRACT

Block conversion and dense wavelength division multiplexing (DWDM) have each been used to concentrate multiple independent return path signals onto a small number of fibers. The combination of these technologies results in very fiber-efficient return path transmission.

Performance evaluation of a return path system using these combined technologies could require a prohibitively large number of independent signal sources to load the system. Therefore, a loopback technique has been developed to minimize the amount of test equipment required for transmission testing.

This technique was used to characterize a DWDM block converted return path link carrying 72 independent 5 to 42 MHz return signals.

INTRODUCTION

The number of return bands requiring independent transport from a hub back to the headend can be quite staggering. A hub may serve 50 or more nodes and often these node returns must be subdivided to support high take rates for services. This leads to a situation in which conventional return techniques require a large number of fibers, thereby requiring technologies to reduce fiber count.

Reducing the hub to headend fiber count has several advantages: It lowers cable costs in new installations; it can avoid additional cable installation; it can free up fibers to allow redundant fiber path diversity; and it reduces the time to fusion splice fibers after a cable cut.

Block conversion and DWDM have each been used independently to concentrate returns from the hub to headend. Block conversion by itself allows up to eighteen, 5 to 42 MHz, or twelve, 5 to 65 MHz, returns to be carried in the traditional forward band frequency range of 45 to 870 MHz[1]. Initially, the DWDM return path architecture used eight wavelengths[2], while early installations generally equipped no more than four. Recently reported work[3], along with experimental verification, derived optical crosstalk design rules for analog DWDM systems with up to 32 optical channels. Using both of these technologies together further economizes fiber usage. We will eventually be able to carry at least 18 x 32 = 576 independent 5 to 42 MHz return path signals on a single fiber, using externally modulated DWDM transmitters.

TEST CONFIGURATIONS

The testing performed on DWDM with block conversion consisted of noise power ratio (NPR) measurements and dynamic range for “error free” 16 QAM transmission from a cable modem to a cable modem termination system (CMTS).

Based on availability of hardware, this testing was limited to 8 wavelengths and we used directly modulated transmitters. Since directly modulated optical transmitters carried by standard single mode fiber create a significant amount of second order distortion, the range of block converted signals was restricted to less than an octave, i.e. each transmitter was loaded with 9 blocks instead of 18. Thus, this verification testing was done for 72 independent returns.

Noise Power Ratio

During early block conversion NPR testing, we learned the importance of having independent signal sources to characterize dynamic range. Initially, we simply split the output from a noise generator to drive multiple upconverters. The measured NPR dynamic range was far worse than predicted. The correlation of the input signals was the culprit. Once we decorrelated the test signal sources applied to each upconverter, the measurements agreed with expectations. Therefore, to test this 9 block, 8-wavelength return transport system, one would like to have 72 independent signal sources, 72 up and down converters, 8 transmitters and receivers, etc. This leads to a very complex test configuration. We have found two effective means for generating decorrelated test signals from a single noise generator. One is to put the output of a 1 GHz noise generator into a bank of downconverters. Each downconverter samples a different portion of the noise generator's output spectrum and frequency shifts it down to 5 to 42 MHz. The second technique is to introduce time shifts between the upconverter input signals. A combination of these methods is used in the test configuration block diagram in Fig. 1. To conserve the number of up and down converters, we recycled a receiver output from one path to the input of a DWDM transmitter. Again, the 40-km of fiber provides more than enough delay to decorrelate the signals loading the International Telecommunications Union (ITU)

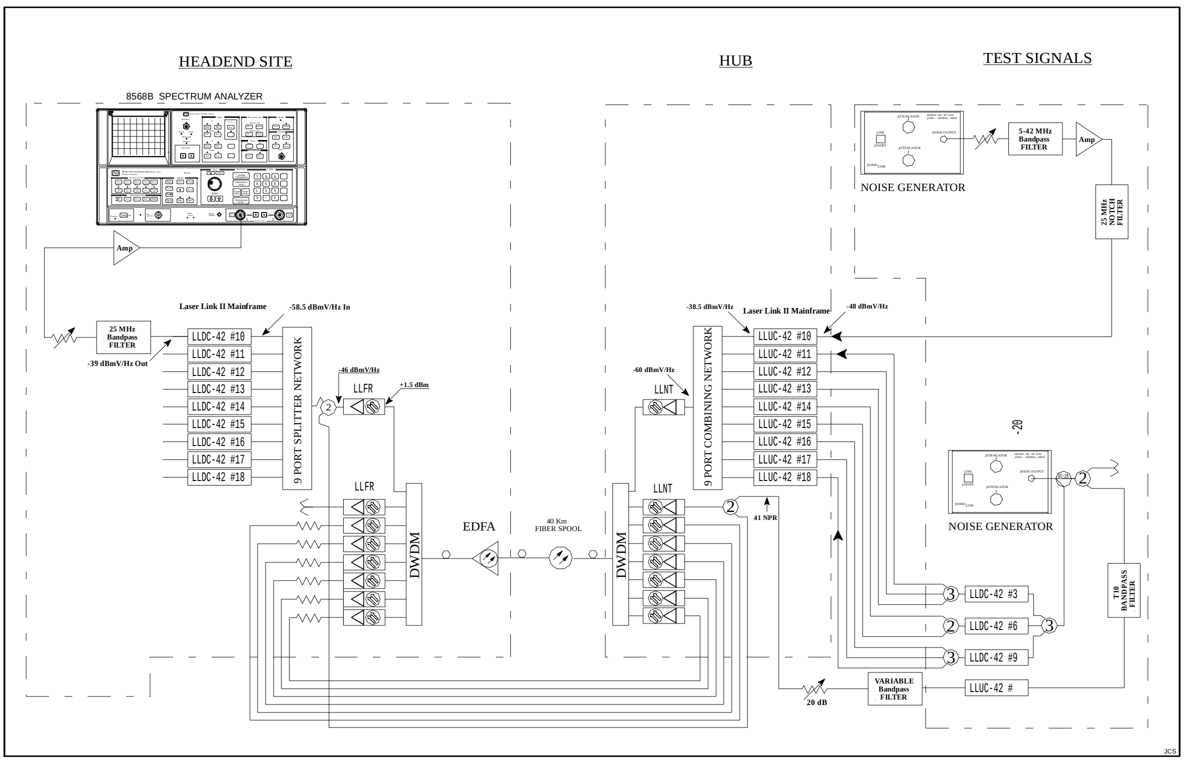

Figure 1 Test Configuration for NPR Testing of DWDM with Block Conversion

grid DWDM directly modulated transmitters.

Figure 1 shows the path under test as the top upconverter/downconverter pair and top optical transmitter/receiver pair. The signal for the path under test comes from an automated NPR test set. The inputs to the other upconverters come from the split outputs of three down converters. More downconverters crosstalk. To correct for this problem, a narrow band of noise was inserted into the noise slot for the second and subsequent optical paths.

<u>DOCSIS Return Path</u>

The second area of testing used two RCA DOCSIS compliant cable modems purchased off the shelf at a retail store and a

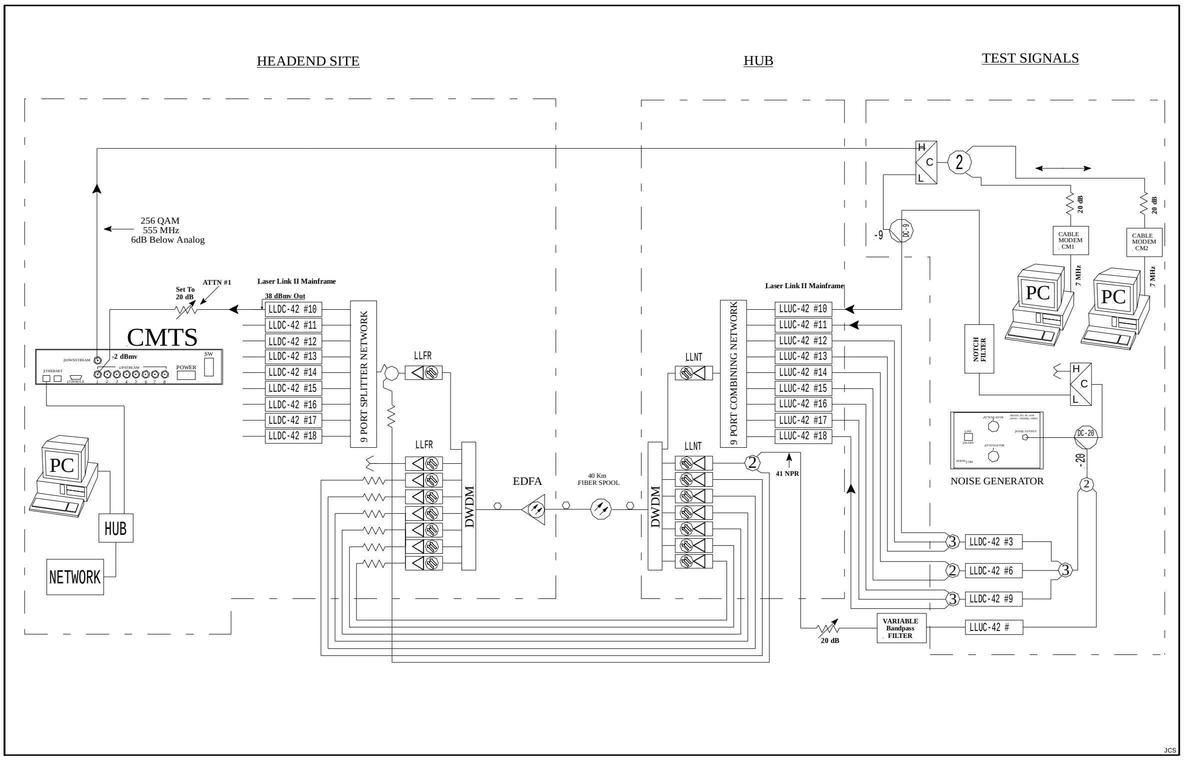

Figure 2 Test Configuration for Cable modem Dynamic Range

could have been used so that all input signals are uncorrelated, so the test results may be somewhat penalized by taking this short cut. Looping back a receiver output to the next transmitter's input derived the RF inputs for the other seven DWDM transmitters. There is just one difficulty with doing this: Unless something intentional is done, there will be no crosstalk contribution to the measurement. At the notch frequency the inputs to all transmitters will be low in level and hence there will be no measurable model 1000 CMTS from Arris Interactive. We tested the dynamic range of the transmission path to demonstrate the amount of headroom relative to level changes.

The block diagram of this test configuration is shown in Fig. 2. The CMTS generates a 6 MHz wide 256 QAM signal at 555 MHz. This signal is "dropped" to two cable modems through a diplexer and an RF splitter. The 3.2 MHz wide, 9 MHz, 16 QAM return signals from the cable modems are directed to the return path transmission equipment by the low pass section of a diplexer. A 5 to 40 MHz band of noise is notched at 9 MHz, combined with the cable modem signals and then it is inserted into the upconverter of the path under test. See Fig. 3 for a plot of the upconverter's input signal. Eight other block converters are noise loaded, and then the set of nine block converters is combined to drive a 1550 nm directly modulated

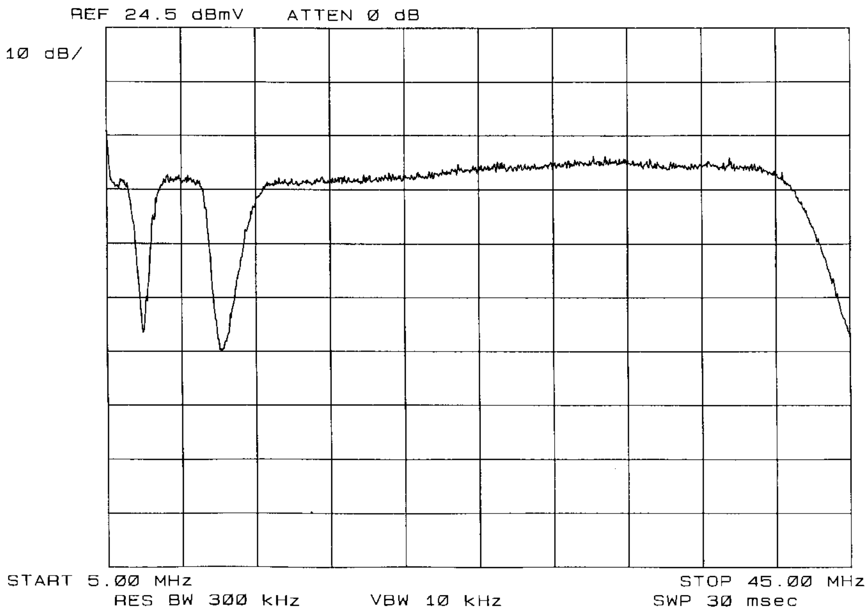

Figure 3 RF Input to Upconverter with Cable Modem Signal and Noise Load

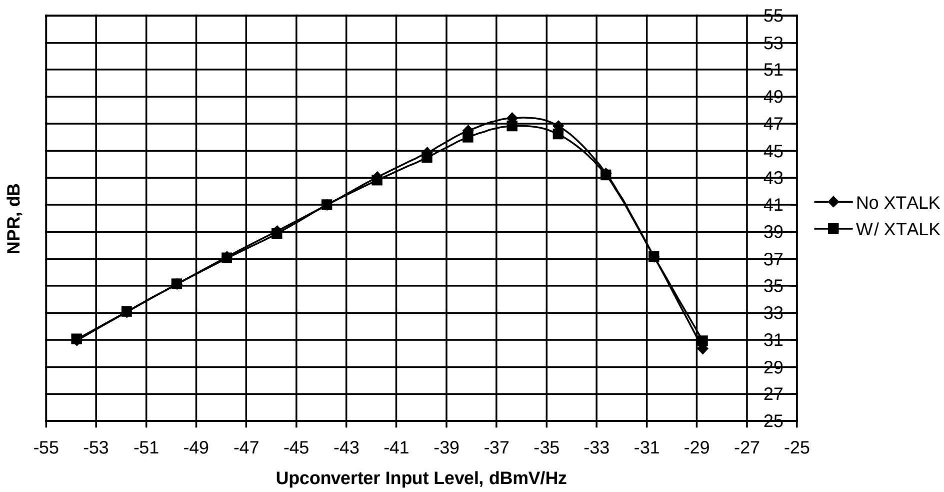

Figure 4 Noise Power Ratio, with and without Crosstalk

transmitter. Eight transmitters are optically multiplexed and sent over 40 km of standard single mode fiber. At the headend, they are optically amplified before being separated into individual optical signals in a DWDM. The optical receiver output with 9 return bands is split 9 ways. Then the bands are downconverted to 5 to 40 MHz and connected to the CMTS return input.

TEST RESULTS

NPR

The NPR tests were conducted in three blocks: 10, 15 and 18. The measured NPR dynamic ranges for several values of NPR are shown in Table 1:

NPR, dB	Block 10	Block 15	Block 18
25	29.3	31.3	30.8
30	24.5	26.5	26.2
35	19.3	20.9	19.9
38	16.3	17.1	15.6
40	14.3	14.5	13.1

Table 1 NPR Dynamic Range for DWDM with Block Conversion

A previous estimate of the NPR performance for an 8-wavelength system using directly modulated DWDM transmitters was 15-dB dynamic range at a noise power ratio of 38 dB[4]. The impact of crosstalk interference is seen in Fig. 4 by comparing the NPR curves with and without modulation on the other 7 DWDM optical transmitters. It can be seen in that figure that the influence of crosstalk is negligible for NPR values less than about 41 dB.

Cable Modem Dynamic Range

The block converter input signal, composed of the cable modem return signal and the notched noise, was varied in level to determine how sensitive the end to end DWDM with block conversion system is to input level. As shown in Fig. 2, the CMTS is connected to a PC to display data packet errors. The dynamic range as used here is based on the limits of signal level providing error free transmission of the 10 Mb/s, 16 QAM signal.[5] The test time is based on sending a 50-MB file multiple times with zero correctable bit errors, so the bit error rate is about 10^{-9}. As a worst case scenario, we used block 10 for this test (see Table 1). The nominal level at the input to the upconverter was set to be the noise density that produces approximately 41 dB NPR. We were able to raise the cable modem signal and band of noise by 16 dB in 1-dB steps or lower them by 13 dB in 1-dB steps without encountering bit errors during a file transfer. Thus we observed at least a 29-dB total dynamic range.

Comparison of NPR and Cable Modem Dynamic Range Measurements

Theoretically, 16 QAM reaches a bit error rate (BER) of 10^{-9} at a signal to noise ratio of about 22.5 dB. Practically, a modem will produce that BER at a slightly higher signal to noise ratio. Table 1 indicates that the dynamic range for an NPR of 25 dB is about 29 dB. This is show good agreement between NPR and BER dynamic range performance.

CONCLUSIONS

The measurements confirmed that the impact of optical crosstalk is negligible in block converted DWDM return band transmission. Furthermore, the performance correlations among predicted, measured and actual QAM bit error rate are very good.

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