A BALANCED FIBEROPTIC COMMUNICATION LINK FEATURING LASER RIN CANCELLATION

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Abstract

This paper presents a novel scheme of a balanced optical communication link intended to reduce the effect of the transmitter laser RIN on the total noise figure and dynamic range of the link. The method is based on splitting the laser's power into two fibers, and modulating only one branch by the RF signal. Maintaining perfect amplitude and phase balancing allows complete cancellation of the laser RIN. In practice, to achieve 20 db of laser noise reduction an amplitude balancing of 0.5 db or phase balancing of 6 degrees is required. To maintain the balancing under changing conditions it might be necessary to use an adaptive circuit. The method presented is particularly important for microwave high dynamic range links, which may be limited by laser noise.

Introduction

Today optical communication links are being used for a variety of applications, from computer local area networks up to long-haul telephone links. For most applications the existing commercially available links can meet all the important specification requirements. The limitations of existing links are apparent for high frequency (microwave) applications, for high dynamic range systems and specially for applications combining both. As far as frequency is concerned, today commercially available links exist up to 12 GHz, and it is expected that shortly it will reach the 20 GHz mark. The dynamic range of most available links is quite low (40-50 db), specially for digital applications, where high dynamic range is not required. However, increasingly analog applications are emerging that require high dynamic range. In the low frequency range (below 1 GHz) the dynamic range for these analog systems can be fulfilled, in general, and there exist links with dynamic range as large as 70 db. At higher frequencies existing optical links are limited in their dynamic range. In this paper a technique is presented to appreciably improve the dynamic range of an analog microwave optical link.

Dynamic range and noise figure

The dynamic range of an optical link is calculated by the expression:

$$DR = 2/3\,(IP3 - EIN) \qquad (1)$$

where DR is the dynamic range in db, IP3 is the third order intercept point in dbm referred to the input and EIN is the equivalent input noise of the link in dbm. IP3 is usually determined by the laser's modulation linearity, while EIN is determined by the total noise of the link. From the above expression it is obvious that to increase the dynamic range one should either increase IP3 or decrease EIN or both. In recent years, appreciable improvements have been made in laser modulation linearity, and IP3 of 30dbm up to 2-3 GHz , 25 dbm to 5 GHz and 22 dbm to 10 GHz are commercially available. Further improvements are possible by decreasing the link's noise. In general:

$$EIN = EIN_L + EIN_T + EIN_S \qquad (2)$$

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where EIN_L is due to laser noise, EIN_T is due to thermal noise and EIN_S is due to shot noise in the optical detector. The quantities in Eq. 2 are in watts. Under normal operating conditions the shot noise is negligible. The thermal noise is proportional to the link loss (kTBL). The laser noise is usually the largest, and it determines the noise floor (EIN). The laser noise (RIN - relative intensity noise) is an AM noise, and its spectrum has a typical characteristic: for low modulation frequencies (near the carrier) the noise decreases to a flat minimum in the range 20-1000Mhz, then it increase monotonically and reaches a maximum at the relaxation oscillation frequency, beyond which it decreases again. The decrease of IP3 combined with the increase of laser noise at high frequencies causes the sharp decrease of dynamic range at microwave frequencies.

The noise figure of the optical link is defined as the ratio between the actual output noise and the output noise for a noiseless link. It can be shown that the noise figure is:

$$NF = EIN/kTB = L + EIN_L/kTB \qquad (3)$$

In Equation 3 the shot noise is assumed negligible. Obviously, to reduce the overall noise figure of the link one should reduce the link loss, L, and reduce laser noise. The reduction of link loss has been discussed extensively in the literature, and the approaches to achieve it are well documented (optical and electrical coupling improvements, laser and detector efficiency improvement, etc.). In this paper we present a method to reduce the effect of laser noise, which might be the largest source of noise for microwave optical links.

The new link architecture

Several attempts have been made in the past to cancel the laser noise of optical links, most of which concentrate on noise reduction of the LO laser in a heterodyne detection scheme+. In this paper we present a dual detection architecture, which allows almost perfect cancellation of the transmitter laser RIN without using an LO laser (thus avoiding the LO noise), thereby appreciably increasing the dynamic range and decreasing the noise figure of the optical link. The proposed link architecture is depicted in Fig. 1. In the transmitter the laser optical power is divided equally between two fibers by means of an optical power divider. In one of the fibers the light is not modulated, while the second branch includes an optical modulator, which is used to modulate the light by the RF signal. The receiver features a double detection scheme using two identical optical detectors. The output signals of the two detectors are combined in an out-of phase RF (microwave) combiner. The two "AMP & PH" boxes represent amplitude and phase equalizers intended to achieve equal loss and delay in the two branches.

For an ideal balancing of the optical link there is a complete cancellation of the transmitter laser RIN. To achieve this result the loss and the delay of the two paths must be exactly equal. It is important to note that any delay difference between the two paths should be very small relative to the RF period (not the optical period), which is a reasonable requirement. It is easy to verify that under ideal balancing conditions the output of the first optical detector is proportional to the laser noise, while the output of the second detector is proportional to the sum of the RF signal and the laser noise. Thus, the out-of-phase combiner cancels out the laser noise contribution, and an AM noise-free signal is reproduced at the receiver's output. The disadvantage of the proposed dual link is the increased cost due to

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+ G. L. Abbas, V. W. S. Chan, T. K. Yee, "A Dual Detector Optical Heterodyne Receiver for Local Oscillator Noise Suppression", Journal of Lightwave Technology, October 1985, pp. 1110-1122.

additional hardware requirements compared to the single-ended link (optical power divider, two optical detectors, equalizers, combiner and two fibers). Therefore, this link is recommended for applications in which the increased dynamic range and decreased noise figure are of importance.

Analysis of the proposed link

The degree of laser RIN cancellation is strongly dependant on the amplitude and phase balancing. Denote k_{db}=20log(k)the amplitude unbalance in db (the link loss difference between the two paths). Denote ϕ the phase unbalance (phase difference between the two paths).

Assuming a single sine wave at microwave frequency as the modulating signal it is possible to calculate the signal to laser noise ratio at the receiver output for both a "conventional" single-ended link and the new balanced link. The improvement achieved by the balanced link can be demonstrated by the ratio, R, of the two S/N. The result is:

$$R = k^4 / (k^4 - 2k^2 \cos\phi + 1) \qquad (4)$$

Eq. 3 can be used to investigate the sensitivity of the link to unbalance effects. This is best demonstrated by plotting curves of constant R in the k-ϕ plane. From Eq. 3 the constant R curves are:

$$(1-1/R)\, k^4 - 2k^2 \cos\phi + 1 = 0 \qquad (5)$$

Fig. 2 depicts the effect of amplitude and phase unbalance on the degree of laser RIN cancellation. 15 db and 20 db cancellation curves are shown. The graphs show that a 20 db RIN reduction is difficult but feasible - amplitude balancing of 0.5 db with perfect phase or phase balancing of 6 degrees with perfect amplitude is required. To maintain the RIN cancellation feature under changing conditions, such as temperature, it is necessary to use an adaptive scheme to control the amplitude and phase balancing.

Conclusion

In this paper we presented a novel balanced architecture for an optical link intended to reduce laser noise. Laser RIN cancellation is very important for microwave links requiring high dynamic range. Since the laser RIN increases with frequency the dynamic range of "regular" optical links decreases with frequency, as witnessed in the manufacturer's data sheets. The balanced scheme presented here enables practically a RIN reduction of around 20 db, which greatly improves the noise floor of the link (EIN), which is dominated by laser RIN for a single-ended link. For commercial links a dynamic range increase of 10 to 15 db is possible by employing the method presented here.

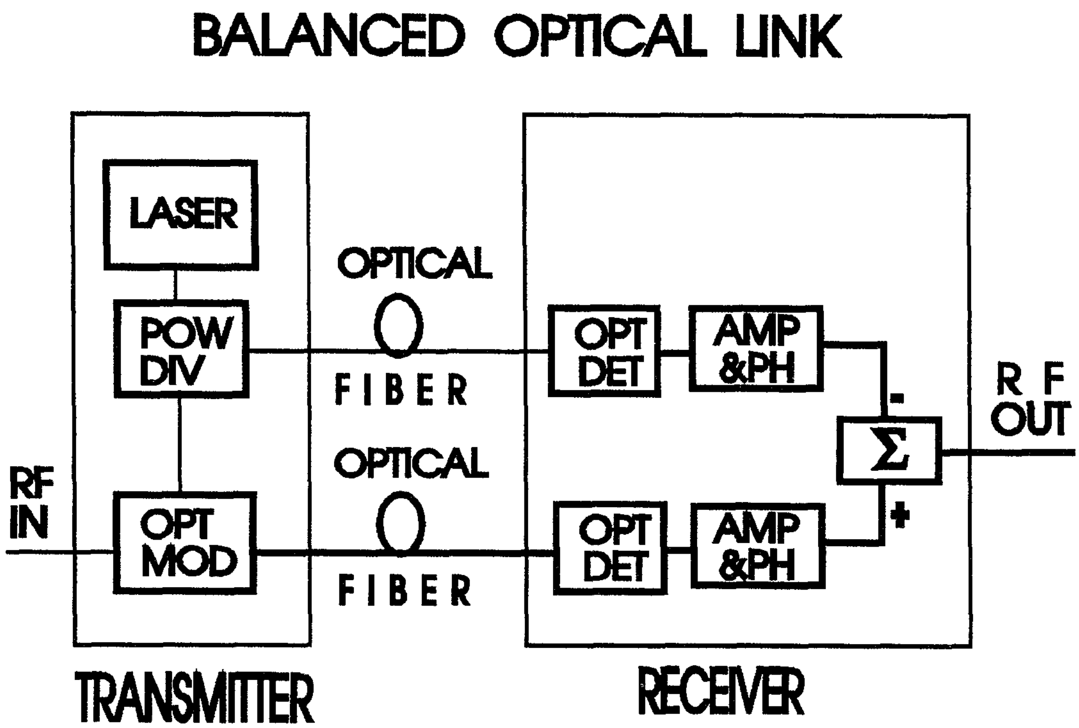

Fig. 1 The novel balanced optical link architecture

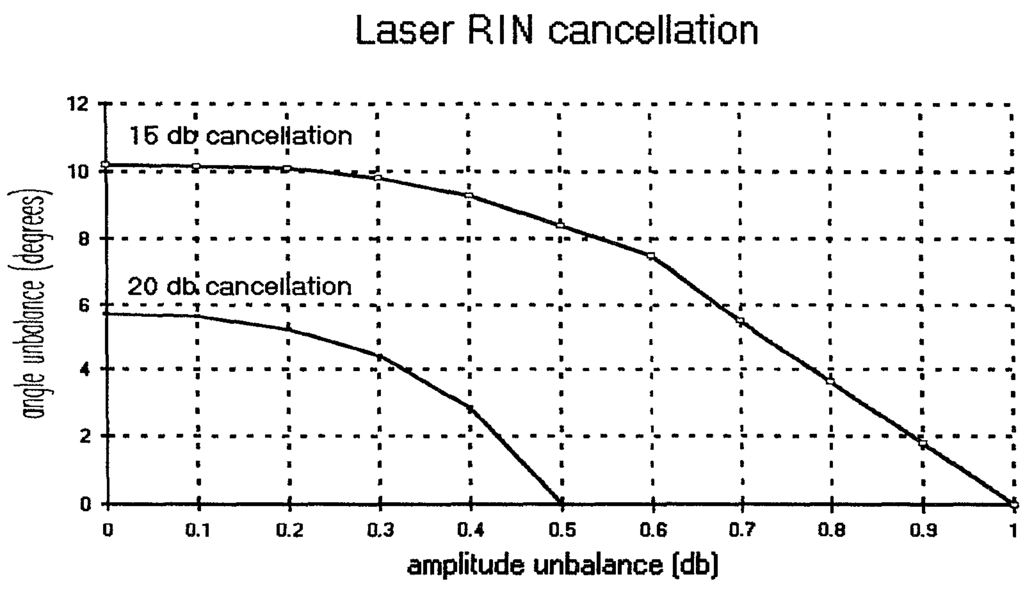

Fig. 2 Sensitivity of the new optical link to amplitude and phase unbalance