Microwave Photonic Links with Gain and Low Noise Figure

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***Abstract* — We review reports of microwave photonic links with gain > 0 dB in the absence of electronic amplifiers, and their corresponding noise figures.**

I. Introduction

Recently there have been dramatic improvements in the microwave gain and noise figure of photonic links that have made them more attractive to designers of systems that can benefit from the characteristics of optical fiber. In this paper we review the techniques that have been used to achieve the best microwave link gain and noise figure results.

II. Methods for Improving Link Performance

Fig. 1 shows the intrinsic (i.e., amplifierless) gains (a) and noise figures (b) for 14 different links reported in 13 different papers [1 – 13] using the five techniques listed in this section. The figure includes only those links whose gain exceeded 0 dB and for which a corresponding noise figure was also reported. Gains and noise figures of 40 other links that did not meet these criteria have been previously summarized [14].

i. Resonant Impedance Matching

In any range of frequencies over which circuits can be designed to transform the modulation device and photodetector impedances to match the impedances of the link's input and output ports (both usually 50 Ω), adding these matching circuits will increase the link's intrinsic gain [1 – 5].

ii. Reflective External Modulator

Mach-Zehnder modulator-based external modulation link gain is inversely proportional to the square of the modulator's halfwave voltage V_π. In two links reported here [5, 6], V_π was reduced by a factor of two by using a reflective design that doubled the duration of interaction between the optical carrier and microwave modulation signal.

iii. Cascaded Directly Modulated Lasers

One can arrange several semiconductor lasers electrically in series and optically in parallel so that the link input signal current generates several modulated optical carriers for summing in a single photodetector or in several arranged in parallel, so that their photocurrents add at the link output [7]. Because the optical carriers are mutually uncorrelated, the total noise out of a link with an N-laser cascade is only N times that of a one-laser link, whereas output signal is boosted by a factor of N^2.

iv. Balanced Differential Modulation and Detection

Whereas a conventional Mach-Zehnder external modulator produces a single modulated optical output carrier, a balanced Mach-Zehnder outputs two identical (i.e., in-phase) optical carriers modulated in antiphase. If the two modulated outputs are guided to two detectors arranged to output the difference between what they detect, the link's output signal is enhanced while the optical intensity noise is zeroed out [3, 8 – 11].

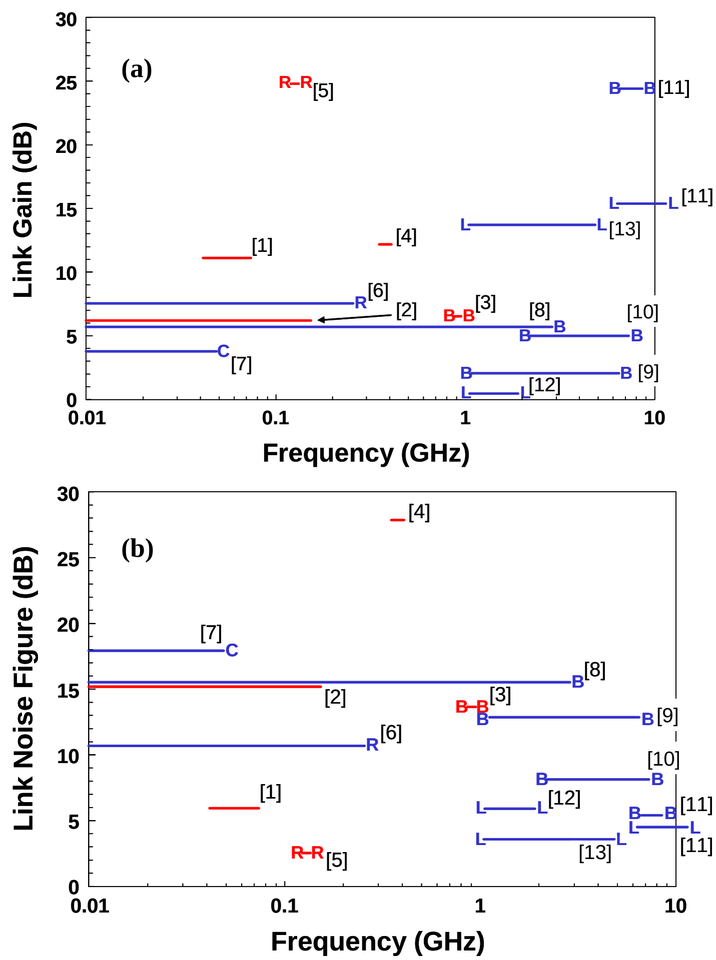

Fig. 1. **(a)** Gains and **(b)** noise figures of intrinsic microwave photonic links. Links using resonant impedance matching are reported in red, all others in blue. Alphabetic characters indicate links using a **R**eflective external modulator, **C**ascaded directly modulated lasers, **B**alanced differential modulation and detection, and **L**ow-biasing, respectively.

v. Low Biasing

Biasing a Mach-Zehnder modulator at the quadrature point on its optical output power vs. voltage transfer function curve yields maximum link gain. If this maximum gain is high, however, biasing at a lower point on the curve (i.e., where the optical output power is lower) generally results in lower noise figure. This occurs because the dominant output noise terms in most links are proportional to either the average detected power or the square of this power, whereas the link output signal is proportional to the square of the curve's *slope*, and moving downward from the quadrature bias point decreases the average power by more than the square of the slope.

III. Summary

Table I compares the five techniques briefly defined in Section II by indicating with a yes or no (Y/N) whether or not the technique achieves an improved noise figure by boosting the signal gain, suppressing the noise, or both.

TABLE I. COMPARISON OF NOISE FIGURE IMPROVEMENT TECHNIQUES A – E.

Technique	Refs	Improves noise figure by:	
		Boosting the signal?	Suppressing the noise?
i. Resonant impedance matching	1–5	Y	N
ii. Reflective external modulator	5, 6	Y	N
iii. Cascaded directly modulated lasers	7	Y	Y
iv. Balanced differential modulation, detection	3, 8–11	Y	Y
v. Low biasing	11–13	N	Y

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