Achieving Low-Noise-Figure Photonic Links without Pre-amplification

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***Abstract* — Using optical fiber to retrieve signals from remote sensors has several advantages compared to remoting by means of metallic waveguides such as coaxial cable. Fiber-optic retrieval of an RF signal can be achieved by down-converting and digitizing the signal for conveyance by a digital fiber-optic link, or it can be achieved by conveying the RF signal over an analog fiber-optic link before digitization. The latter approach can be realized with a minimum of hardware and dc power required at the sensing site, provided that the analog fiber-optic link has a sufficiently low noise figure without a pre-amplifier.**

Early demonstrations of "amplifierless" analog fiber-optic links typically reported very high noise figures—in excess of 30 dB. In the last decade or so, several techniques have been developed to improve this situation. We describe five such techniques and show that they have resulted in much lower measured noise figures for amplifierless links. One technique, for example, has yielded noise figures < 5 dB for amplifierless links at frequencies of up to 10 GHz. The existence of amplifierless links with such low noise figures may enable remote sensing of signals in situations where the size, weight, and power (SWAP) of the remote hardware is of primary concern.

I. Introduction

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

Fig. 1 shows the gains (a) and noise figures (b) for 14 different amplifierless links reported in 13 different papers [1 – 13] using the five techniques we describe. 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].

II. 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), inserting these matching circuits will increase the link's amplifierless gain [1 – 5]. In Fig. 1 the five links that benefited from the insertion of resonant impedance matching circuits are shown using red lines. In some of these links resonant impedance matching was combined with one of the other four techniques we describe.

III. 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. In Fig. 1 the two links that benefited from the use of a reflective external modulator are indicated by R's at either end of the plotted lines.

IV. 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 the output signal is boosted by a factor of N^2. In Fig. 1 the one link that benefited from the use of cascaded directly modulated laser diodes is indicated by C's at either end of the plotted lines.

V. BALANCED DIFFERENTIAL MODULATION AND DETECTION

Whereas a conventional Mach-Zehnder external modulator produces a single modulated optical output carrier, the two outputs of a balanced Mach-Zehnder are identical (i.e., in-phase) optical carriers modulated in antiphase relative to one another. 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]. In Fig. 1 the five links that benefited from the use the balanced differential modulation and detection architecture are indicated by B's at either end of the plotted lines.

VI. 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. In Fig. 1 the three links that benefited from the low biasing technique are indicated by B's at either end of the plotted lines [11 – 13].

VII. SUMMARY

Table I compares the five techniques briefly defined in Sections II – VI 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.

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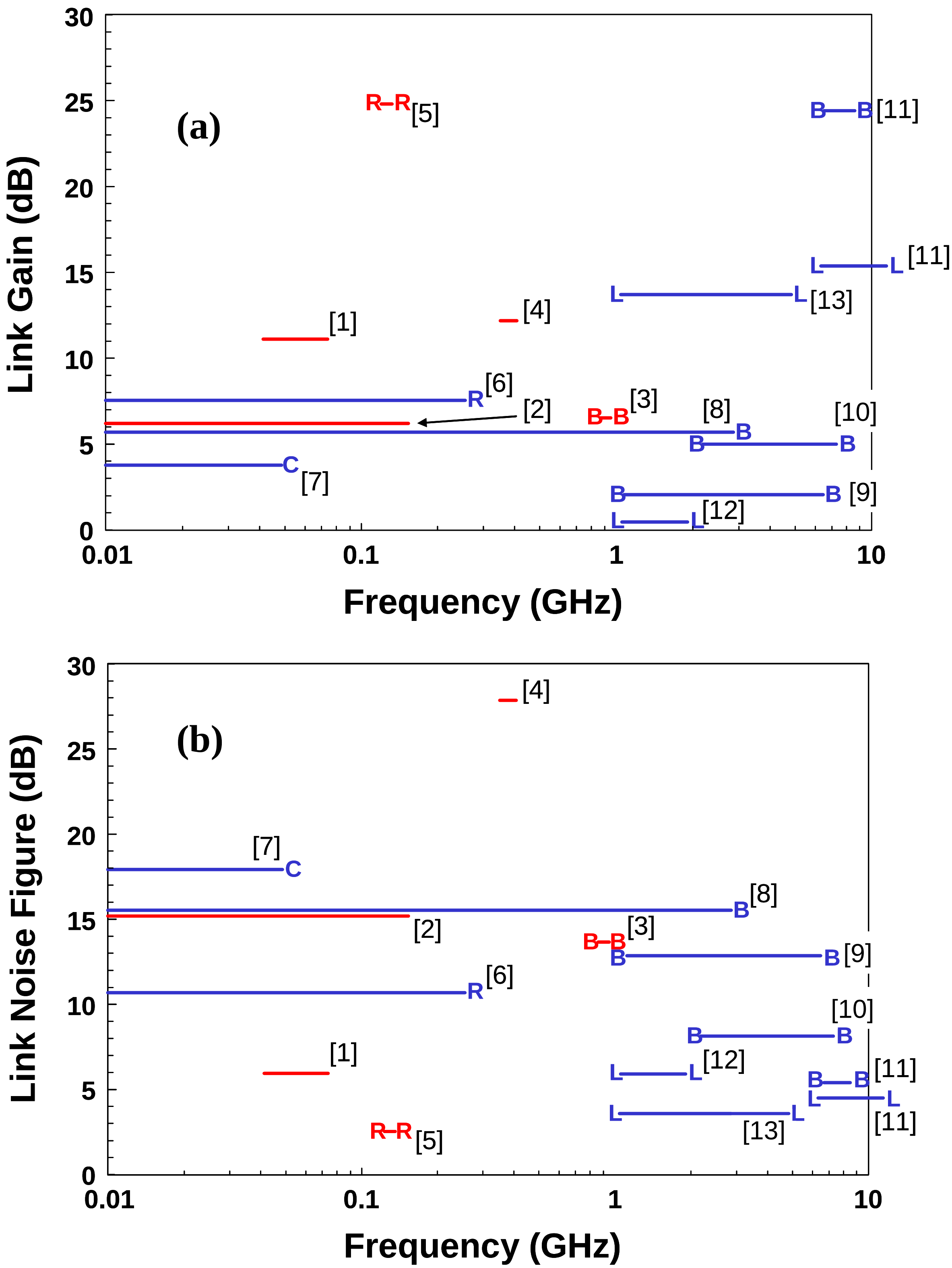

Fig. 1. **(a)** Gains and **(b)** noise figures of amplifierless microwave photonic links. Links using resonant impedance matching are reported in red, all others in blue. Alphabetic characters indicate links using a **R**eflective external modulator, **C**ascaded directly modulated lasers, **B**alanced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

TABLE I. COMPARISON OF NOISE FIGURE IMPROVEMENT TECHNIQUES II – VI.

Technique	Inherently narrower bandwidth ?	Improves noise figure by:	
		Boosting the signal?	Suppressing the noise?
II. Resonant impedance matching	Y	Y	N
III. Reflective external modulator	N	Y	N
IV. Cascaded directly modulated lasers	N	Y	Y
V. Balanced differential modulation, detection	N	Y	Y
VI. Low biasing	Y/N (< octave)	N	Y