Spurious-Free Dynamic Range (SFDR) improvement in a true-time-delay system based on highly dispersive photonic crystal fiber

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Abstract— Spurious Free Dynamic Range improvement of a true-time-delay system based on highly dispersive photonic crystal fibers is achieved using a high power EDFA. The system exhibits a SFDR of 114 dB measured in a 1-Hz bandwidth.

I. INTRODUCTION

Fiber Optic technology offers several advantages such as low loss, high bandwidth, no electromagnetic interference, low weight etc in various applications. These advantages are also extended to RF link applications. However, RF signal distortion limits the performance of such systems. The higher order harmonic distortion terms usually fall outside the analog bandwidth and can be filtered out. The third-order intermodulation products fall within the useful bandwidth of the system and are a cause of major concern. While considering such analog optical links, few important features such as the noise figure and the spurious-free dynamic range (SFDR) must be evaluated in order to determine the performance of the system.

In our previous work, we have used such an analog system for antenna beamforming in the X-Band [1-3]. In this work, we present the results of improving the SFDR of the system from 106 dB to 114 dB measured in a 1-Hz bandwidth by utilizing a very high power Erbium-doped fiber amplifier (EDFA) at the input of the modulator. A very high SFDR of 122dB in a 1-Hz bandwidth was also achieved by Karim et al., using this method [4].

II. NOISE FIGURE

The photonic link studied is shown in Fig. 1.

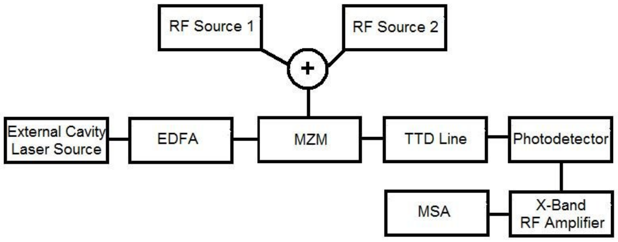

Fig. 1. Block diagram of the system under consideration. EDFA: Erbium-Doped Fiber Amplifier; MZM: Mach-Zehnder Modulator; TTD: True-Time-Delay; MSA: Microwave Spectrum Analyzer.

The carrier wavelength from the laser source is 1550 nm with an output power of 5 mW. An Erbium-doped fiber amplifier (EDFA) is used to amplify the optical input power to the modulator as required. The RF signals from signal generators are combined and modulated onto the optical carrier via a Mach-Zehnder modulator (MZM). The optical signal is passed through the true time delay (TTD) line consisting of 3.5m of dispersion shifted fiber (DSF) and 7m of highly dispersive photonic crystal fiber (PCF). The SEM cross section of the fabricated PCF is shown in Fig. 2. The PCF consists of microscopic air holes running down the entire length of the fiber. The dispersion coefficient of the fabricated fiber is -600ps/nm/km at a wavelength of 1550nm [1-3]. After passing through the TTD line, the optical signal is fed to a high-speed photodiode. The electrical output is amplified using a low noise amplifier and sent to a microwave spectrum analyzer (MSA).

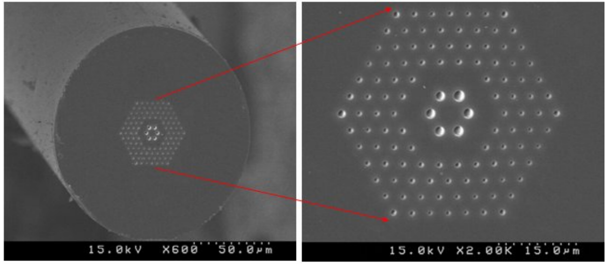

Fig. 2. Scanning electron microscope (SEM) cross section of the fabricated photonic crystal fiber (PCF). An enlarged view of the photonic crystal area is also shown. The periodicity of air holes is 3.5micron.

It is possible to change the modulator bias angle between 90^0 (quadrature) and 180^0 (transmission minimum) by changing the dc bias voltage of the modulator. Normally analog fiber-optic links are operated at quadrature in order to maximize RF gain and avoid even-order distortion. As the bias angle is shifted towards 180^0, the link gain is reduced due to a decrease in modulator slope efficiency. By increasing the optical input power to the modulator, the gain can be increased and this can be used to compensate for the reduction in gain due to shift in modulator bias angle. For example, in our system, an optical input power of 20 mW at a bias angle of 90^0 and an optical input power of 200mW at a bias angle of 165^0 both result in approximately the same overall gain. However, the received photocurrent also reduces as the bias angle is shifted to transmission minimum. This reduces the shot noise power density as it is proportional to the received photocurrent. The RIN and signal-spontaneous beat noise power densities are proportional to the square of the received photocurrent.

978-1-4244-2611-9/09/$25.00 IEEE

Shot noise, RIN, and signal-spontaneous beat noise fall faster compared to the gain as the modulator bias angle is adjusted towards 180^0 [5]. At any given optical input power, there will be a modulator bias angle that minimizes the link noise figure and therefore, the optical input power can be increased and the bias angle shifted in order to minimize noise figure without reducing link gain.

The link noise figure in our link is measured using the gain method. The optical power from the EDFA is varied from 20mW to 200mW by adjusting the gain of the EDFA. The measured noise figures as a function of modulator bias angle for various optical input powers are shown in Fig. 3. For a modulator optical input power of 20mW, the link noise figure is 37 dB at quadrature.

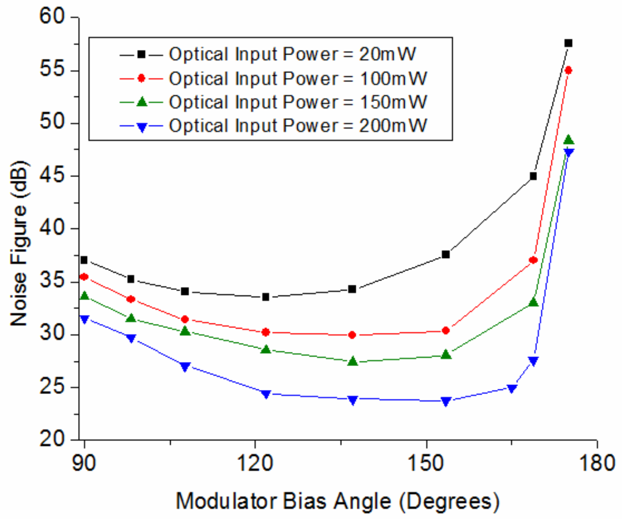

Fig. 3. Measured link noise figure as a function of modulator bias angle for different optical input powers.

For a modulator optical input power of 200 mW, the link noise figure can be reduced from 31.55 dB at quadrature to 25 dB at a bias angle of 165^0 without sacrificing the RF gain of the system.

III. SPURIOUS-FREE DYNAMIC RANGE

The SFDR of an RF link limited by third-order intermodulation distortion is given by:

$$SFDR = \frac{2}{3} * (IIP3 - NF + 174)$$

where IIP3 is the linearly extrapolated input power in dBm at which the fundamental and third-order intermodulation output powers would be equal and NF is the link noise figure in dB. The value of 174 refers to the noise power in dBm present in a 1-Hz bandwidth at a noise temperature of 290 K.

The measured RF output powers as a function of input RF power are shown in Fig. 4. The optical input power to the modulator is 200 mW and the modulator bias angle is 165^0. The fundamental frequencies used are at 8 and 8.1GHz. Therefore, the third order intermodulation products (IMD3) are located at 7.99 and 8.02 GHz respectively. The input power in dBm corresponding to the point of intersection of the linear fits to these plots (also shown in the figure) gives the third order intercept point (IIP3). The IIP3 value from the graph is obtained as 22 dBm. The link gain is 11 dB and the link noise figure is 25 dB. The combination of IIP3 and noise figure results in a SFDR of 114 dB, normalized to a 1-Hz bandwidth. Similarly, for optical input power of 20mW, the SFDR is found to be 106 dB measured in a 1-Hz bandwidth. Therefore, it can be seen that the improvement in the SFDR of the system and noise figure can be achieved by controlling the dc modulator bias and optical input power to the modulator.

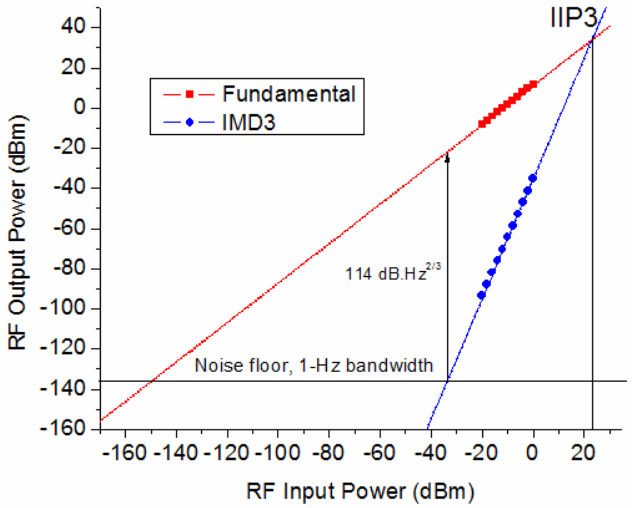

Fig. 4. Fundamental and IMD3 RF output powers as a function of input RF power. Data points are marked with squares and circles. Extrapolated straight line fits to the data points are also shown. The extrapolated lines intersect at a point whose corresponding RF input power gives IIP3.

No additional optical or electronic linearization schemes are applied in improving the SFDR. Although the EDFA can provide up to 1000 mW of optical power, the fundamental limitation in achieving very high SFDR is the optical power handling capacity of the modulator, which is 200mW for our device. Utilizing higher power handling MZMs, the SFDR can further be improved.

IV. REFERENCES

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