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Radar signal transmission and switching over optical networks

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ABSTRACT

In this paper, we experimentally demonstrate a radar signal distribution over optical networks. The use of fiber enables us to distribute radar signals to distant sites with a low power loss. Moreover, fiber networks can reduce the radar system cost, by sharing precise and expensive radar signal generation and processing equipment. In order to overcome the bandwidth challenges in electrical switches, a semiconductor optical amplifier (SOA) is used as an all-optical device for wavelength conversion to the desired port (or channel) of a wavelength division multiplexing (WDM) network. Moreover, the effect of chromatic dispersion in double sideband (DSB) signals is combated by generating optical single sideband (OSSB) signals. The optimal values of the SOA device parameters required to generate an OSSB with a high sideband suppression ratio (SSR) are determined. We considered various parameters such as injection current, pump power, and probe power. In addition, the effect of signal wavelength conversion and transmission over fiber are studied in terms of signal dynamic range.

1. Introduction

Radio spectrum scarcity becomes a real challenge for telecommunication and other technologies including radar systems. Millimeter wave (MMW) and sub-terahertz radio frequencies (RFs) are a promising candidate, as their large bandwidth can be exploited in the increased number of bandwidth-hungry applications [1]. Such bands can be useful in radar systems, as they reduce the cost, size, and power consumption of the system. Moreover, at these high frequencies, a wider bandwidth can be used in order to improve object detection resolution [2]. However, high-frequency signals in the MMW range, or beyond, are subject to a high free space attenuation of the order of 1 dB/km or more. This attenuation value can increase, depending on the weather conditions, which, in turn, limits their reach range, from tens to only few hundreds of meters [3].

Using optical fibers for the distribution of radar signals provides better compensation of the free space loss and weather effect. Long reach distances with low power loss, high immunity to electromagnetic interference, and large surveillance area can be achieved. Optical fibers have a very low power attenuation ~0.2 dB/km at 1550 nm wavelength. In addition, the use of fiber networks reduce the system cost. The precise and sensitive radar equipment that involves signal generation and processing can be shared between the installed radars in the network, while the front-end devices can become simple and colorless [4].

Radar signal transmission over fiber has been studied recently in Refs. [5–11]. In Refs. [5,6], an ultra-wide band (UWB) noise radar signal is demonstrated. A radar signal is generated and transmitted over a 3 km-long single mode fiber (SMF). The RF front end (base station) is designed as colorless. The same principle is used to generate a UWB radar signal, transmitted over a 24 km-long SMF for a remote ranging [7] and over a 10 km-long SMF for a remote imaging [8]. In Ref. [9], an optical switch is used in the remote node to select one branch of the fiber network, which allows a transmission of a UWB radar signal over a 24 km-long SMF for remote ranging applications. Using microwave photonic (MWP), a 96 GHz radar signal is generated and transmitted over a fiber network for detecting a foreign object debris in runways [10].

In this work, we propose and experimentally demonstrate transmission and distribution of radar signals over a fiber based network that has a wavelength conversion capability. The radar signal distribution over the network is achieved by employing a semiconductor optical amplifier (SOA) device. By implementing SOA in our setup, we achieve the following advantages:

1. The SOA enables a radar signal switching by converting the incoming signal's wavelength to a new wavelength that fits a

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specific channel of the wavelength division multiplexing (WDM) network.

2. The conversion process is all-optical with no need for electrical to optical or optical to electrical conversion for signal switching as used in electronic switches. Electronic switches limit the signal bandwidth while SOA is transparent for signal bandwidth and type.
3. The SOA can be optimized to generate an optical single sideband (OSSB) signal at the desired wavelength, rather than a double sideband (DSB) signal. The DSB occupies twice the bandwidth of single sideband (SSB). In addition, in DSB signals, the fiber chromatic dispersion changes the phases of both sidebands, which induces a self cancellation at detection. Each sideband suffers a different power penalty that degrades the transmission distance and signal performance [11,12]. This challenge can be overcome by generating an SSB using an SOA.
4. The SSB signal is generated simultaneously with the wavelength conversion, using the same scheme.

The remainder of this paper is organized as follows. In Section 2, we discuss the experimental setup of the radar signal transmission and routing in fiber networks. In Section 3, we investigate the SOA operation in order to generate an OSSB. Transmission of radar signals over a fiber network is analyzed in Section 4. We outline the conclusions of this study in Section 5.

2. Experimental setup

The experimental setup of radar signal transmission and wavelength switching over a fiber network is shown in Fig. 1. The radar signal is generated electrically using an arbitrary waveform generator (AWG, Keysight M8190A, sampling rate of 12 GSa/s). The radar signal is a chirp that has a bandwidth of 100 MHz, a pulse width of 1 μs, and a pulse repetition interval (PRI) of 4 μs. Then, a vector signal generator (Keysight PSG E8267D) is used to carry the radar signal at the desired RF frequency. The output electrical signal is then amplified and applied to a Mach Zehnder modulator (MZM).

The MZM converts the electrical radar signal into an optical domain using a tunable laser light source (Keysight N7714A). The output of the MZM is an optical signal called probe signal. This optical signal is then amplified using an erbium doped fiber amplifier (EDFA, represented in Fig. 1 as EDFA 1), in order to compensate the modulator power loss. A pump signal is combined with the probe signal using a 50:50 polarization maintaining optical coupler (PMOC). The two outputs of the PMOC device are processed as follows. One of them is applied to a Kamilian NL-L1-C-FA SOA, while the other one is used to measure the signal spectrum using an optical spectrum analyzer (OSA). Optical attenuators (OAs) and polarization controllers (PCs) are used to control the power level and polarization of the SOA's input signals. The output of the SOA is then applied to an optical tunable band pass filter (TBPF), in order to pass the switched signal and block the unwanted signals. Then, the signal is amplified using another EDFA (EDFA 2 in Fig. 1), and transmitted over an SMF towards the photodetector (PD, electrical bandwidth of 65 GHz), in order to extract the RF radar signal from the optical one. An optical coupler with a 98:2 coupling ratio is used to monitor the signal spectrum after the TBPF. A digital storage oscilloscope (Keysight DSO-x-93204A, bandwidth of 32 GHz) is used to analyze the performance of the radar signal.

3. Optimization of wavelength conversion

In order to transmit a radar signal over a WDM network, a wavelength conversion is required so that the radar signal can be assigned to a specific WDM channel. In this study, we consider the usage of an SOA device as a wavelength converter. SOA is an all-optical device capable to change the optical signal wavelength without the need of performing optical to electrical conversion, which is considered as a bottleneck for a successful data transmission in optical networks. In order to generate a wavelength switched signal with a high sideband suppression ratio (SSR), the SOA's injection current and its input power need to be optimized. The SSR is defined as the difference in power between the first two side lobes around the carrier. The probe and pump signals are adjusted at wavelengths of 1551.7 nm and 1550.2 nm, respectively. The radar signal carrier has a frequency of 24 GHz (i.e. K band), and a power of 8 dBm. The SOA's total input power is 9.2 dBm. Fig. 2(a) shows the dependence of the optical SSR as a function of the SOA's injection current. We can notice that as the SOA's injection current increases, the suppression ratio improves, reaching a maximum of SSR = 21 dB at 240 mA. Next, using the obtained value of the injection current, we study the effect of the probe and pump signals' power on the SSR. Fig. 2(b) illustrates the effect of the probe signal power, while Fig. 2(c) illustrates the effect of the pump signal power. The maximum SSR is achieved at a probe signal power of 7.7 dBm, and a pump signal power of 6.6 dBm.

Using the obtained optimization parameters, the optical power spectrum of the SOA's output signal that includes the switched, pump, and probe signals, is shown in Fig. 3(a). The spectrum of the down-converted switched signal at the output of the SOA is shown in Fig. 3(b) with 21 dB SSR. Generating an OSSB combats the chromatic dispersion issue and saves the bandwidth, compared to the generated DSB signal shown in Fig. 3(c). The generated upper side band at 1548.89 nm carries the radar signal, while the carrier at 1548.7 nm will be used as a beating signal in the PD to demodulate the RF radar signal after the transmission over the optical fiber. In addition, the effect of variations of the radar signal power on the SSR is investigated, as shown in Fig. 4(a). We can notice that when the radar signal power increases, the SSR improves. However, due to the limited input power of the RF amplifier, we set the maximum radar signal power to 8 dBm. Next, we studied the effect of variations of the radar signal carrier frequency on the SSR. The curve in Fig. 4(b) shows an improvement in SSR as the carrier frequency increases. In addition, we investigate the effect of variations of the pump signal wavelength, which, in turn, affects the switched signal wavelength and the SSR. The results in Fig. 4(c) show that the SSR decreases with the pump signal wavelength; a fixed probe signal wavelength of 1551.7 nm was used.

4. Signal transmission and performance evaluation

After adjusting the values the wavelength converter in the previous section, we analyze the performance of the chirp radar signal that is transported over the optical network at a carrier frequency of 24 GHz (K-band). First, we study the radar signal characteristics. Fig. 5 illustrates the normalized power spectrum and normalized pulse shape of the radar signal at four different points in the system: output of the radar signal generator; after optical modulation, after wavelength conversion, and after transmission over the SMF. We can notice that the radar signal preserves the good spectrum and pulse shape quality before and after optical wavelength conversion. At each point, we calculated the signal dynamic range from the power spectrum as the maximum difference in power between the signal and the noise. The obtained dynamic range is 48 dB, 36.5 dB, 36 dB, and 23 dB at the signal generator output, after modulation, after wavelength conversion, and after transmission over a 37.247 km-long SMF, respectively. By comparing the dynamic range of the radar signal at the SOA input and the converted signal after the SOA, we obtained that the effect of wavelength conversion is negligible and leads to a difference in dynamic range of only ~ 0.5 dB. This means that the wavelength conversion is transparent and does not considerably disrupt the transport of the radar signal.

In Fig. 6, we study the effect of the generated radar signals' power and carrier frequency on the converted signal dynamic range. We can notice an improvement in the signal dynamic range as the RF signal power or carrier frequency increases. In addition, we investigate the