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# Multi-band microwave photonic satellite repeater scheme employing intensity Mach-Zehnder modulators

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## Abstract

To solve the satellite repeater's flexible and wideband frequency conversion problem, we propose a novel microwave photonic repeater system, which can convert the upload signal's carrier to six different frequencies. The scheme employs one 20 GHz bandwidth dual-drive Mach-Zehnder modulator (MZM) and two 10 GHz bandwidth MZMs. The basic principle of this scheme is filtering out two optical sidebands after the optical carrier suppression (OCS) modulation and combining two sidebands modulated by the input radio frequency (RF) signal. This structure can realize simultaneous multi-band frequency conversion with only one frequency-fixed microwave source and prevent generating harmful interference sidebands by using two corresponding optical filters after optical modulation. In the simulation, one C-band signal of 6 GHz carrier can be successfully converted to 12 GHz (Ku-band), 28 GHz, 34 GHz, 40 GHz, 46 GHz (Ka-band) and 52 GHz (V-band), which can be an attractive method to realize multi-band microwave photonic satellite repeater. Alternatively, the scheme can be configured to generate multi-band local oscillators (LOs) for widely satellite onboard clock distribution when the input RF signal is replaced by the internal clock source.

**Keywords** fiber optics and optical communication, radio frequency photonics, microwave photonics

## 1 Introduction

With the increasing demands on great capacity and large bandwidth of satellite communication, the RF repeaters are now converting signals among multiple bands to mitigate the frequency spectrum congestion and orbital resource depletion problems [1]. The RF repeaters in communication satellites, for example, are now converting signals among C-band, Ku-band, Ka-band and even V-band to mitigate the above problems while fulfilling the increasing requirements on the throughput [1]. Furthermore, to realize broadcast transmission, one RF signal's carrier frequency need to be changed to several higher frequencies on communication satellite repeaters. For the inter-band conversion, conventional electrical repeaters use multiple stage conversion scheme to avoid deleterious spurs, where incoming RF signals within different bands are first down-converted to intermediate frequencies (IFs) and then up-converted again to the desired output bands after executing processing like switching, amplification, etc. Thus, multiple stage conversion would severely reduce the system dynamic range and conversion efficiency [2].

The microwave photonic technology is probably the very candidate to accomplish this kind of frequency conversion with its obvious advantages such as high bandwidth, low loss, parallel processing capability,

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transparency to signal formats, high RF isolation as well as immunity to electromagnetic interference (EMI) [3–5].

In some emergencies, different terminals (such as ground stations, aircrafts, airships and ground mobile unit) require the same real-time observation data. However, different terminals usually use the respective frequency band with different volume, power consumption and mobility requirements. Thus, the microwave photonic repeaters should have the multicast and broadcast capabilities that can convert the signals from one frequency to several different frequencies simultaneously.

Recently, dual optical frequency combs (OFCs) technique is proposed for the application of flexible photonic microwave conversion. This method takes advantages of broadband, coherent nature of the dual OFCs [6]. However, OFC based on $LiNbO_3$ MZM need high output power electrical drivers and meticulous adjusting of bias voltages. OFCs consisting of tens of optical sidebands with almost equal amplitude cause power dispersion problem, which would further aggravate the difficulty of optical and electrical amplification and waste precious satellite resources. In the proposed scheme, the main optical sidebands are reserved before the heterodyne detection on photodiode (PD), which would ease the following amplification.

In comparison with the microwave photonic schemes proposed before [7–21], there are three main advantages of this method. Firstly, the input RF signal's carrier can be changed to six frequencies higher than the input carrier with one 20 GHz bandwidth dual-drive MZM and two 10 GHz bandwidth MZMs, which can widen the repeater's bandwidth and decrease the complexity of the frequency conversion structure [22–24]. The proposed schemes [25–30] need the fine-adjusting of the polarization states, bias voltages and time delays of the dual-parallel MZM (DPMZMs). Meanwhile, the used structures need four $LiNbO_3$ modulators and three microwave oscillators, which further increase the difficulty of tuning [6,31]. Also, the system's cost can also be reduced largely to generate high frequency RF signals, for avoiding using the expensive wide-bandwidth modulators and relevant RF amplifier drivers. In order to perform frequency conversion, DPMZM, polarization modulators and even semiconductor optical amplifiers are applied in the methods of Refs. [25–31] respectively, as the expensive modulators and amplifiers can generate different signal sidebands combinations. Lastly, all optical bands participating in the heterodyne detection possess the input data information after the optical modulation, which can generate more frequency-conversed RF signals and less useless discreet RF clock signals. The proposed scheme [32–35] can realize only one kind of frequency conversion and the method in Ref. [36] can realize configurable frequency up conversion of one kind of frequency.

In this paper, a novel microwave photonic satellite repeater structure is proposed, followed by the concept and theoretical analysis. Then, simulation parameters and results discussion are presented to demonstrate the theory. And the conclusions are achieved in the end.

## 2 Principle

In the microwave photonic repeater systems, both the overall architecture design and the RF signal generation scheme are the key points to successful deployments on real communication satellites. The basic principle of the proposed approach is based on the transfer function of MZM and narrow optical band pass filters. Fig. 1 shows the system structure and the principle of the microwave photonic frequency conversion.

In Fig. 1, after the polarization controller ($PC_1$), the 10 dBm continuous-wave light with the central frequency of $\omega_c$ is injected into the dual-drive modulator ($MZM_1$), the $MZM_1$ is configured as OCS modulation. $E_0$ is the output optical fields of the distributed feedback (DFB) laser. The two 1st order optical sideband signals with the center frequencies of $\omega_c - \omega_2$ and $\omega_c + \omega_2$ are reserved, while the higher order signals and optical carrier are decreased. The output optical field of the $MZM_1$ at the plot *a* can be written as follows:

$$E_1(t) = \frac{E_0}{4}\mathrm{e}^{\mathrm{j}\left[\omega_c t + \frac{\pi V_0}{V_\pi}\sin(\omega_2 t) + \pi\right]} + \frac{E_0}{4}\mathrm{e}^{\mathrm{j}\left[\omega_c t - \frac{\pi V_0}{V_\pi}\sin(\omega_2 t)\right]} \tag{1}$$

In the repeater, the local 20 GHz RF clock signal (LO2) in the repeater is expressed as $V_0 \sin(\omega_2 t)$, while $V_0$ is the amplitude of the local 20 GHz RF clock signal. Voltage of the bias-upper $V_{bu}$ and voltage of the bias-lower $V_{bl}$ of the $MZM_1$ are $V_\pi$ and 0 respectively to realize OCS modulation. $J_n()$ is the first kind of Bessel function of order *n*. Eq. (1) can also be written as follows:

$$E_1(t) = \frac{E_0}{2}\mathrm{J}_1\left(\frac{\pi V_0}{V_\pi}\right)\mathrm{e}^{\mathrm{j}[(\omega_c - \omega_2)t]} - \frac{E_0}{2}\mathrm{J}_1\left(\frac{\pi V_0}{V_\pi}\right)\mathrm{e}^{\mathrm{j}[(\omega_c + \omega_2)t]} \tag{2}$$

Then, the optical signal is passing through two optical band-pass filters ($OBPF_1$ and $OBPF_2$) to separate two