Photonic-assisted RF frontend operating at U-band and V-band based on Si$_3$N$_4$ ultra-high-Q bandpass filter

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Abstract: A multi-band photonic-assisted RF photonic frontend based on the high Q bandpass filter has been experimentally demonstrated at U- and V-band. The SFDR from 40 GHz to 65 GHz are larger than 95 dB-Hz$^{2/3}$.

OCIS codes: (070.1170) Analog optical signal processing; (230.3120) Integrated optics devices; (060.5625) Radio frequency photonics.

1. Introduction

Radio frequency (RF) frontends have many applications no matter in civil communication or the military application, for instance the wireless communication, satellite communication, phased array and the electronic warfare. Especially, during the past decades, inspired by software-defined radio (SDR) methods with reconfigurable and tunable features, the RF frontends seem to be adaption to variable environments and carrier frequencies. However, the frequency range that can be flexibly processed is typically limited to several GHz [1,2], considering the power consumption and effective number of bits (ENOB) of the analog-digital converter (ADC) before digital signal processing. It appears inherently difficult with electrical methods for multi-band application. The photonic means of RF photonic frontends as shown in Fig. 1, can overcome the bandwidth limitation in electrical frontends [3,4], thanks to the advantages of low loss, large bandwidth, tunability, and immunity to electromagnetic interference (EMI) [5,6]. Recently, many photonic-assisted RF frontends have been published [7-11], such as in [7]. V. S. Ilchenko et al. proposed a photonics RF receiver based on the whispering-gallery mode resonator operating at ~35 GHz. In [8], the research group from Italy proposed the multi-band RF transceiver working in X-band and S-band in 2014. In [9], a broadband RF photonic frontend using the microwave photonic filter working at 12.7 GHz is proposed. In our previous work [10], we proposed a frontend based on the optical filtering and down-conversion at the X- to Ka-band and in [11], we have first proposed the potential full-band (from the L-band to W-band) RF photonics frontend and experimentally demonstrated the frontend from L-band to Ka-band (from 1 GHz to 40 GHz). However, till now, this is none experimentally demonstration of the RF photonic frontend which can work higher than 40 GHz, as far as we know.

In this paper, we have extended the working band from 40 GHz to 65 GHz, i.e. operating at the U-band and the V-band. A carrier suppression modulation scheme is adopted in our system to make full use of the two first modulated sidebands, which are used as the local oscillator and the optical carrier for the RF signal, respectively. So that the frequency of the LO can be lower to nearly half of the frequency of the RF signal. The ring resonator-based tunable bandpass filter with 420 MHz bandwidth and more than 220 GHz FSR is used to select the desired signal, which can process the signal from L-band to the W-band. The performance of the RF photonic frontend based on these technologies has been measured and the spurious free dynamic ranges (SFDRs) from 40 GHz to 65 GHz are also presented. To our knowledge, this is the first demonstration of the RF photonic frontend, which can work at the U- and V-band.

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Fig. 1. Schematic of the multi-band RF photonic frontend. EO-M: electro-optical modulator.
2. Principle and Experimental Results

![Schematic diagram of the RF photonic receiver](image)

**Fig. 2. Schematic diagram of the RF photonic receiver.** The LO signal is null-biased modulated to the MZM to realize the carrier suppressed modulation to lower the frequency of the LO to be half of the signal. The desired signal is extracted by the proposed full-band microring-based signal processor. The BPD used in this system can suppress the even-order nonlinear signal.

An experiment is performed based on the setup shown in Fig. 2. A continuous wave laser (CWL) with 1550.07 nm wavelength, 1 kHz linewidth and 15 dBm optical power is sent to the phase modulator (PM1) with 40 GHz bandwidth driven by a tunable local oscillator (LO) produced by a signal generator (Agilent 8257D). Two coherent optical sideband generated from PM is then separated by the multi-ports optical bandpass filter (OBPF), which is realized by the Santac 4-ports filter. The bandwidths are both 32.5 GHz and center frequencies of the two ports are 193.381 THz and 193.4305 THz, respectively. As the optical power at any frequency would be only processed by one port, the passbands of the four ports cannot have any overlap. With such a property, the optical carrier would be suppressed, as it is just in middle of the center frequency of the two ports. The upper sideband is used as an optical LO for downconversion and lower sideband is served as the optical carrier and phase-modulated by the input RF signal (40-65 GHz). The bandwidth of PM2 is 65 GHz. The optical signal is then processed using our proposed high Q bandpass filter, which has bandwidth and FSR of 420 MHz and 225 GHz, respectively [11]. Thanks to the narrow-passband and large FSR of the filter, the processor can precisely filter out the interesting signal over a wide RF frequency band of from L-band to W-band. The filtered signal and the optical LO are then combined in a 50:50 optical coupler and detected by balanced photo-detector (Thorlab 100 MHz BPD). Figures 4(a)-(f) show the measured optical spectra. The electrical spectrum is measured by an electrical spectrum analyzer (ESA).

![Measured optical spectra in the experiment](image)

**Fig. 3. Measured optical spectra in the experiment (a) optical source, (b) after PM1, after the multi-ports filter (c) the upper first-order sideband LO and (d) the lower first-order sideband amplified signal, (e) after PM2 and (f) after the filter**

The two-tone test RF signals from 40 GHz to 65 GHz are generated by the mixer (Marki Microwave M9D-2065 Mixer) as can be seen in Fig. 2. The RF signal ($f_{RF}$) is constructed with the IF signal ($f_{IF}$) and the LO signal ($f_{LO}$).
according to the relationship as \( f_{\text{RF}} = f_{\text{IF}} + 2f_{\text{LO}} \). The IF signal is a two-tone signal centered at 10.0065 GHz and 10.0085 GHz, which is generated by a vector signal generator (Agilent 8267D). The LO from 15 GHz to 25 GHz is generated by a signal generator (Agilent 8257D). The conversion loss is around 12 dB. Based on the carrier suppression modulation scheme, the frequency requirement of the LO is lower to half of the frequency of the RF signal. The frequency of LO altering from 20 GHz to 32.5 GHz is tracked to transfer the input RF signal (40–65 GHz) applied to the PM into a fixed IF band at ~7.5 MHz, and the LO power is ~21.6 dBm.

To evaluate the performance of the RF photonic frontend, the SFDRs at frequencies ranging from the 40 GHz to 65 GHz were measured. As an example, the experimental result of the two-tone test signal of 60 GHz is discussed below. According to the principle presented in our previous work [11], the signals filtered by the proposed filter are detected by the BPD and down-converted to 6.5 and 8.5 MHz as well as the third-order intermodulation distortion (IMD3) at 4.5 and 10.5 MHz, induced by the nonlinear behavior of the transfer response of the entire receiver system due to the phase modulation and photo-detection scheme. The SFDRs of the system with a frequency from 40 GHz to 65 GHz with a separation of 2 GHz were measured, which are presented in Fig. 4. In such a frequency range (the largest range that could be realized in our experiment), good uniformity in the performance was maintained; the largest SFDR measured was 111.8 dB-Hz, and the lowest SFDR measured was 95 dB-Hz. The SFDR seems to have a slightly decrease as the signal frequency increases from 40 GHz to 65 GHz, which is mainly because of the conversion loss of the mixer increases and the PM2 modulation efficiency decreases with the RF frequency increasing in this frequency range.

![Fig. 4. Experimental results of the RF photonic frontend. The measured SFDR from 40 GHz to 65 GHz.](image)

3. Conclusions

In this paper, an RF photonic frontend based on the high-performance bandpass filter has been proposed and experimentally demonstrated, which can work up to W-band (110 GHz). Limited by the bandwidth of the EOM, the frontend operating below 65 GHz has been demonstrated. The SFDR of the frontend based on the signal processor has been measured to be larger than 95 dB-Hz from 40 GHz to 65-band.

4. Acknowledgments

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5. References