A full-band RF photonic receiver based on the integrated ultra-high Q bandpass filter

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Abstract: A full-band RF receiver ranging from L- to W-band based on the ultra-high Q bandpass filter has been proposed and experimentally demonstrated. The SFDR of the receiver from C- to K-band are larger than 114dB*Hz^{2/3}.

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

1. Introduction

RF receivers have been developed rapidly during the past-decades for adapting to the variable environment and carrier frequency, especially the software-defined radio (SDR) receivers with the reconfigurable and tunable features have inspired the researchers, but the frequency range can be flexibly processed is usually limited to several GHz [1,2]. To meet the future requirement of full-band microwave receiver, the microwave photonics have to be introduced to such microwave systems [3,4], owing to the advantages of low loss, large bandwidth, tunability, immunity to electromagnetic interference (EMI) and so on [5,6].

The schematic diagram of the full-band photonics-based microwave transceivers is shown in Fig. 1. The broadband signals received by the antenna are up-converted to optical domain by the EO modulator and the desired information band is extracted by the high performance microwave photonic filter. Then the desired signal is mixed with the local oscillator (LO) to down-convert to IF or baseband for sampling by the analog-digital converter (ADC) and post-processed by the digital signal processor (DSP). In such a system, the bandwidth of the commercial modulators has already reached 110 GHz [7], and the only limit would be the full-band tunable high performance signal processor with the resolution reaching hundreds of MHz and processing range larger than 110 GHz. Several methods have been introduced to approach this [8,9], but no signal processors reported can possess such performance as far as we know.

In this paper, a resolution of about 420 MHz and processing range larger than 110 GHz (FSR = 225.78 GHz), micro-ring bandpass filter has been realized. The center frequency of the filter can be altered by the micro-heaters top on the ring for more than one FSR continuously and the out-band suppression-ratio is larger than 40 dB. Employing the proposed high performance device in the full-band RF photonic receiver, the processing range of the photonic receiver can cover from L-band to W-band and the spurious free dynamic range (SFDR) of the RF photonic receiver has been measured to be larger than 114.76 dB*Hz^{2/3} at the frequency from C- to K-band (limited by the bandwidth of the modulator in our experiment).

Figure 1. Schematic diagram of the RF photonic transceiver. The transceiver contains two parts, the transmitter and the receiver. In the receiver, the full-band signal received by the broadband antenna would be processed by the photonics method. Owing to the large bandwidth of the photonics methods, it is possible to realize such a full-band RF photonic receiver.
2. Filter Design and Experiment Results

The microring filter is fabricated by the TriPleX™ technology of double-strip Si₃N₄ waveguide, with a waveguide loss of lower than 0.2 dB/cm [10]. To meet the requirement of the full-band (from L-band to W-band) RF signal processing in the RF photonic receiver, the parameters of the devices are designed as listed below, the radius of the ring is 125 um, the gaps between the waveguides and the ring are 2 um, so that the FSR can be larger than 220 GHz (the processing range of the filter is nearly half of the FSR) and the bandwidth of the filter can be lower to hundreds of MHz. The performance of the filter is measured by the optical vector analyzer (LUNA, OVA) as shown in Fig. 2(a). The processing band of the filter can be tuned for more than one FSR by the micro-heater top on the microring as presented in Fig. 2(b).

![Figure 2. Device measurement. (a) Transfer response of the filter measured by the OVA. (b) The thermal tuning response of the filter for more than 1 FSR.](image)

The schematic of the proposed full-band RF photonic receiver is shown in Fig. 3. The RF local oscillator (LO) is up-converted to the optical domain by a null-biased MZM to achieve a carrier-suppressed modulation. The modulated two-sidebands are separated by the interleaver (a multi-band bandpass filter), the upper band and the lower band. The upper band is employed as the clear optical LO for the down-conversion of the RF signal to the IF or baseband. The lower band is used as the optical carrier for phase modulation of the RF input signal. Before sending to the PM, the signal would be amplified by the EDFA to compensate the optical loss of the system. The received optical signal is modulated by the PM and then sent to the proposed Si₃N₄ microring-based bandpass filter for signal extracting. The target signal extracted by the proposed high resolution filter would be combined with the clear optical LO in the upper band at a 1:1 coupler and detected by the balanced-photo-diode (BPD) for down-converting. The down-converted signal would be monitored by the ESA or the oscilloscope. In this system, as the RF LO is carrier-suppressed modulated to optical domain and the separation between the upper band LO and the lower band carrier is two-times the LO signal, that is to say that the LO frequency would be nearly half of the RF signal, e.g. for 100 GHz signal, the LO would be only 50 GHz.

![Figure 3. Schematic diagram of the RF photonic receiver. The LO signal is null-biased modulated to the MZM to realized 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.](image)

The parameters of the system are listed below. The center frequency and the optical power of the continuous wave laser (CWL) are respectively 1549.407 nm and 16.7 dBm; the bandwidth of the MZM is 10 GHz, the power of the RF local oscillator (LO) is 20 dBm to drive the null-biased MZM to achieve the carrier-suppression larger than 20 dB and the separation of the multi-band bandpass filter is nearly 25 GHz, the gain of the EDFA is 20 dBm and the power after the EDFA is 17dBm, the bandwidth and the half-wave voltage of the PM are respectively 40 GHz and 7V.
To evaluate the performance of the receiver, the SFDRs at the frequency ranging from C- to K-band have been measured as shown in Fig. 4(a-d). The SFDR of C-band (Signal: 4.8065 GHz and 4.8085 GHz, IF: 6.5 MHz and 8.5MHz), X-band (Signal: 10.0065 GHz and 10.0085 GHz, IF: 6.5 MHz and 8.5MHz), Ku-band (Signal: 13.5065 GHz and 13.5085 GHz, IF: 6.5 MHz and 8.5MHz) and K-band (Signal: 19.0065 GHz and 19.0085 GHz, IF: 6.5 MHz and 8.5MHz) are respectively 118.63dB-Hz^2/3, 116dB-Hz^2/3, 114.76dB-Hz^2/3, 119.09dB-Hz^2/3.

Figure 4. Experiment results. The SFDR of the RF photonic receiver from C- to K-band measured with two-tone test signals. (a) C-band, (b) X-band, (c) Ku-band, (d) K-band.

3. Conclusions
In this paper, a full-band RF photonics receiver based the ultra-high Q bandpass signal processor has been proposed and experimentally demonstrated. The resolution and the processing range of the signal processor are respectively 420 MHz and the 112.9 GHz, which can cover from L- to W-band. The SFDR of the receiver based on the signal processor has been measured to be larger than 114 dB-Hz^2/3 from C- to K-band.

4. Acknowledgments
This work is supported by National Program on Key Basic Research Project (973) under Contract 2012CB315703, and NSFC under Contract 61120106001 and 61322113, and Tsinghua University Initiative Scientific Research Program.

5. References