An All-Optical Microwave Mixer with Gain

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An all-optical microwave mixer with 8 dB RF gain is demonstrated by using a semiconductor optical amplifier (SOA). 6 GHz RF signal on a 1312 nm optical carrier is up-converted and down-converted to 1 GHz and 11 GHz by a 5 GHz local oscillation (1 ●) signal on a 1320 nm optical carrier. Such a mixer could readily extend to millimeter wave range.

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Fiber optic transmission of microwave signals has attracted significant attention for photonic RF communication systems such as satellite communications [1] and subcarrier multiplexed (SCM) systems [2]. Recently a novel fiber-optic link architecture has been proposed [3], where the baseband data is up converted by an external modulator (EO), transmitted through a fiber link, and mixed down to IF by another external modulator at the receiving end. Such a scheme offers the advantage of the infinite RF isolation and also avoiding the need of high speed photodetectors and microwave mixers. However, it also has several problems, specifically at the receiving end. First, an external modulator is intrinsically polarization sensitive, and the optical links already laid out arc not polarization maintained. Secondly, the external modulator has additional loss of -5 dB, potentially requiring optical amplification, In this paper, wc propose a novel microwave mixer for photonic microwave systems based on cross gain saturation in a semiconductor optical amplifier (SOA). in the experimental demonstration an optical signal at 1312 nm carrying a 6 GHz RF signal is down and up converted to 1 GHz and 11 GHz by another optical signal at 1320 nm carrying a 5 GHz local oscillator (LO). A lossless up/clown conversion operation is also achieved. Such a mixer offers the advantage of **polarization independence** and **optics] amplification.**

The mixing mechanism is illustrated in Fig. 1a. When a strong optical signal carrying LO modulation is coupled into an SOA, the gain of the SOA, G(t), is modulated at fundamental and harmonics of 1,0 frequency. If a relatively weak $P_{in}(t)$ signal is introduced concurrently into SOA, the output of the RF, $P_{out}(t)$, equals to the product of G(t) and $P_{in}(t)$, which will contain the mixing products at frequencies of $|RF-LO|$ and (RF+ 1,0). A similar scheme has previously been investigated for all-optical wavelength shifting for digital communication [4]. Recent work has demonstrated 30 GHz bandwidth for single SOA and 50 GHz two cascaded SOAs [5], implying such an all-optical mixing process could well extend to millimeter wave regime (>30 GHz). The potential advantages of using an optical 1.0 and a SOA for microwave mixing arc two folds: (1) all--optical gain saturation is much faster than electrical modulation of the bias current of the SOA, and (2) optical 1.0s with frequency up to millimeter wave have already been demonstrated by heterodyning two lasers.

Figure 1b shows the experimental setup. An optical Signal at 131 211111 is modulated by an external modulator at 6 GHz to simulate the incoming RF signal, To demonstration the concept, the optical LO at 1320 nm is modulated by another external modulator at 5 GHz. These two signals are coupled into a SOA. The optical power measured at the input of the SOA is 3 dBm and -6 dBm for 1320 nm and 1312 nm respectively. The SOA is biased at 300 mA and the small signal bandwidth of the SOA is measured at 9 GHz by using an HP network analyzer. The RF signal is filtered and detected by a detector with flat response up to 15 GHz. The output optical spectrum also is shown as an insert in Fig. 1 b. The output optical power of the 1312 nm signal is 7.8 dBm, indicating about 11 dB optical gain or 22 dB RF gain including SOA coupling and filtering loss.

Figure 2a and 2b show the detected input RF and LO spectra measured by a HP RF spectrum analyzer. The input RF power is measured to be -40.0 dBm. The optical modulation index (OMI) for LO and RF are 50% and 25% respectively. Figure 2c and 2d show the RF spectra of the mixing products at 1 GHz and 11 GHz. The resulting products are around -40.00 dBm for both signals. All the RF spectra are measured direct] y from the photodetector with no RF amp] ificat ion.

Figure 3a shows optical modulation index (OMI) of the converted RF signal as a function of the OMI of the input LO. When the OMI of the 1.0 is below 25 %, the OMI of the converted RF signal increases linearly with a slope of 1. However, in the. large modulation range, the OMI of the converted signal increases more quickly with a slope of -1.5. "l'his might be due to efficiency enhancement of the external modulator in the over-drive regime and also the nonlinearity of the gain as a function of the OMI of input RF power for the large modulation regime. The other interesting fact is that the up converted RF signal tends to saturate above 70 % OMI of the 1.0. Fig. 3b shows the detected RF power as a function of detected input RF power (@ 6 GHz). 'l'he detected RF signal increases linearly with the input RF power with a slope of 1. in the regime of the low OMI of the input 1.0 (<30%), the 1 GHz and the 11 GHz RF are almost equal, however in the high OMI regime (90 %), 1GHz RF signal is about 6 dB bigger than 116117. RF. Most significantly, the 1GHz signal exhibits about 8 dB RF gain compared to the case where the 6 GHz RF is direct] y detected without up/down conversion. Therefore a single device as **a mixer with gain is** demonstrated. More. detailed properties such as noise figure and intermodulation will be also presented,

Figure Captions

1, (a) Conceptual diagram of an all-optical microwave mixer, (b) Experimental setup of the mixer

2.. Measured RF spectrum for (a) input RF signal @ 6 GHz, (b) input LO signal @ 5 GHz, (c) down-converted signal @ 1 GHz, and (d) up-converted signal @ 11 GHz. Both RBW and VBW are 100 KHz.

3. Performance of the all-optical mixer (a) the output optical modulation index (OMI) as a function of the OMI of the input LO, (b) the detected up/down converted signal RF power as a function of the input RF power which is detected without conversion.

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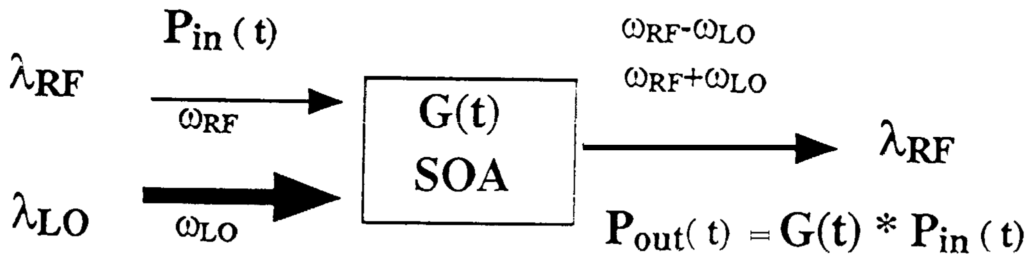
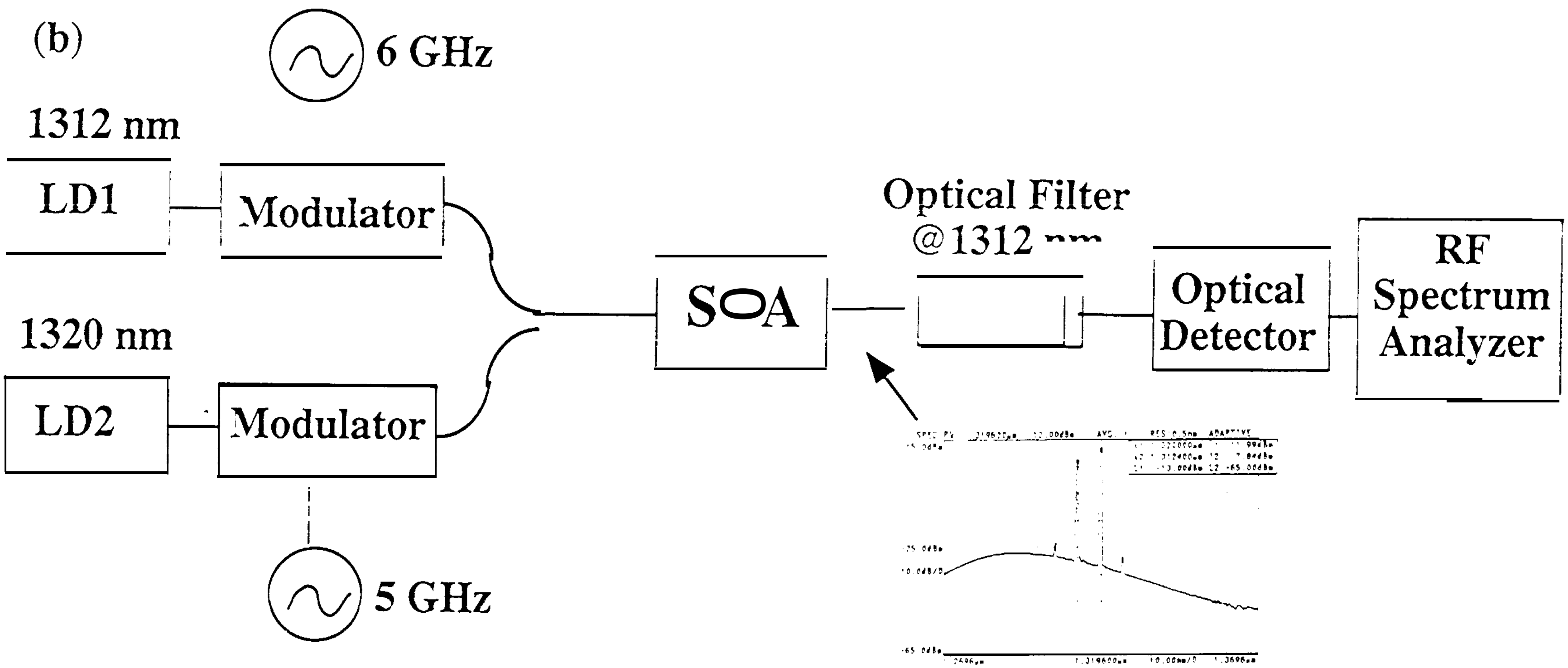
a)



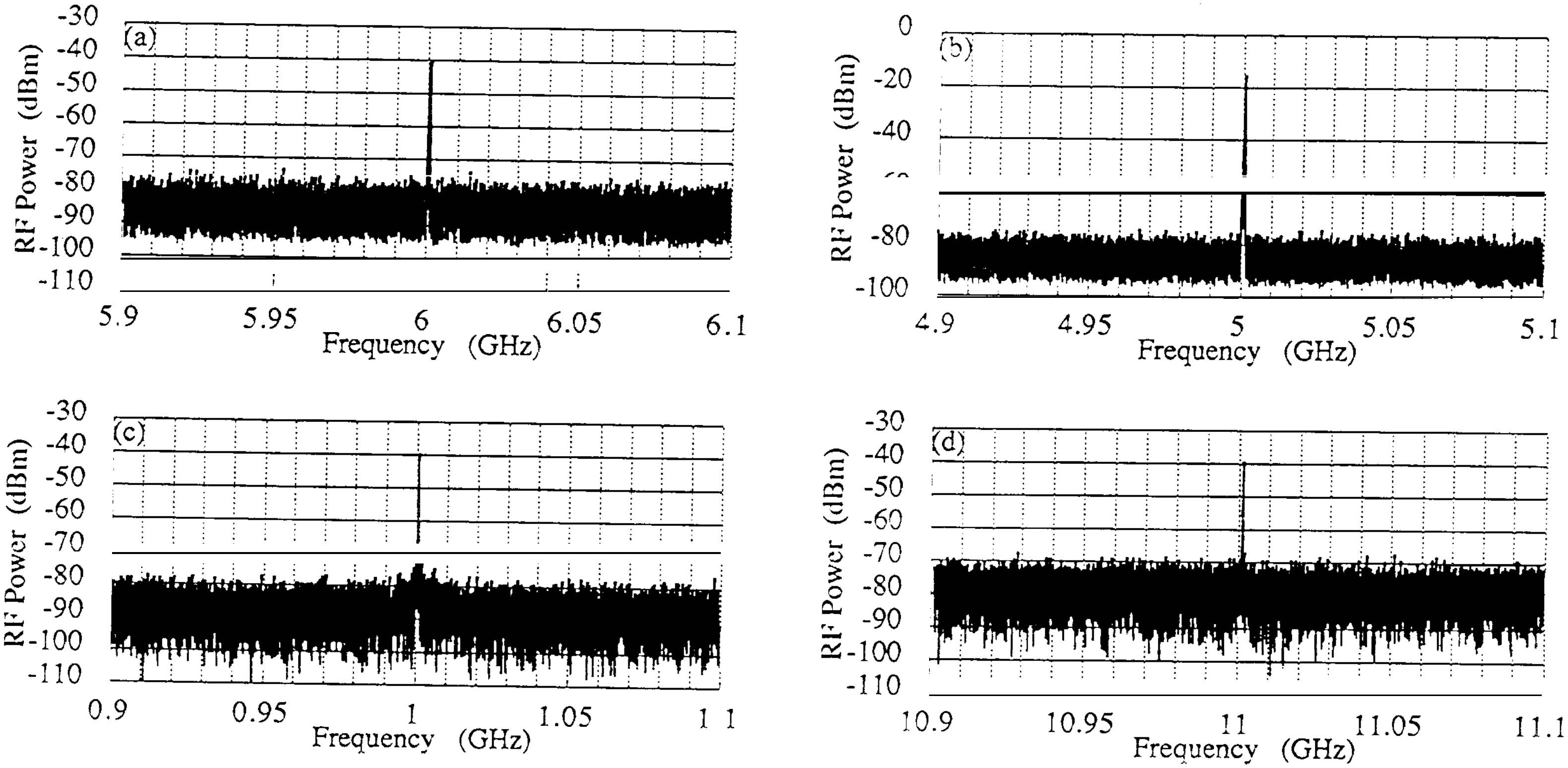
λRF
λLO
Pin (t)
ωRF
ωLO
G(t)
SOA
ωRF-ωLO
ωRF+ωLO
λRF
Pout(t) = G(t) * Pin (t)

(b)



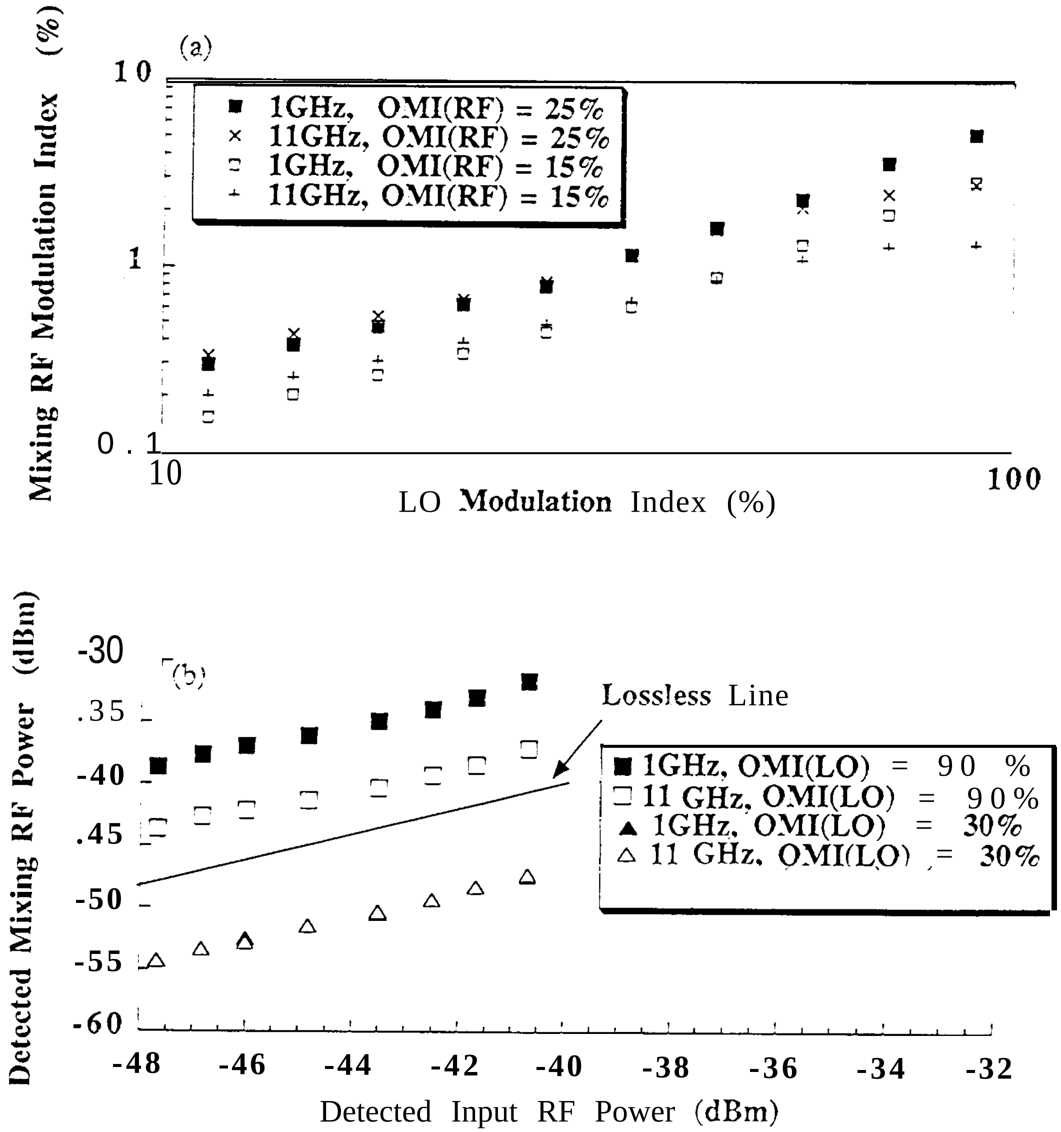
6 GHz
1312 nm
LD1
Modulator
1320 nm
LD2
Modulator
5 GHz
SOA
Optical Filter
@1312 nm
Optical
Detector
RF
Spectrum
Analyzer

Figure 1



(a)
RF Power (dBm)
-30
-40
-50
-60
-70
-80
-90
-100
-110
5.9
5.95
6
6.05
6.1
Frequency (GHz)
(b)
RF Power (dBm)
0
-20
-40
-80
-100
4.9
4.95
5
5.05
5.1
Frequency (GHz)
(c)
RF Power (dBm)
-30
-40
-50
-60
-70
-80
-90
-100
-110
0.9
0.95
1
1.05
1.1
Frequency (GHz)
(d)
RF Power (dBm)
-30
-40
-50
-60
-70
-80
-90
-100
-110
10.9
10.95
11
11.05
11.1
Frequency (GHz)

Figure 2



(a)
1GHz, OMI(RF) = 25%
11GHz, OMI(RF) = 25%
1GHz, OMI(RF) = 15%
11GHz, OMI(RF) = 15%
Mixing RF Modulation Index (%)
LO Modulation Index (%)
10
1
0.1
10
100
(b)
Lossless Line
1GHz, OMI(LO) = 90 %
11 GHz, OMI(LO) = 90%
1GHz, OMI(LO) = 30%
11 GHz, OMI(LO) = 30%
Detected Mixing RF Power (dBm)
Detected Input RF Power (dBm)
-30
-35
-40
-45
-50
-55
-60
-48
-46
-44
-42
-40
-38
-36
-34
-32

Figure 3